Wendell Hull & Associates, Inc.

Oxygen Systems Engineering and Test Group

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Fire Origin Investigation Involving a DOT 3AL Cylinder Failure in Luraville, FL

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Introduction

Wendell Hull & Associates, Inc. (WHA) was requested to provide consultation to the US Department of Transportation (DOT), Pipeline and Hazardous Materials Safety Administration, in their investigation of the catastrophic failure of an aluminum oxygen cylinder. The oxygen cylinder failed on July 27, 2004, at approximately 3:45 p.m., when Ms. Sara Francis Slaughter was refilling a DOT 3AL cylinder with gaseous oxygen in order to prepare for a Nitrox (generally considered approximately 40% oxygen/60% nitrogen) diving mix[1]. During the refilling operation a fire erupted within the cylinder and attached filling assembly, including the cylinder valve, and the cylinder ruptured at its neck. Ms. Slaughter was fatally injured, and three others suffered minor injuries, during the incident.

The accident occurred at a professional dive shop located in Florida where Ms. Slaughter was an employee. The exact circumstances and sequence of events leading up to the fire are unknown at this time to WHA, but it is understood that Ms. Slaughter was standing near the subject cylinder during the re-filling process. It has been reported to WHA that Ms. Slaughter did not mishandle the subject cylinder based on information from the investigating Sheriff's Office Offense Incident Report. Ms. Slaughter suffered a large laceration to her abdomen, presumably inflicted by the shrapnel generated from the exploding cylinder.

WHA Investigation – Scope and Activities

WHA was contacted to provide consultation pertaining to the following two areas of the DOT investigation:

1) During the incident the cylinder valve was energetically ejected from the ruptured cylinder and was not located during the initial scene investigation. Several weeks after the incident a Nitrox diving valve was found outside of the dive shop some distance away[2]. Due to the remote location where the valve was discovered and the uncertainty about whether the valve was associated with the incident in question, WHA personnel were requested to analyze the valve to determine whether its condition was consistent with the incident in question.

2) The ruptured cylinder and the associated fill assembly which were recovered after the accident exhibited signs of internal fire. Therefore, WHA personnel were requested to evaluate the fire-damaged condition of these components and develop opinions regarding the origin location for the fire that developed under the oxygen-enriched conditions.

[1] A Nitrox mixture is assumed due to the "oxygen" label on the aluminum cylinder, the "Nitrox" label on the recovered cylinder valve, and the evidence of combustion on the aluminum cylinder, which requires elevated oxygen concentrations to self-support combustion as was evident.
[2] The exact distance was not reported to WHA but it is understood to have been more than 100 feet away).

In order to pursue these objectives the failed and fire-damaged components were sent to WHA for analysis and documentation. Initially, all components were inspected visually and with the aid of a stereo microscope; and, the surface features and combustion patterns were documented. Attachment 1 accumulates all of the documentation photographs taken by WHA during the course of the investigation. This attachment organizes the photographs according to the investigation activity underway at the time the photograph was taken. The physical condition (i.e., fracture patterns, melt-flow/burn patterns, etc.) of each component was documented with macro and micro photography and also with the aid of an internal viewing boroscope where visual access was hindered by the configuration.

The materials that were analyzed by WHA are depicted in Figures 1 and 2 in their "as-received" condition. The following provides a summary list of the components submitted to WHA for analysis:

1) Isolation valve that had been connected to a gas supply system at its inlet and to a flexible hose (fill whip) at the outlet. This component was identified as a 6000 psig rated Sherwood valve stamped with date code 4302.

2) Flexible hose (fill whip) identified as Parker Parflex and marked with the following: 520N-4 SAE 100R8 ¼ W. P. 5000 psi PATENT # 4142554 – USE 55 SERIES FITTINGS 133118

3) Fill valve connected between the flexible hose and the cylinder valve fill adapter. This component was identified as a 6000 psig rated Sherwood valve stamped with date code 0503.

4) Fill Adapter connected between the fill valve and the cylinder valve. No specific identification markings were located. The configuration was consistent with a DIN fill adaptor with bleed port. Examples of various components of this type for SCUBA fill operations are provided in Attachment 2.

5) THERMO cylinder valve marked with "Nitrox Use Only" imprinted on an attached decal.

6) Aluminum Cylinder with markings are as follows: CTC/DOT-3AL3000-S30 UU02900LUXFER 9A87, Also, there are marks 9 $^{A8}{}_{21}$ 02)

The initial WHA inspection and documentation of the combustion and fracture patterns resulted in the recommendation that complete disassembly of the valves (i.e., cylinder valve and both isolation valves attached to the fill hose) be performed and samples be identified for chemical and metallurgical analysis. The chemical and metallurgical analysis was required in order to analyze the fracture features/morphology observed on the physical evidence and to also analyze the combustion residue for evidence related to the ignition. In order to conduct this analysis, WHA prepared a disassembly and testing protocol to establish the anticipated procedure and control any evidentiary concerns that might be raised by manufacturers of the components. The protocol that was prepared by WHA is provided in Attachment 3.

The components addressed in the protocol were disassembled on May 10, 2006 at the WHA Test Facility in Las Cruces, NM. The parties in attendance for this inspection are indicated Attachment 4. Each component was disassembled/documented in the order provided by the protocol with a view toward following the general direction of gas flow (i.e., from the most upstream component toward the most downstream component). Attachment 1 provides the chronological sequence of the disassembly steps as a photographic record. The disassembly steps were also documented on standard video.

During the disassembly the components were individually inspected at high magnification with the aid of a stereo microscope. The microscope photographs are provided in Attachment 1. Further, the WHA disassembly notes and measurements are provided in Attachment 5.

On May 11, 2006, the samples that were identified and selected during the disassembly were transported to the National Aeronautics and Space Administration (NASA) White Sands Test Facility (WSTF) for chemical and metallurgical analysis. Chemical analysis was conducted by Fourier Transform Infrared Spectroscopy (FTIR) to identify organic combustion residue and organic surface contaminants. Metallurgical analysis was conducted on the fracture surfaces by Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS).

The following samples were collected for analysis at NASA-WSTF, and the accumulated results of this analysis are provided in Attachment 6:

- FTIR Analysis Results:
  - Solvent Wash of the Flexible Hose Interior
  - Solvent Wash of the Interior Surfaces of the Upstream Fill Valve
  - Solvent Wash of a ~1-in^2 segment of the Bottom Interior Surface of the SCUBA Cylinder
- SEM/EDS Analysis Results:
  - Cylinder Valve Body Thread Residue
  - Particulate Residue Removed from Cylinder Valve Inlet Bore
  - Residue Removed from Cylinder Valve Outlet
  - Downstream Fill Valve Fracture Surfaces
  - Fill Valve Adaptor Fracture Surfaces
  - Thread Root Comparison Features for Fill Valve and Adaptor

WHA Investigation – Results and Discussion

Fracture Condition Analysis – Objective 1:
The WHA inspection revealed that the isolation/fill valve, attached to the downstream end of the fill hose (or fill whip), exhibited a fracture pattern on its downstream threads, shown in Figure 3, consistent with a bending overload failure. The exterior body of the valve as well as the fracture surface exhibited a surface residue condition consistent with combustion products, also shown in Figure 3.

It was noteworthy that the THERMO cylinder valve, found after the initial scene investigation, also exhibited a fracture on the end of the valve adaptor fitting that was attached to the cylinder valve inlet, where an isolation valve would have been originally attached, as shown in Figure 4. The adaptor fitting fracture included a threaded end that was dimensionally the same OD and ID as the fractured end of the downstream valve. The dimensional measurements are documented in Figure 5 and the notes of Attachment 5 comparing the dimensions of the fracture on the adaptor fitting to the downstream fill valve.

It was also considered significant that the fracture patterns for the two surfaces (i.e., adaptor and fill valve) were very similar in appearance and surface morphology as shown in Figure 6 and both fractures developed at the thread root under a bending overload. As is illustrated in Figure 6, the fracture pattern and surface morphology extending from the inside diameter of the two pieces through the thread form (*see right side photograph of Figure 6 showing the inside diameter pattern*) match very closely. The fracture discontinuity on the inside diameter of the adaptor fitting is mirrored on the fracture of the downstream fill valve. Further, the sharp discontinuity on the thread of the fill valve is mirrored on the thread fracture of the adaptor fitting.

These similarities were considered significant and strongly indicated that the THERMO cylinder valve recovered several weeks after the incident had probably been attached to the fill assembly when the incident occurred. In order to further evaluate this probability, the fracture surfaces were analyzed by SEM/EDS to compare the elemental composition and the fracture morphology. This analysis is summarized in Figure 7 through Figure 12.

Figures 7-12 show microscope and SEM photographs obtained of each fracture surface and the EDS analysis for the major elemental constituents that are dominant in the locations where the scans were obtained. The locations of the individual scans are indicated in each figure. The elemental analysis indicated that the base material was consistent with brass (copper/zinc alloy), as would be expected for these components. This analysis confirmed that both fragments/remnants were probably comprised of the same base alloy. It was further significant that the EDS analysis also indicated that both surfaces contained aluminum-oxide deposits. This result was considered significant since the fracture probably developed during the combustion event and would have included burning aluminum from the SCUBA cylinder, which would have deposited on the surfaces during the venting of combustion gases while the fitting was failing.

One noteworthy difference was the presence of fluorine detected on the EDS scans for the adaptor fitting. Fluorine was not detected on the surface of the downstream fill valve. However, since the adaptor fitting still contained obvious residues from PTFE – Teflon® tape, which is a fluorocarbon-based material, this difference was considered to be insignificant. The remaining PTFE tape remnants on the adaptor fitting would have been expected to slough off onto the fracture surface during handling.

Figure 12 provides side by side comparisons at the thread root of a fracture pattern on both the adaptor fitting and the fill valve. This comparison shows that the estimated distance between similar features measured on each remnant was highly similar and varied by less than 200 microns. Since the measurement locations for the comparable features were selected arbitrarily, and since the morphologies of the two features were visually highly similar (Figure 6), ***the two fractures were confirmed to be highly consistent and represented two mating surfaces of the same fracture***.

Fire Origin and Residue Analysis – Objective 2:
Figures 13 through 28 provide a summary of the disassembly sequence and results of the analysis performed at NASA-WSTF to identify the residues identified. As indicated previously, Attachment 5 provides the WHA notes for the disassembly. These figures are selected from the full documentation photographs that are provided in Attachment 1 of this report. Each component was carefully disassembled according to the protocol (Attachment 3) starting with the most upstream component (Upstream Fill Valve – Figure 13) and progressing in the direction of gas flow toward the most downstream component (THERMO Cylinder Valve – Figures 17-28).

The upstream fill valve (Figure 13) did not exhibit evidence of internal combustion and the main seat of this valve was intact. The seat did exhibit evidence of extrusion where the plastic seat interacts with the valve body nozzle; but, no combustion was observed. A discoloration was noted on the compressed section of the seat (i.e., where the seat seals against the nozzle) but experience indicates this condition is common and consistent with abrasion and brass transfer to the plastic. In order to evaluate the potential presence of contaminants within the gas supply components, the internal surfaces of this valve were washed with a solvent (AK225)[3]. The results of this analysis will be discussed later in this report.

Figures 14 through 16 depict the disassembly of the downstream fill valve as well as the flexible hose that was attached to the upstream fitting of this valve. The exterior of this valve exhibited deposits consistent with combustion residue (Figures 3-5), consistent with its close proximity to the burnout when the cylinder failed. However, disassembly of the valve indicated that the plastic seat was not consumed and did not exhibit evidence of combustion residue (Figure 15d). In addition, the nozzle of the valve was also intact and did not exhibit visual evidence of combustion residue (Figure 15c). Figure 16 depicts the condition of the flexible hose fitting that was attached to the upstream fitting of this fill valve. As with the fill valve interior surfaces, an AK225 solvent rinse was performed within the flexible hose to evaluate whether contaminants could be identified on the interior surfaces. The results of this analysis will also be presented and discussed later in this report.

Figures 17 through 28 depict the various steps taken in the disassembly and analysis of the THERMO cylinder valve. This component exhibited extensive combustion deposits on its external surfaces for both the fill adaptor (attached to the outlet of the valve) and the valve body itself (Figures 1, 4, 17-18). Further, this valve exhibited a melt/flow pattern consistent with combustion deterioration on its inlet threaded port[4]. Within the inside diameter of the valve's inlet port a resolidified residue fragment (particulate) was observed, see Figure 19. This figure also depicts the obvious melt/flow patterns that were observed at this location of the cylinder valve. The residue fragment was removed and analyzed by SEM/EDS (Figure 20) and determined to be comprised of copper/zinc, consistent with the valve's base alloy and aluminum (probably aluminum-oxide from the cylinder combustion). Based on the morphology of this residue and its deposit within the valve's inlet port, it was considered consistent with a metallic melt/slag that had resolidified at this location once the valve was ejected. WHA test experience indicates that most brass alloys in these thicknesses will not self-support combustion in high-

[3]AK225 has been qualified and baselined by NASA-WSTF previously for use in sampling of this nature.
[4]The threaded connection was consistent with a standard 3/4-14 UNS (14 thread per inch) SCUBA interface and was verified to fit correctly in the inlet thread for an exemplar cylinder also provided to WHA by DOT.

pressure oxygen at the pressures understood to have existed. However, if provided with sufficiently strong ignition mechanisms[5], the aluminum can be ignited and would be expected to self-support combustion. Therefore, the melt flow character observed at the inlet to the cylinder valve and the resolidified melt mass that comprised a mixture of brass and aluminum oxide further supported the conclusion that the THERMO valve had been attached to the cylinder at the time of the fire. This residue mass was considered consistent with combustion residue from the cylinder back-flowing through the valve prior to the valve being energetically ejected from the cylinder during the event.

Figures 21 and 22 depict the disassembly of the fill adaptor from the cylinder valve outlet. A very significant amount of combustion residue, also comprised of a resolidified mass of brass and aluminum-oxide (see Figures 23-25), was observed in the outlet port of the cylinder valve where the adaptor fitting would hinder free gas flow due to the change in flow direction. The adaptor fitting interface was also heavily deposited with brass and aluminum-oxide combustion residue (Figure 22). This resolidified mass was consistent with combustion product back-flow from the cylinder after combustion of the aluminum had developed. Based on the significant degree of combustion observed with the neck and upper crown of the aluminum cylinder (Figure 2), especially at the threaded connection, this mass was consistent with the melting of the base of the brass valve while exposed to the significant thermal energy release of aluminum combustion in oxygen[6].

Figure 26 depicts the condition of the cylinder valve's plastic seat as well as the condition of the seat interface (or nozzle) within the valve. Based on the amount of combustion product that was ingested by the valve during the fire it was considered unusual that the plastic seat was not consumed. While the seat was heavily damaged and exhibited extensive thermal trauma, it was intact and not consumed. This was probably a result of the valve being open during the fire's initiation which helped to redirect the short duration of the combustion backflow[7] around the valve seat and into the valve outlet prior to the cylinder's rupture. WHA experience indicates that aluminum alloys burn very rapidly in high-pressure oxygen. Therefore, it is considered likely that the valve was ejected and the cylinder ruptured very shortly after ignition developed. The short duration of the plastic seat's exposure to the combustion products and the redirection of the backflow toward the valve outlet was believed to have protected the seat from ignition. In any event, it was clear that the cylinder valve was exposed to combustion backflow from the cylinder during the fire and that one possible ignition origin (i.e., the cylinder valve seat) could be ruled out.

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[5] WHA testing indicates that most aluminum alloys consistent with cylinder construction will self-support combustion at elevated oxygen pressures but require a significant energy to ignite. The minimum ignition energy for surface ignition of various aluminum alloys is currently under investigation by WHA. Testing conducted to date indicates aluminum surface treatments/oxides are very adherent and protective of the underlying substrate and must be disrupted or compromised before ignition of the aluminum will occur.

[6] WHA experience indicates that aluminum alloys consistent with cylinder construction can develop between 7000 and 8000 calories per gram during combustion in high-pressure oxygen. This energy release, along with the very rapid rate of combustion for aluminum, would be expected to be more than sufficient to cause the melting of brass even in the thicknesses utilized for the cylinder valve.

[7] The term backflow is used to indicate a flow direction opposite the normal predominant flow, which in this case was into the cylinder since the cylinder was being filled at the time of the accident. Therefore, for a flow into the cylinder, the combustion event would produce a significant pressure rise in the cylinder and would backflow out of the cylinder, with respect to the initial flow into the cylinder.

Figures 27 and 28 depict the SEM/EDS analysis of the threaded portion of the cylinder valve inlet, just above where the melt/flow patterns were observed. As was observed on the melt/flow residue in the valve's inlet port, a significant amount of aluminum-oxide was observed on the remaining threads. This result was considered consistent with the burning of the threaded portion of the cylinder neck, with deposits of aluminum-oxide to the valve threads, prior to the valve being ejected energetically from the cylinder.

Chemical Analysis by FTIR:
Figures 29 through 34 provide a summary of the FTIR analysis of several components of the assembly. The analysis was performed in an effort to evaluate whether contaminants could be identified that would aid the determination of the fire's origin and cause. Solvent washes were obtained by on the upstream fill valve[8] (interior oxygen-wetted surfaces), the inside surfaces of the flexible hose, and a small portion of the fire-damaged oxygen cylinder at the extreme base of its inside surface. The infrared spectra of the solvent wash residue was compared to typical greases and plasticizers based on the stretch frequencies that were observed in the spectrographs.

All of the FTIR spectra obtained in the chemical analysis indicated that an aliphatic hydrocarbon (characteristic stretch frequencies between ~2700 to 2900 wavenumbers) was present in every analysis. Since the baseline analysis of the AK225 did not show these stretches the hydrocarbon absorbance wavelengths observed were clearly part of the residues removed from the solvent rinse procedures. The fill valve and the cylinder (Figures 31 and 34) provided the best spectra and are considered the most significant since they do not suffer from alternate explanations as does the flexible hose (see below).

Figures 29 and 30 depict FTIR spectra of the residue removed from the flexible hose. The characteristic stretch frequencies observed between 2700 to 2900 wavenumbers indicate the presence of an aliphatic hydrocarbon (C-H stretches); however, due to the nonmetallic liner of the flexible hose, a solvent rinse could yield some hydrocarbon-like spectra due to leaching of the plasticizer in its liner. The spectra of N-butylbenzenesulfonamide, which is a plasticizer typically used in Nylon polymers consistent with the Parker Parflex 520N-4 hose lining, was overlaid with the spectra from the solvent rinse of the flexhose as shown in Figure 30. Based on this data, the hose spectra could be consistent with plasticizer leaching during the AK225 (solvent) wash or could also be indicative of a hydrocarbon residue within the hose. Due to the potential for both explanations, no conclusions were drawn from the analysis of the flexible hose. It was noteworthy that other stretch frequencies were also present in the spectra; but, they were masked by the plasticizer absorbance such that firm conclusions could not be drawn about potential contaminants from the hose analysis alone.

Figures 31 through 34 show FTIR sprectra for the upstream fill valve wash and the swab of the interior base of the fire-damaged cylinder. Figures 31 through 33 were prepared to identify the very complex spectral appearance of the residue removed from the interior of the upstream fill valve and the cylinder. The spectra obtained indicated that several materials were involved and contributed to the spectral response both in the upstream valve and in the cylinder. It was concluded that the most likely explanation for all the frequencies observed was a mixture of compounds. Therefore, commonly used

[8]NOTE: The spectra labeled "downstream" fill valve was mislabeled. Please note this is the wash sample that was obtained while you (DOT) were present with me at NASA while we were doing the SEM/EDS work.

lubricants were compared to the spectra obtained and overlaid by adding the individual spectra electronically (see Figure 33). The spectra for dimethylsiloxane (silicone greases common to the diving industry), hydrocarbon greases/oils common to diving compressors, and perfluorinated lubricants (also common to Nitrox diving operations) provided matching absorbances in the spectra for both the fill valve and cylinder residue[9]. When the spectra of siloxane grease, perfluorinated grease, and hydrocarbon grease/oil were added electronically and overlaid with the fill valve flush, the spectrum was nearly identical to that of the fill valve (and cylinder) especially if weighting factors were included.

This result was consistent with the migration of all of these contaminants into the system components. Significantly, since both the upstream fill valve and the cylinder both indicated this mixture of compounds, a contaminated fill system at the dive shop was considered probable. It was especially noteworthy that the hydrocarbon elements of this mixture were clearly evident and were discovered in every sample analyzed. Experience indicates that if poor attention to maintaining cleanliness during handling, maintenance or cleaning for Nitrox service occurred, then cross-contamination from many sources including oil-lubricated compressors could easily result. The spectra obtained were consistent with a "dirty" (hydrocarbon contaminated) system at the dive shop.

Conclusions

Based on the investigation and analysis completed to date and the materials provided to WHA pertaining to the incident in Luraville, FL, the following conclusions have been developed:

1) The THERMO valve recovered several weeks after the accident was installed on the fire-damaged cylinder at the time of the incident. While this valve was recovered a distance away from the accident site after an extended duration, the fracture pattern morphology on the attached valve adaptor (compared to the fill valve), the combustion residue on the threads and body, the severe melt/flow indications around the inlet threads, and the backflow of aluminum-oxide into the valve carrying brass melt/slag are all consistent with this accident. Each of these considerations indicates that this valve was attached to the cylinder at the time of the fire and was energetically ejected under pressure from the cylinder when it ruptured while burning internally.

2) The origin of the fire in question cannot be pinpointed definitively due to the extensive burning associated with the upper neck and threads of the cylinder and the extensive combustion backflow prior to the cylinder's rupture. However, several considerations indicate that a probable region of origin was either within the upper neck of the cylinder itself or else in the threaded region of the cylinder valve where it attaches to the cylinder. The considerations below were noteworthy:

[9] The perfluorinated greases are generally required anytime Nitrox is used. Silicone greases are common to the diving industry so Dow Corning DC-111 (dimethylsiloxane), common to breathing air applications was used for comparison. Hydrocarbon greases/oils, never recommended for high-pressure oxygen equipment including Nitrox diving equipment, are nevertheless very common in air compressors and with equipment used to pump/provide compressed air.

a. The intact condition of the cylinder valve seat, albeit deteriorated, rules out an origin at this location. WHA experience indicates that the plastic seat of a cylinder valve of this design can ignite due to flow dynamics; however, had this occurred in the accident in question, the seat would have been consumed.

b. An ignition origin within the other components attached to the cylinder (i.e., fill valves and flexible hose) was also ruled out due to the absence of combustion evidence observed within their active elements.

c. The clear evidence of combustion backflow out of the cylinder and into the cylinder valve indicates that combustion overpressure developed in the early stages of the fire (after ignition and kindling of the aluminum) before the pressure system was compromised. This evidence indicates that a promoted ignition kindling chain developed to ignite the aluminum in the early stages of the fire's development and its energy was delivered to the upper neck area of the cylinder. All of the internal combustion within the cylinder was isolated to the upper neck and threads of the cylinder. Furthermore, other than the cylinder, the most significant mass loss due to combustion within the components analyzed was at the base of the cylinder valve associated with its threaded inlet port. The brass alloy used for the valve would require combustion of the aluminum in its proximity to melt in the manner observed; and, this combustion event would necessarily occur prior to the cylinder rupture and the valve being ejected. These considerations strongly support an origin in the near proximity to these components.

d. Since the aluminum cylinder would not be expected to ignite without a strong ignition mechanism or kindling chain the following considerations are noteworthy:

    i. Clear evidence of a hydrocarbon-based contaminant was identified in all of the components analyzed. Since this contaminant was discovered within both the upstream fill valve and on the internal surface of the fire-damaged cylinder, it is considered likely that the flexible hose spectra also contained this contaminant. Therefore, it is probable that the dive shop fill system was contaminated and that this hydrocarbon-based contaminant was migrating into the cylinder during the cylinder filling operation. Experience indicates that hydrocarbon contaminants are easily ignited due to even mild compression heating or flow dynamics. Further, these contaminants would be expected to deliver in excess of 10,000 cal/gram from combustion in oxygen and would be expected to kindle particulate[10] or thread debris which was finely divided. Once finely divided debris was

[10] Any accumulated particulate debris, especially aluminum particulate, would be expected to kindle readily due to hydrocarbon flash fire in oxygen. Since debris that is finely divided is significantly easier to ignite than bulk materials, this kindling chain would readily develop. Any debris inside the cylinder would be expected to accumulate in low spots and on the threads of the valve and cylinder.

kindled, promoted ignition of the bulk aluminum would be expected.

ii. At present, it is unknown whether the cylinder valve was equipped with a “dip-tube” at the time of the incident. It is noteworthy that many diving valves are equipped with such a tube. If a “dip-tube” were present at the time of the fire, then the ignition of surface contaminants within the tube would be expected to concentrate and direct the combustion energy into the cylinder neck proximity, where the aluminum combustion was concentrated. Further, if the dip-tube were crimped on its end and provided with side-drilled flow holes (as some are designed) then the combustion energy would be directed into the side walls of the upper neck of the cylinder for ignition of contaminants within the dip-tube[11].

These opinions and conclusions are based on the materials provided for our review and the inspections and testing completed to date. If further information becomes available, or further testing is requested, then I reserve the right to amend these opinions accordingly.

Sincerely,

Barry Newton

Barry Newton, BSME, PE
VP Research & Development
Wendell Hull & Associates, Inc.

[11] It is cautioned that the presence and design of any dip-tube is unknown at this time. Information received from DOT investigators indicated that the valve was understood to be commonly equipped with a dip tube. If a dip tube were installed, then the concentration of fire associated with the dip tube could have contributed to the ignition of the aluminum cylinder in an area where the combustion energy would be concentrated near the cylinder neck. It is also noteworthy that dip tubes are components in normal function that reduce the particle impact hazards to downstream components during gas discharge from the cylinder, and as such are recommended for use in this application.

Figure 1: As-Received Condition of Components

Figure 2: DOT 3AL Cylinder Rupture

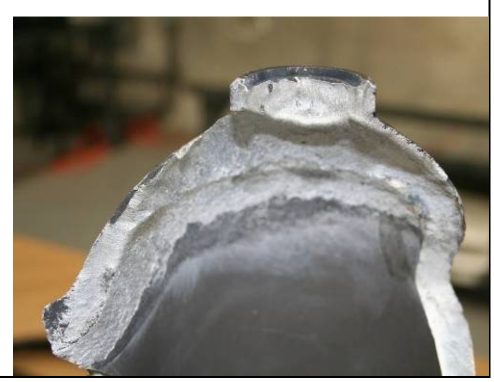


Figure 3: Downstream Fill Valve
(Sherwood Date Code 0503)

Figure 4: Fractured Condition of the Fill Adaptor (connected to cylinder valve) and Fill Valve

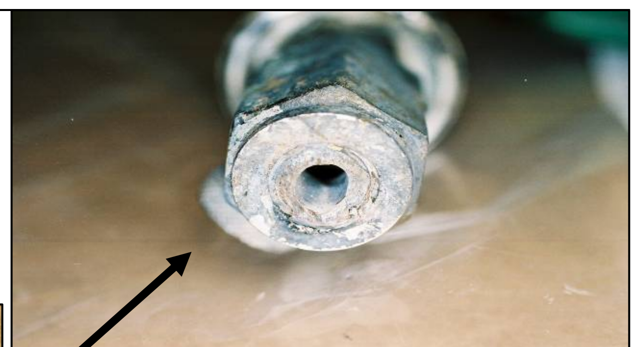


Figure 5: Downstream Fill Valve and CV Adaptor Fitting
(Dimension Comparison of Fracture Surfaces)

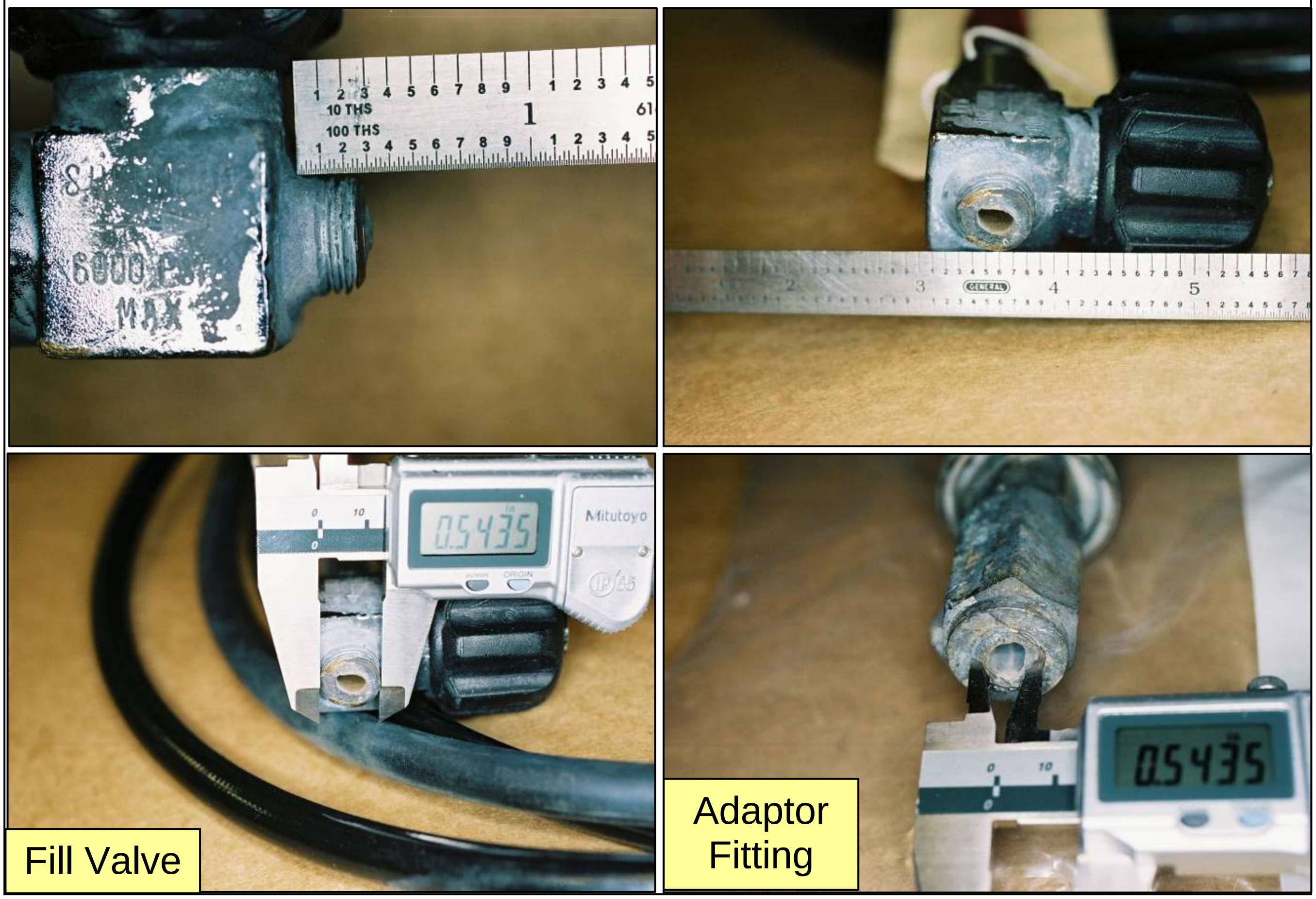


Figure 6 – Fracture Surface Comparison between Downstream Fill Valve
Fracture and Cylinder Valve Adaptor Fitting
(left – top focus; right – bottom focus)

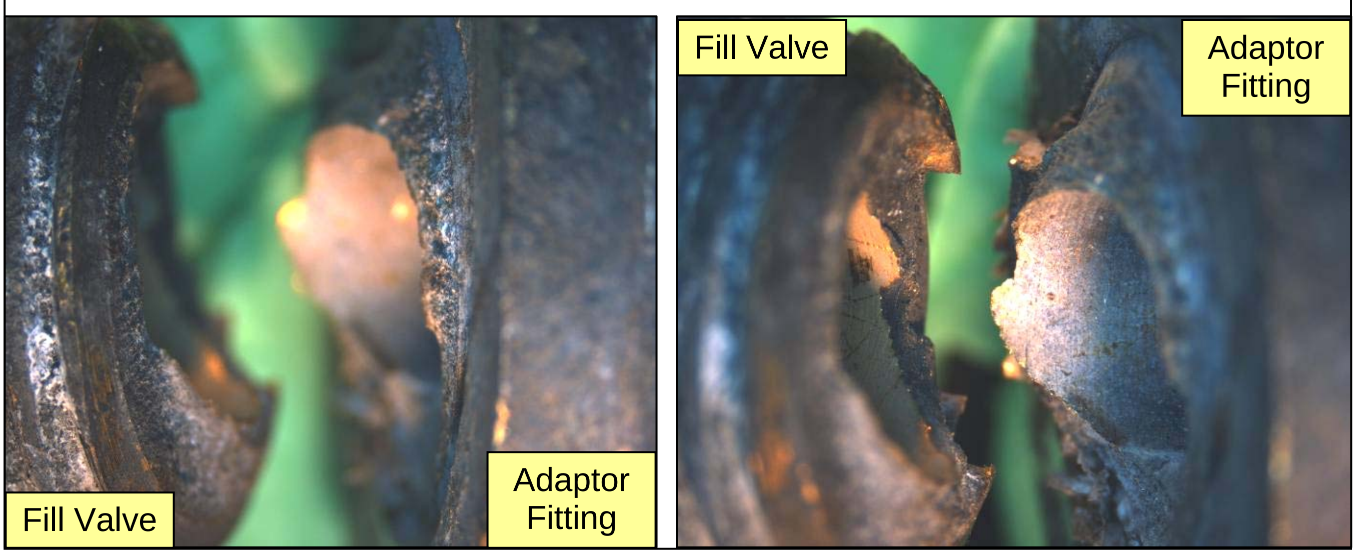


Figure 7 - Downstream Fill Valve Thread Fracture

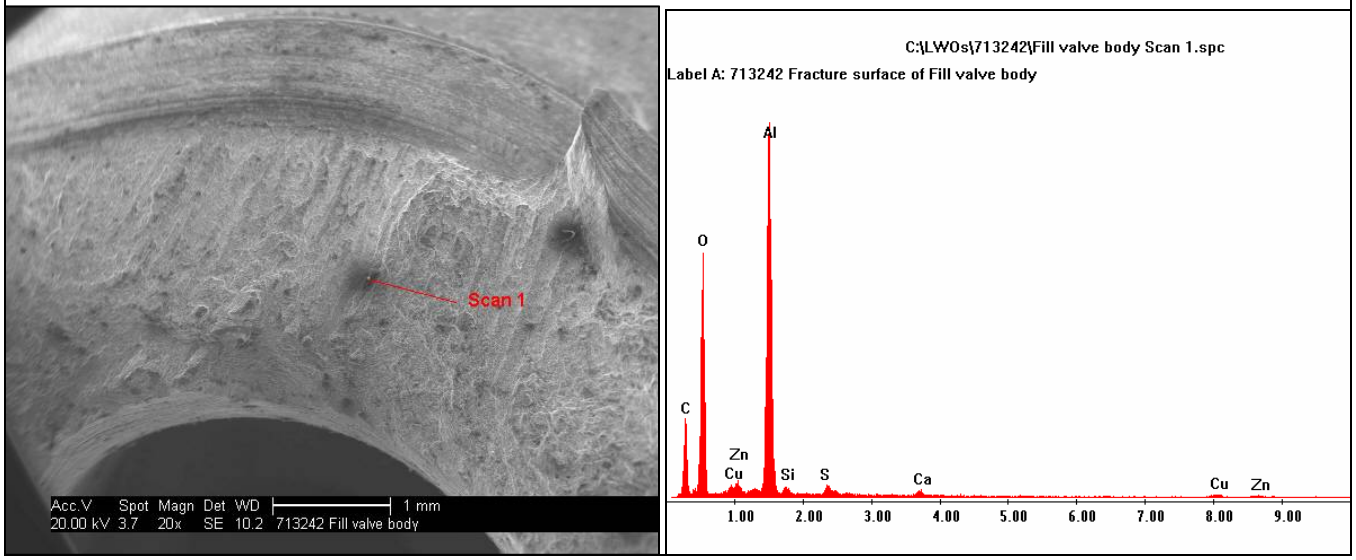
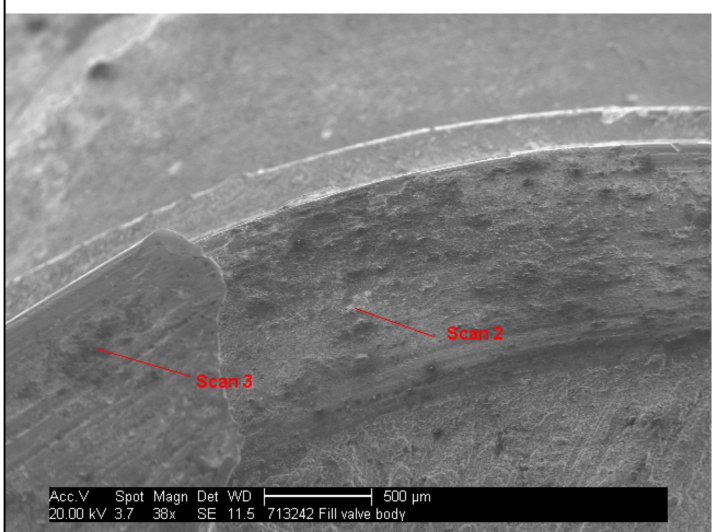


Figure 8 – Downstream Fill Valve
Fracture Surface



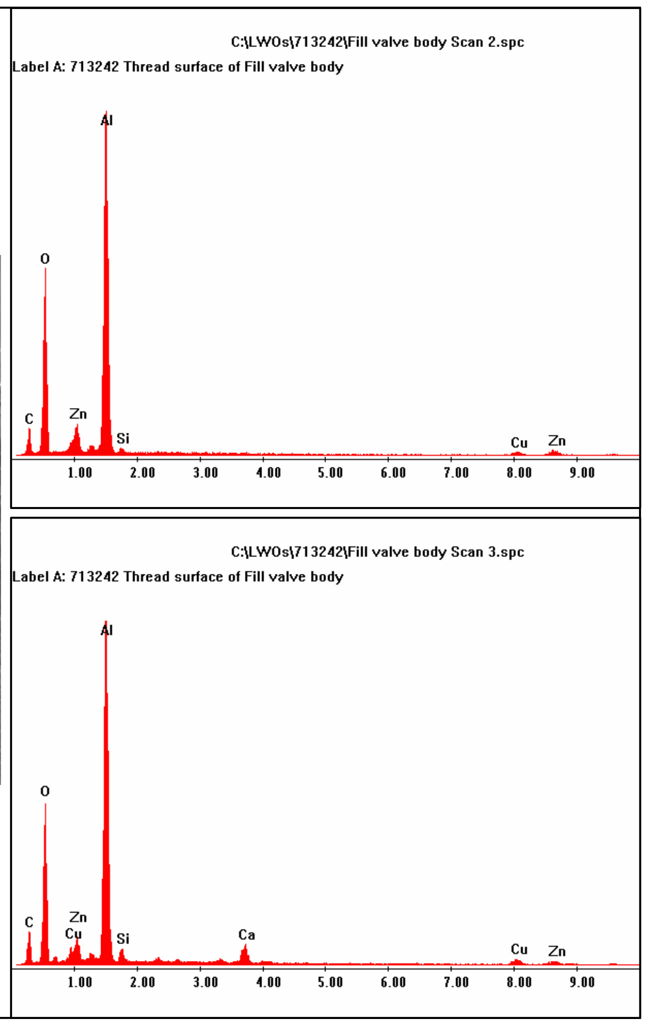


Figure 9 – Fracture Comparison (10X Magnification)

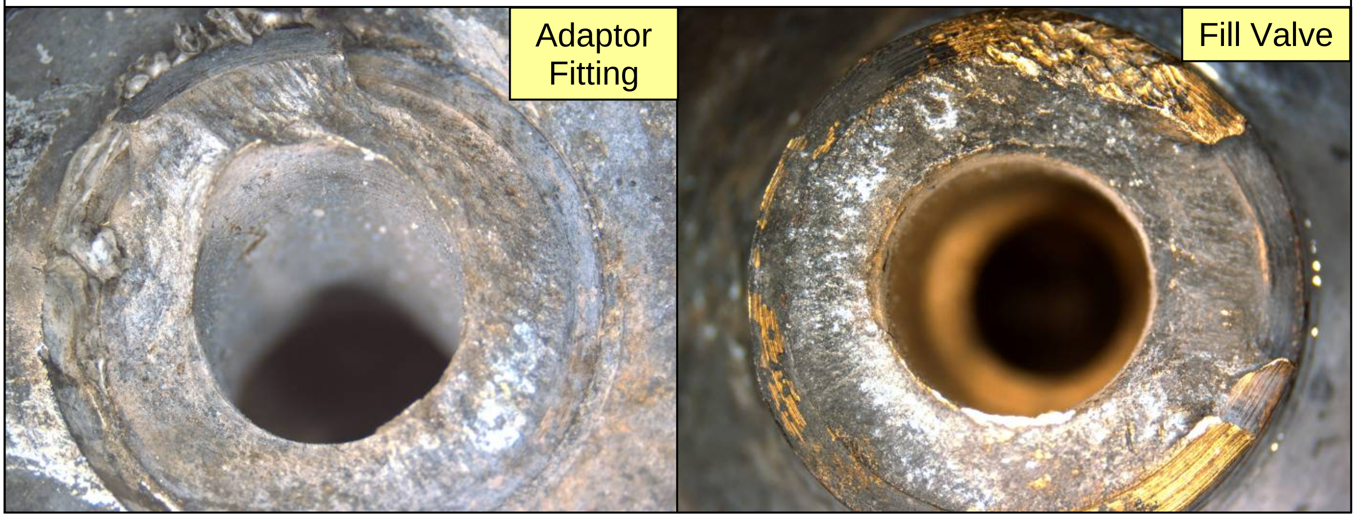
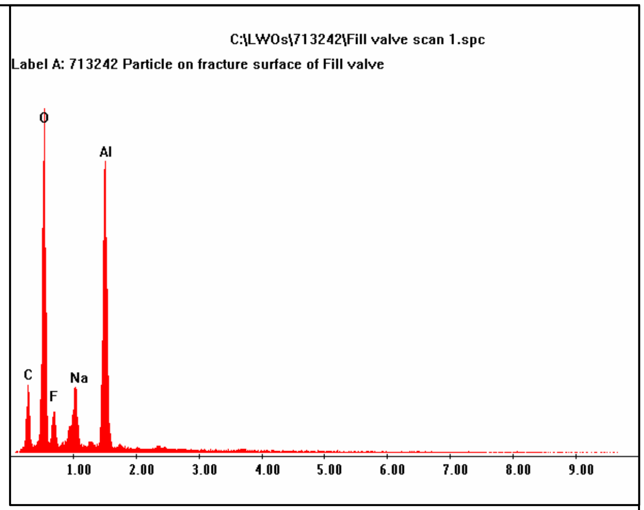


Figure 10: Adaptor Fitting Fracture Surface



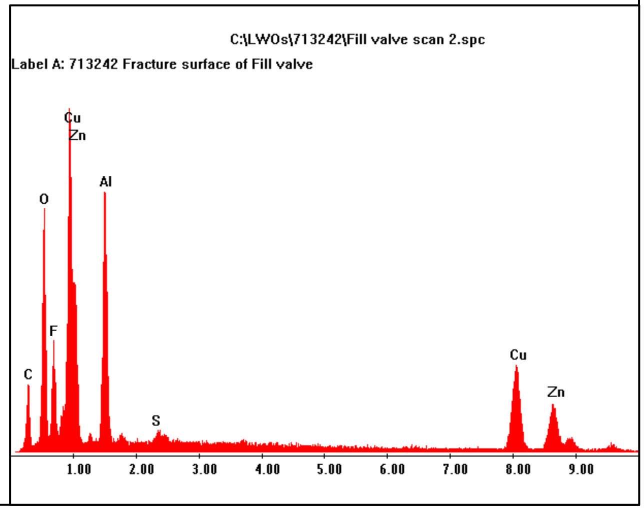


Figure 11 - Adaptor Fitting Fracture Surface

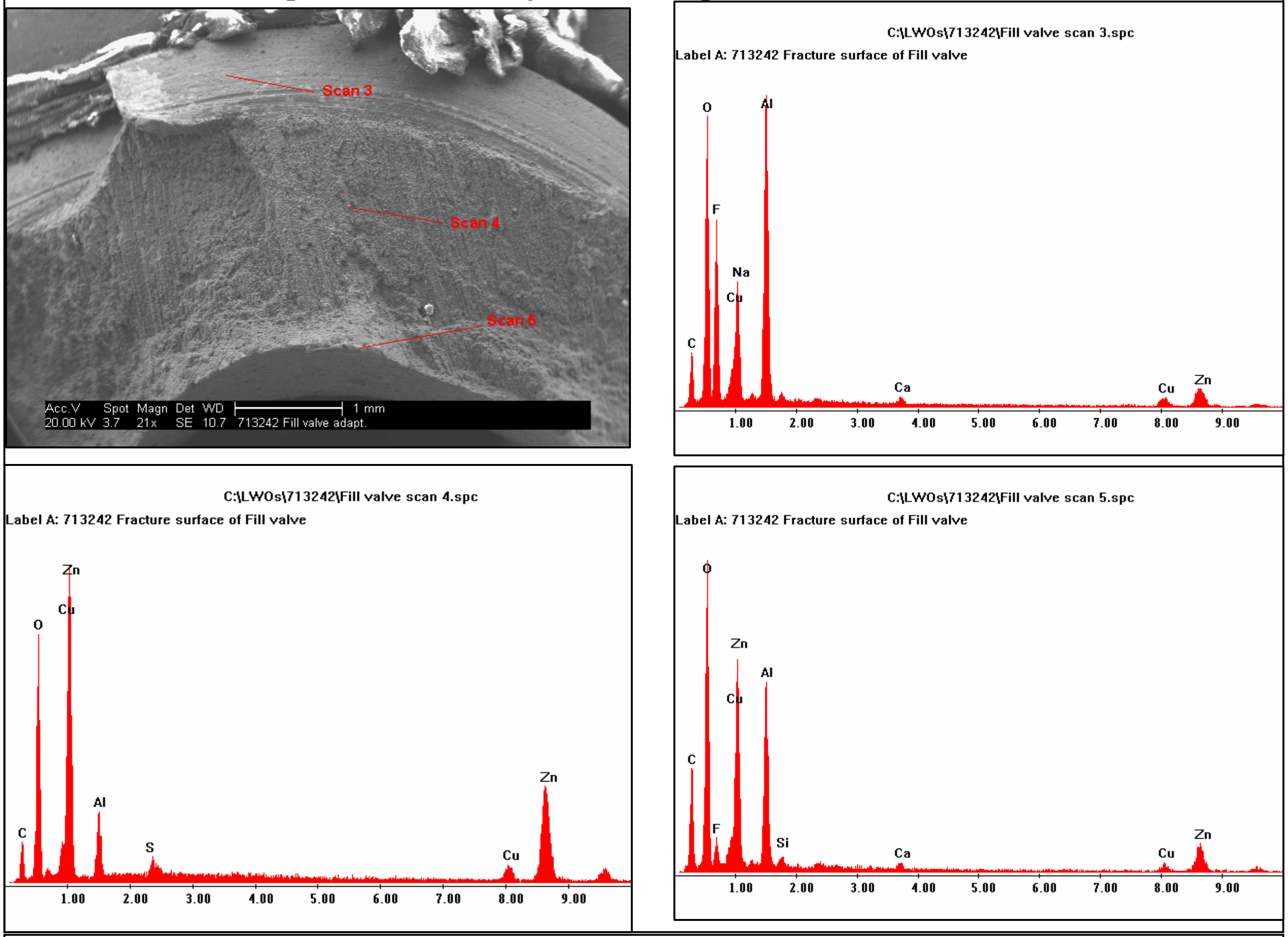
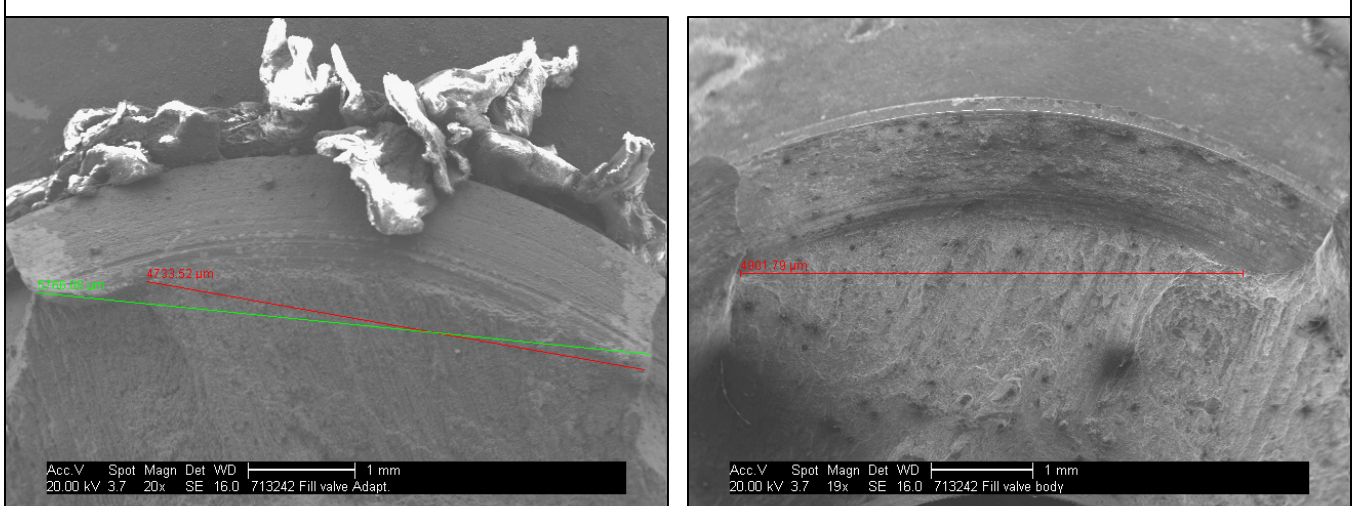


Figure 12 - Thread Root Comparison



Adaptor Fitting Fracture
(4733.5 & 5766.1 microns = 4.7 & 5.8 mm)

Fill Valve Thread Fracture
(4901.79 microns = 4.9 mm)

Figure 13: Upstream Fill Valve Condition
(Sherwood Date Code 4302)

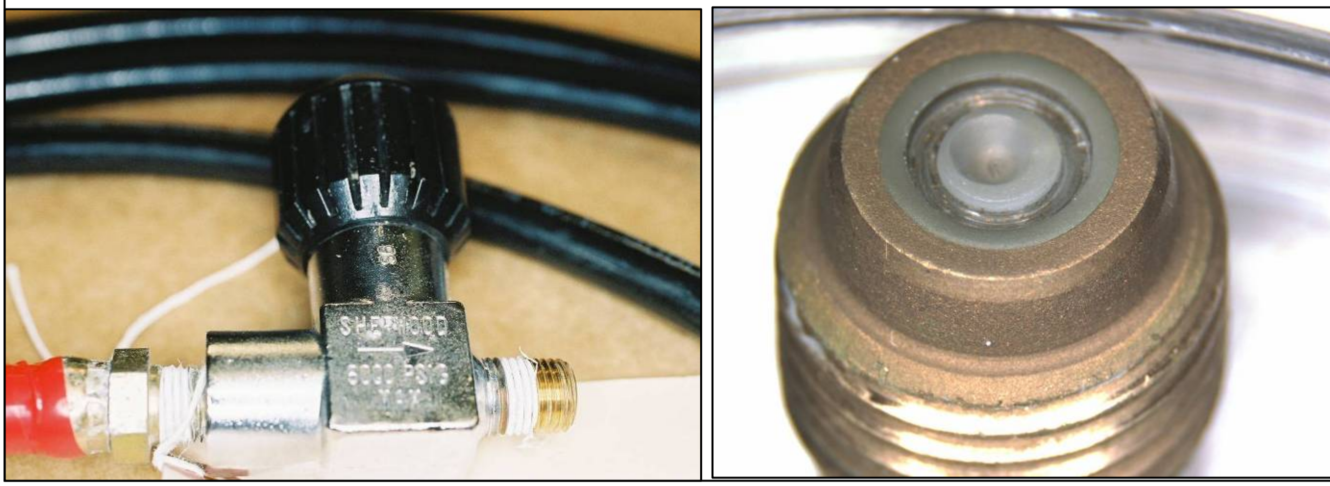


Figure 14 – Downstream Fill Valve
(Sherwood Date Code 0503)

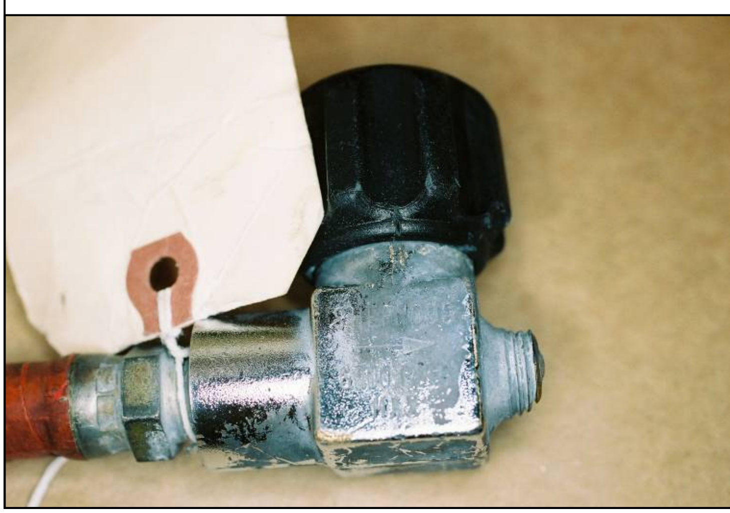


Figure 15 – Downstream Fill Valve Disassembly

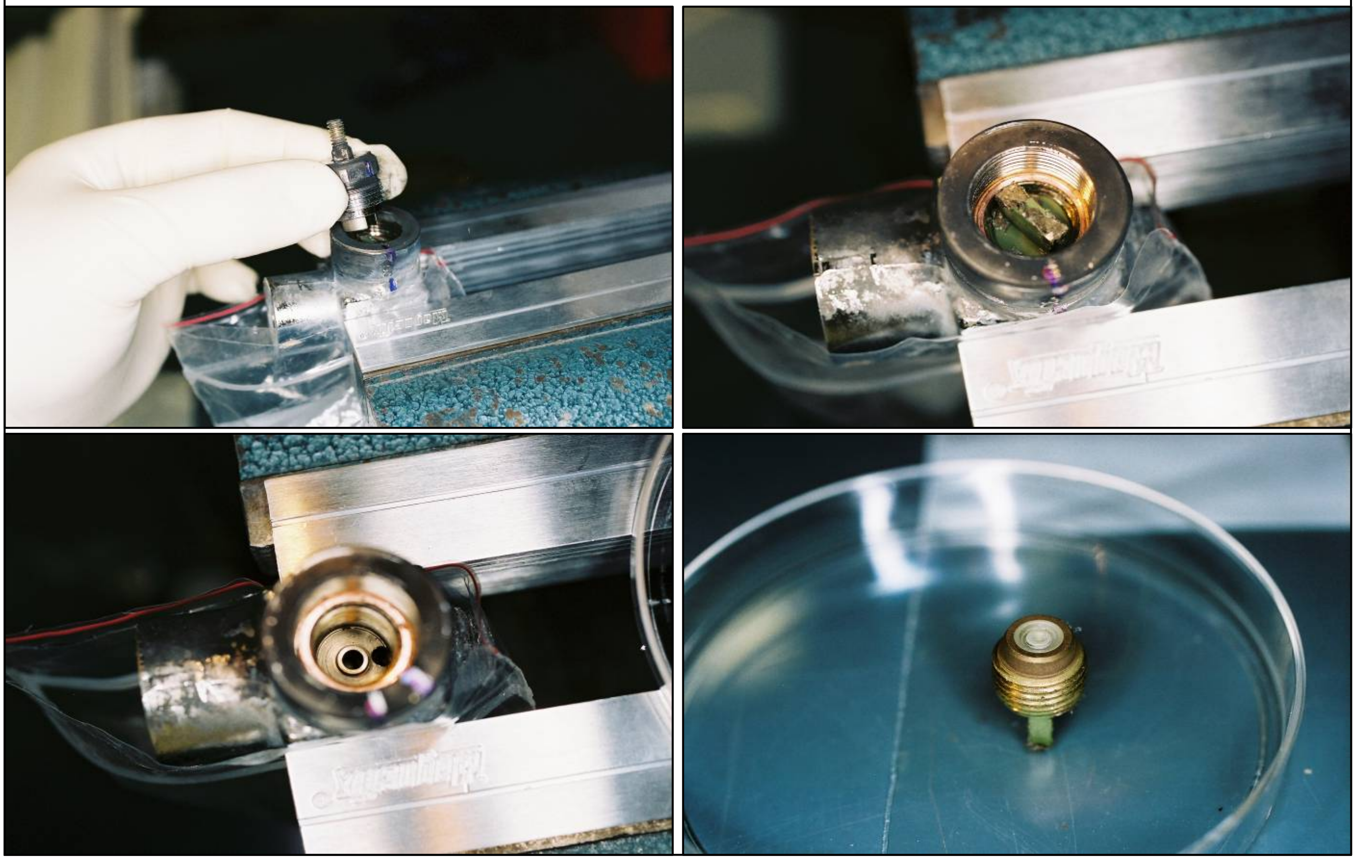
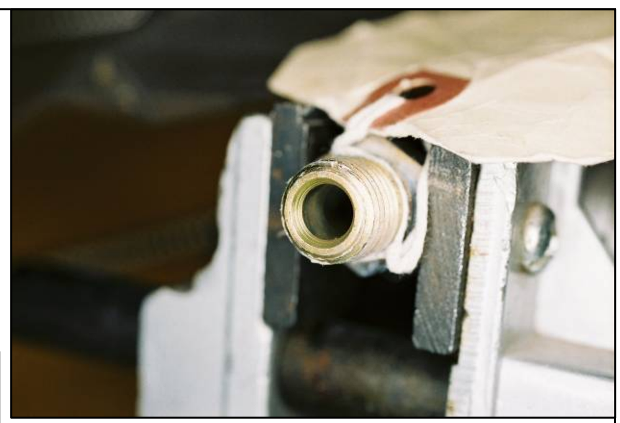
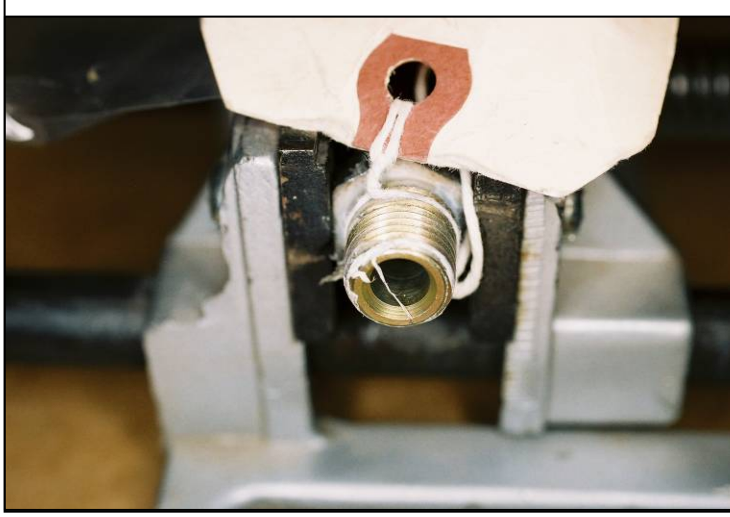


Figure 16 – Flexible Hose Fitting Attached to Downstream Fill Valve





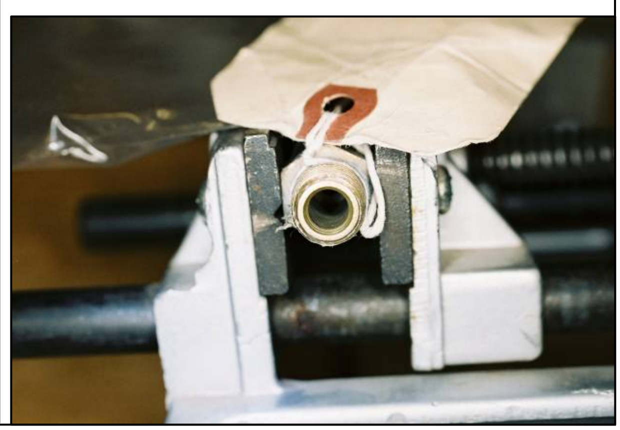
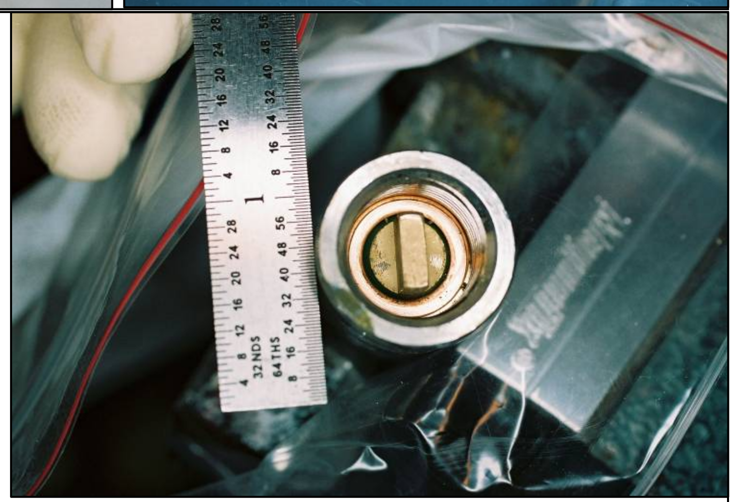
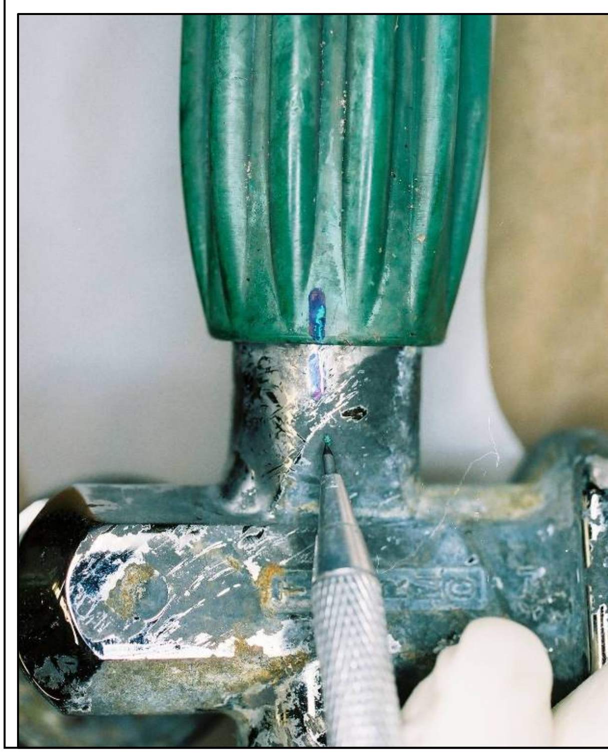


Figure 17 – Cylinder Valve Adaptor Fitting Bleed Valve Disassembly

Figure 18 – Cylinder Valve Disassembly





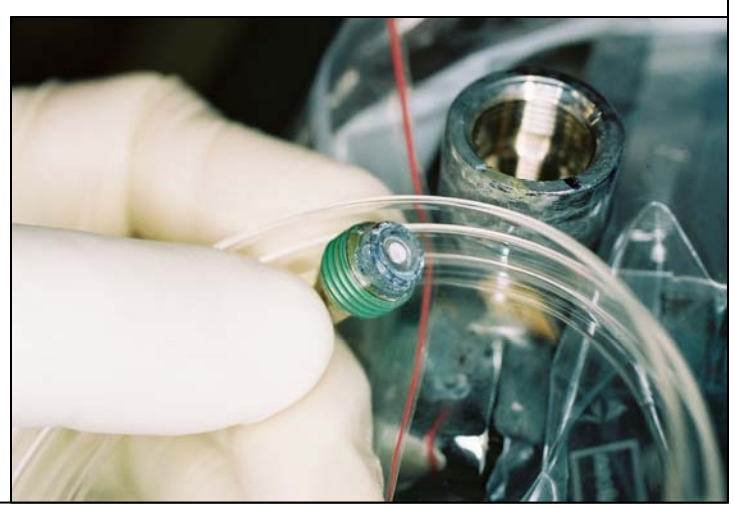
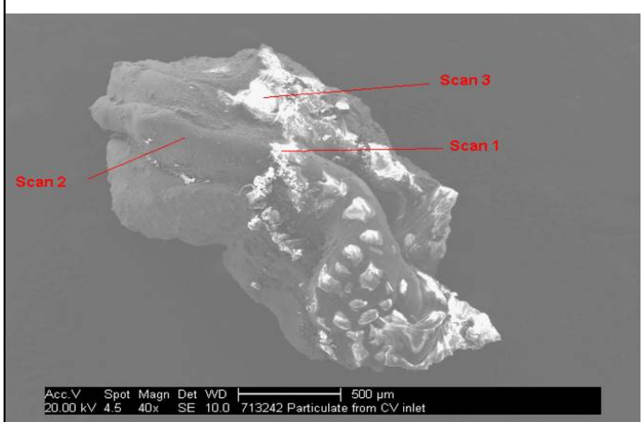
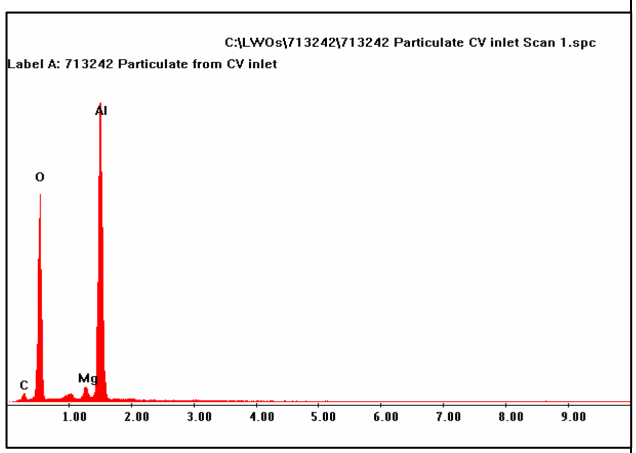
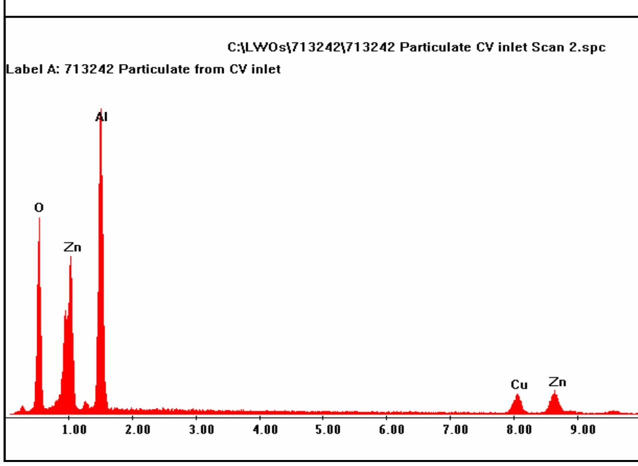


Figure 19 – Cylinder Valve Inlet Debris

Figure 20 - Particulate Residue Removed From Cylinder Valve Inlet Bore







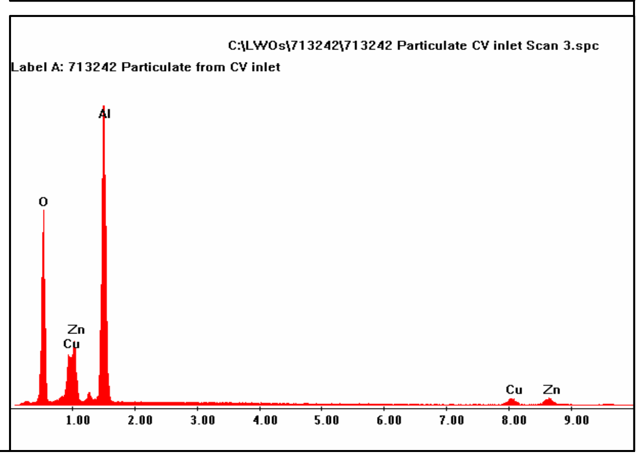


Figure 21 – Cylinder Valve Outlet Condition (Debris Collection)

Figure 22 – Cylinder Valve Adaptor and CV Outlet Condition

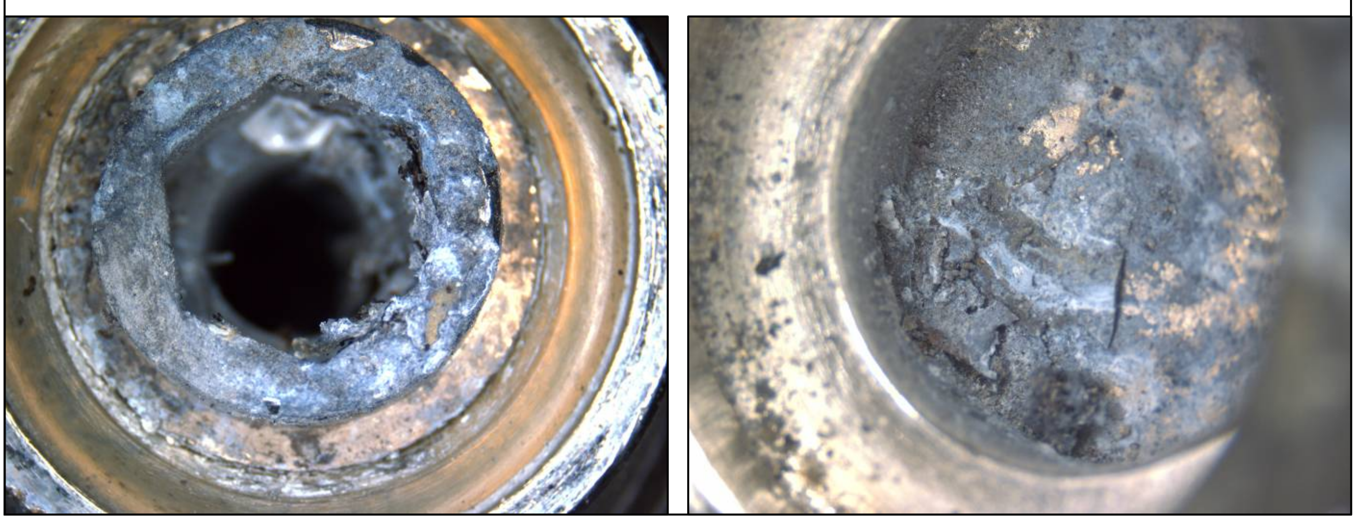
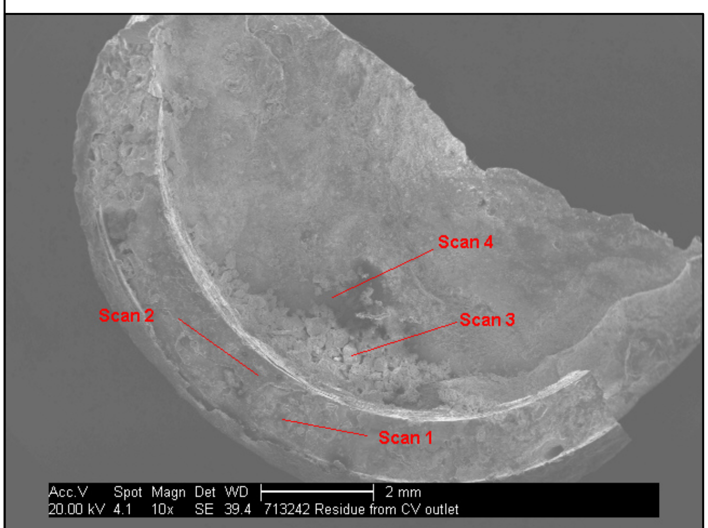


Figure 23 – Debris Recovered From Cylinder Valve Outlet

Figure 24 - Residue Removed from Cylinder Valve Outlet



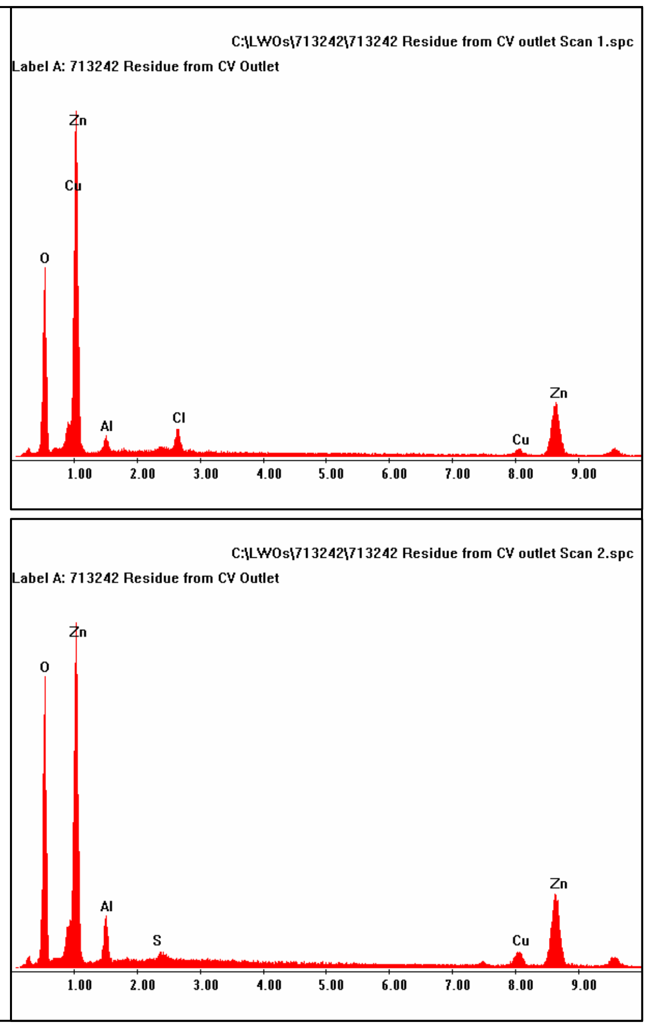


Figure 25 - Residue Removed from Cylinder Valve Outlet
(scans 3 and 4)

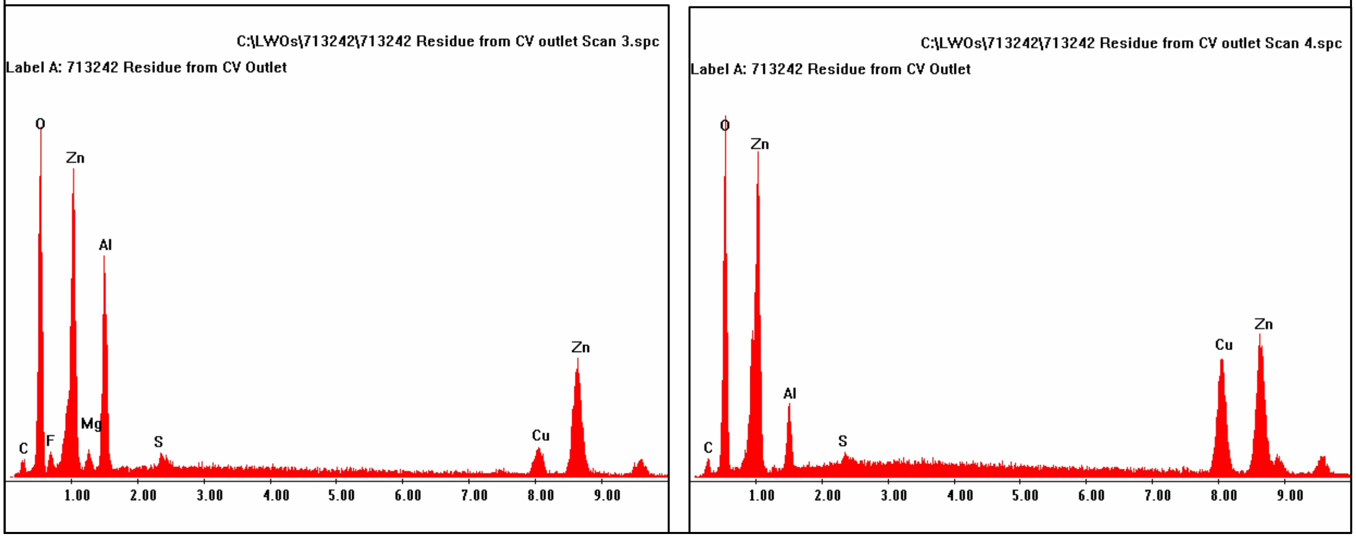
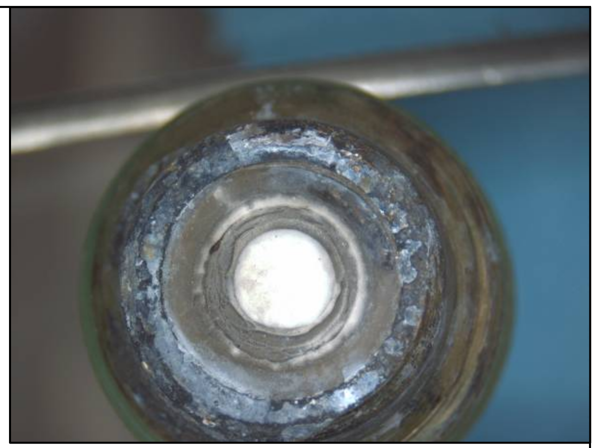


Figure 26 – Cylinder Valve Seat and Nozzle Condition



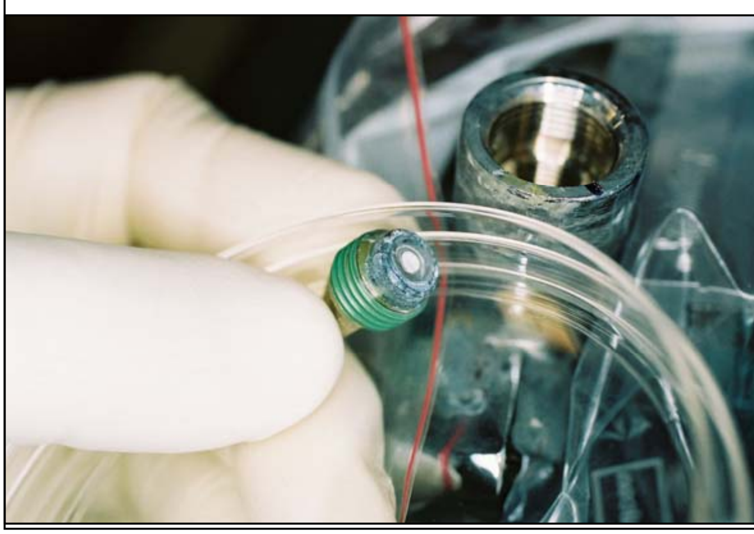
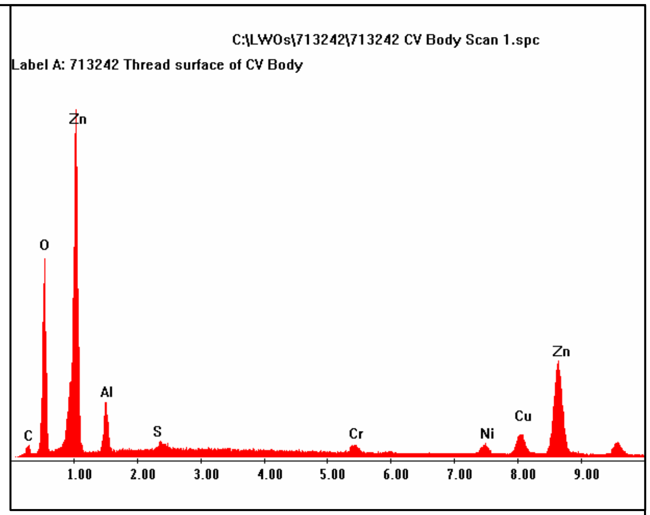


Figure 27 - Cylinder Valve Body Thread Residue



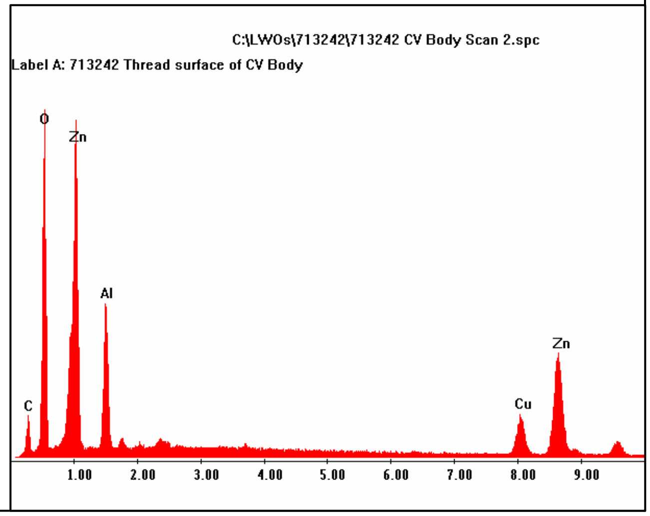
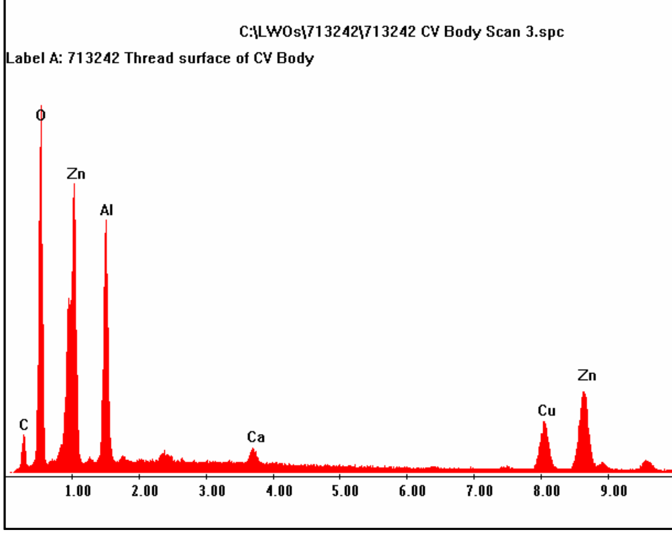


Figure 28 - Cylinder Valve Body Thread Residue
(scans 3 and 4)



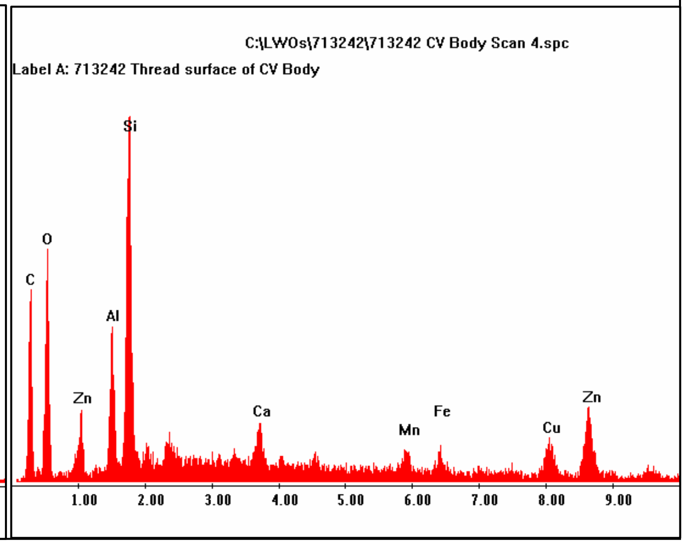


Figure 29 - FTIR of Flexhose Residue
(Internal surface washed with AK225 Solvent)

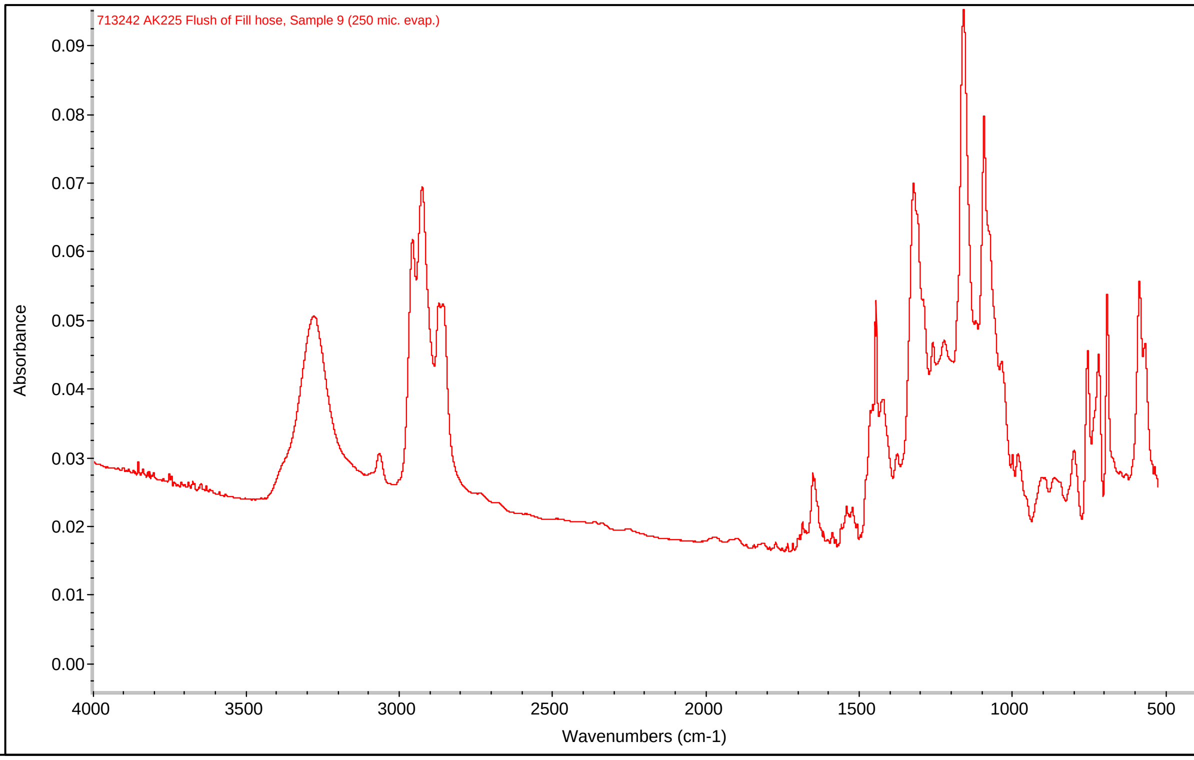


Figure 30 - Comparison FTIR Spectra of Flexhose Flush
and Typical Plasticizer

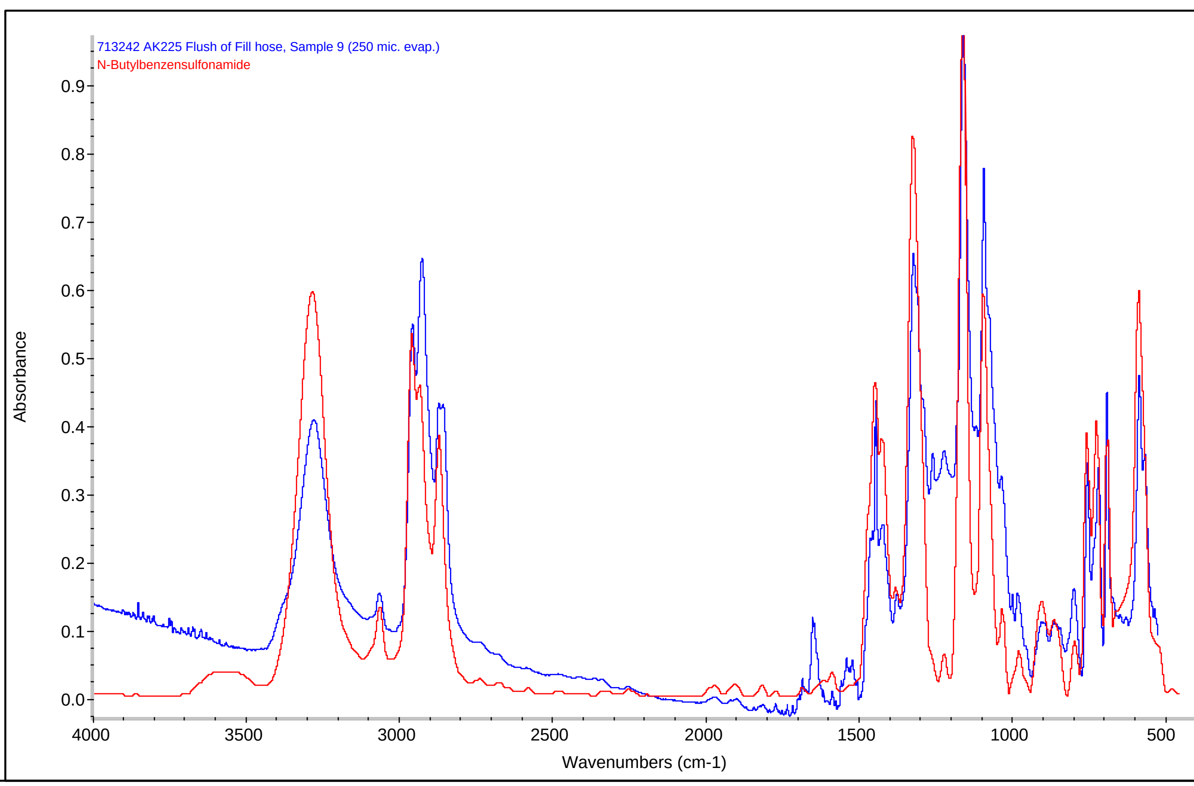


Figure 31 - FTIR of Internal Surface of Upstream Fill Valve
(surface washed with AK225 solvent)

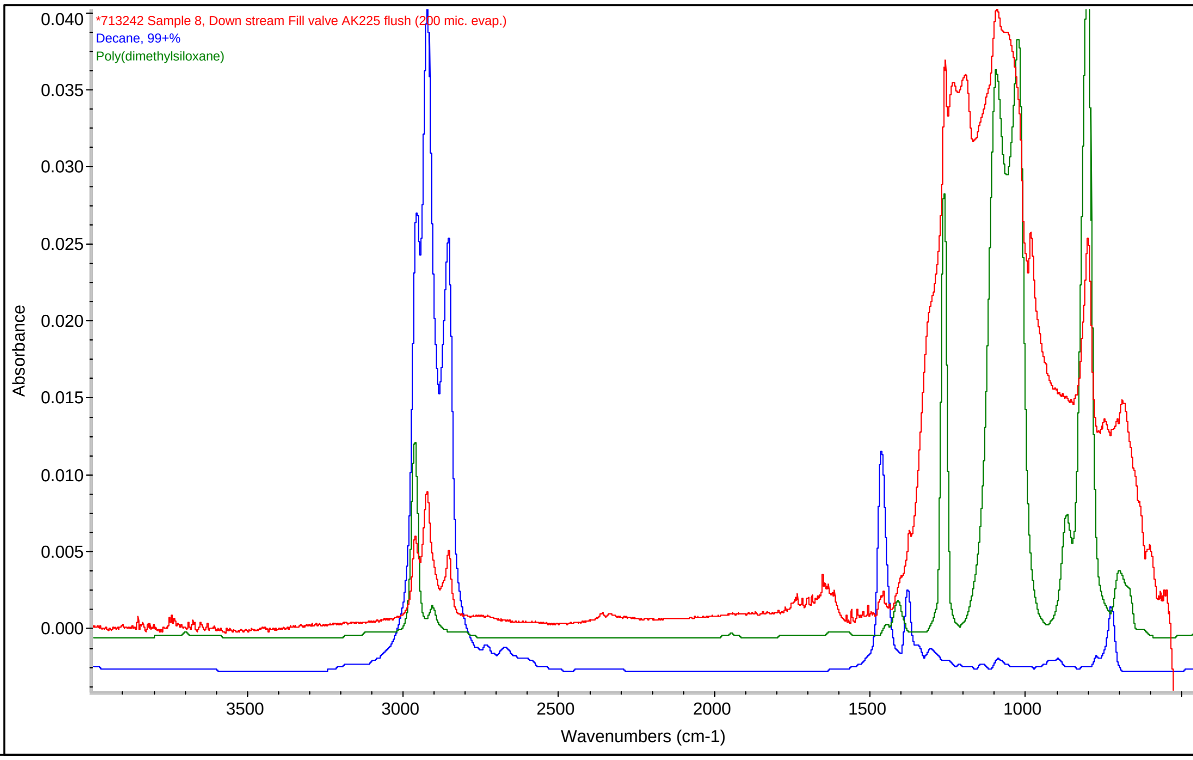


Figure 32 - Comparison FTIR Spectra of Upstream Fill Valve and Lubricant Composite
(Lubricant composite spectra comprised silicone oil, hydrocarbon oil, and fluorinated grease spectra added digitally)

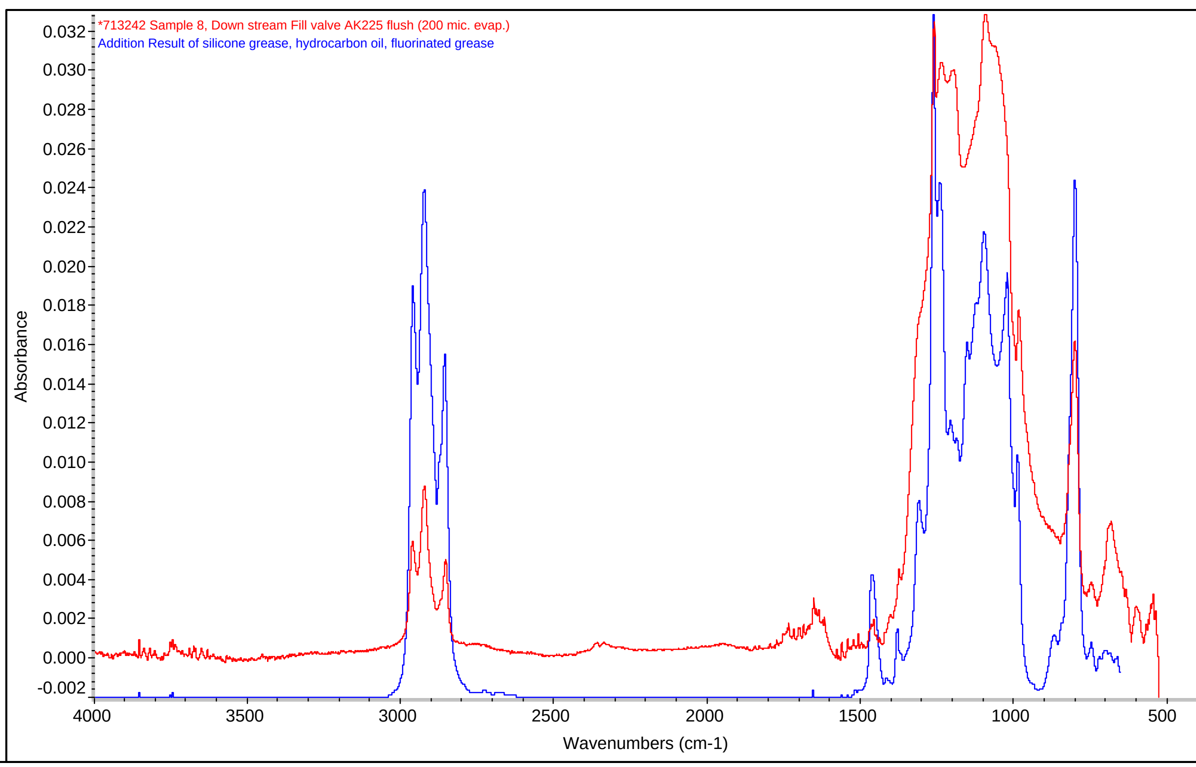
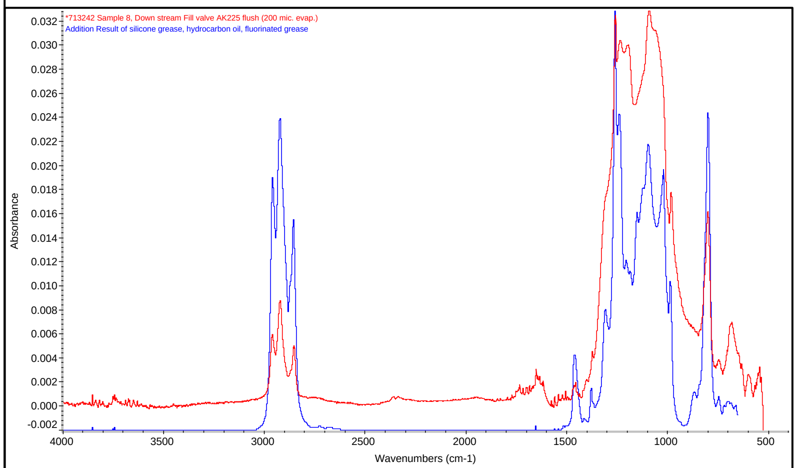
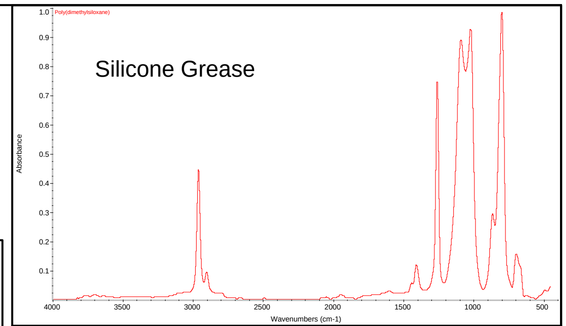
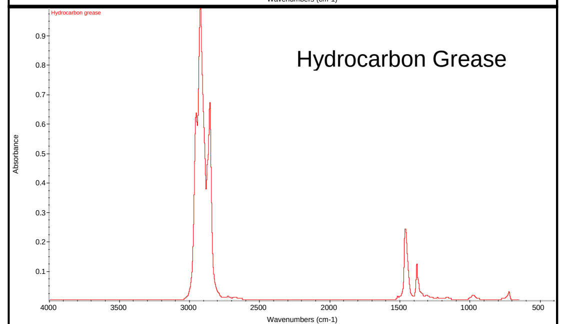


Figure 33 - Upstream Fill Valve FTIR Spectra Compared to Grease Addition Spectra







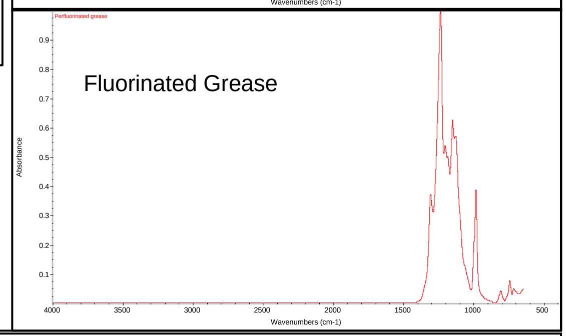
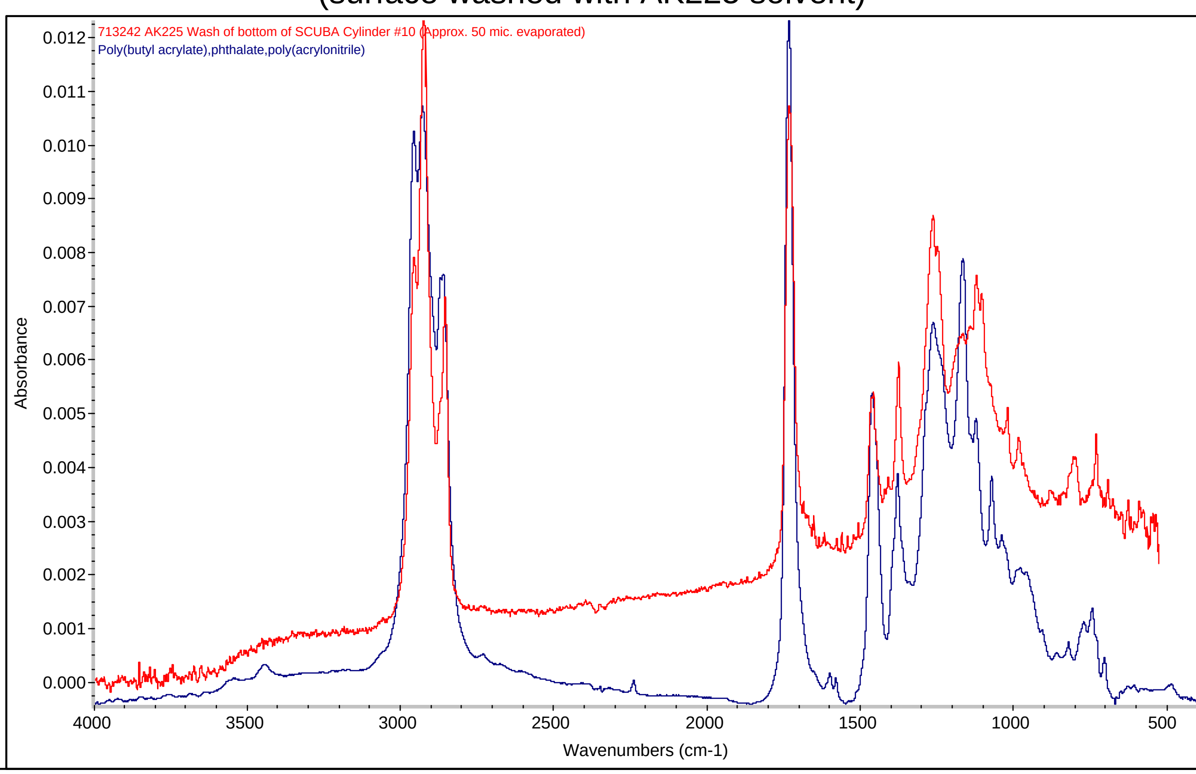


Figure 34 - FTIR on Cylinder Internal Surface
(surface washed with AK225 solvent)



Attachments

Attachment 1: WHA Photographic Documentation
- Receiving Inspection
- Cylinder Valve Analysis
- Disassembly Sequence
- Microscope Photos
  - Upstream Fill Valve
  - Fill Hose
  - Downstream Fill Valve
  - CV Adaptor Bleed Valve
  - Fill Adaptor
  - Cylinder Valve (CV) Outlet
  - CV Seat and Nozzle
  - CV Seat Interface
  - Cylinder Valve
  - CV Burst Disk

Attachment 2: Exemplar SCBA Fill Components

Attachment 3: Protocol for Disassembly and Testing to Determine a Root Cause of the DOT 3AL Cylinder Failure in Luraville, FL

Attachment 4: Sign-in sheet for the WHA disassembly conducted on May 10, 2006

Attachment 5: WHA disassembly notes and measurements

Attachment 6: FTIR and SEM/EDS Conducted at NASA-WSTF on May 11, 2006
- FTIR Analysis Results:
  - Solvent Wash of the Flexible Hose
  - Solvent Wash of the Interior Surfaces of the Upstream Fill Valve
  - Solvent Wash of a Portion of the Bottom Surface of the Cylinder
- SEM/EDS Analysis Results:
  - Cylinder Valve Body Thread Residue
  - Particulate Residue Removed from Cylinder Valve Inlet Bore
  - Residue Removed from Cylinder Valve Outlet
  - Downstream Fill Valve Fracture Surfaces
  - Fill Valve Adaptor Fracture Surfaces
  - Thread Root Comparison Features for Fill Valve and Adaptor

Attachment 1: WHA Photographic Documentation

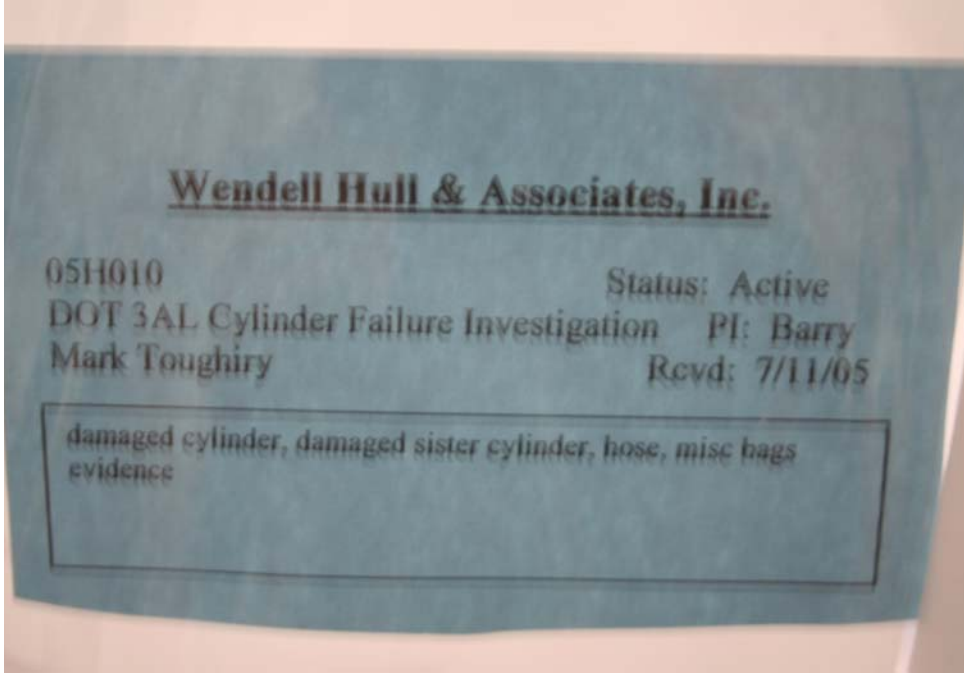
Receiving Inspection

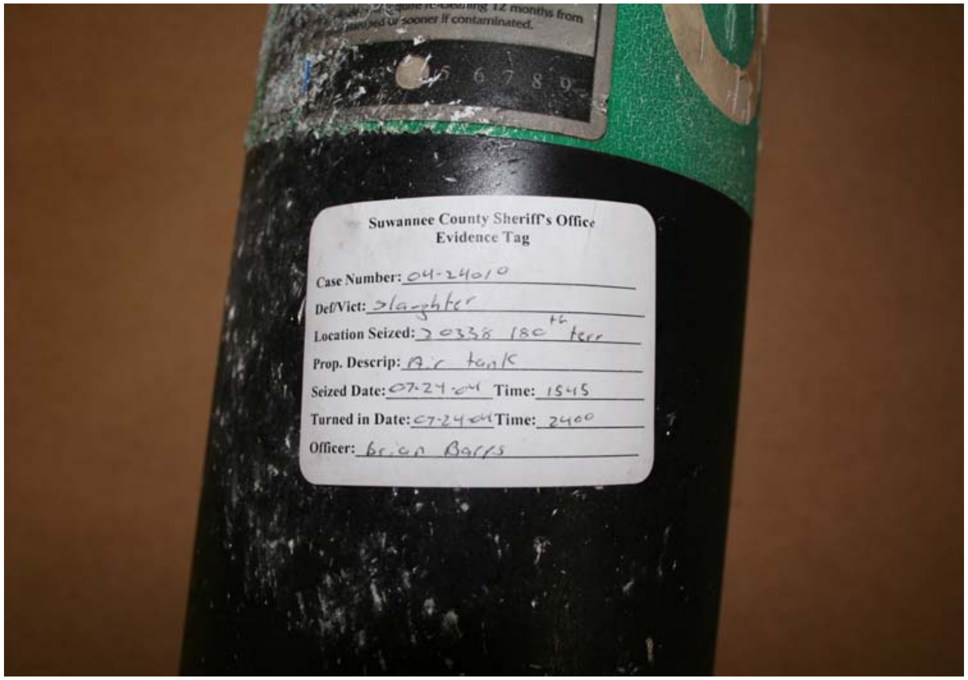
Cylinder Valve Analysis

Disassembly Sequence

Microscope Photos

- Upstream Fill Valve
- Fill Hose
- Downstream Fill Valve
- CV Adaptor Bleed Valve
- Fill Adaptor
- Cylinder Valve (CV) Outlet
- CV Seat and Nozzle
- CV Seat Interface
- Cylinder Valve
- CV Burst Disk


Wendell Hull & Associates, Inc.
05H010
Status: Active
DOT 3AL Cylinder Failure Investigation
PI: Barry
Mark Toughiry
Rcvd: 7/11/05
damaged cylinder, damaged sister cylinder, hose, misc bags evidence


Suwannee County Sheriff's Office
Evidence Tag
Case Number: 04-24010
Def/Vict: slaughter
Location Seized: 20338 180th terr
Prop. Descrip: Air tank
Seized Date: 07-24-04 Time: 1545
Turned in Date: 07-24-04 Time: 2400
Officer: brian Barrs

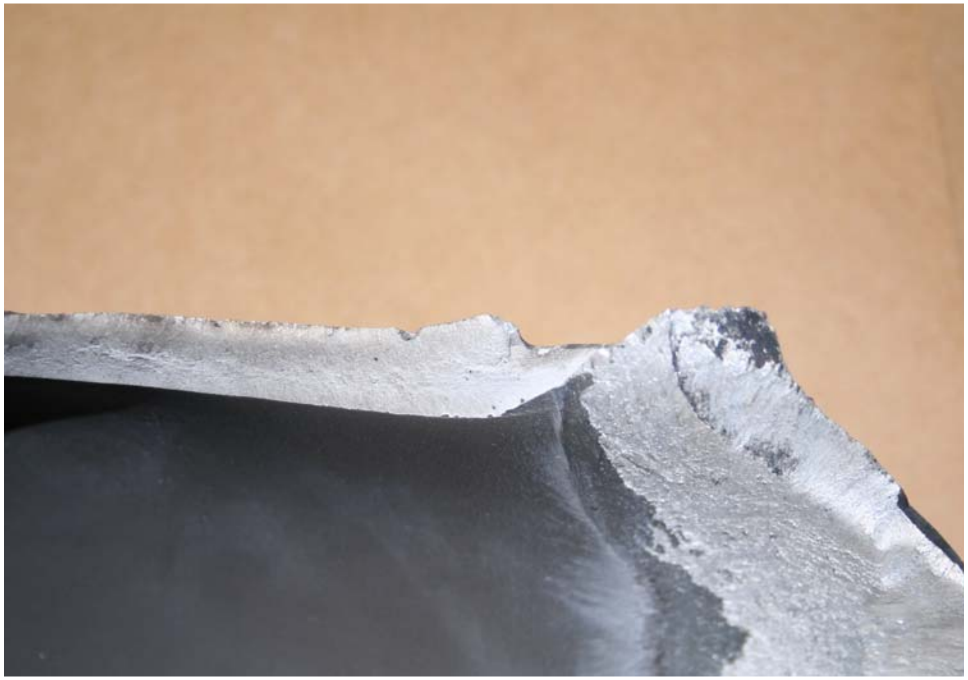
RECEIVING INSPECTION

RECEIVING INSPECTION




RECEIVING INSPECTION

RECEIVING INSPECTION



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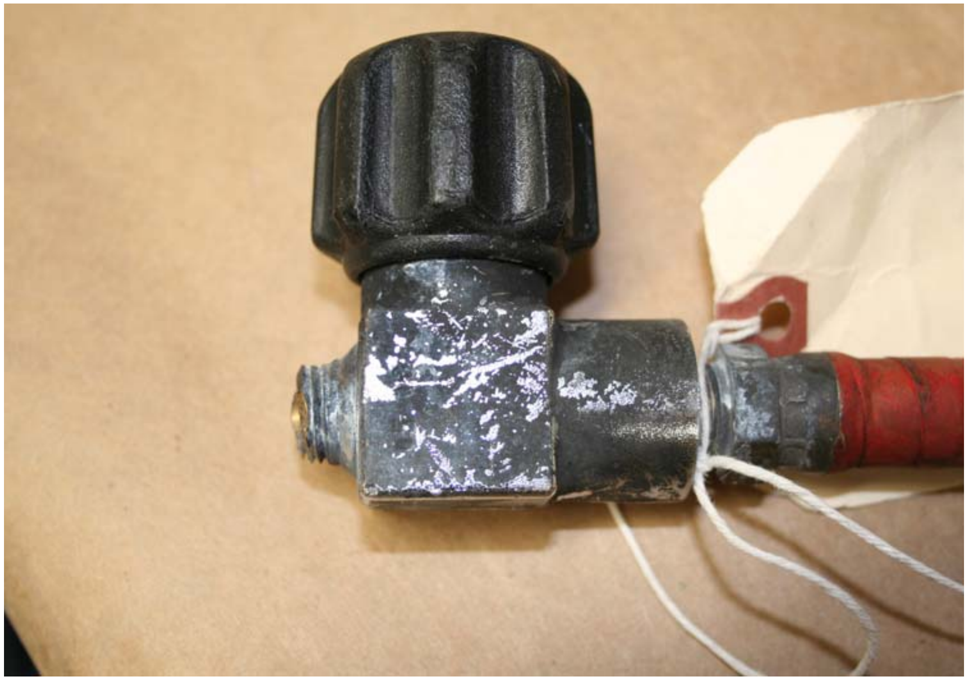
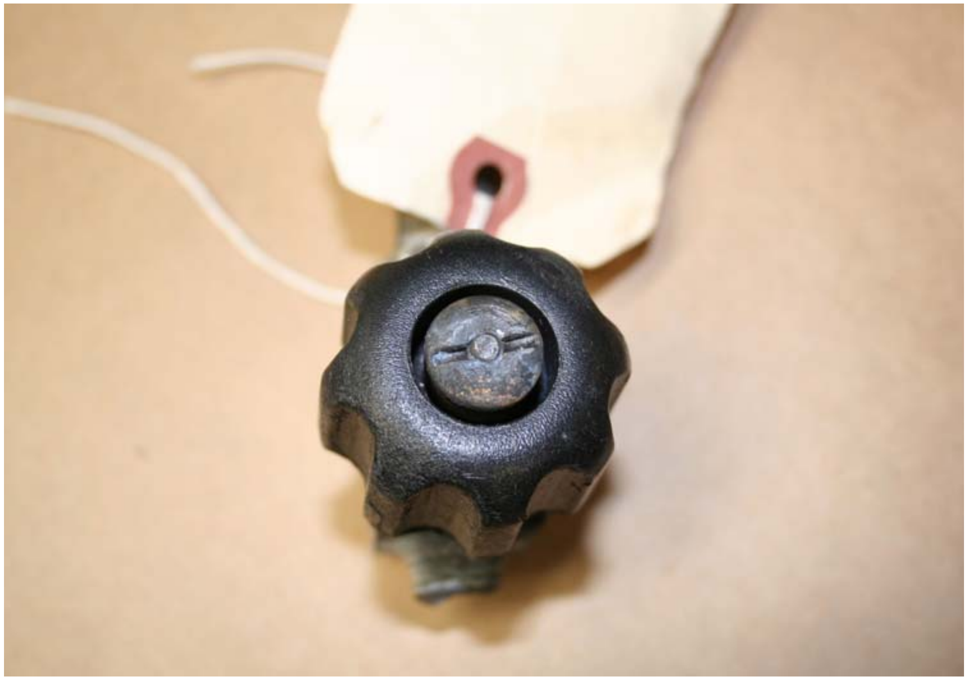
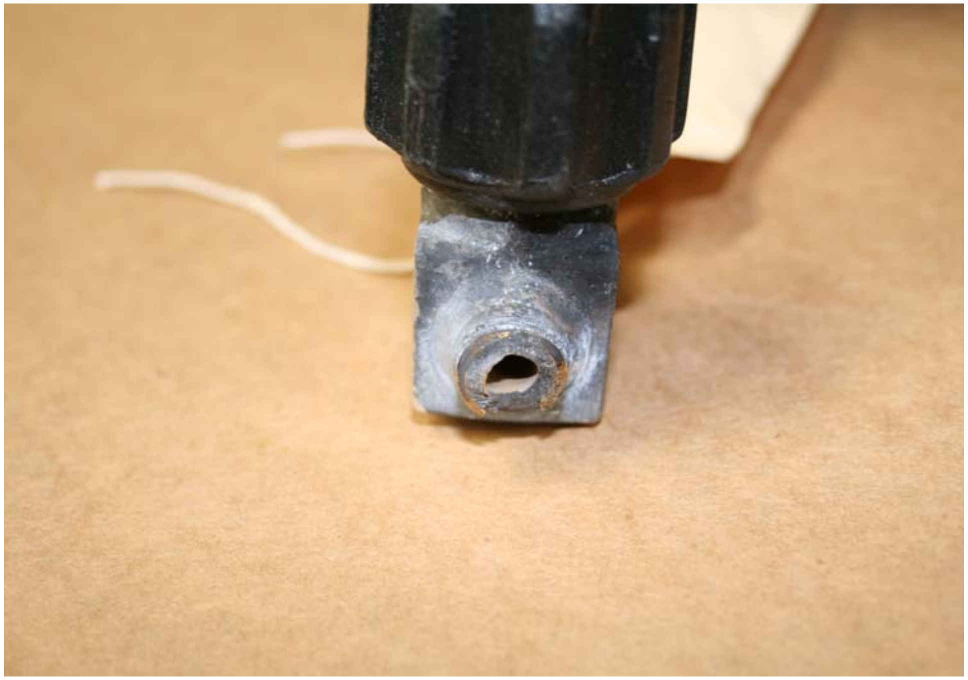
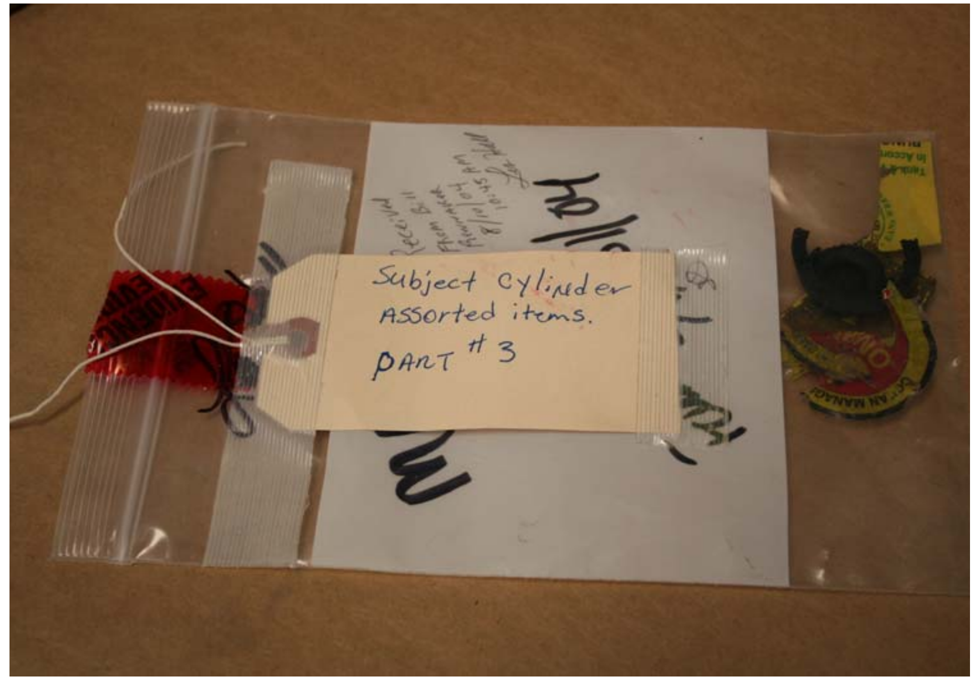







Subject Cylinder
Assorted items.
PART #3


Tank &
In Accord
ved Grade of Gas

CYLINDER VALVE ANALYSIS

CYLINDER VALVE ANALYSIS

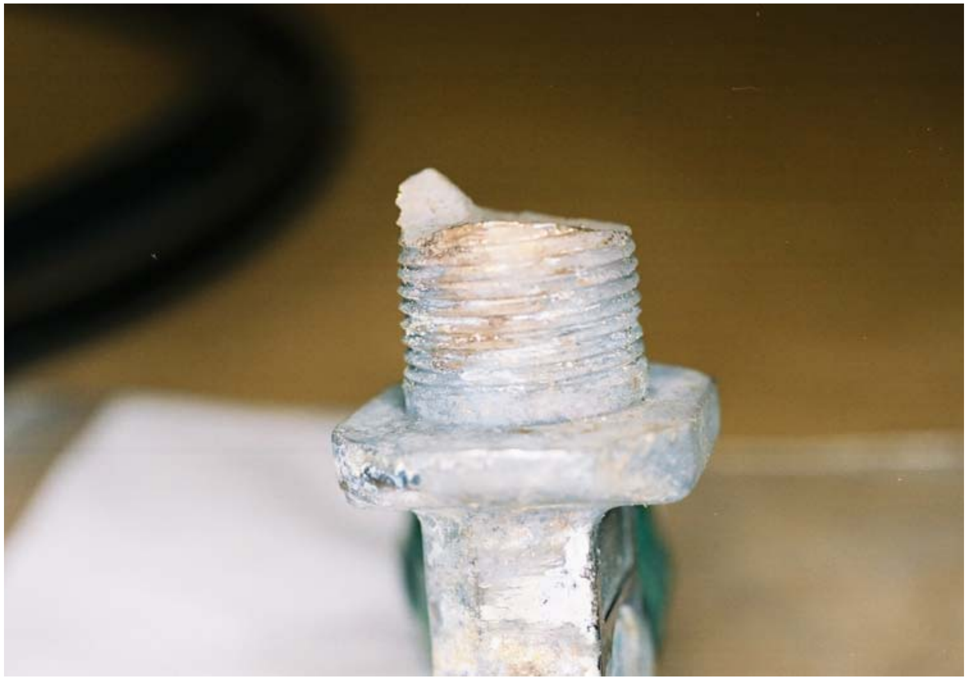
CYLINDER VALVE ANALYSIS

CYLINDER VALVE ANALYSIS

CYLINDER VALVE ANALYSIS

CYLINDER VALVE ANALYSIS

CYLINDER VALVE ANALYSIS



CYLINDER VALVE ANALYSIS

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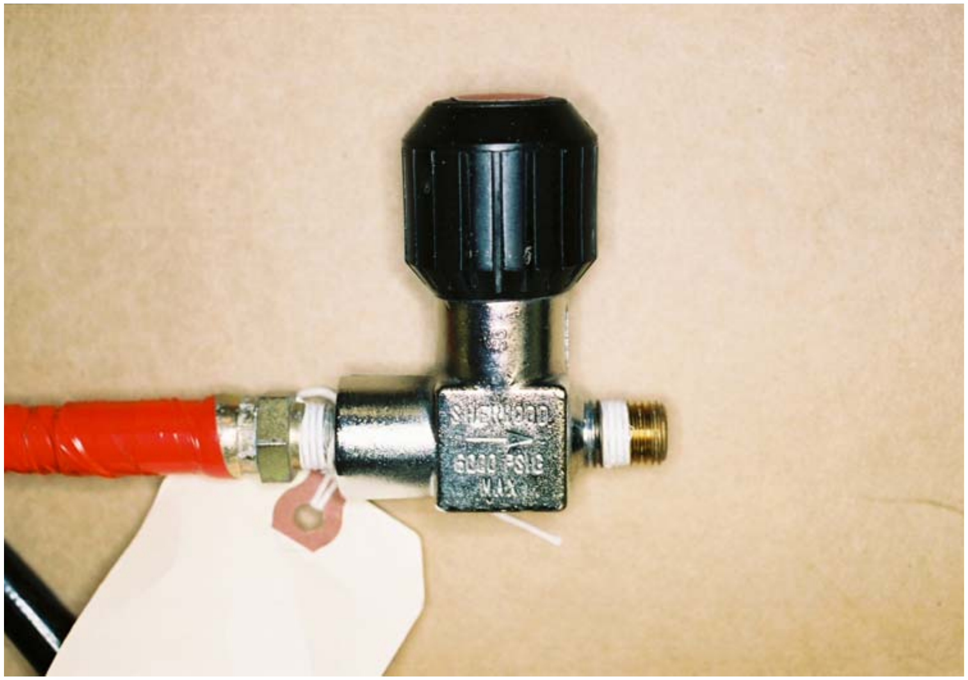
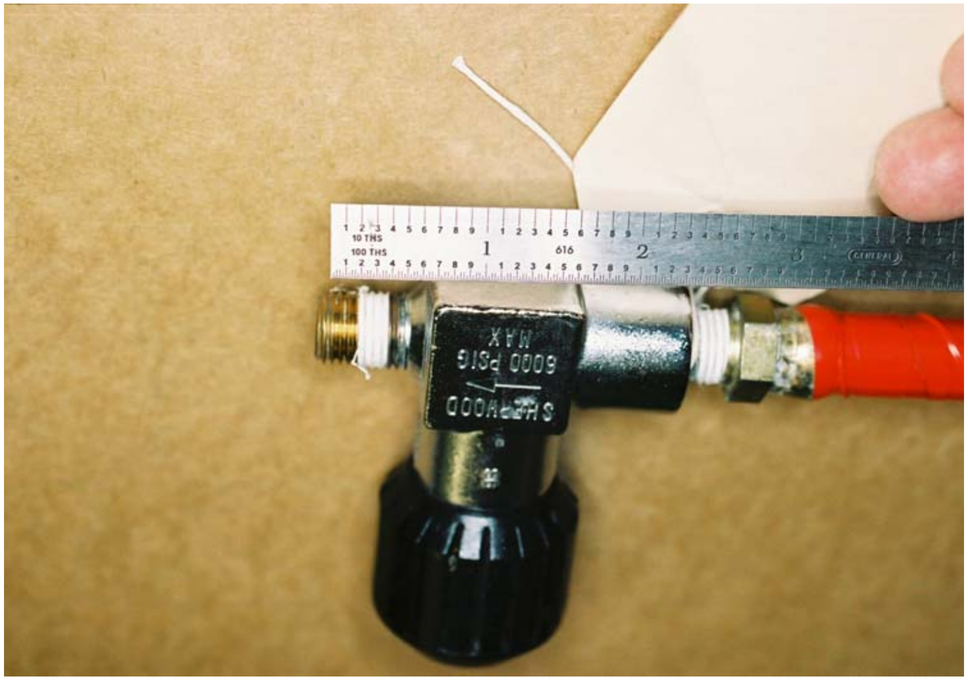


CYLINDER VALVE ANALYSIS



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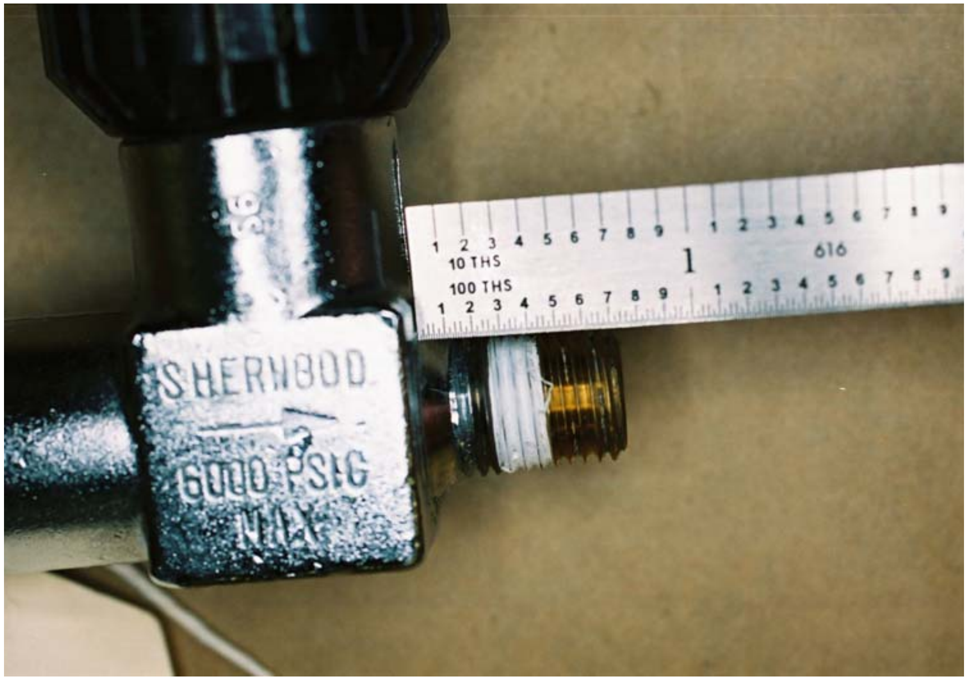

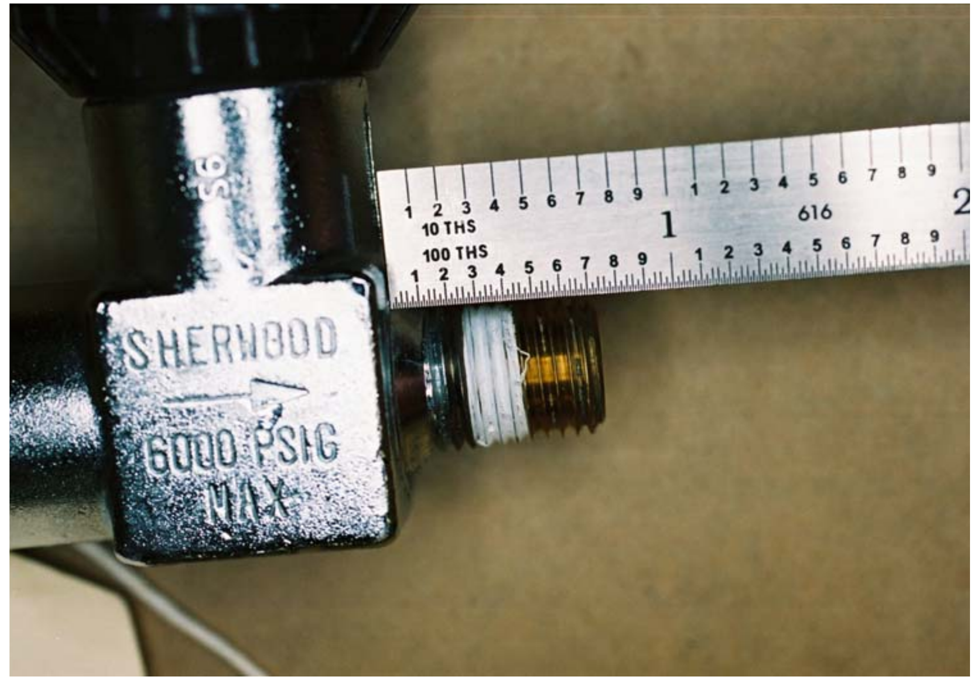

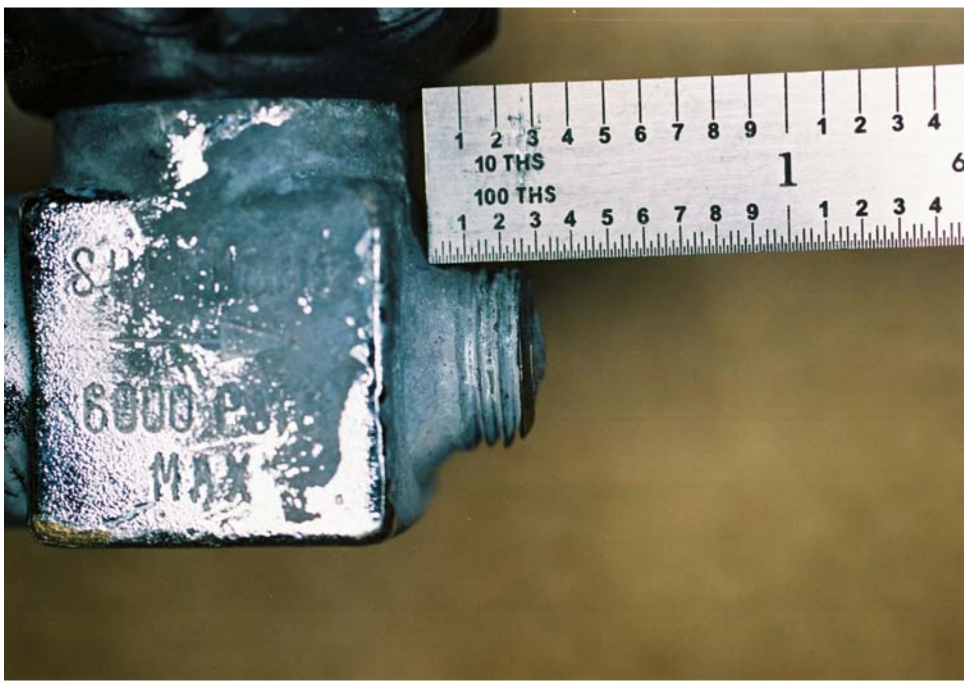

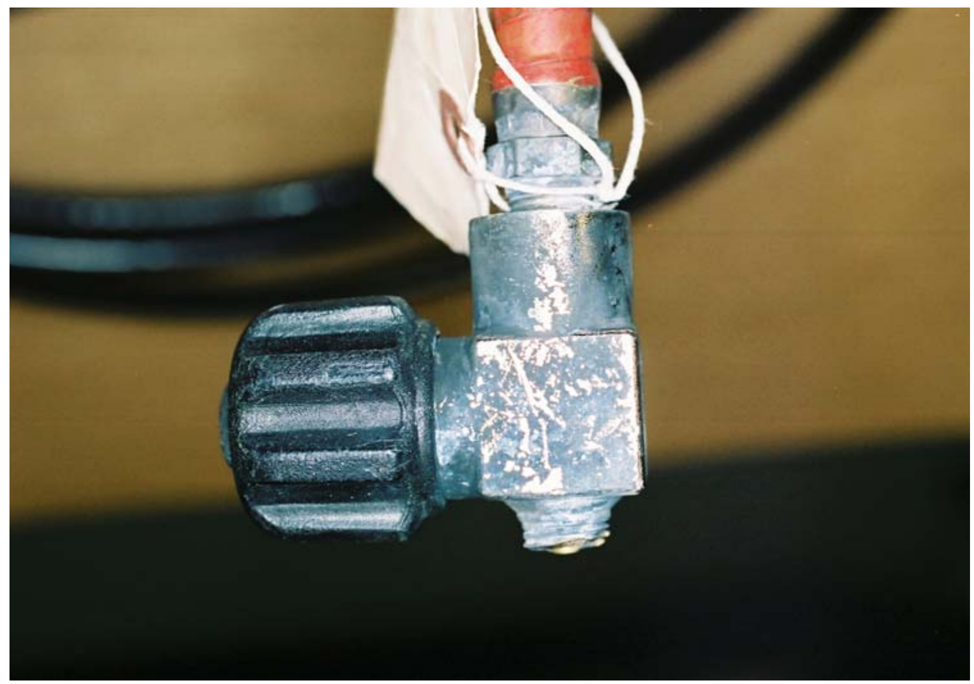

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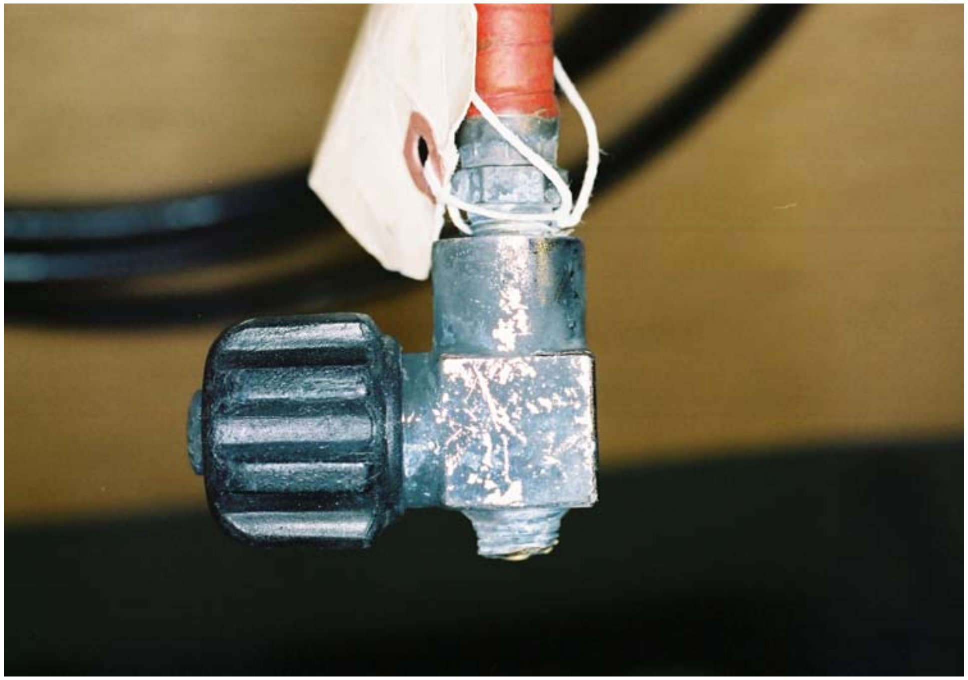
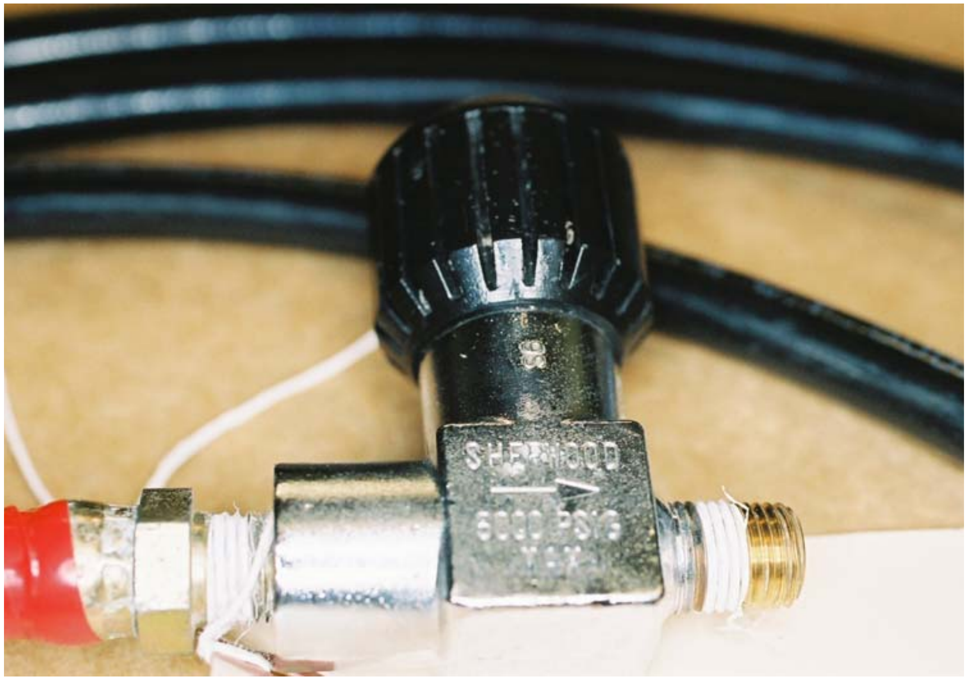



CYLINDER VALVE ANALYSIS

CYLINDER VALVE ANALYSIS

DISASSEMBLY SEQUENCE



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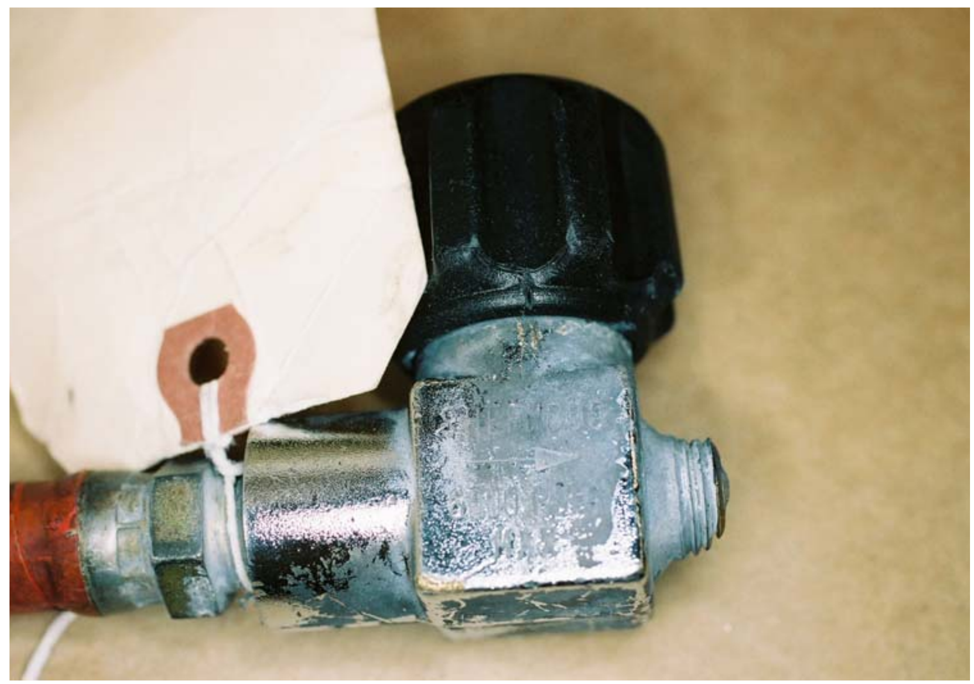

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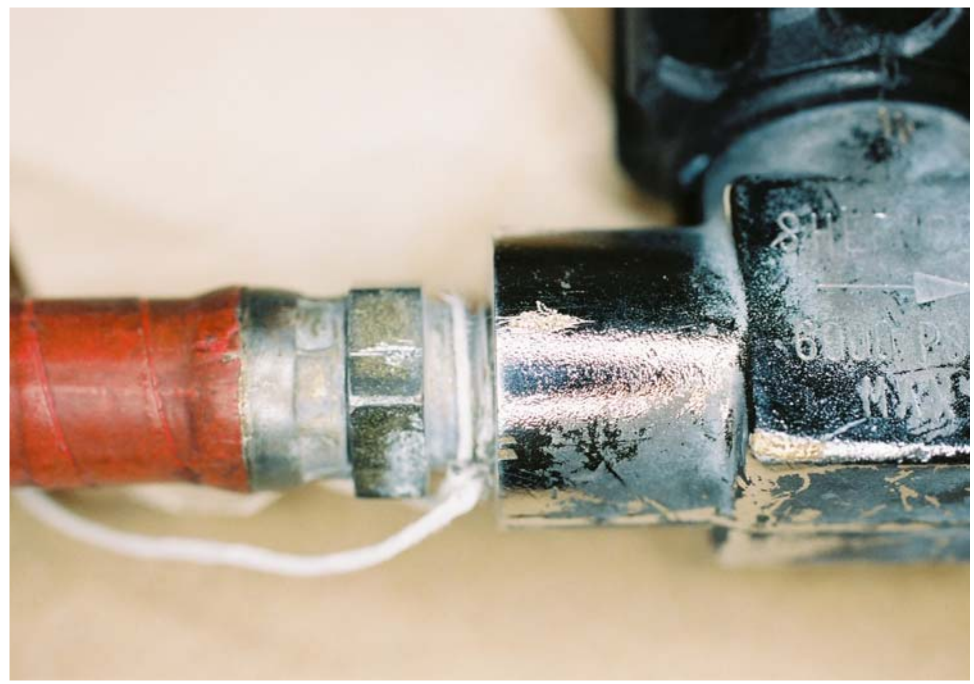

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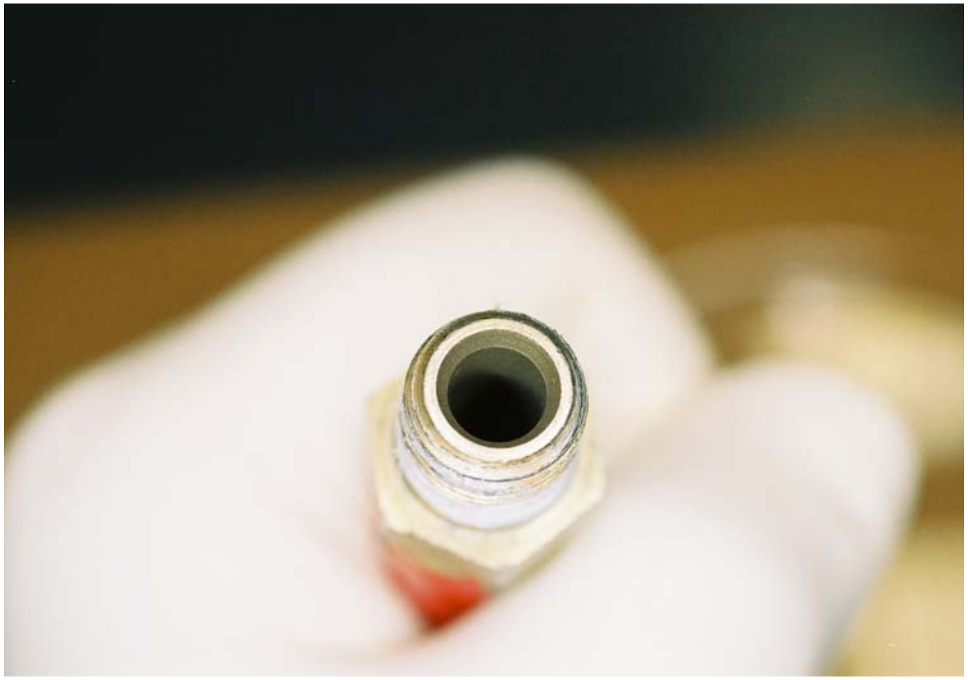
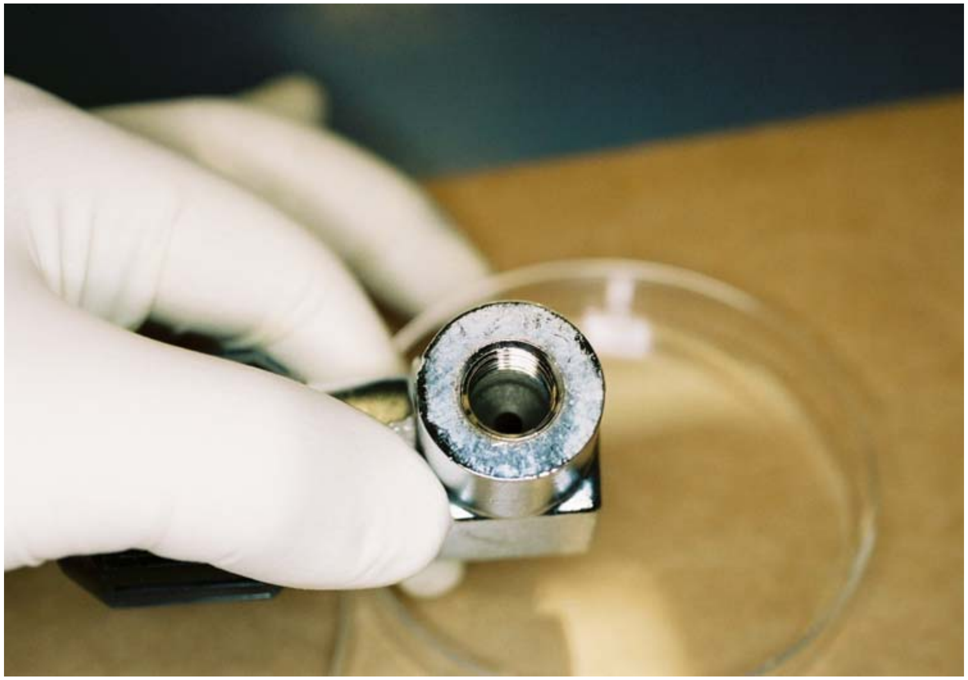

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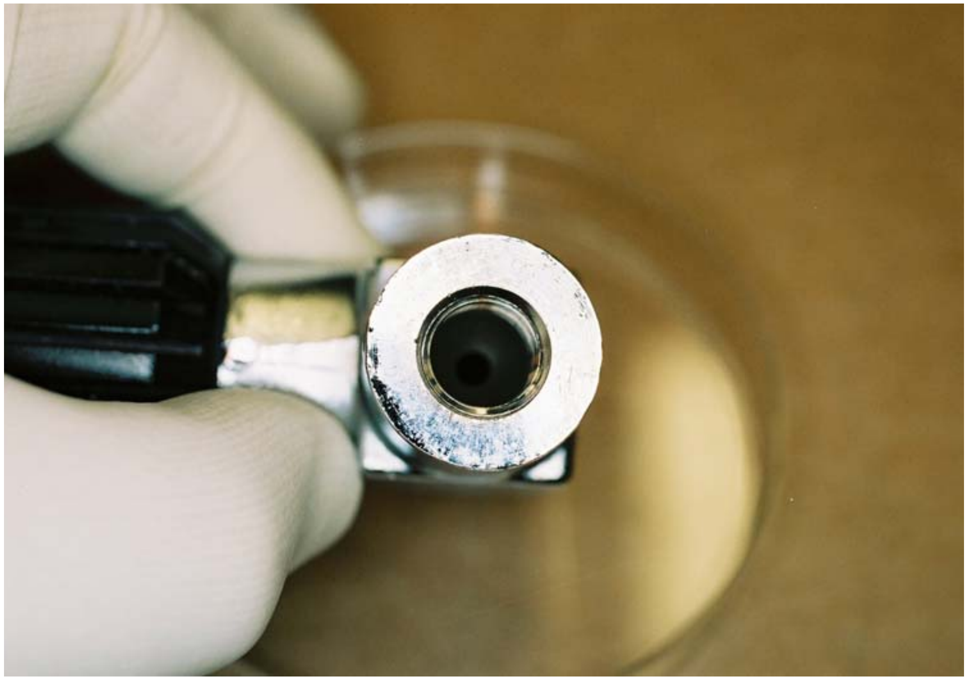

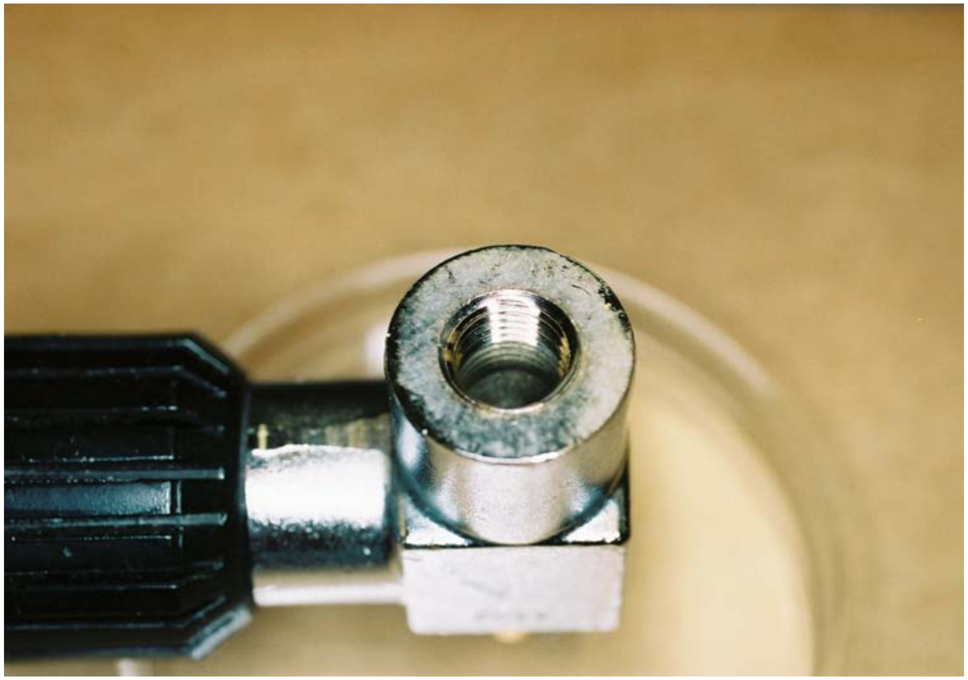

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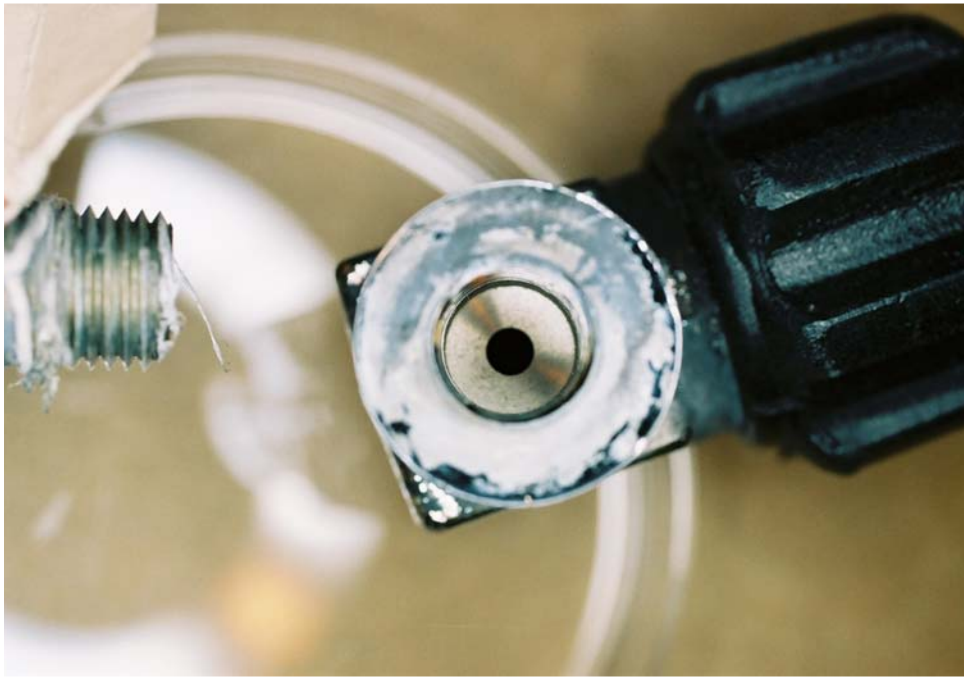

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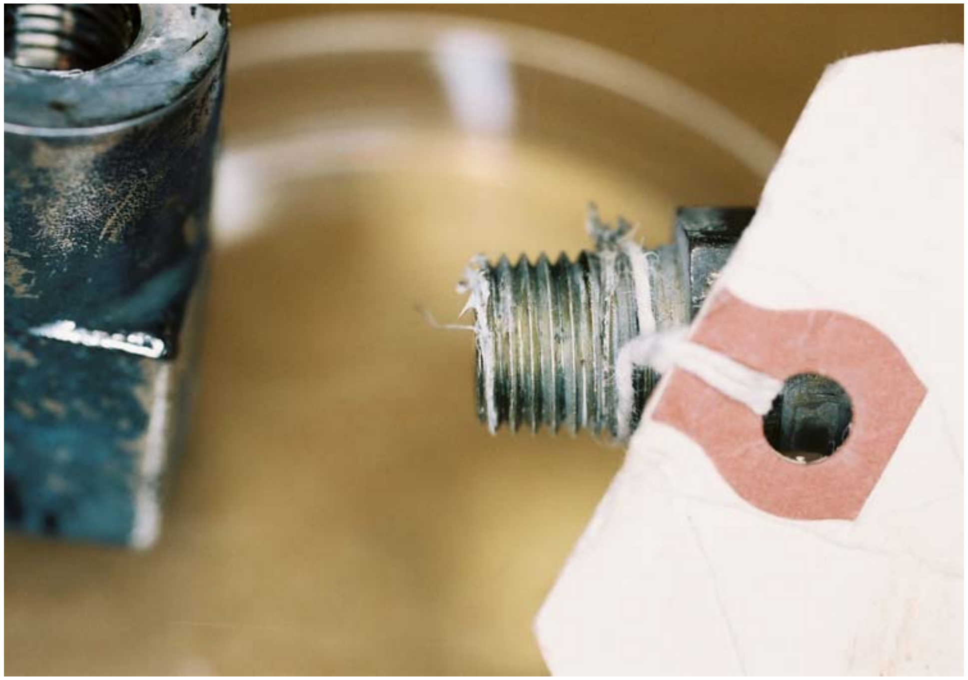

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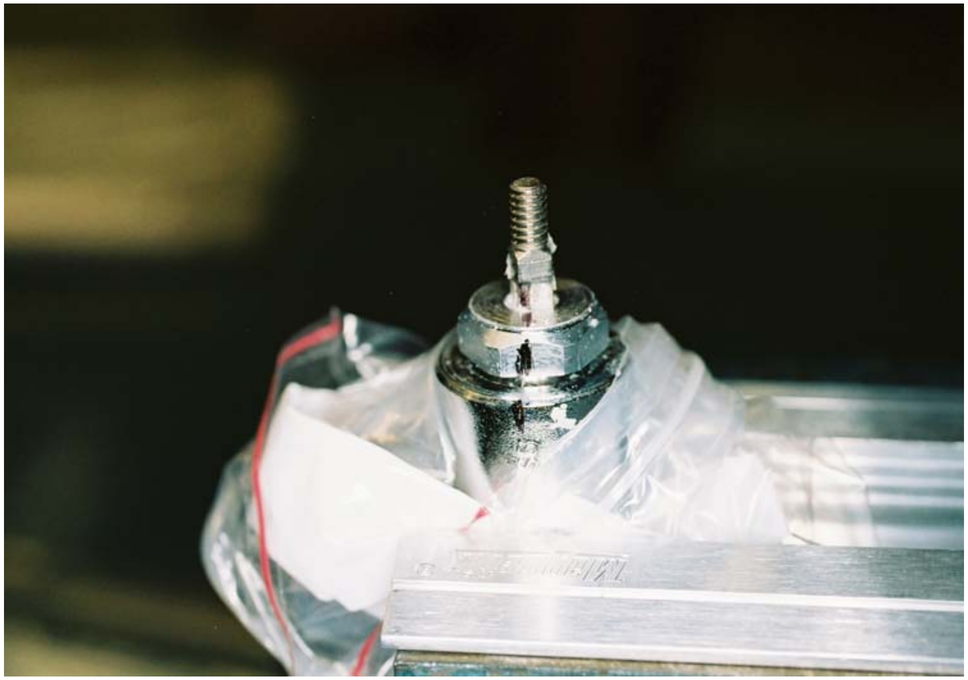

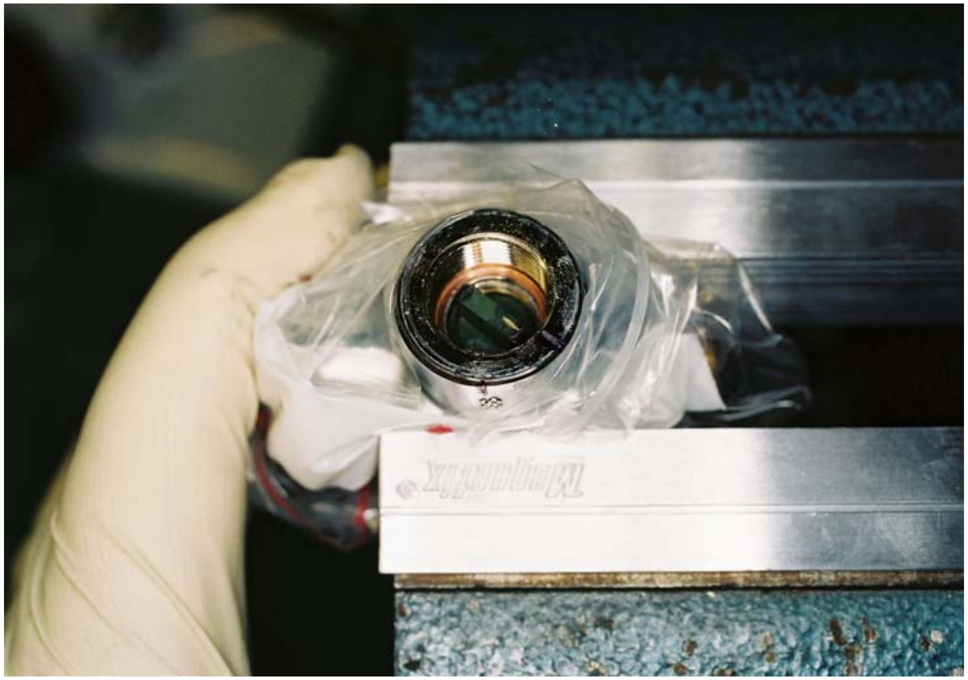

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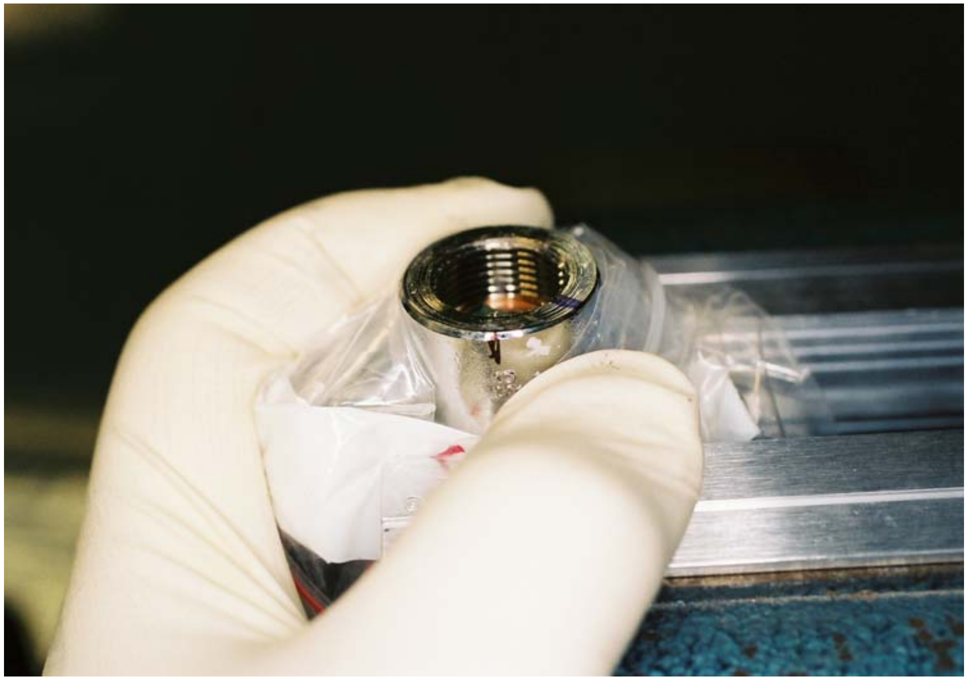

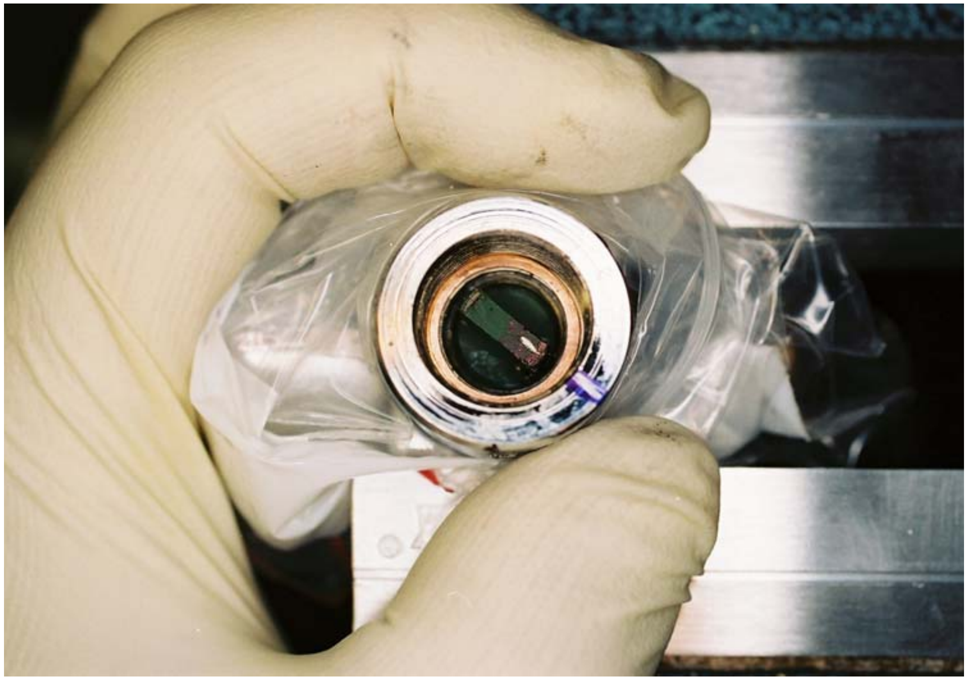

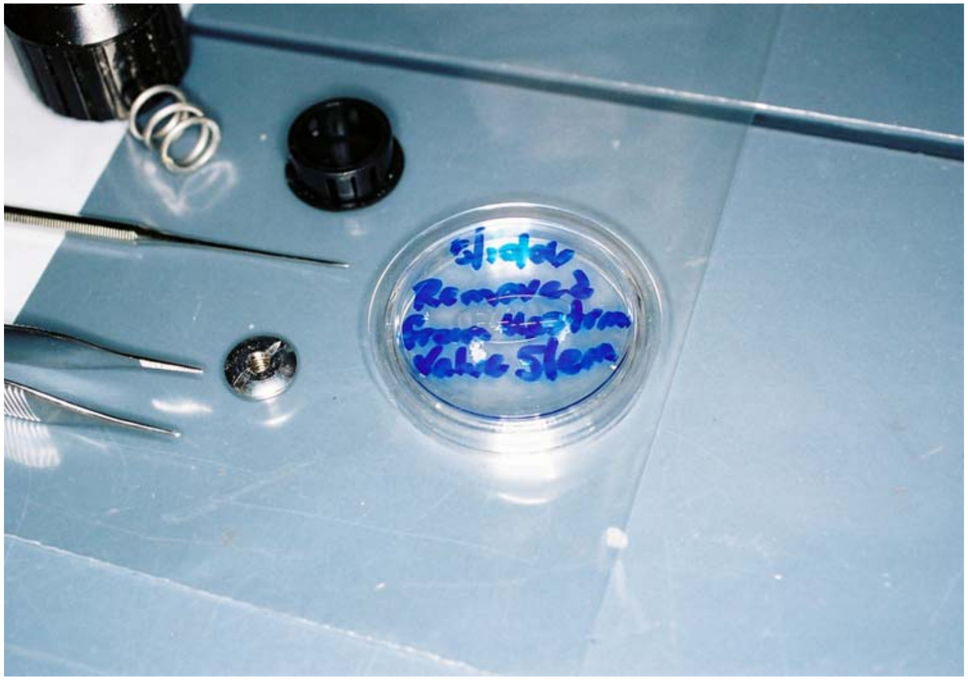

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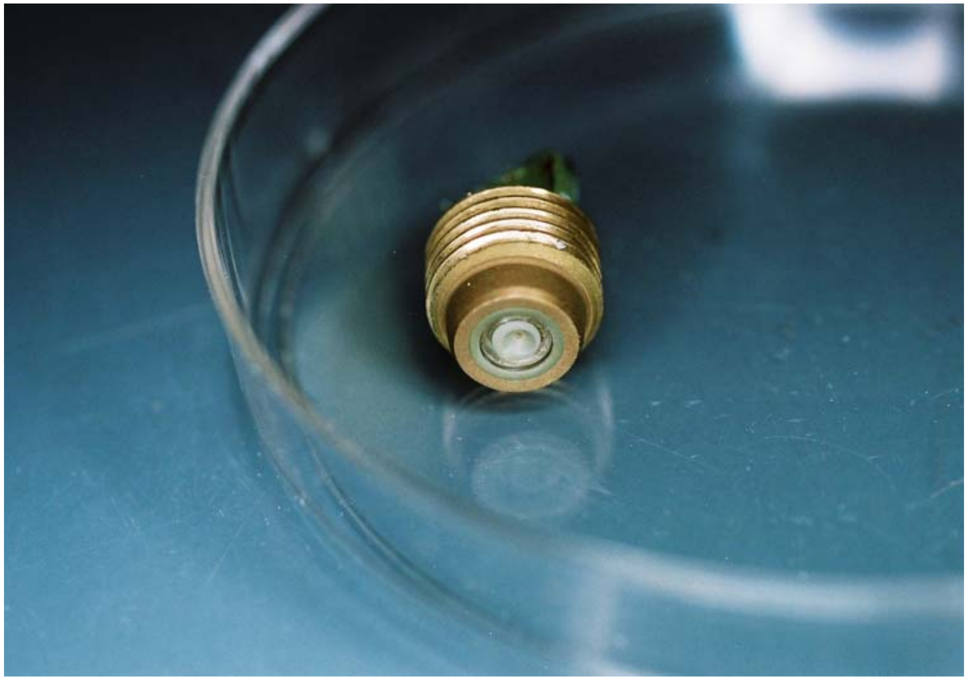

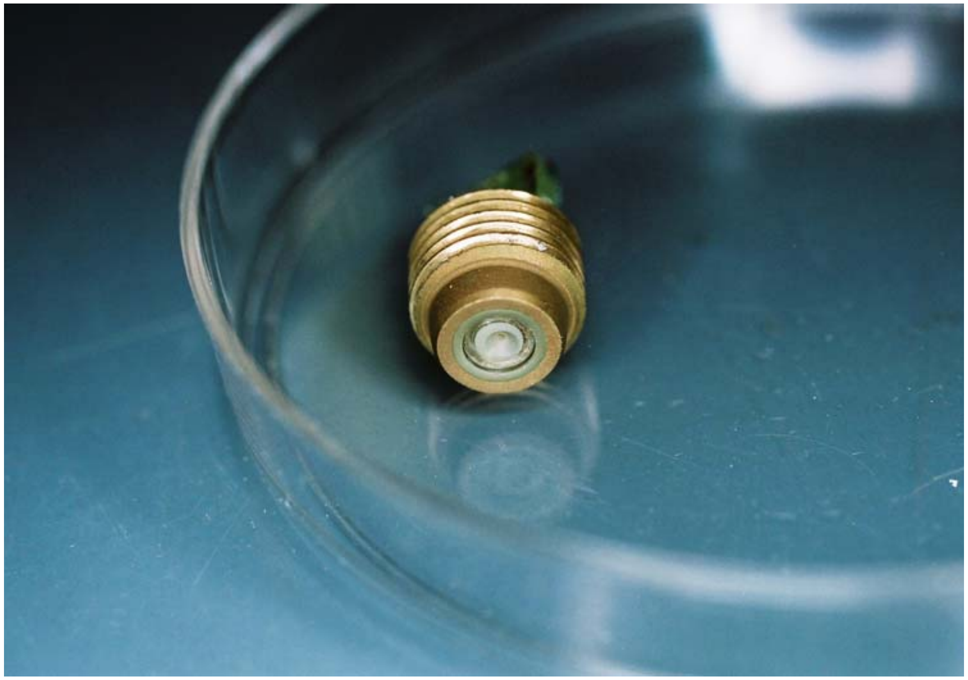

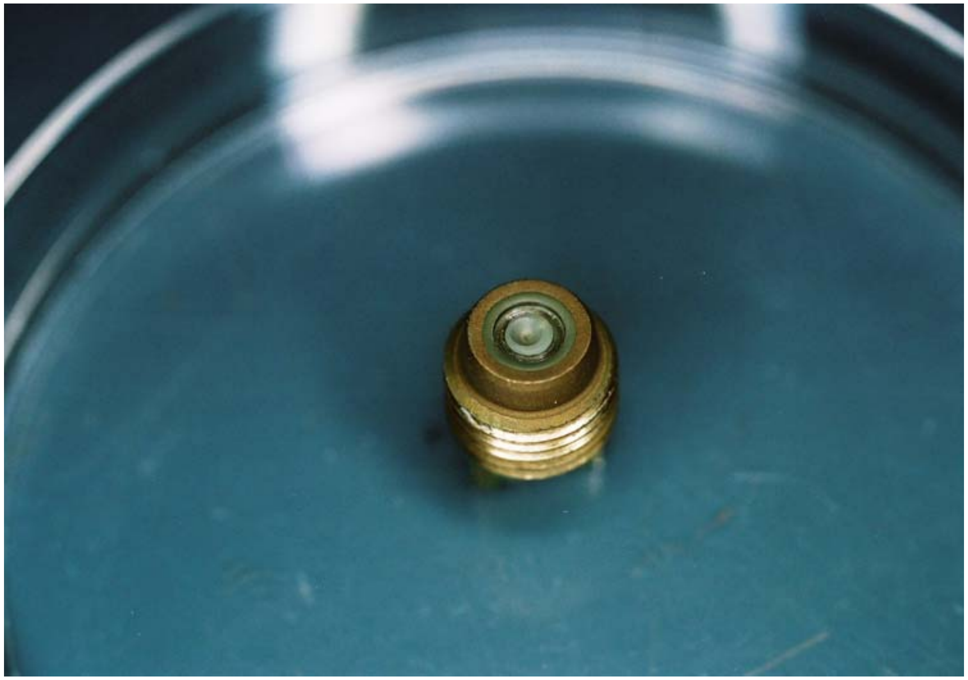

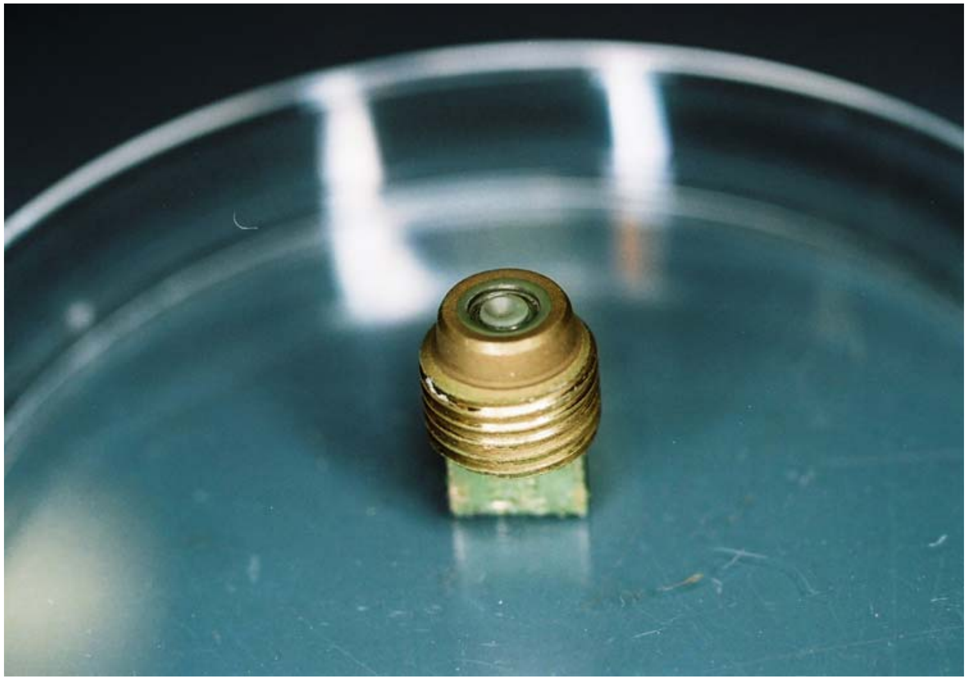

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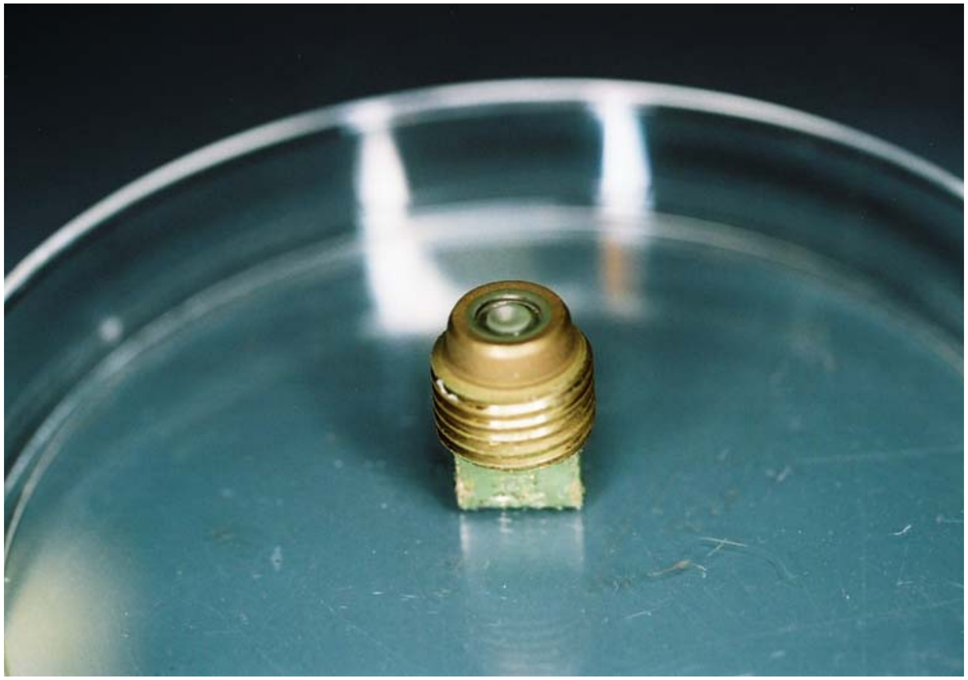

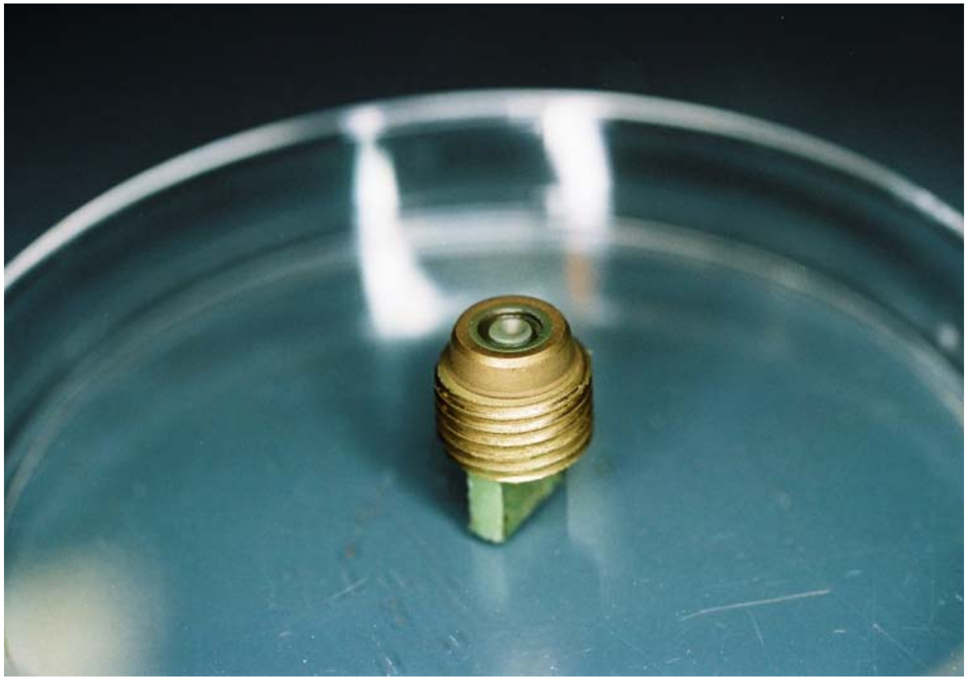

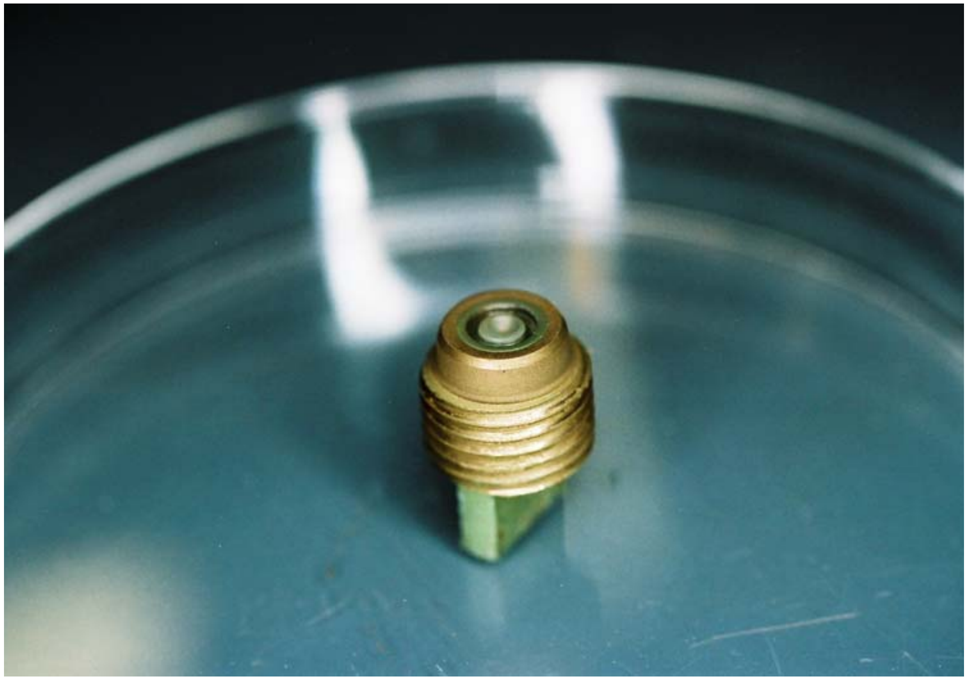

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Upstream fill
valve Seat Plug
5/10/06 Bn
Upstream Fill Valve
Valve Body


5/10/06 Bn
Upstream Fill Valve
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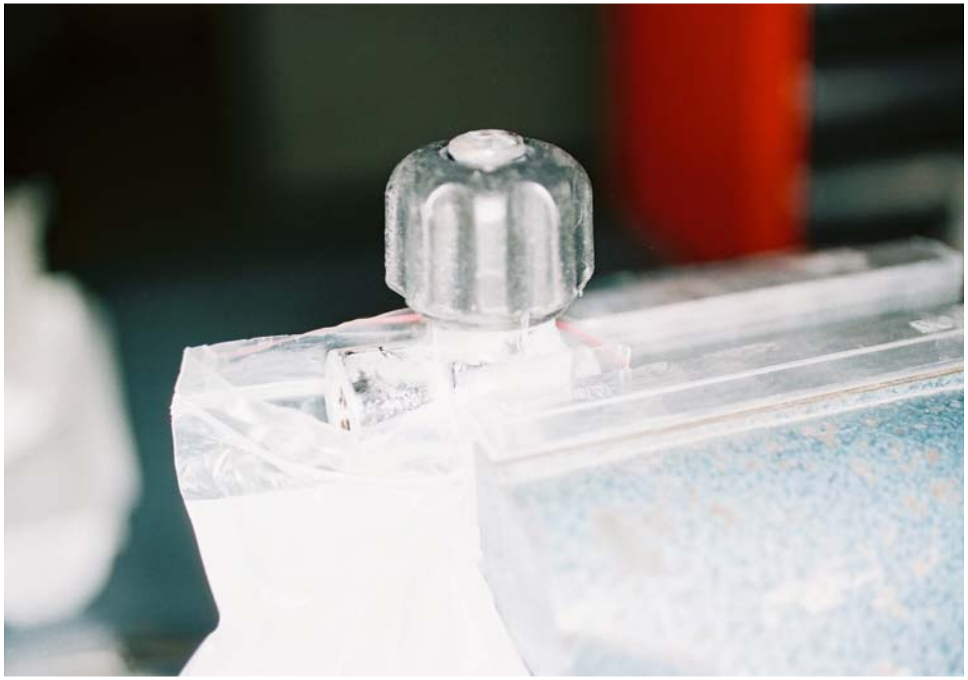
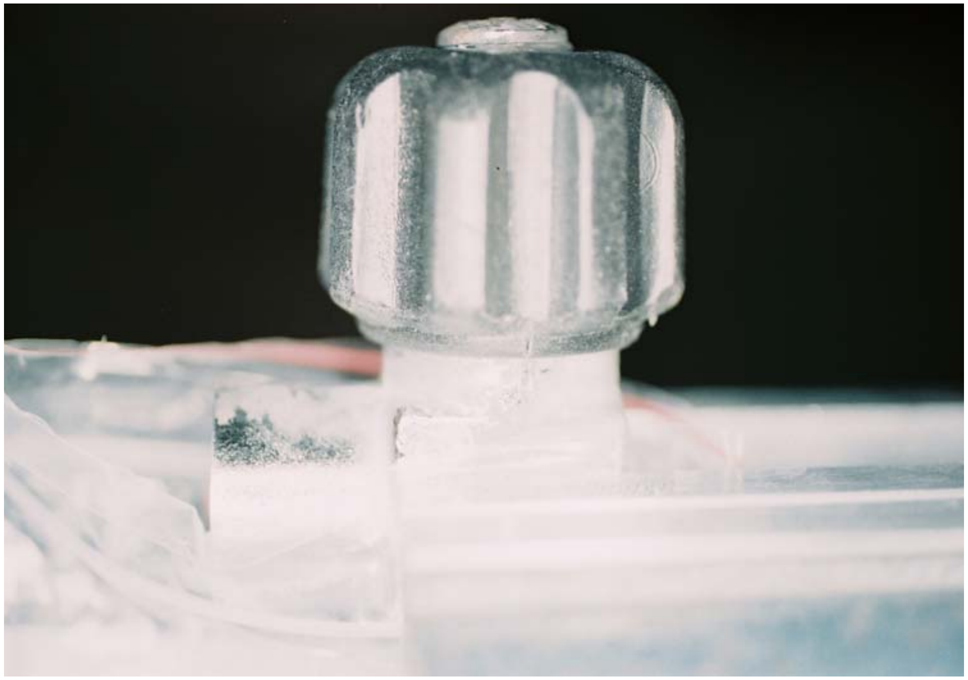
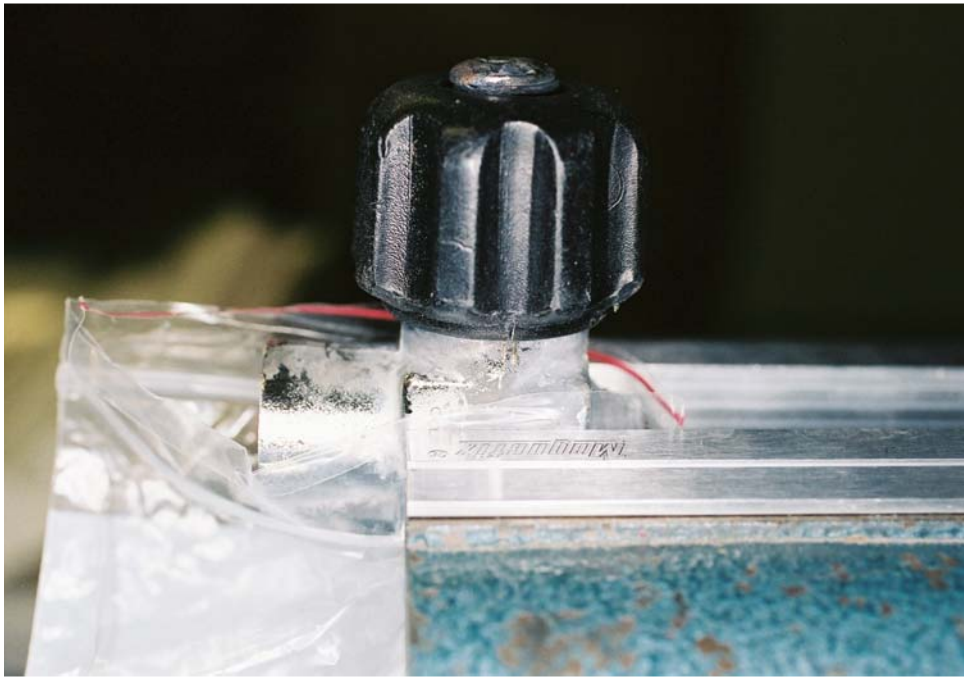

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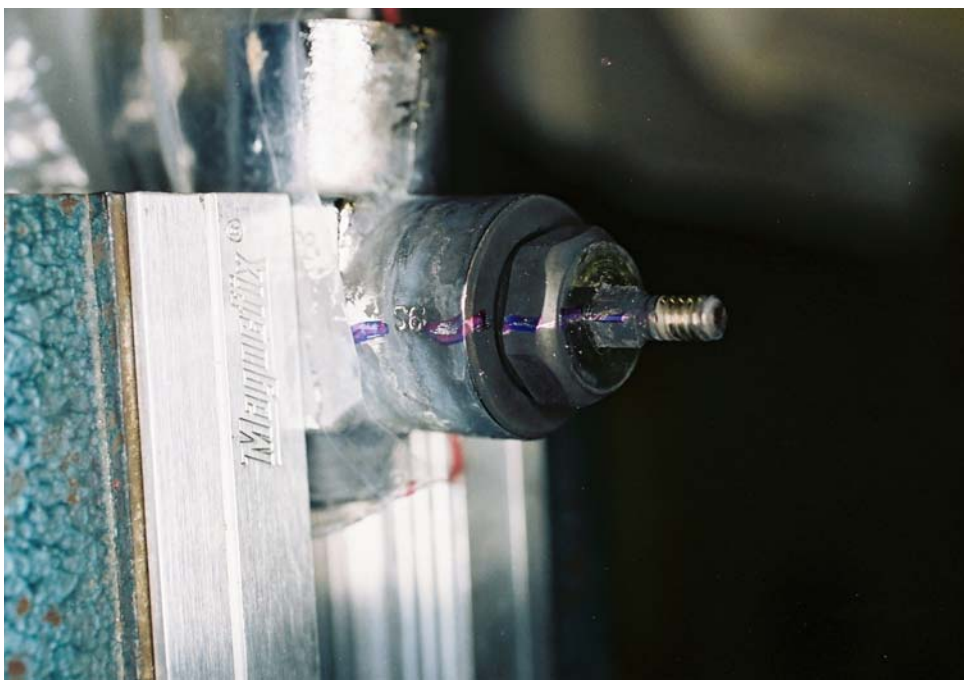

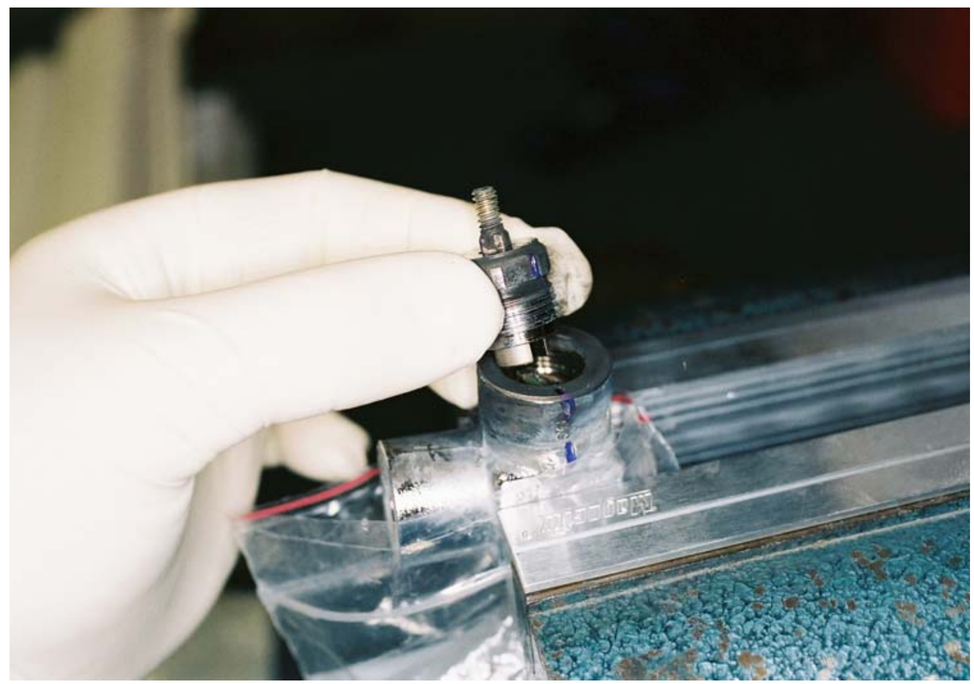

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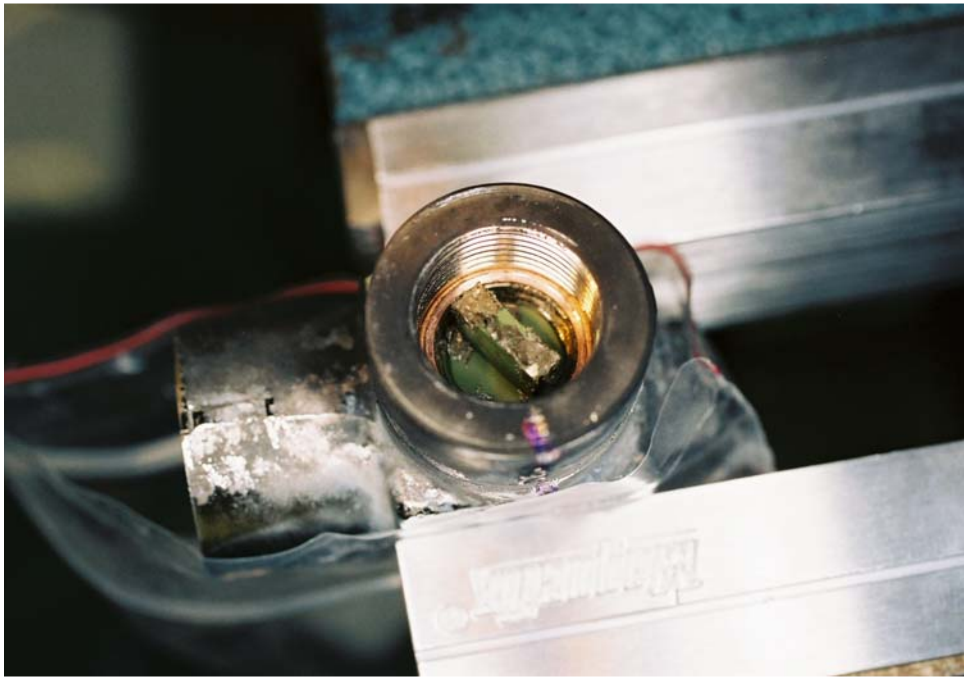

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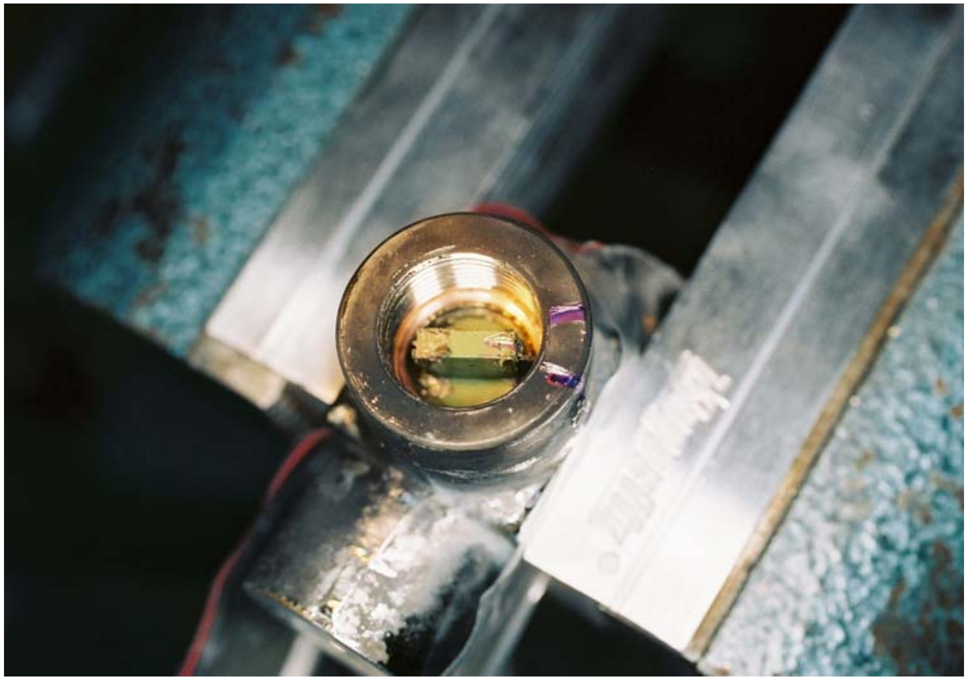

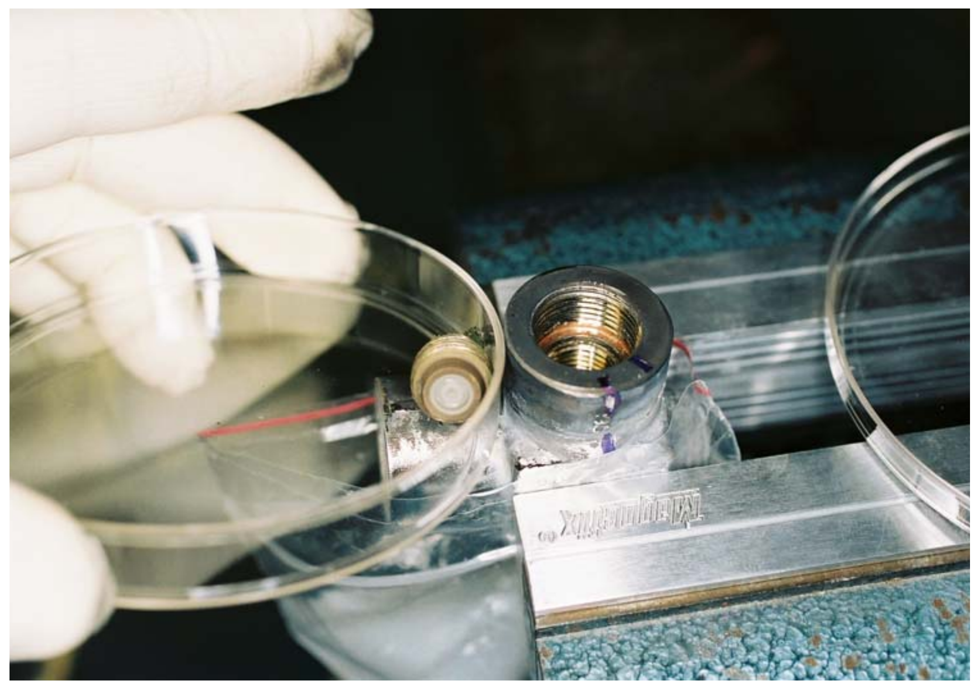

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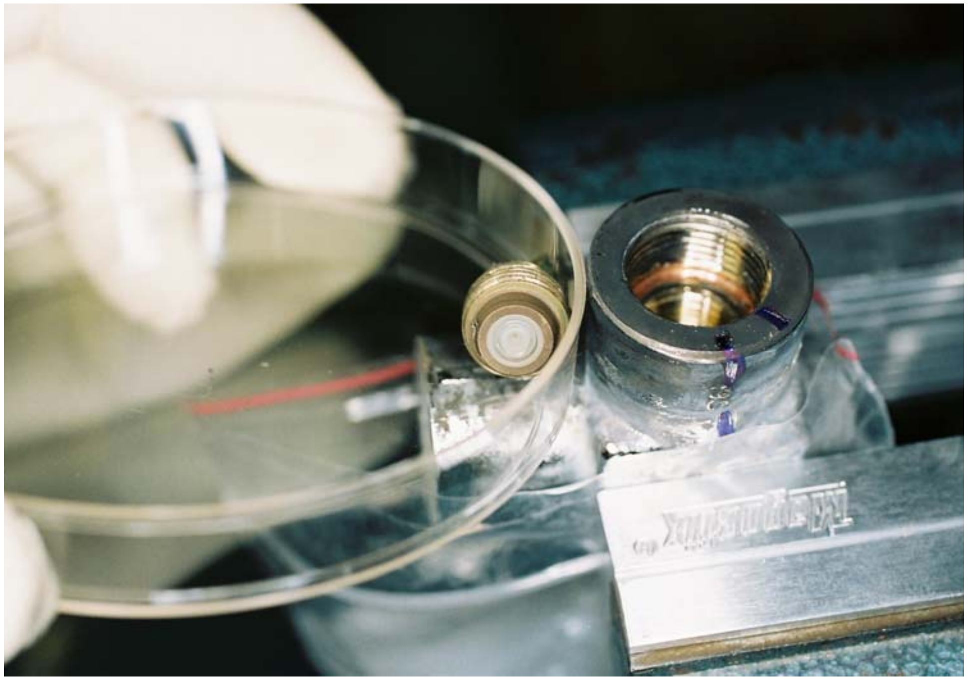

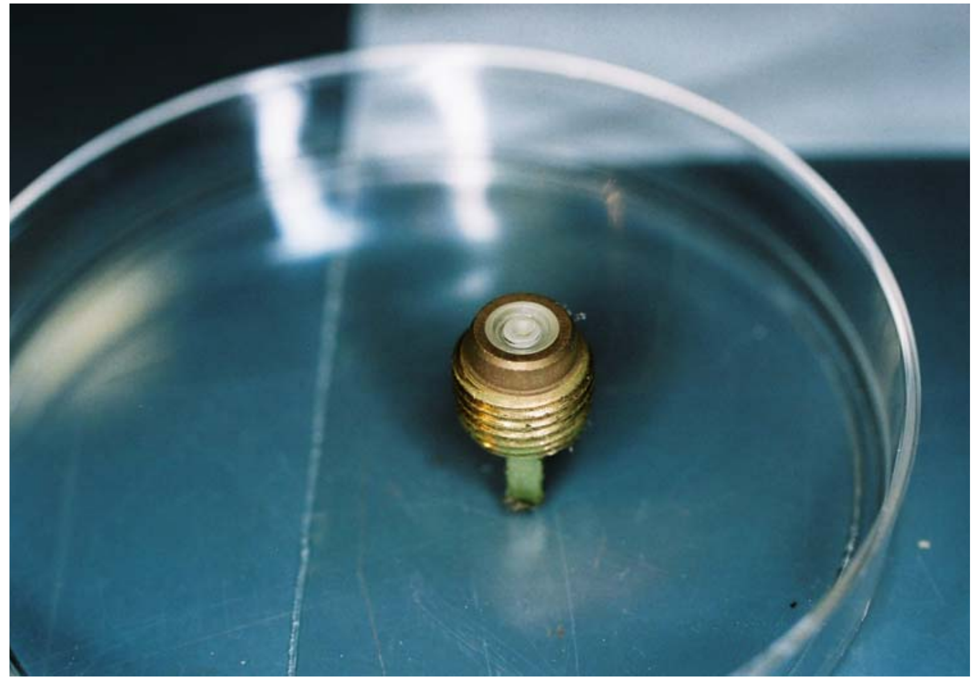

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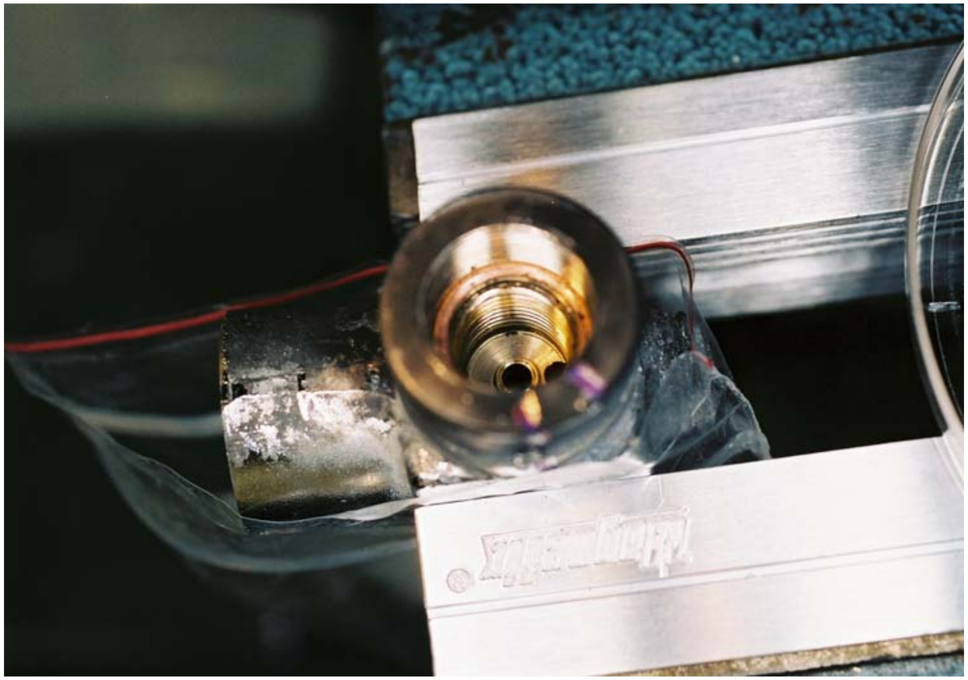

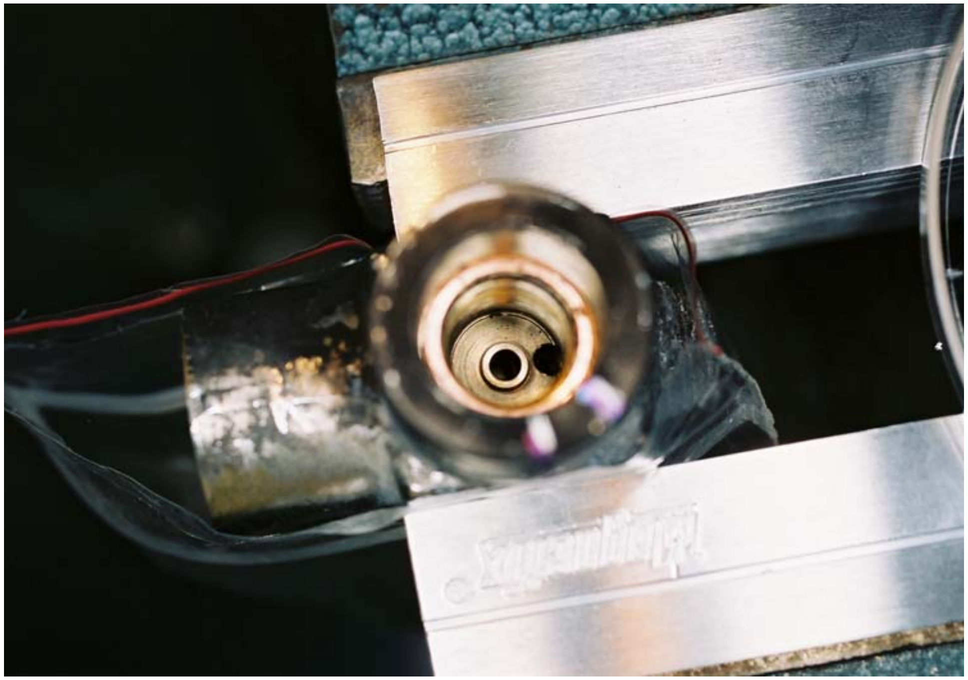

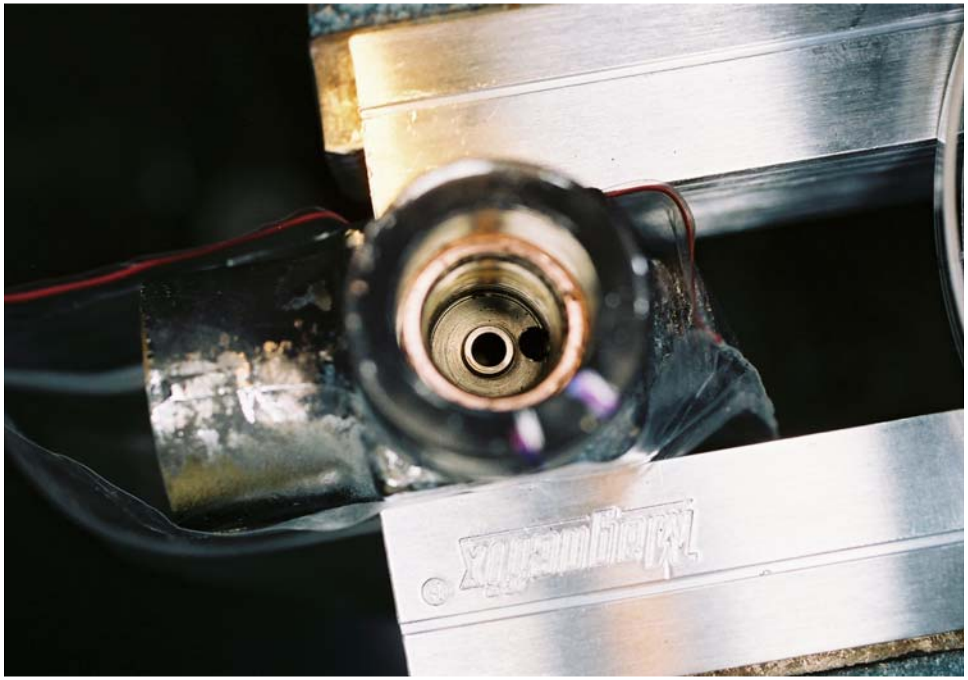

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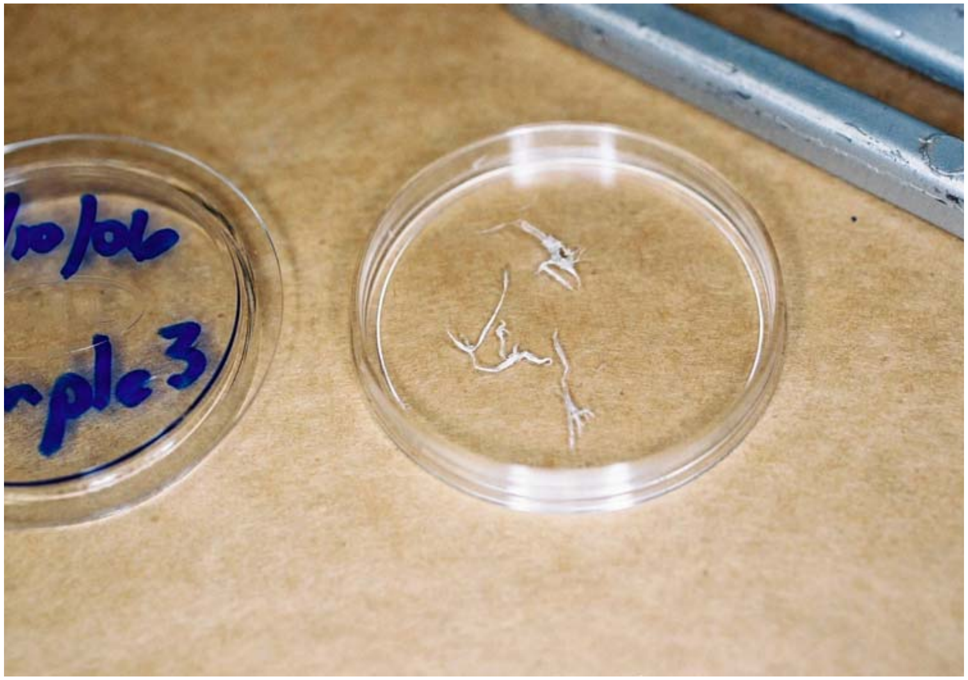

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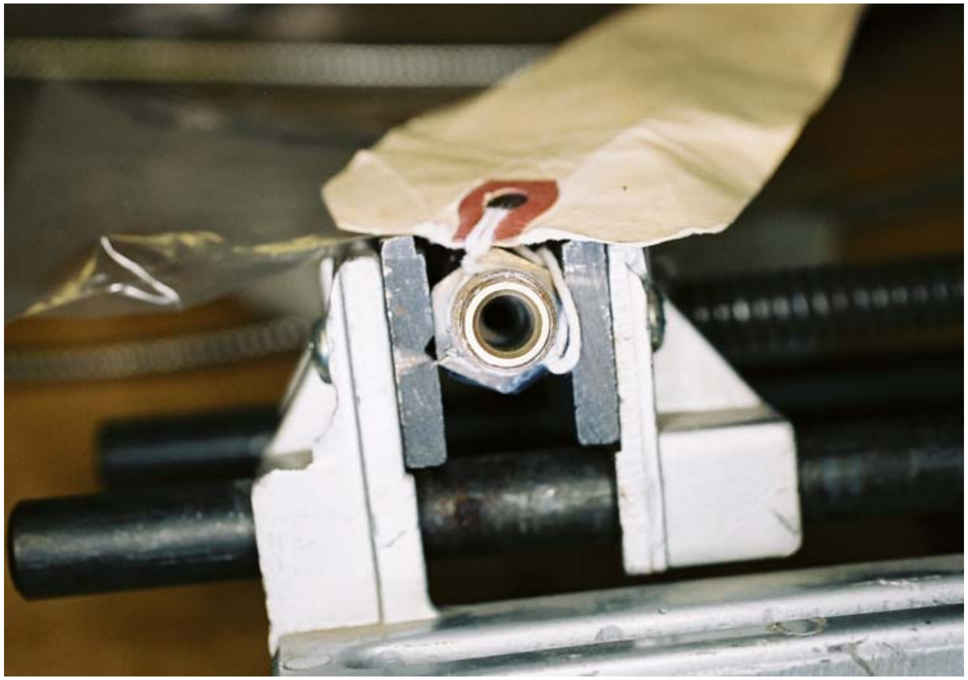

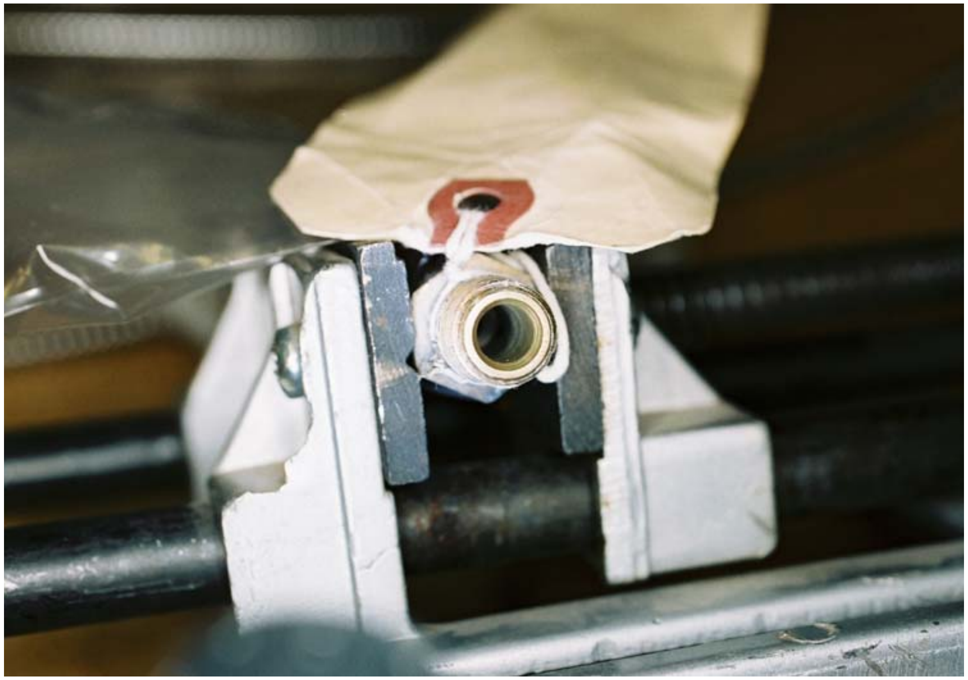

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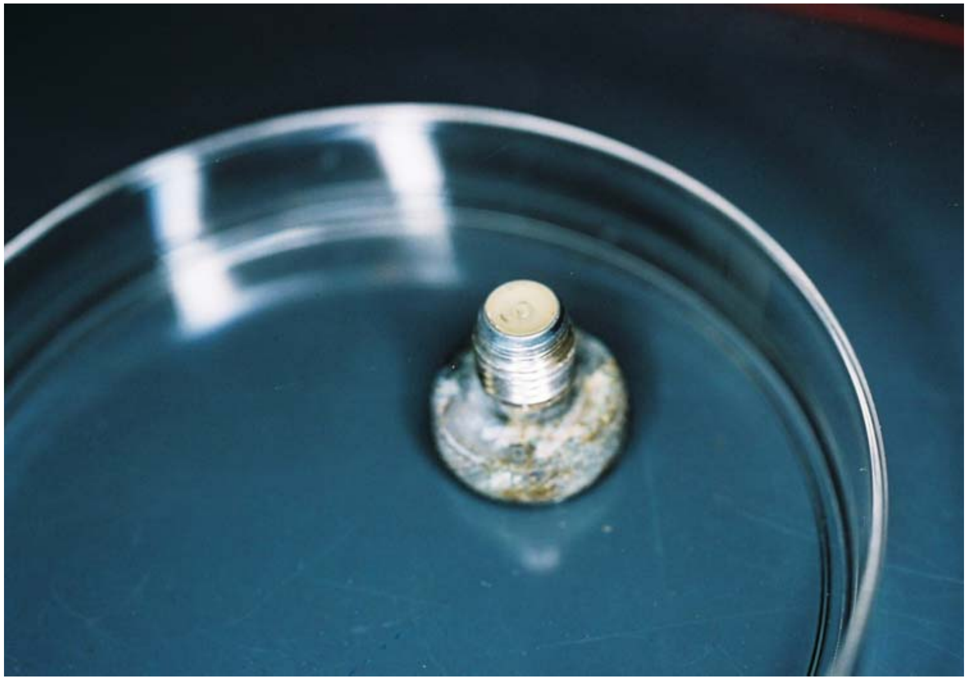

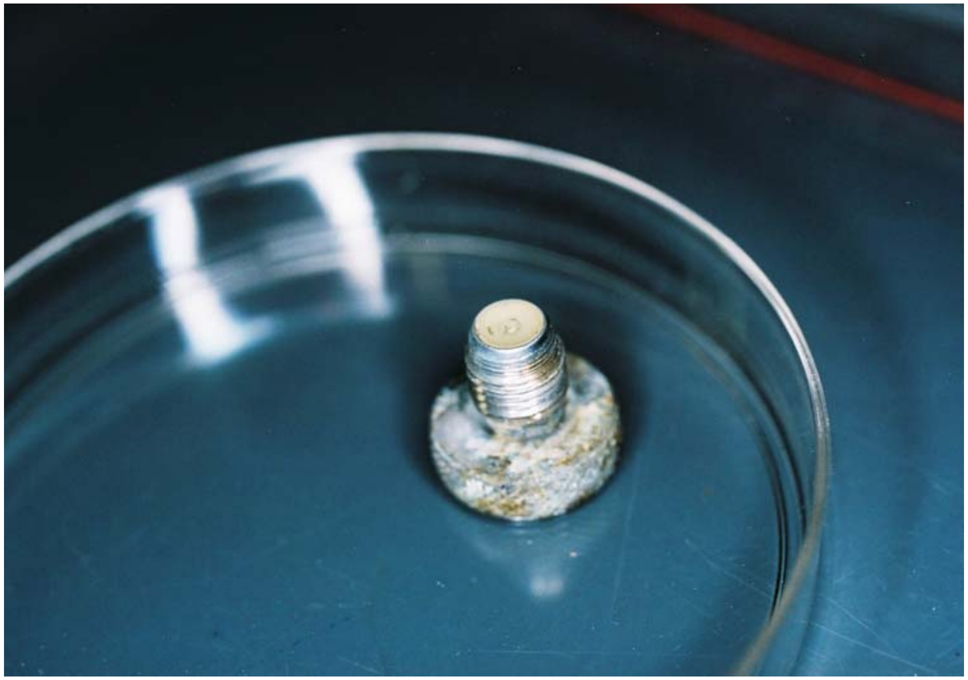

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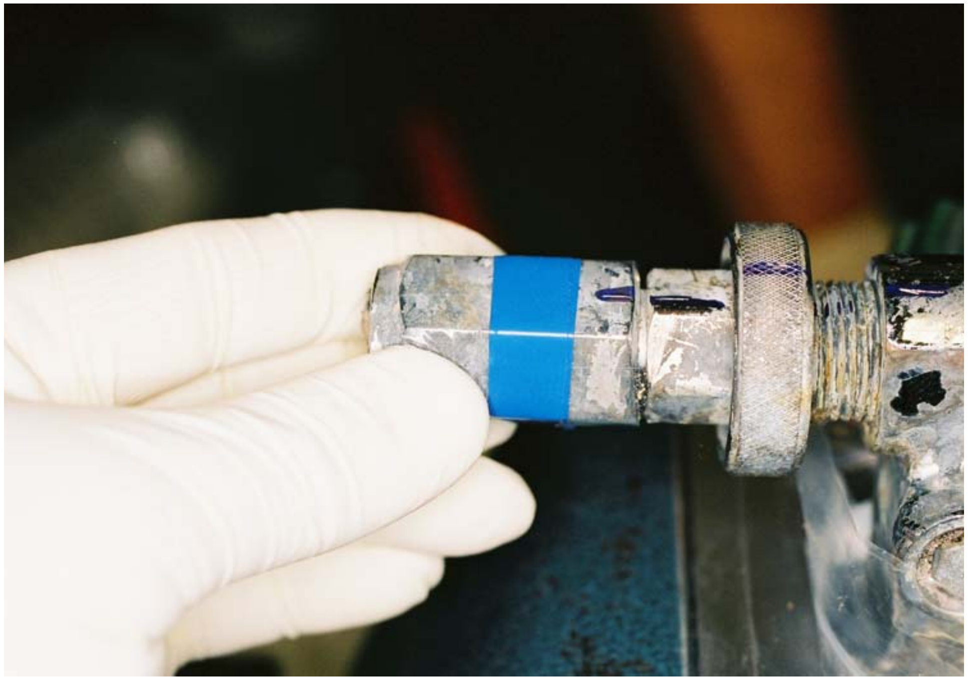

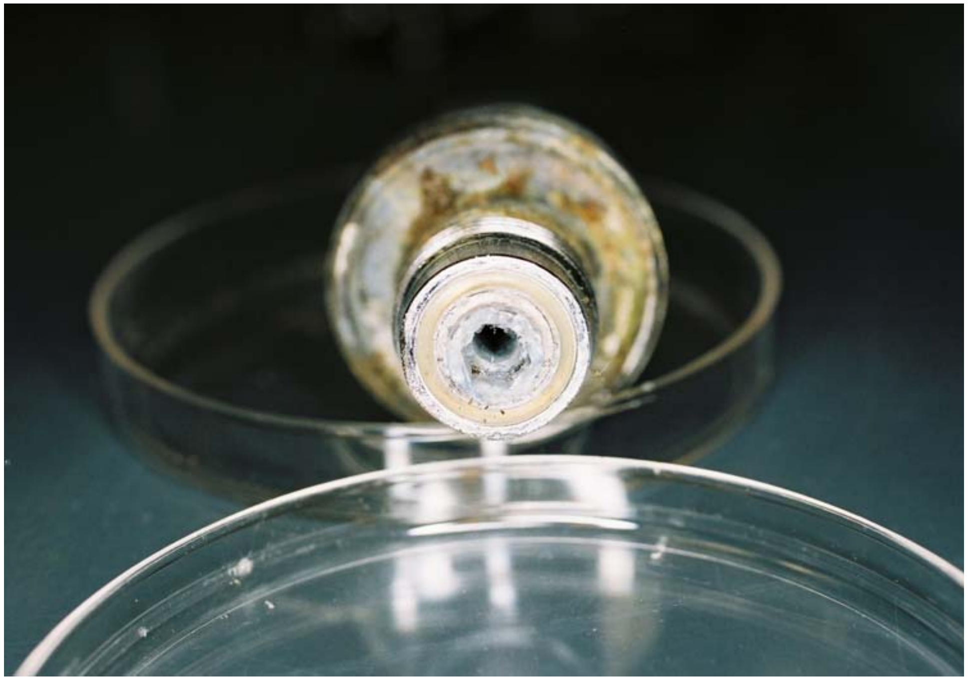

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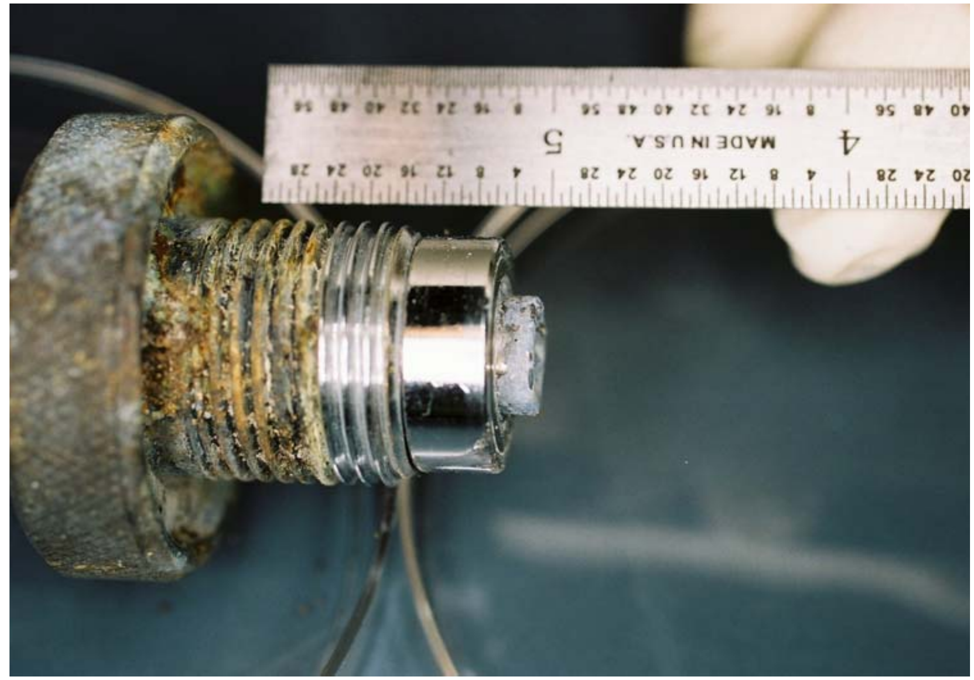

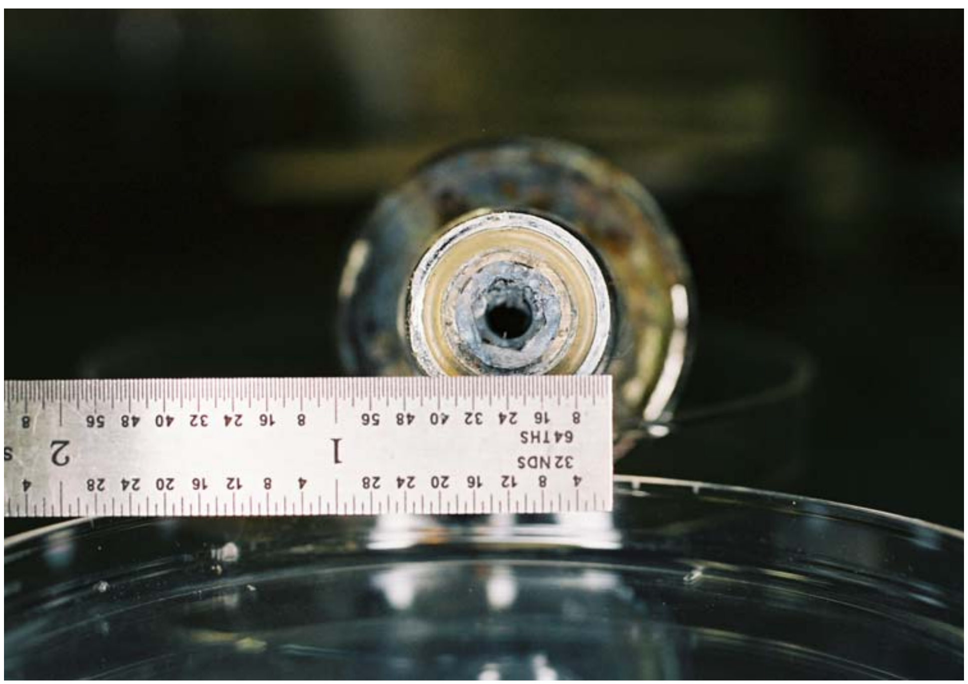

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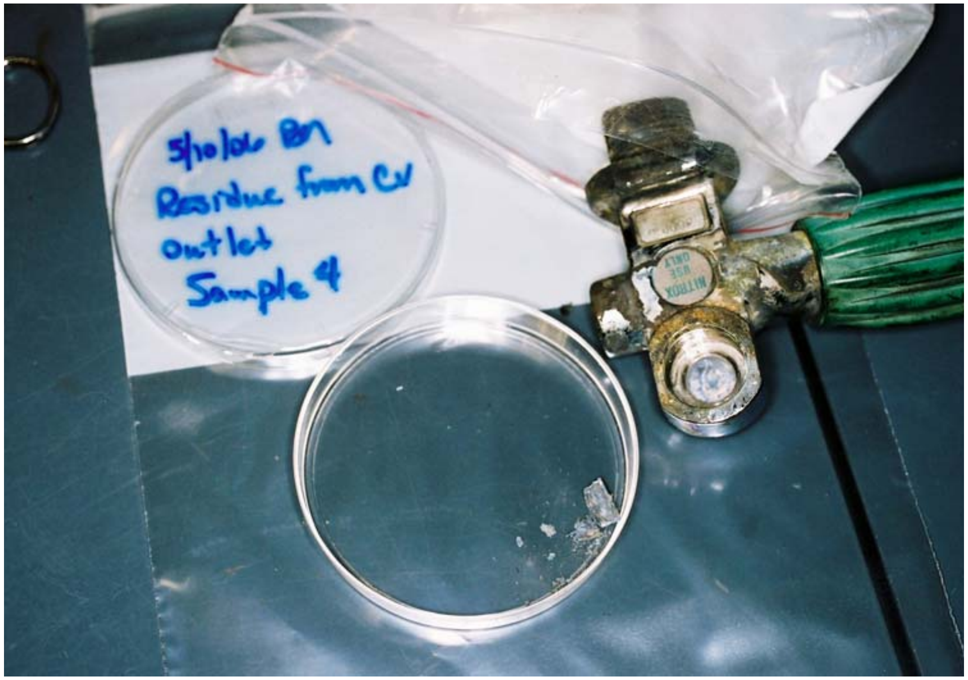

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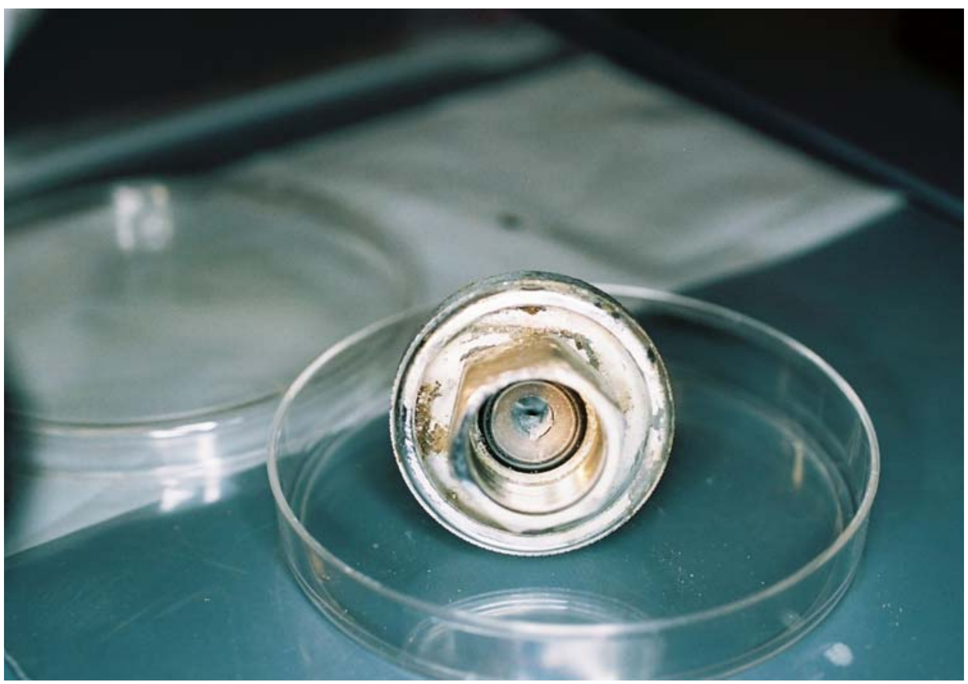

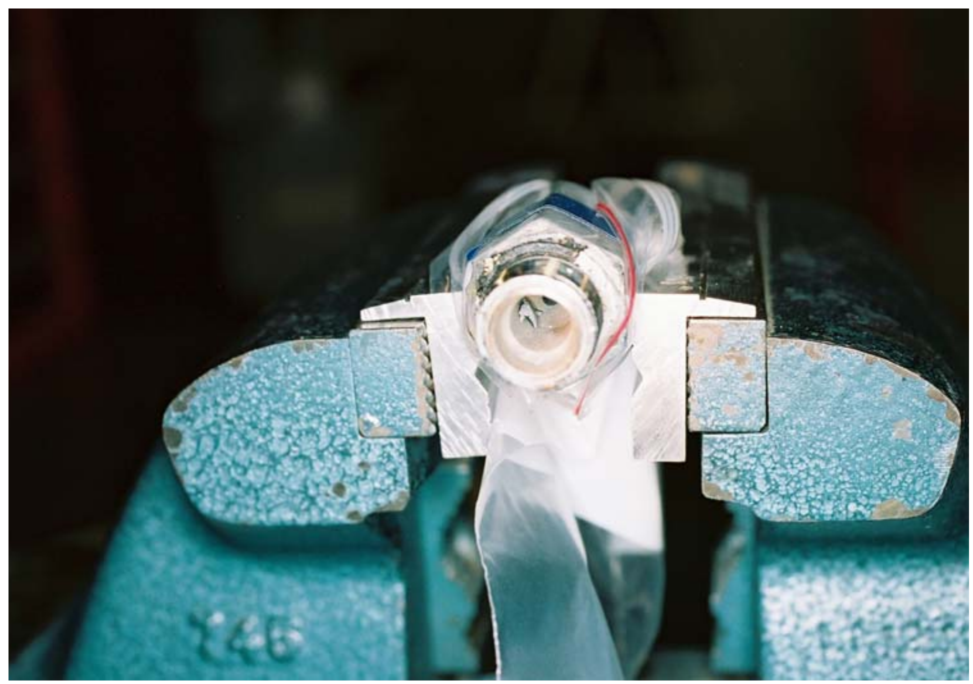

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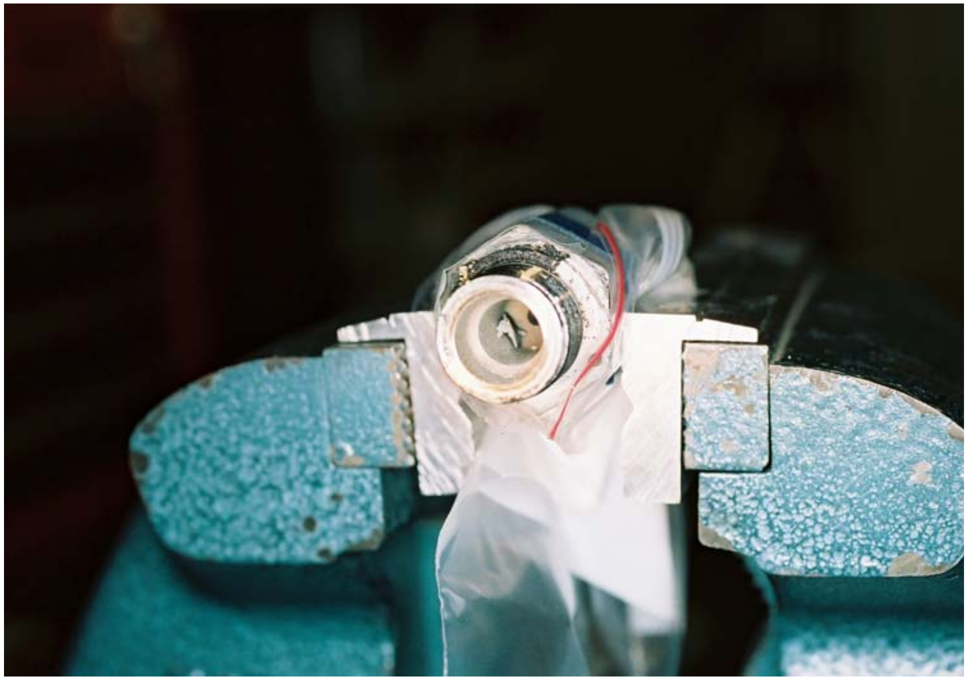

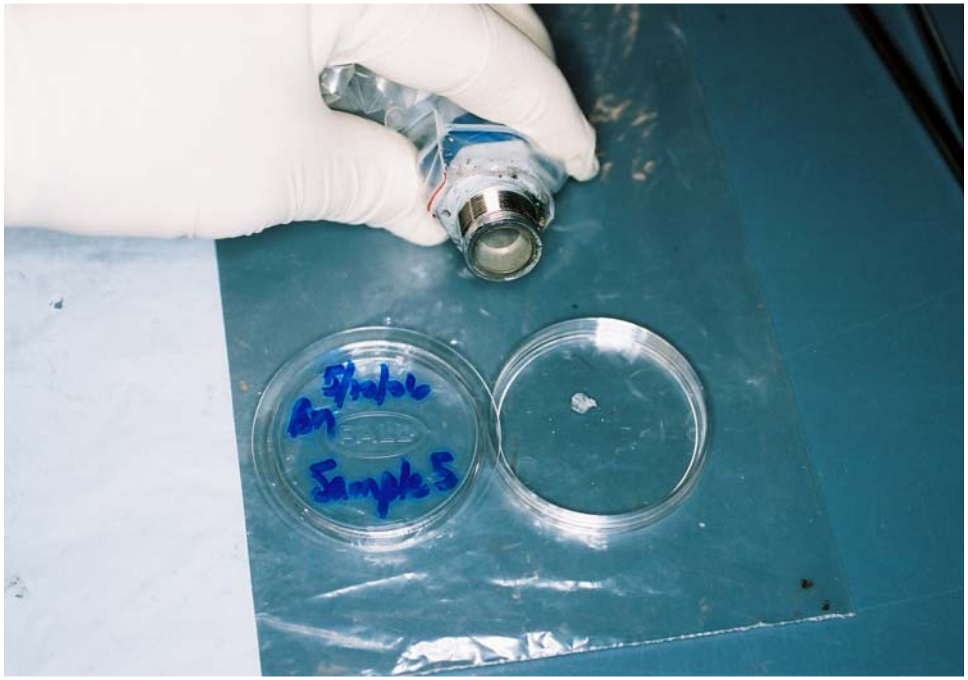

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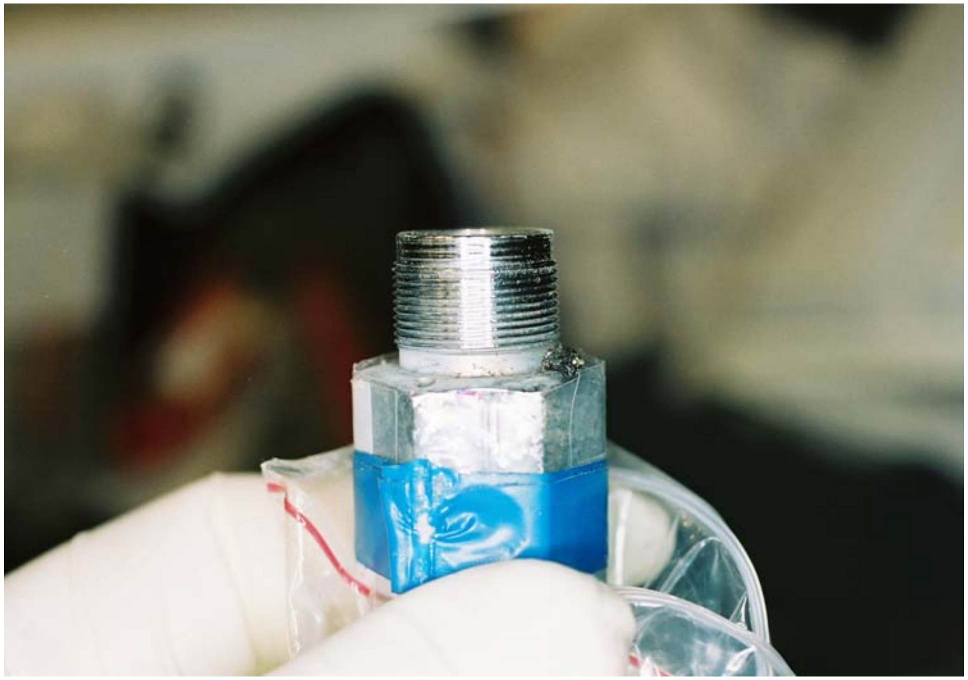

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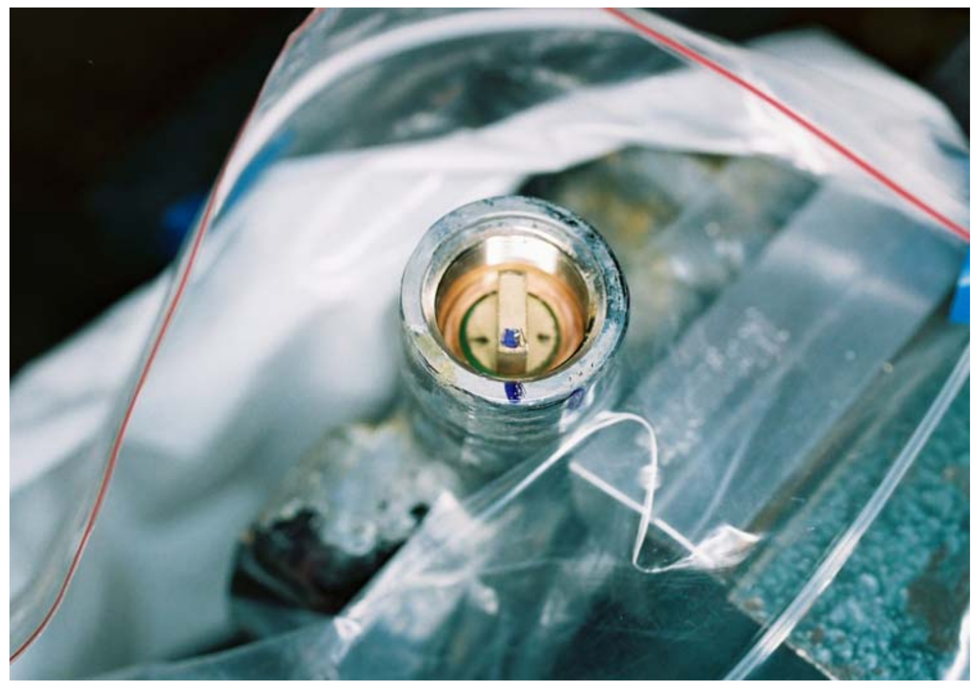

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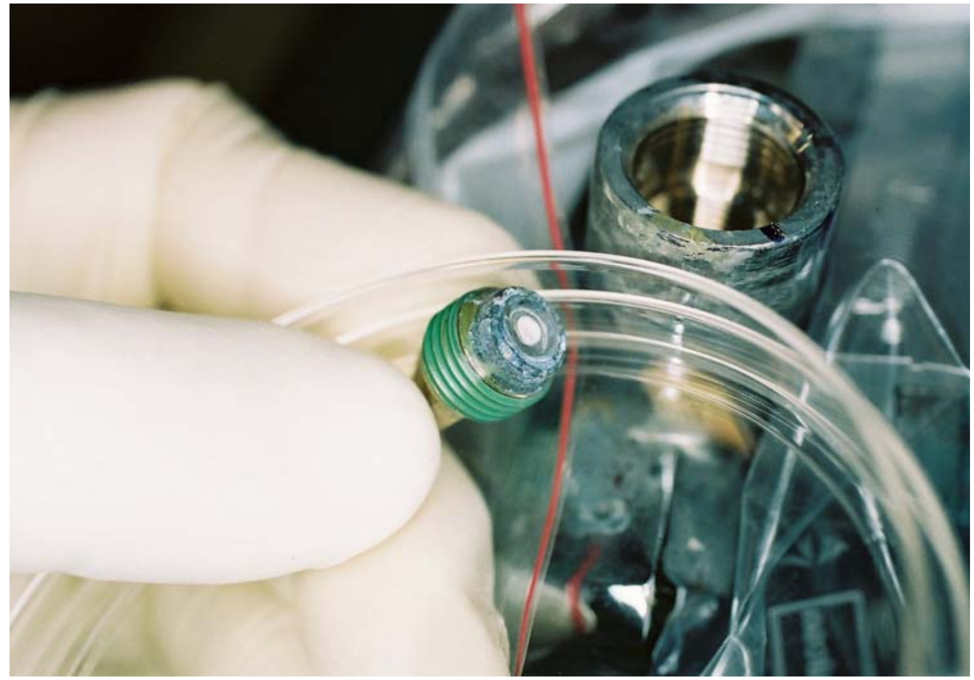

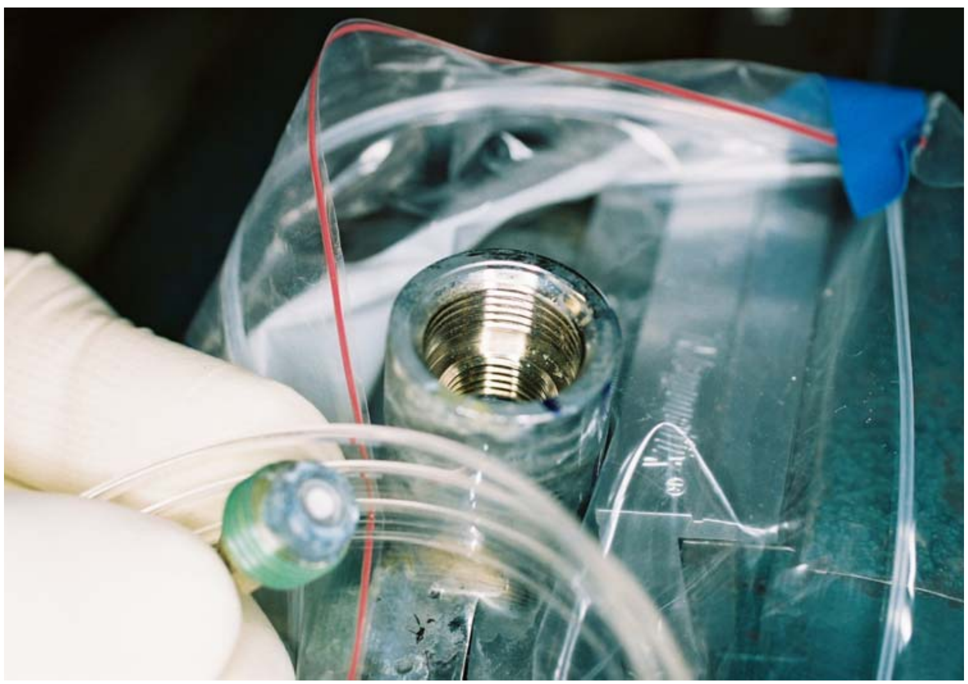

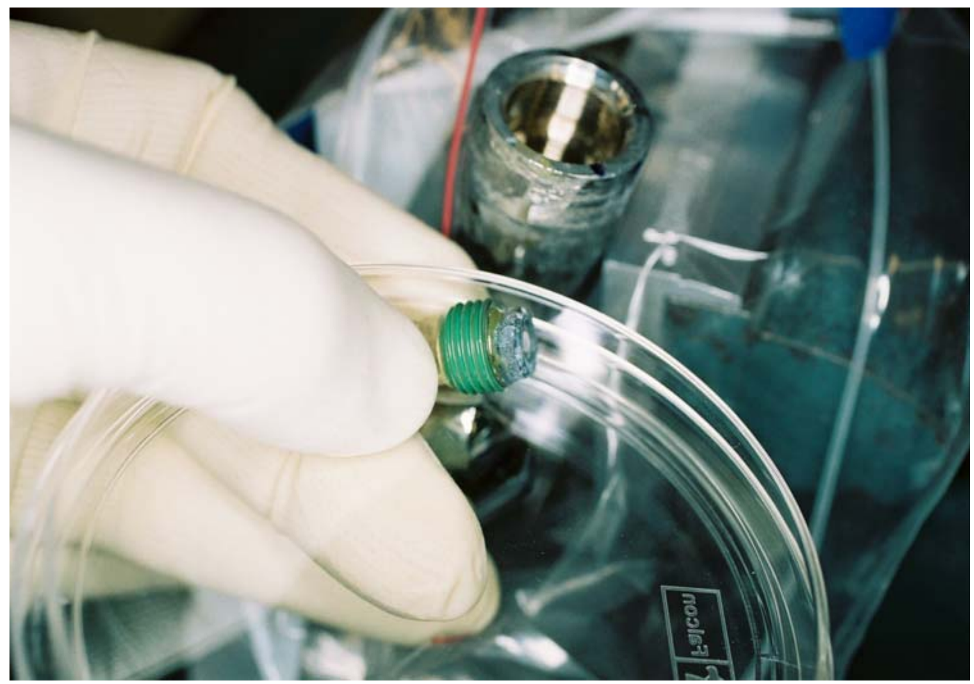

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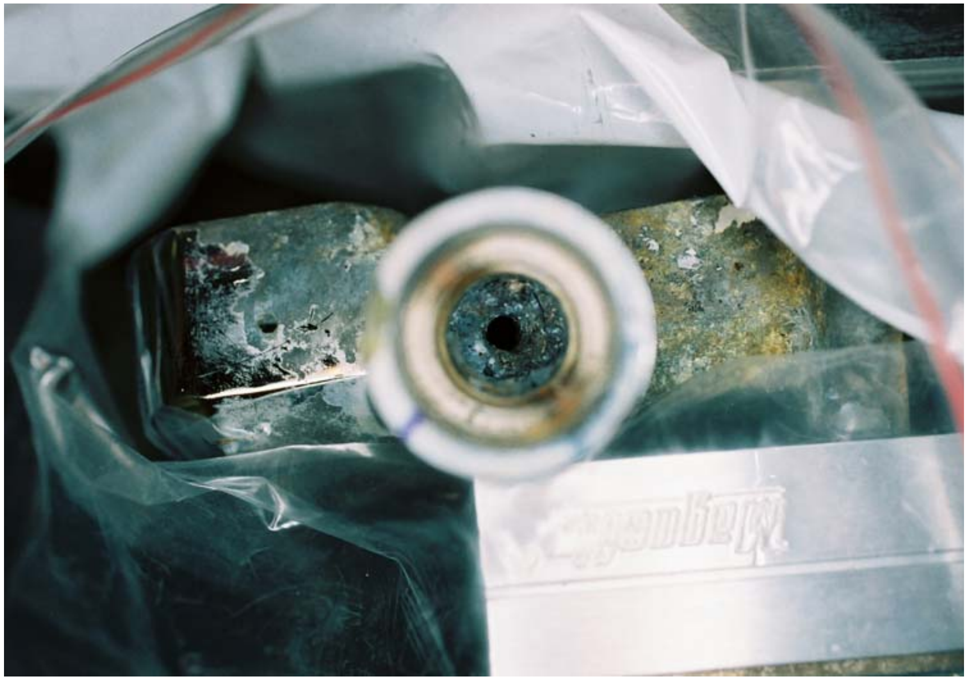

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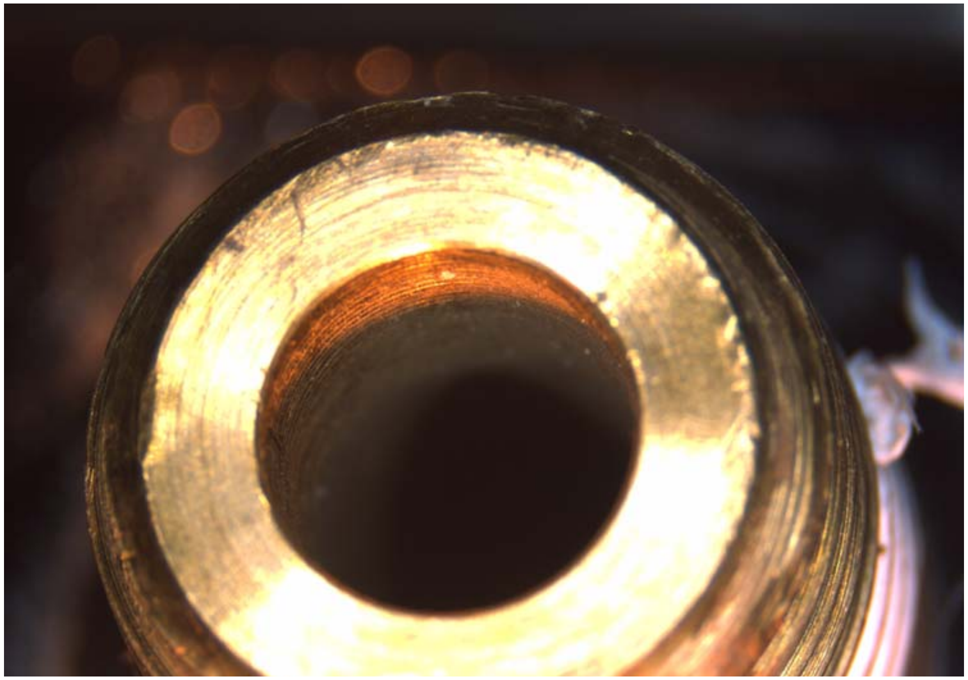

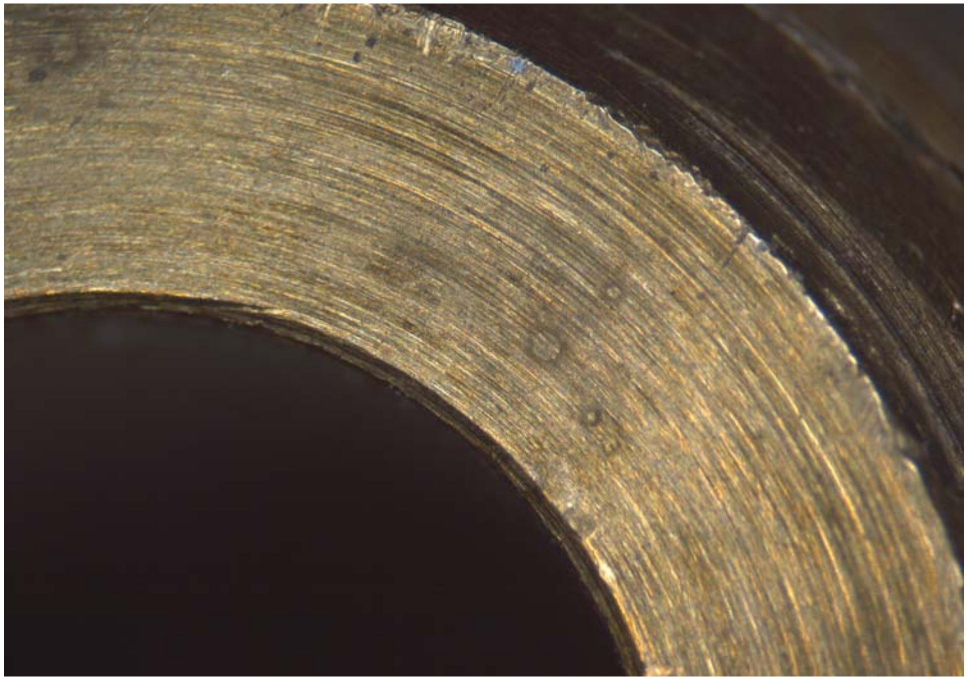
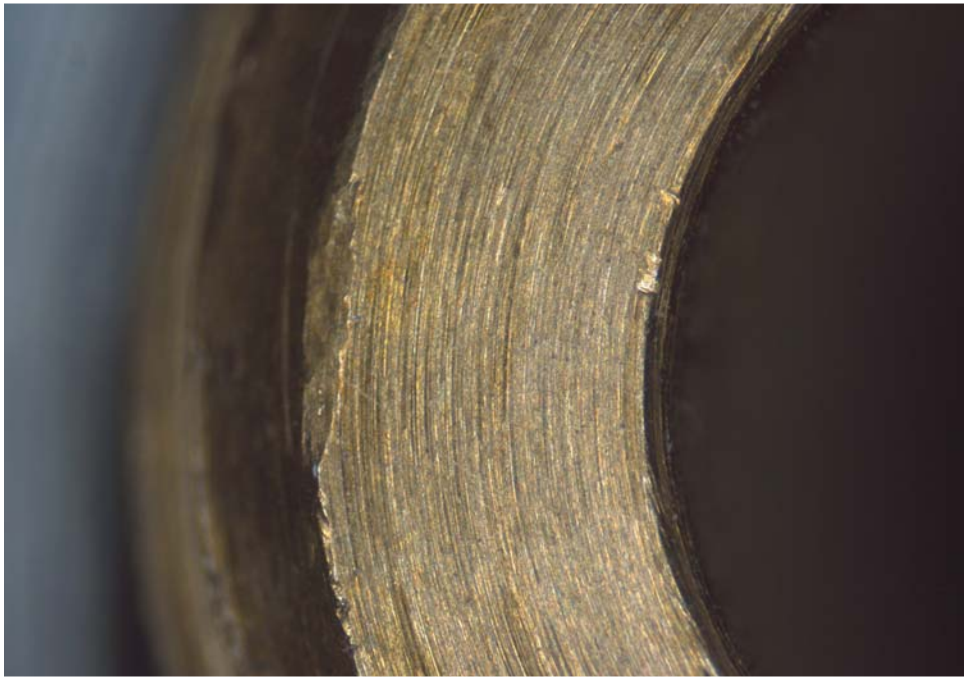

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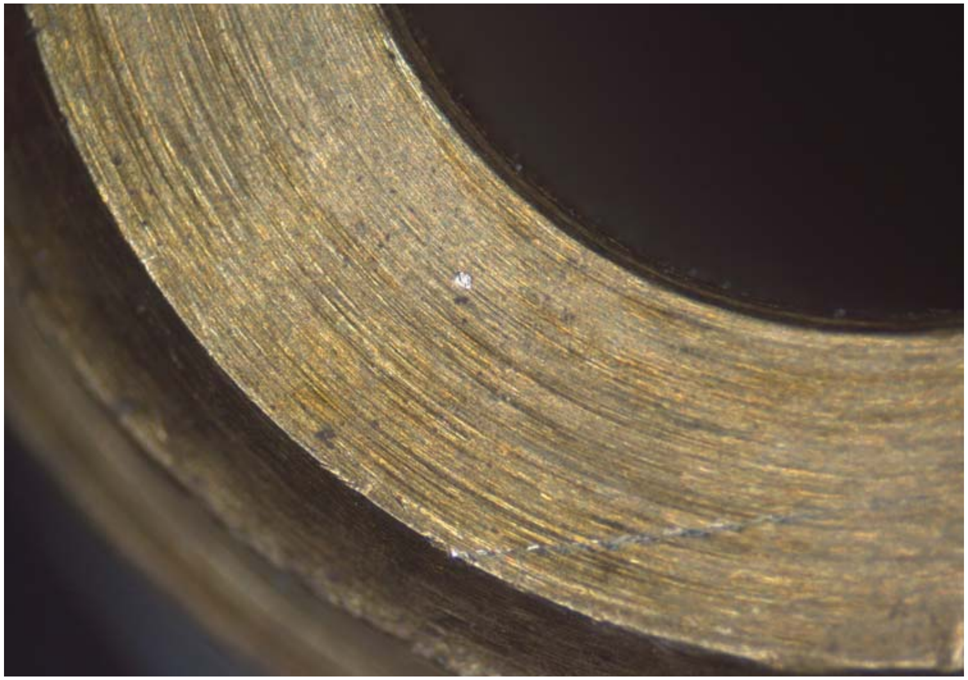

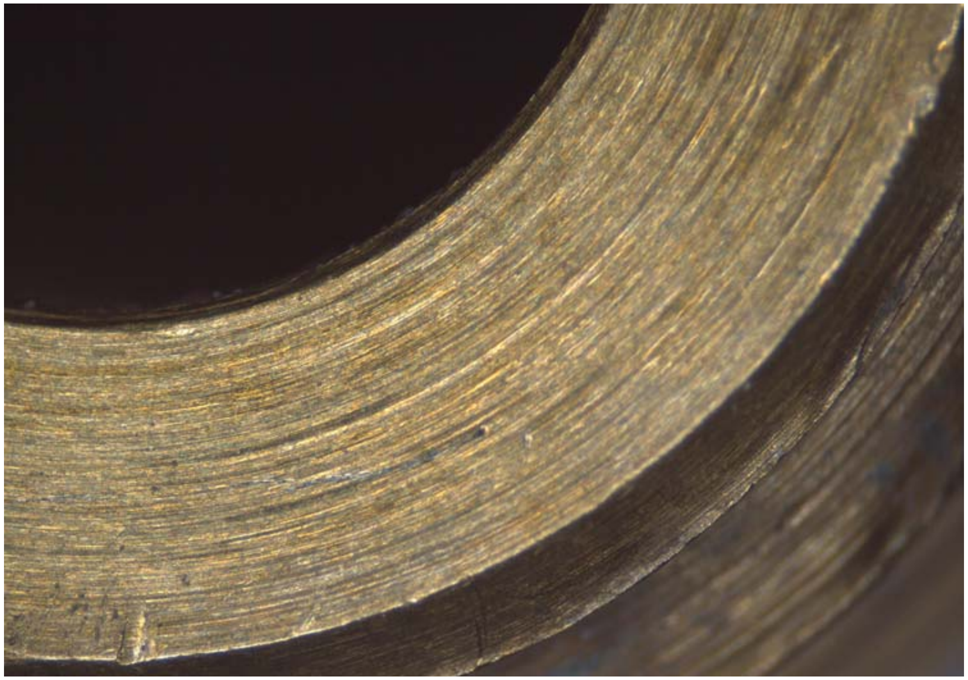

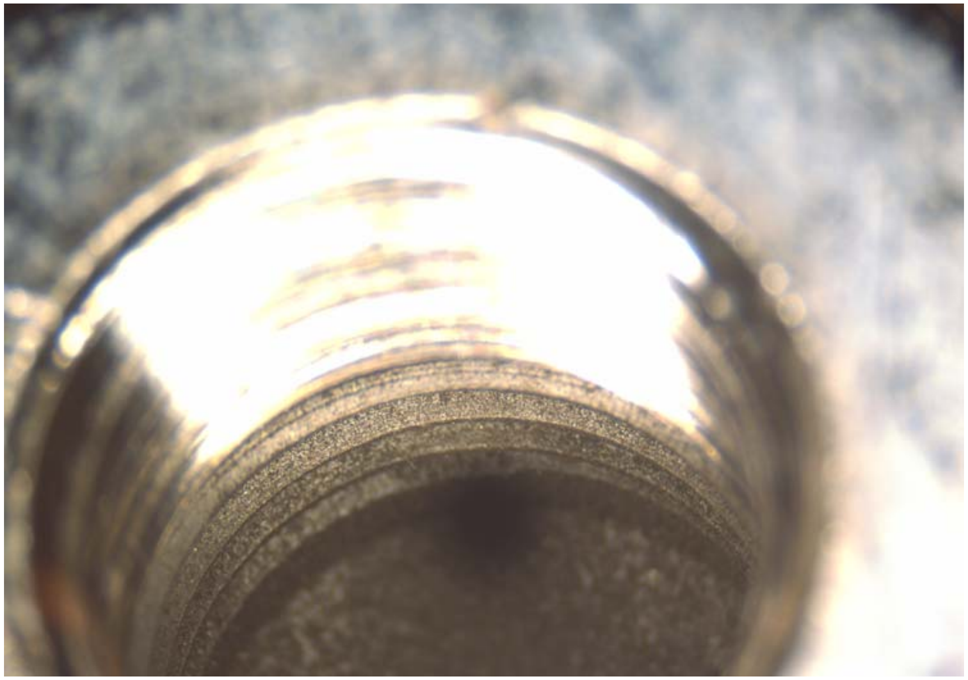

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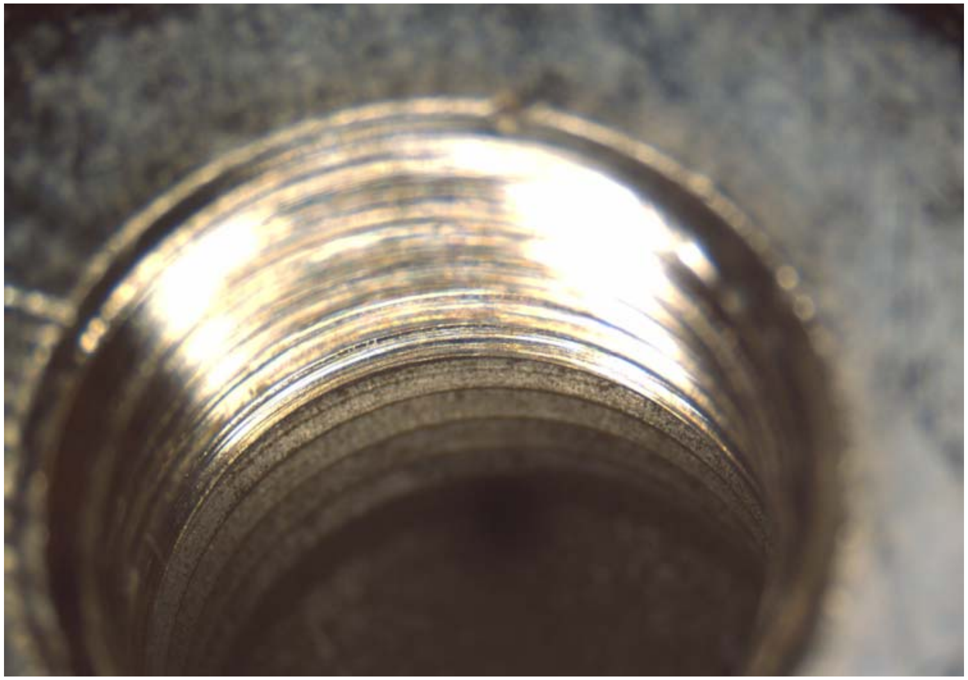

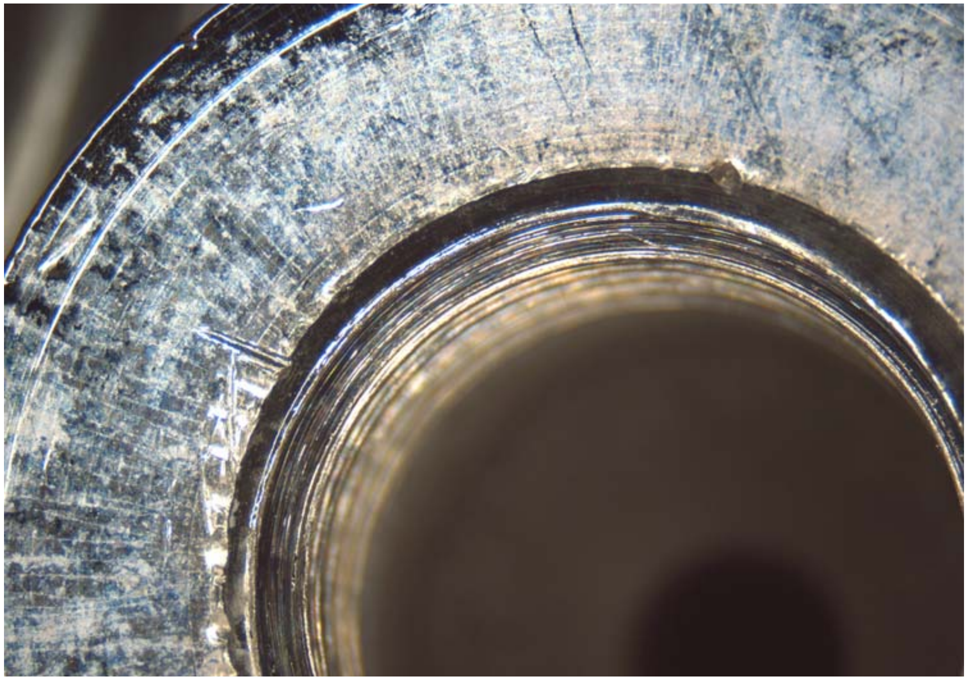

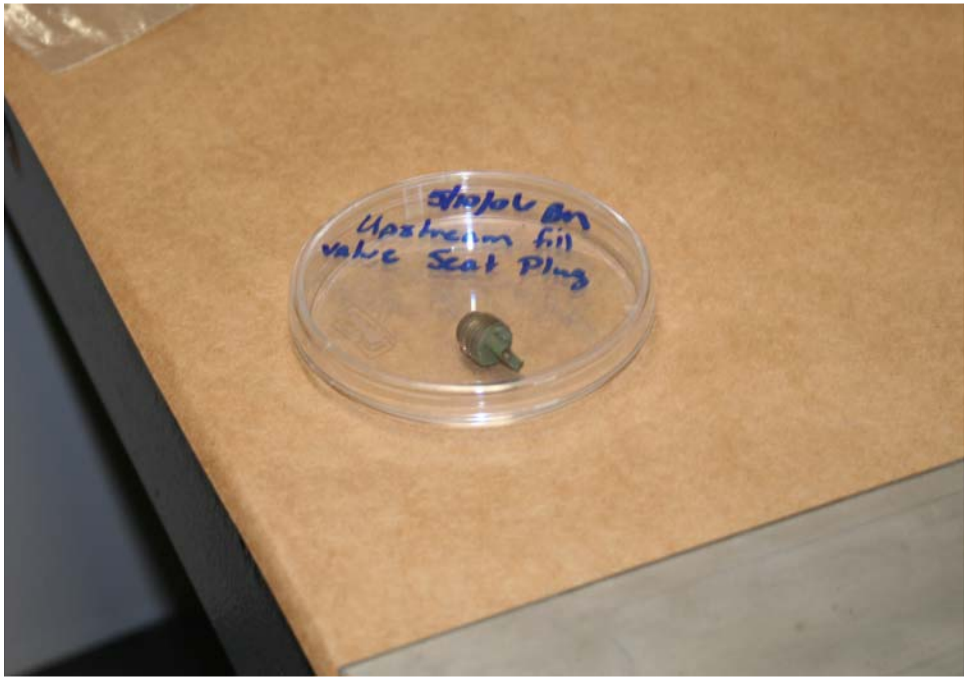

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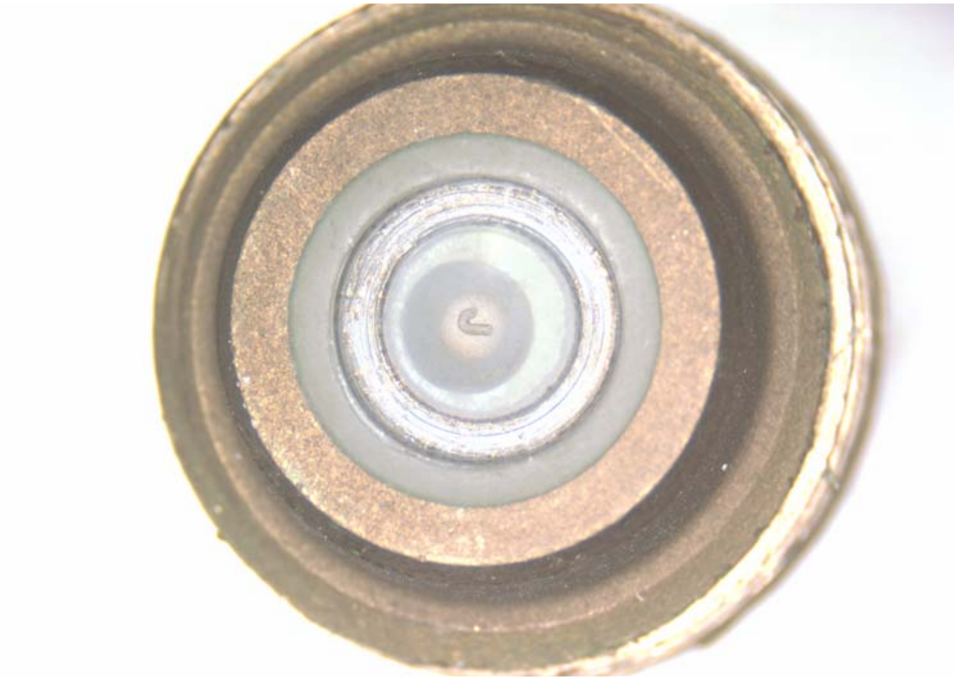

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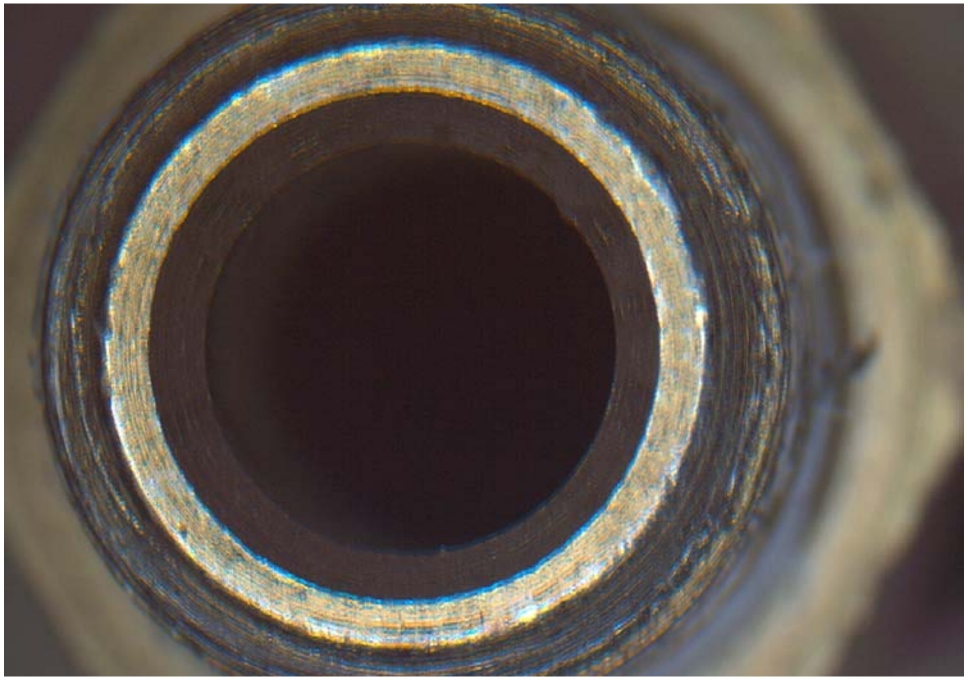

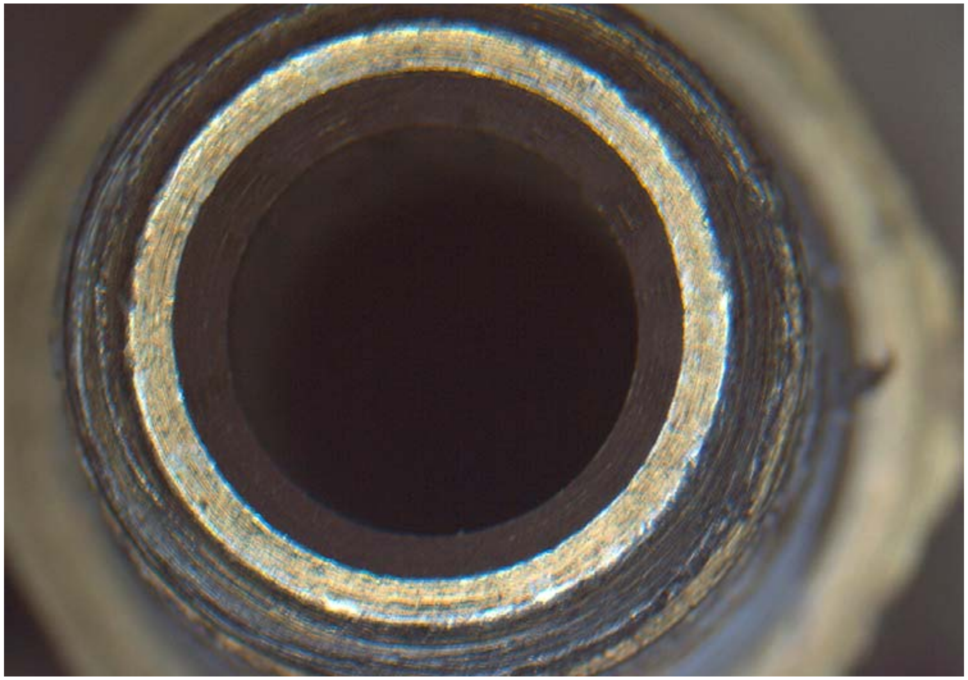

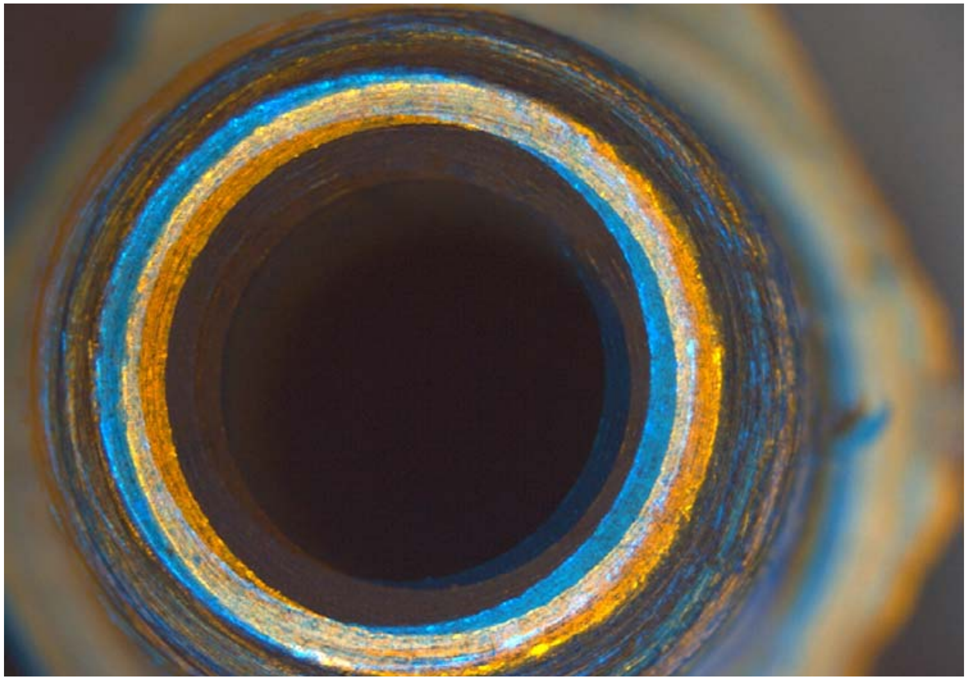

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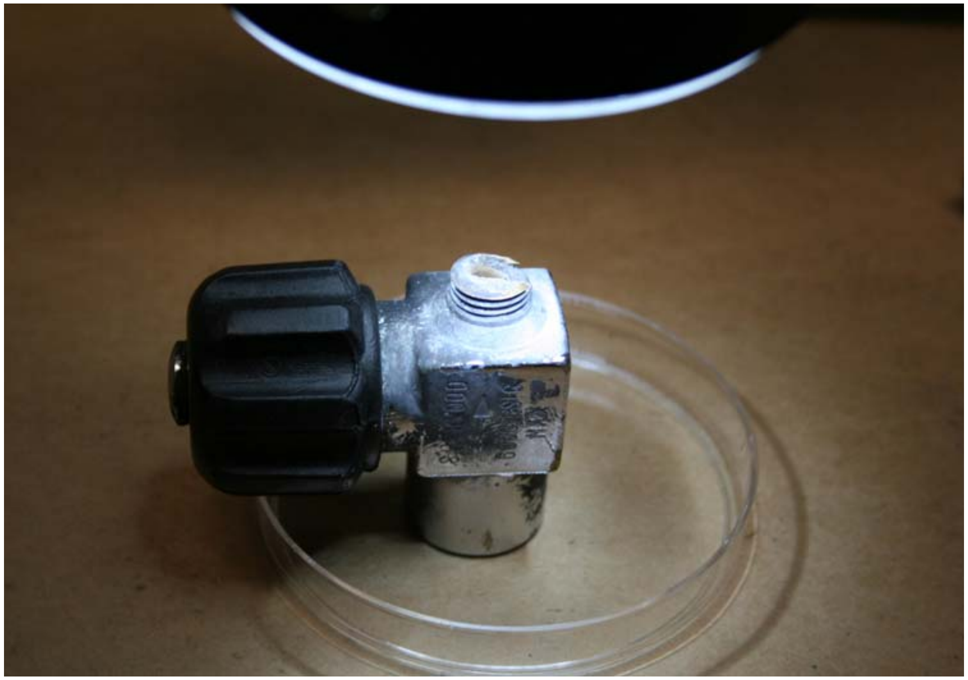

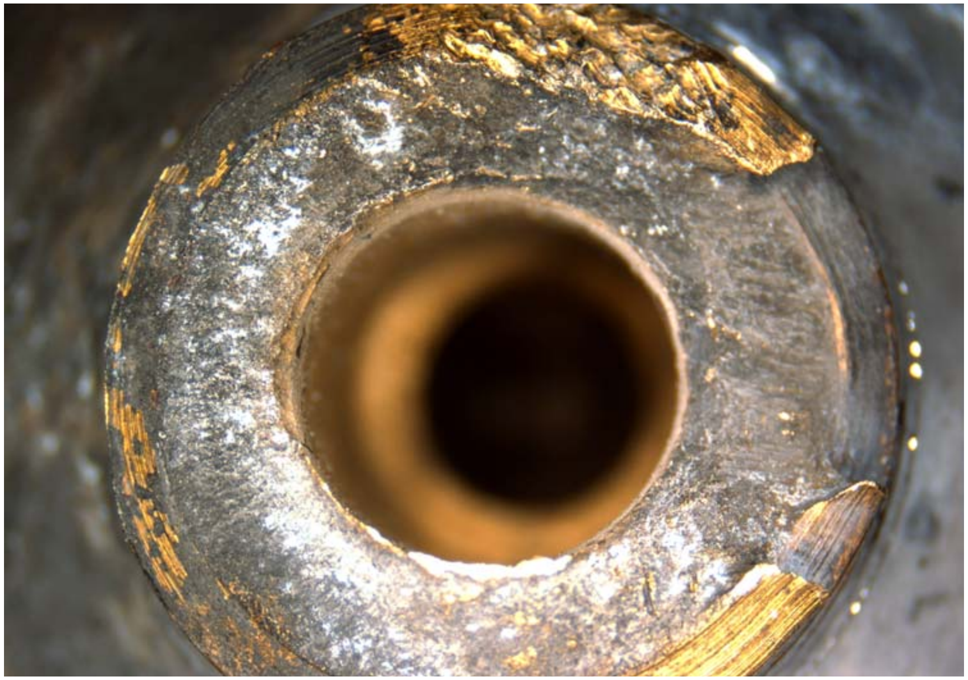

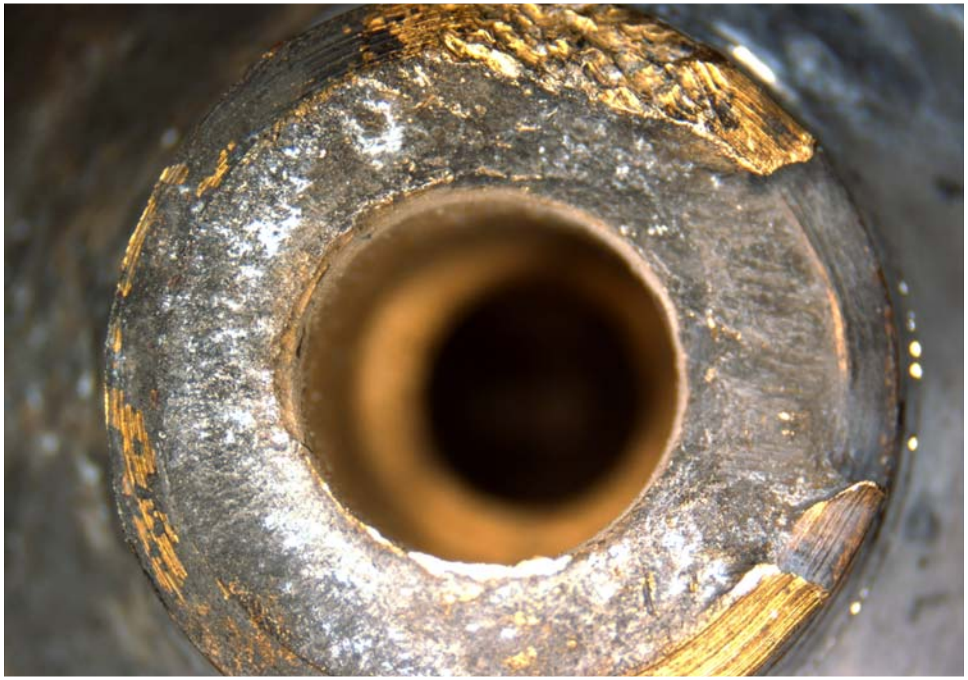

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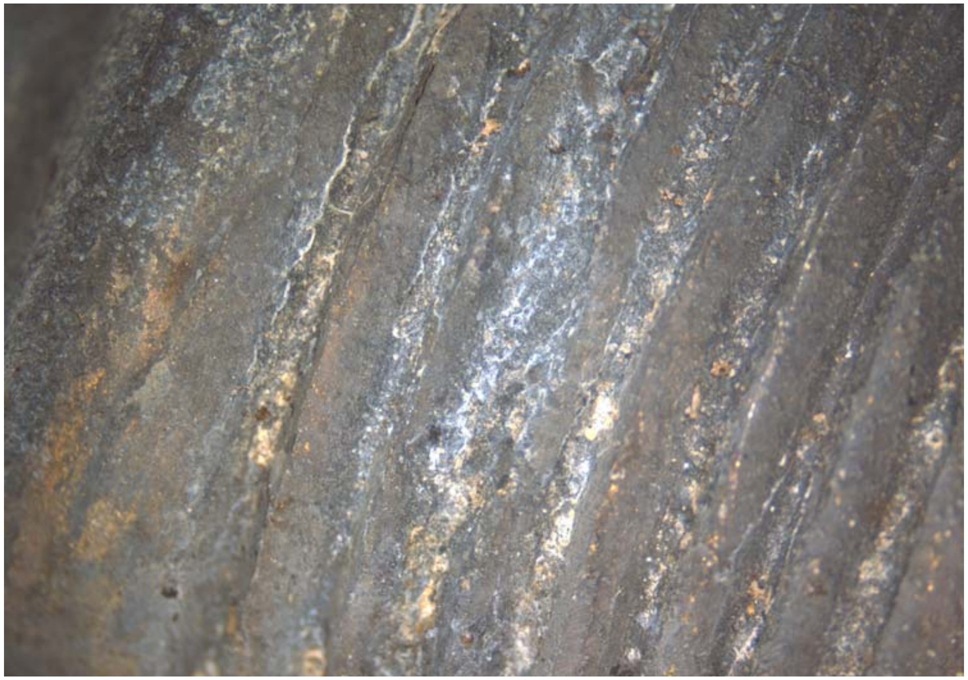

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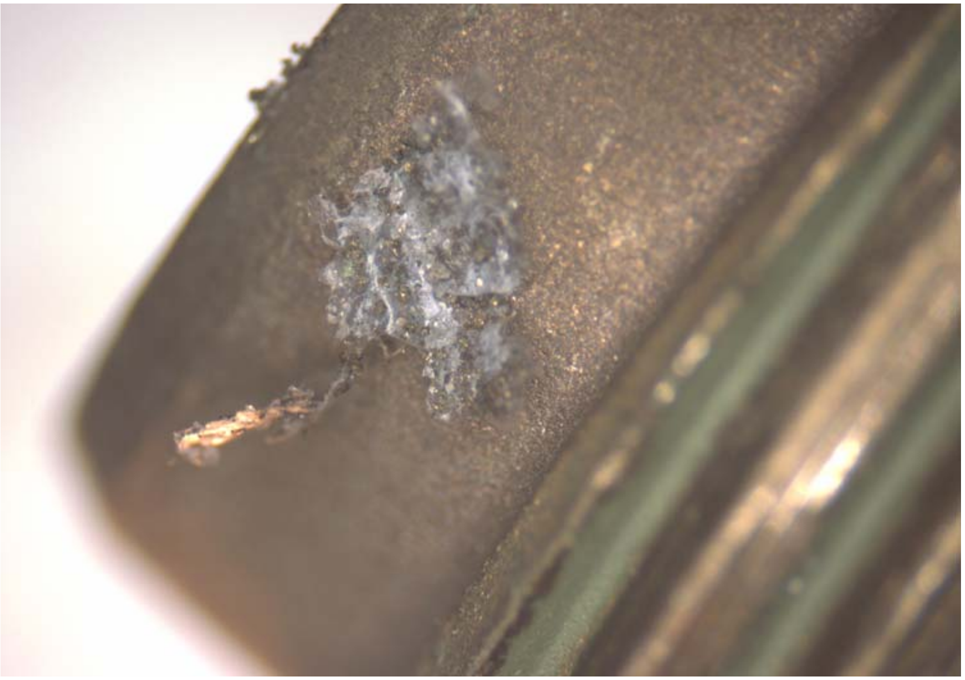
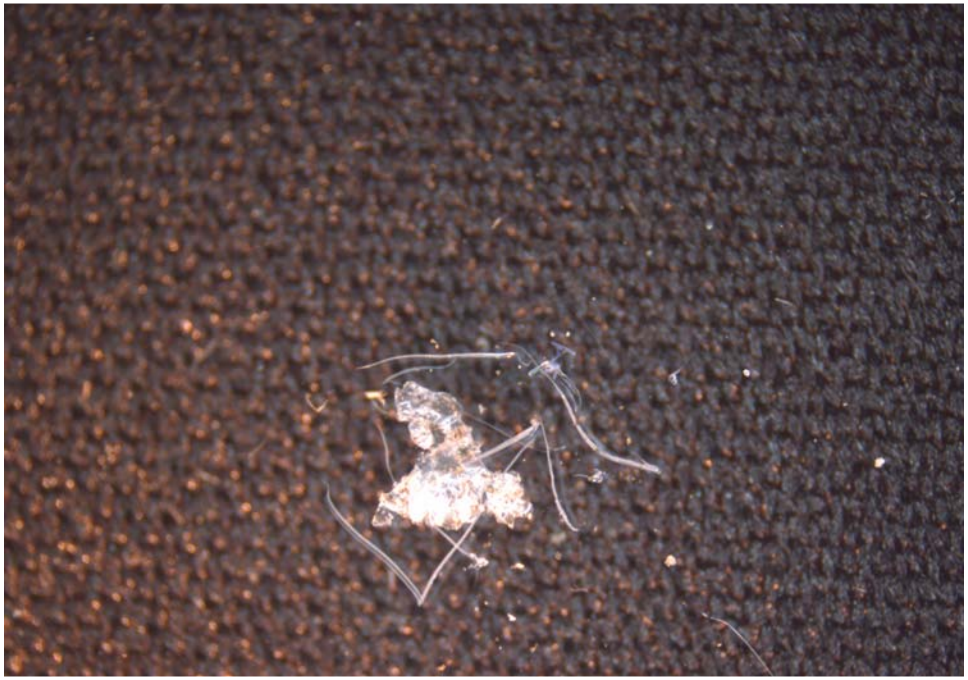
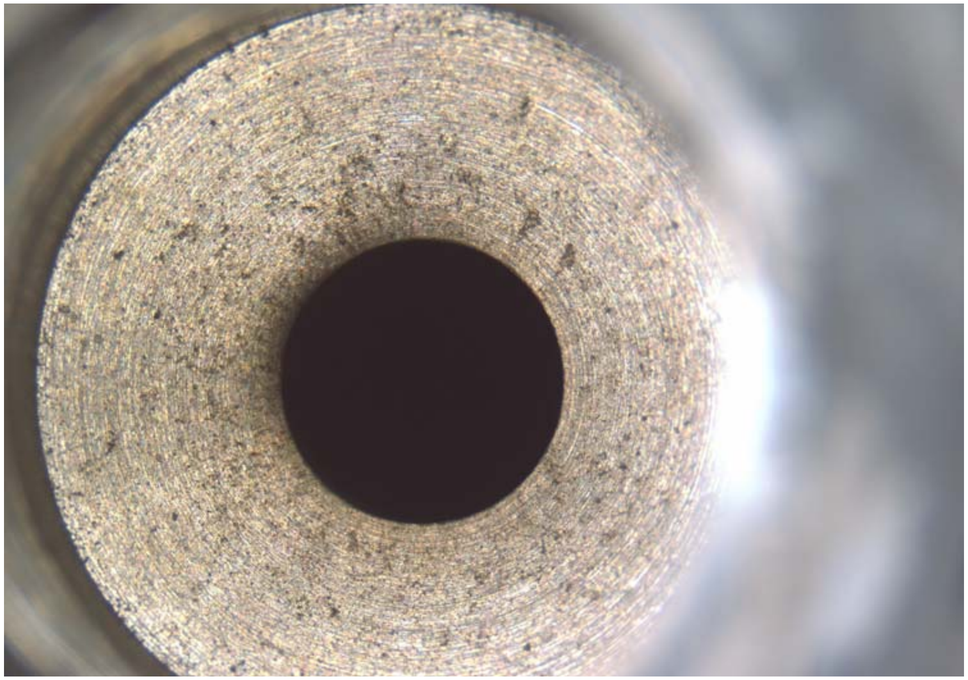




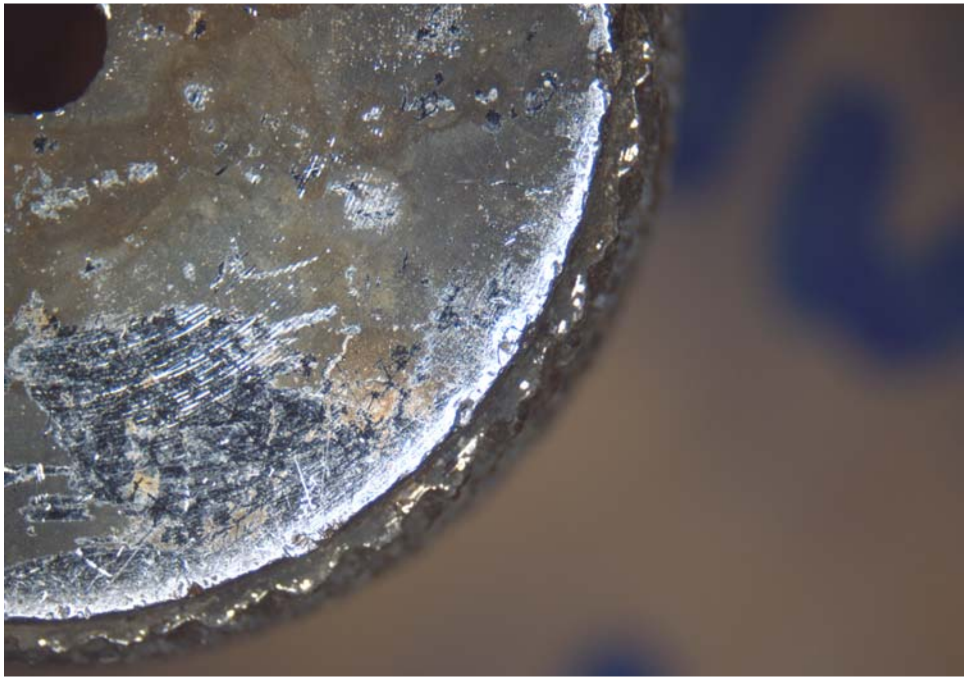


MICROSCOPE PHOTOS - DOWNSTREAM FILL VALVE

MICROSCOPE PHOTOS - CV ADAPTOR BLEED VALVE



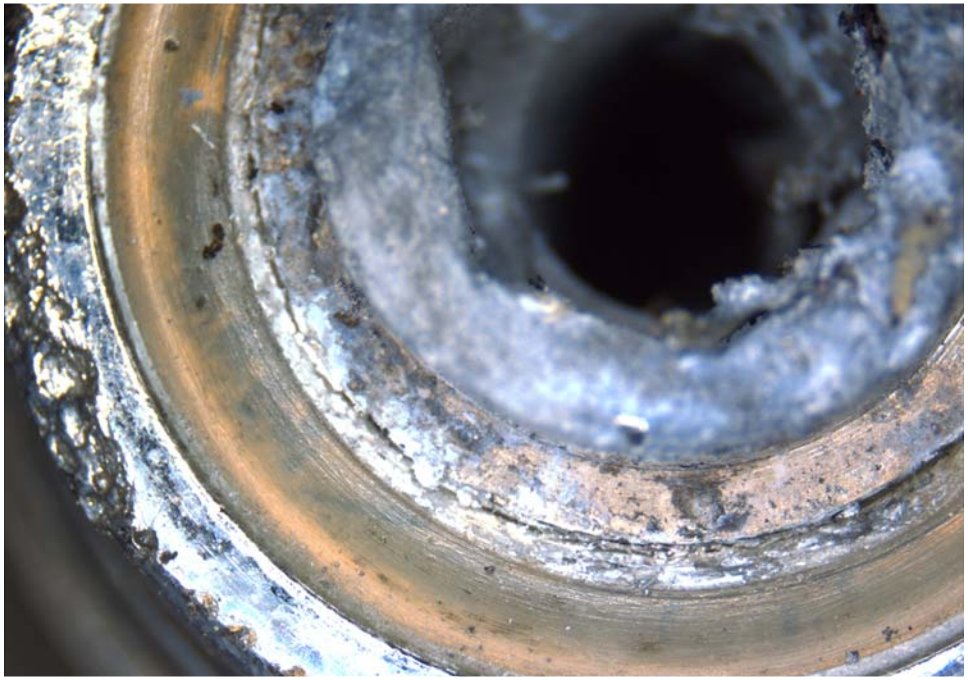

MICROSCOPE PHOTOS - CV ADAPTOR BLEED VALVE

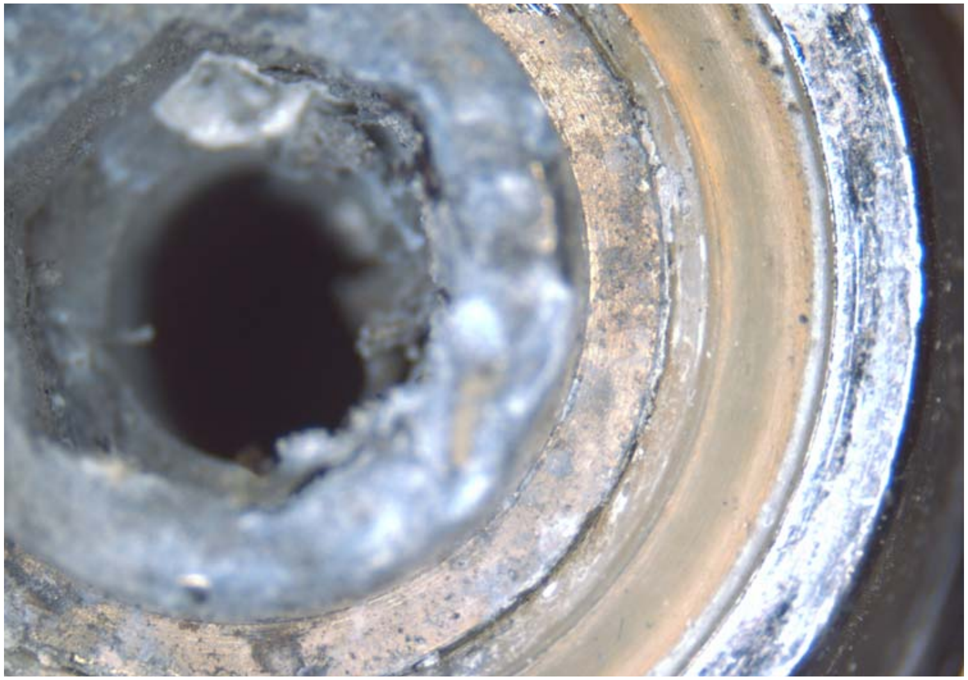


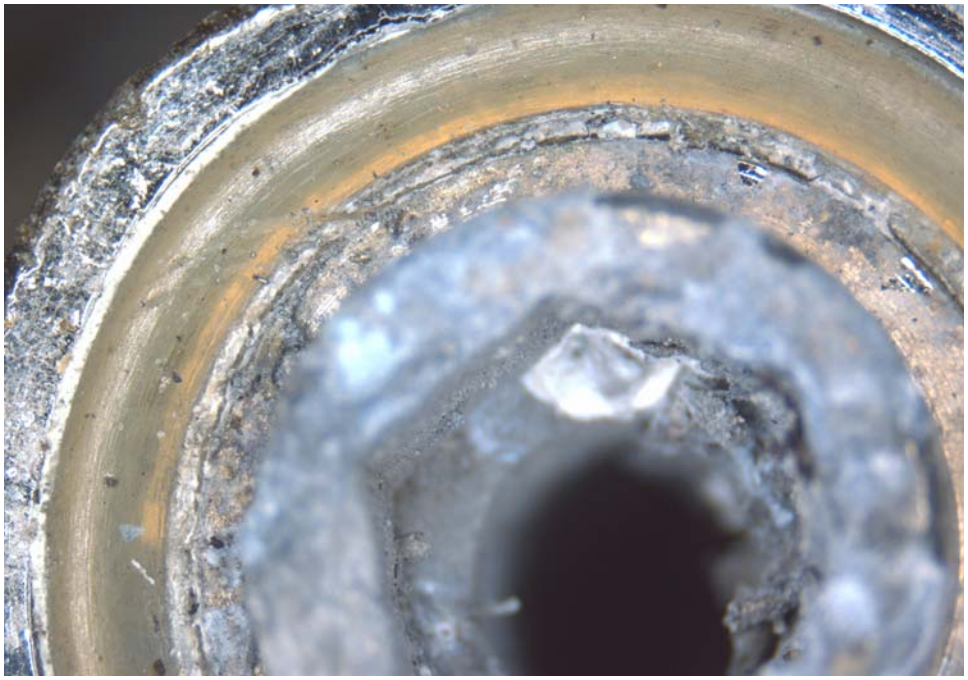
MICROSCOPE PHOTOS - FILL ADAPTOR

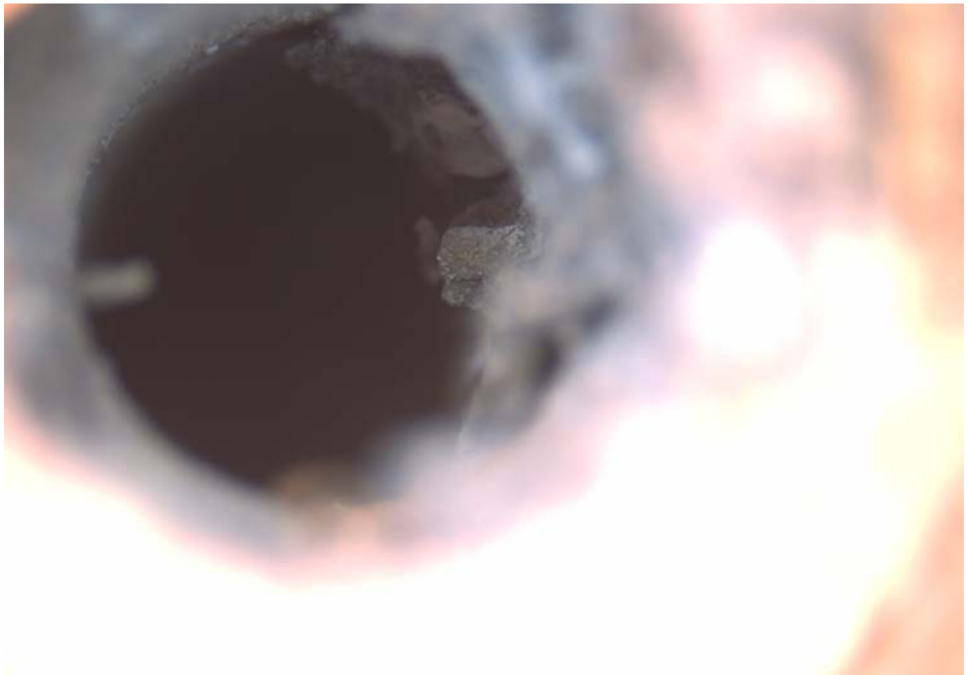



MICROSCOPE PHOTOS - FILL ADAPTOR









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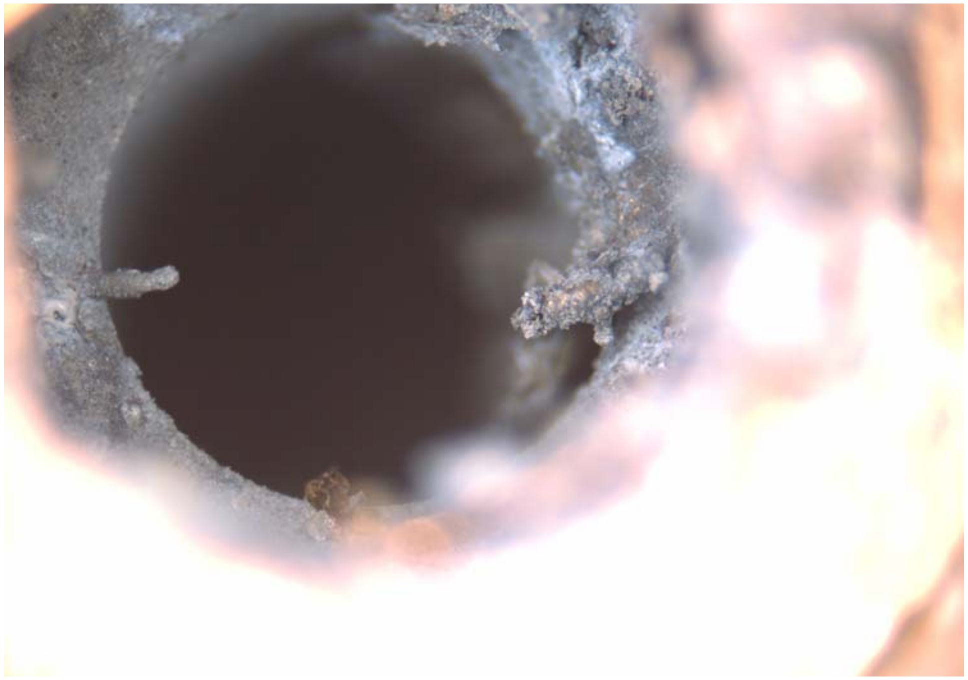
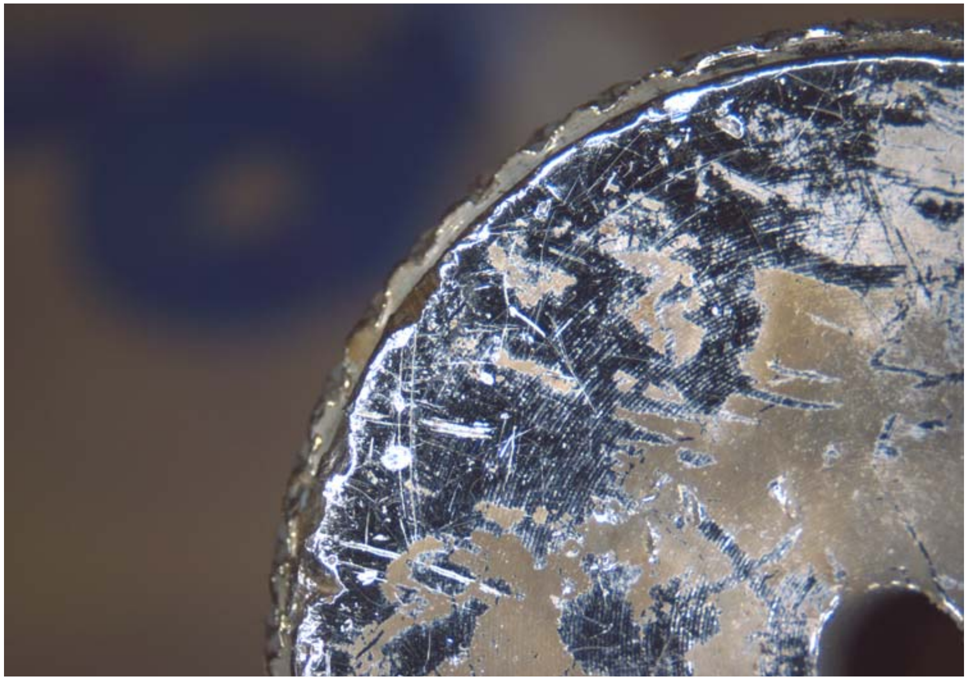
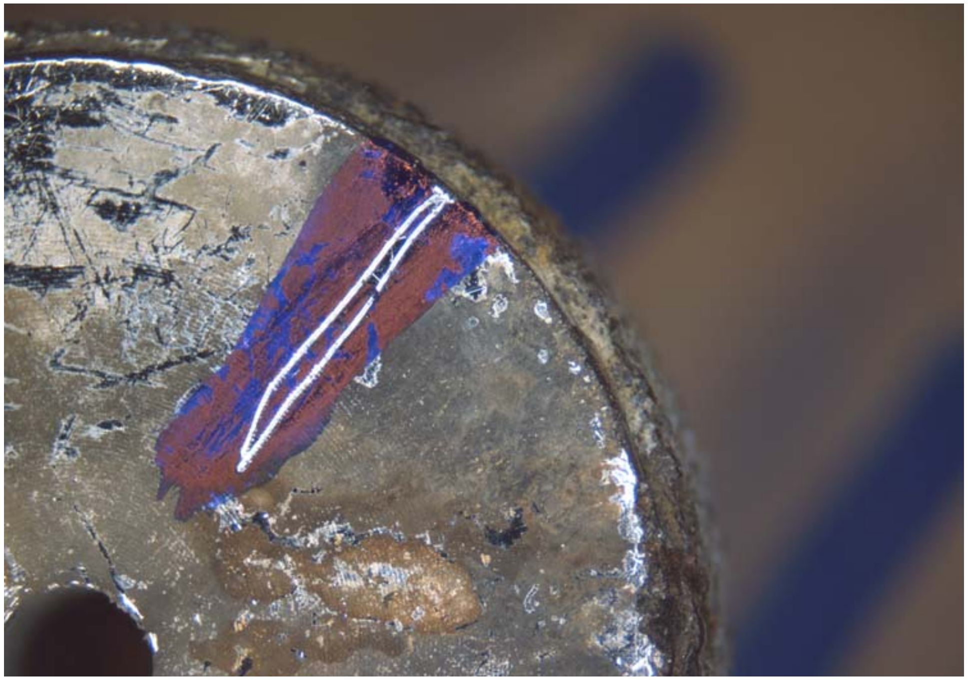
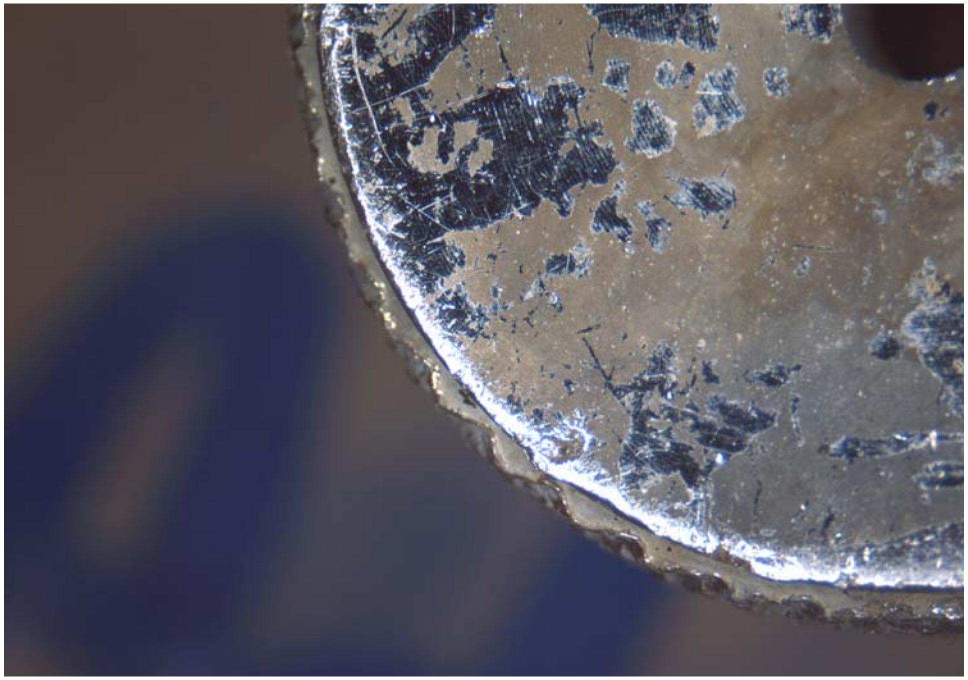
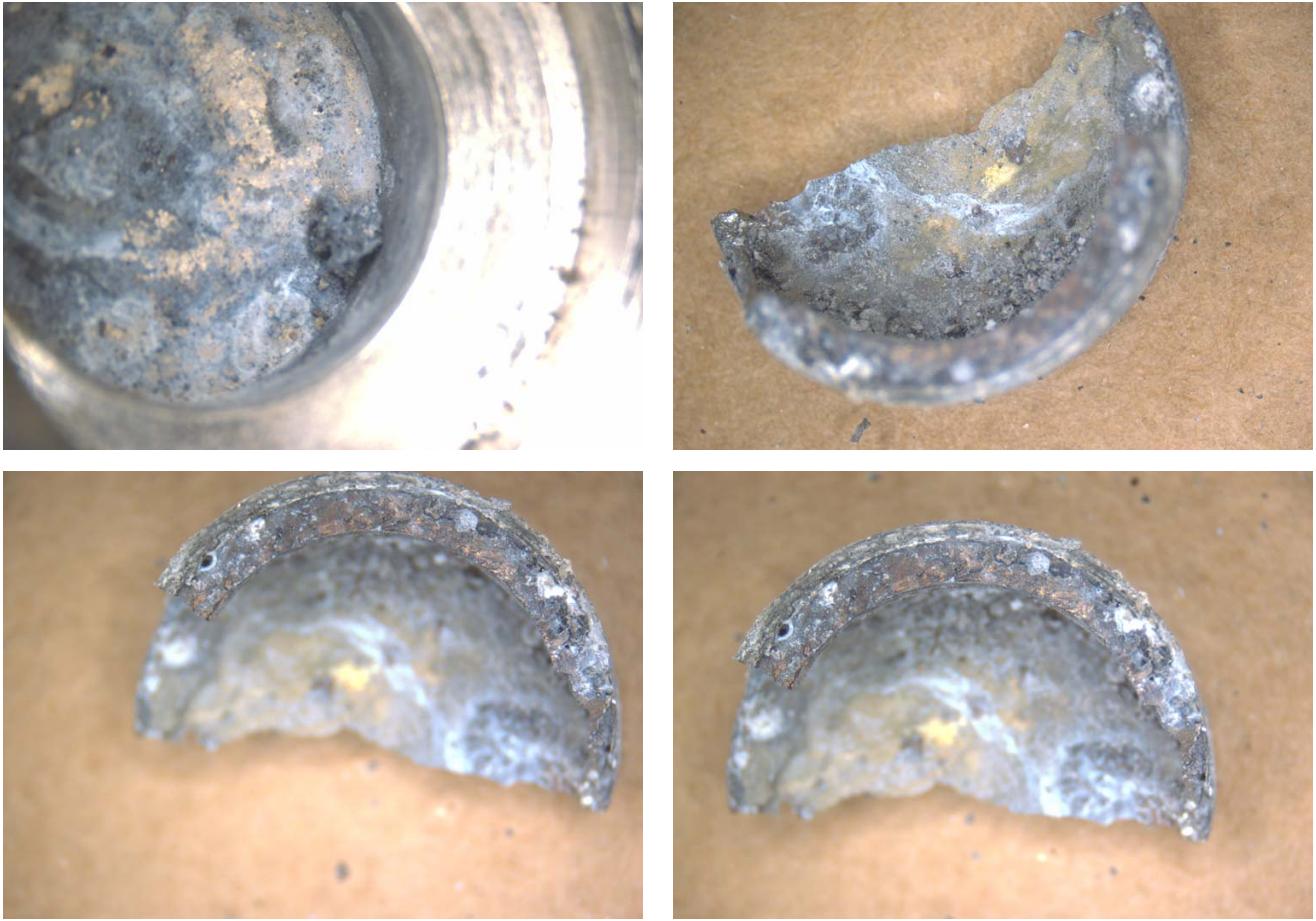
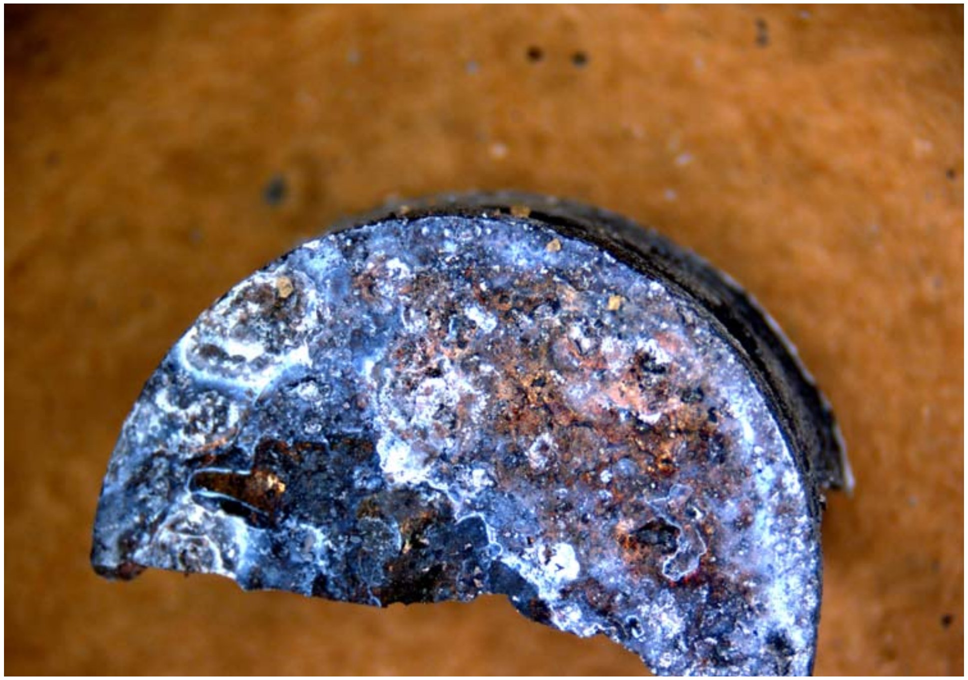





MICROSCOPE PHOTOS - CV OUTLET

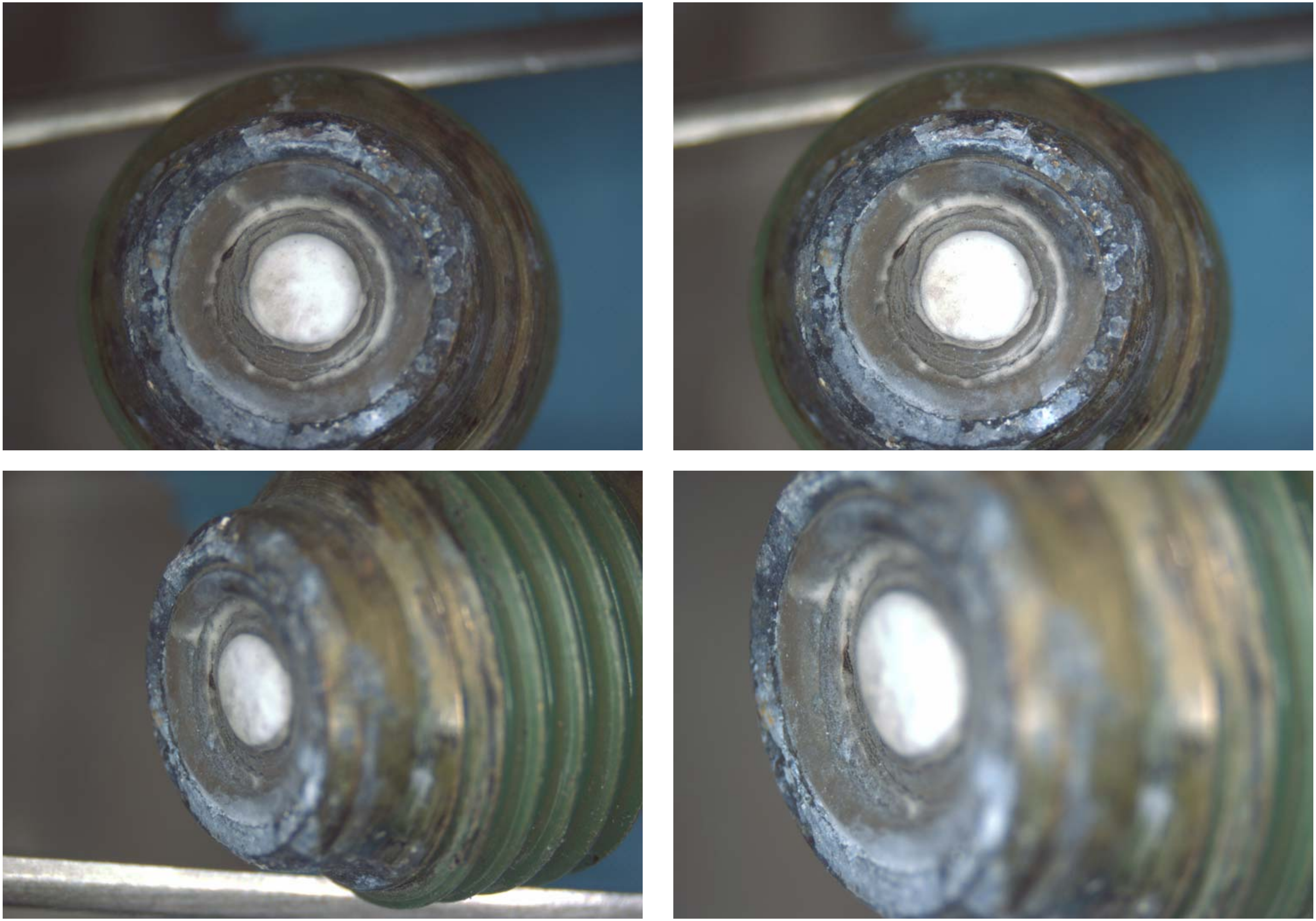
MICROSCOPE PHOTOS - CV OUTLET



MICROSCOPE PHOTOS - CV OUTLET

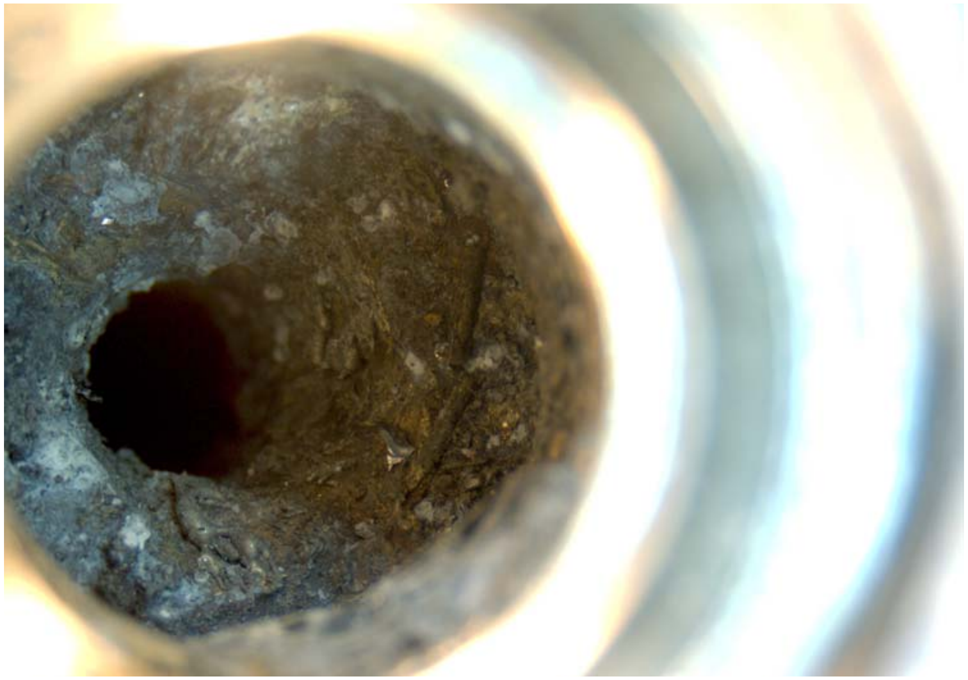


MICROSCOPE PHOTOS - CV SEAT AND NOZZLE



MICROSCOPE PHOTOS - CV SEAT AND NOZZLE

MICROSCOPE PHOTOS - CV SEAT INTERFACE



MICROSCOPE PHOTOS - CYLINDER VALVE

MICROSCOPE PHOTOS - CYLINDER VALVE

MICROSCOPE PHOTOS - CV BURST DISC

Attachment 2: Exemplar SCBA Fill Components

2673 - FILLER YOKE TO 1/4”NPT THREAD

4020 - DIN TO YOKE CONVERTER

4029 - FINE THREADED BLEED BODY ONLY - (SHOWN WITH BLEED SCREW)

4028A -DIN FILLER ONLY 200 BAR

4028B -DIN FILLER ONLY 300 BAR

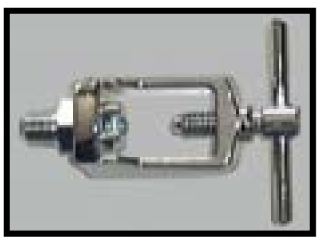
4026A -DIN FILLER WITH BLEEDER FOR FILL WHIPS 200 BAR

4026B -DIN FILLER WITH BLEEDER FOR FILL WHIPS 300 BAR

4024 - YOKE TO DIN FILL ADAPTER

4030 - S.C.B.A./ YOKE FILL ADAPTER HAND TIGHT FITS SCOTT,MSA SURVIVAIR (1/4” MNPT THREADS)

2672 - FILLER YOKE COMPLETE
2675B - YOKE SCREW (HANDLE)
2675C - YOKE ONLY
2678 - STANDARD BLEED SCREW
2679B - DELUXE BLEED SCREW
2679 - PUSH BUTTON BLEEDER
4029 - FINE THREADED BLEED BODY ONLY
4029B - YOKE NUT FOR BLEED BODY



4036 - OXYGEN YOKE MEDICAL GRADE CGA 870 2 PIN YOKE WITH 1/4”MNPT

2670 - PNEUMATIC TANK FILL YOKE WITH BLEEDER

2670A - PNEUMATIC TANK FILL YOKE WITH PUSH BUTTON BLEEDER

2674 - DELUXE FILLER YOKE / BLEED COMPLETE
2675B - YOKE SCREW (HANDLE ONLY)
2675C - YOKE ONLY
2675 - BLEEDER SIDE PLUG/SEAT FOR #2674
2675A - BLEEDER KNOB—PLASTIC
2642 - HANDWHEEL—PLASTIC
2675D - BLEEDER KNOB NUT

EZ CHECK PNEUMATIC TANK CHECKER ©

THE QUICKEST POSSIBLE WAY TO CHECK AIR FILLS. JUST POSITION CHECKER OVER VALVE, THEN TURN ON AIR. NO YOKE SCREWS TO TIGHTEN & UNTIGHTEN

2701A - PNEUMATIC EZ CHECK WITH PUSH BUTTON BLEED

2701B - PNEUMATIC EZ CHECK WITH HEAVY DUTY BLEED SCREW

2700 - TANK CHECKER WITH 0-5000 PSI LIQUID FILLED STAINLESS GAUGE & BLEED SCREW

2700C -TANK CHECKER WITH 0-5000 PSI STEEL GAUGE

2700A - TANK CHECKER WITH 0-5000 PSI STAINLESS STEEL GAUGE & PUSH BUTTON BLEEDER

2700G - DIN - WITH PUSH BUTTON BLEEDER AND 0-5000 PSI LIQUID FILLED STAINLESS STEEL GAUGE

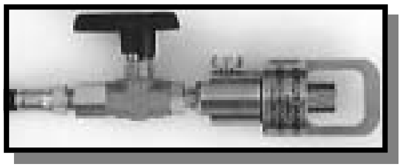
2700E - WITH PUSH BUTTON BLEEDER AND 0-5000 PSI STEEL GAUGE

2700F - DIN - WITH BLEEDER AND 0-5000 PSI LIQUID FILLED STAINLESS STEEL GAUGE

2700D - WITH BLEEDER AND 0-5000 PSI FILLED STEEL GAUGE

GAUGE PROTECTOR

2716 - ADD EXTRA SHOCK PROTECTION FOR YOUR TANK CHECKER WITH THIS THICK RUBBER GAUGE BOOT



EZ FILL YOKE ©

PNEUMATIC YOKE

- NO YOKE SCREWS TO TURN
- BUILT IN BLEED SCREW
- CAN BE USED WITH ANY VALVE OR BLEEDER COMBINATIONS
- FITS INDUSTRY STANDARD BLEED SCREW
- SEALS TO TANK FROM EITHER SOURCE AIR OR TANK AIR
- CAN BE REBUILT IN MINUTES WITH NO TOOLS
- FITS ALL VALVES
- ELIMINATES SORE HANDS

2670 - PNEUMATIC TANK FILL YOKE

– FOR INSTANT TANK FILL LINE ATTACHING
– BLEED SCREW IS NEWLY DESIGNED FOR EASY USE
– ALL BRASS DESIGN-NO HARMING VALVES
– SAVES 75% OF TANK ATTACHING TIME
– **SAVES WEAR AND TEAR ON YOUR HANDS**

2671 - REBUILD KIT FOR ABOVE
2671B - 10 PACK KIT

PUSH BUTTON BLEED

2679 - A SIMPLE, FAST, & DURABLE ALTERNATIVE TO MOST BLEED SCREWS. FITS MOST BLEEDER BODIES AND YOKES.
2679D - REBUILD KIT FOR PUSH BUTTON

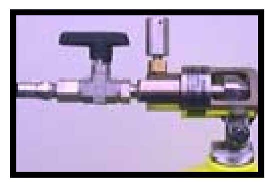
FITS EZ FILL PNEUMATIC YOKES

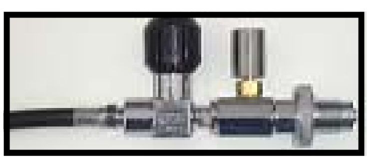
FITS STANDARD SHERWOOD YOKE

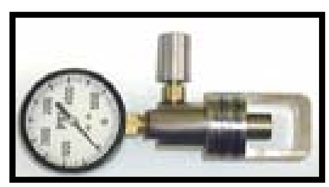
LARGE OVERSIZE PUSHBUTTON

NO MORE SORE HANDS

NO LEAKY BLEED SCREWS



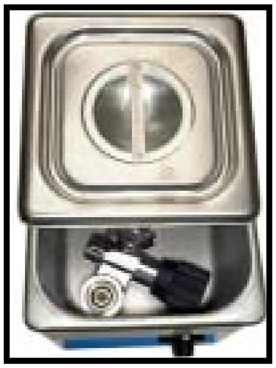




OVERSIZE BLEED SCREW

easy on your hands with its oversize traction grip and replaceable seats

2679B - FITS MOST COMMON BLEEDERS (SHERWOOD, A-PLUS EASY - FILL, ETC.)
2679C - REPLACEABLE SEATS FOR #2679B



2520 - MINI - ULTRASONIC

- TRUE ULTRASONIC CLEANER
- ECONOMICALLY PRICED
- COMPACT - OUTSIDE DIMENSION - 5.25”x5.25”x5”
- STAINLESS 8 OZ. TANK CAPACITY
- COVER AND BUCKET SUPPLIED

2521 - ULTRASONIC CLEANER

- O - 60 MINUTE TIMER
- REMOVABLE COVER
- STAINLESS TANK
- ON/OFF LIGHT
- SELF TUNING, QUIET
- 40 WATTS
- TANK CAPACITY - .30 GALLONS
- TANK SIZE - L = 5.375”
  W = 5.375”
  H = 3”

REPLACEMENT GAUGES

LIQUID FILLED STAINLESS STEEL GAUGES
WITH 2.5” FACE, 1/4” MNPT

	BOTTOM POST	BACK POST	BACK POST AND FLANGE
0-5000 PSI	#2702	#2720	#2703
0-1000 PSI	#2715	#2719	#2725
0-600 PSI	#2714	#2718	#2726
0-200 PSI	#2712	#2717	#2727

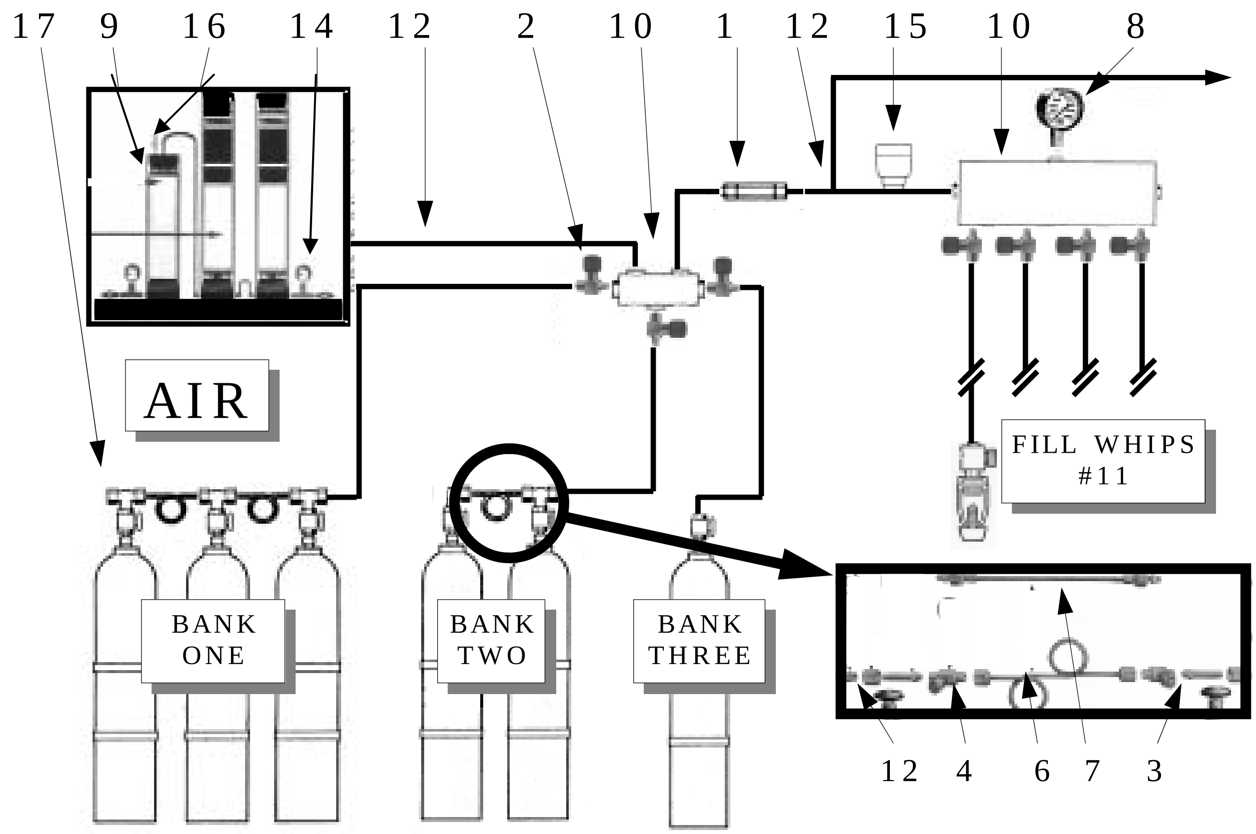
2722 - 0 - 5000 PSI WITH 4.0” FACE, 5.25” MOUNTING FLANGE 1/4” MNPT BACK POST.

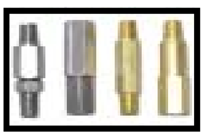
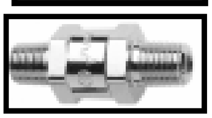
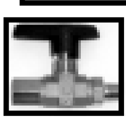
DIGITAL GAUGES
OXYGEN COMPATIBLE - HIGHLY ACCURATE (+/- .25% OVER FULL SCALE) 0-5000PSI DIRECT READ (2x OVER PRESSURE PROTECTION) - AUTO SHUT-OFF - USER REPLACEABLE 9V BATTERY - MORE DURABLE AND ACCURATE THAN ANALOG FOR ABOUT THE SAME PRICE

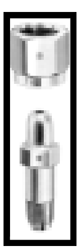
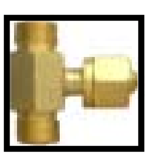
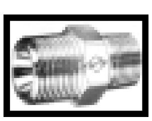
2708 - BOTTOM POST (1/4”MNPT), 2.25” FACE
2708 - PANEL MOUNT, BACK POST (1/4”MNPT)

2710 - 0-4000 PSI OXYGEN CLEAN/COMPATIBLE - NON LIQUID FILLED
2709 - 0-5000 PSI 2.5” FACE - 1/4” MNPT BOTTOM POST - NON LIQUID FILLED

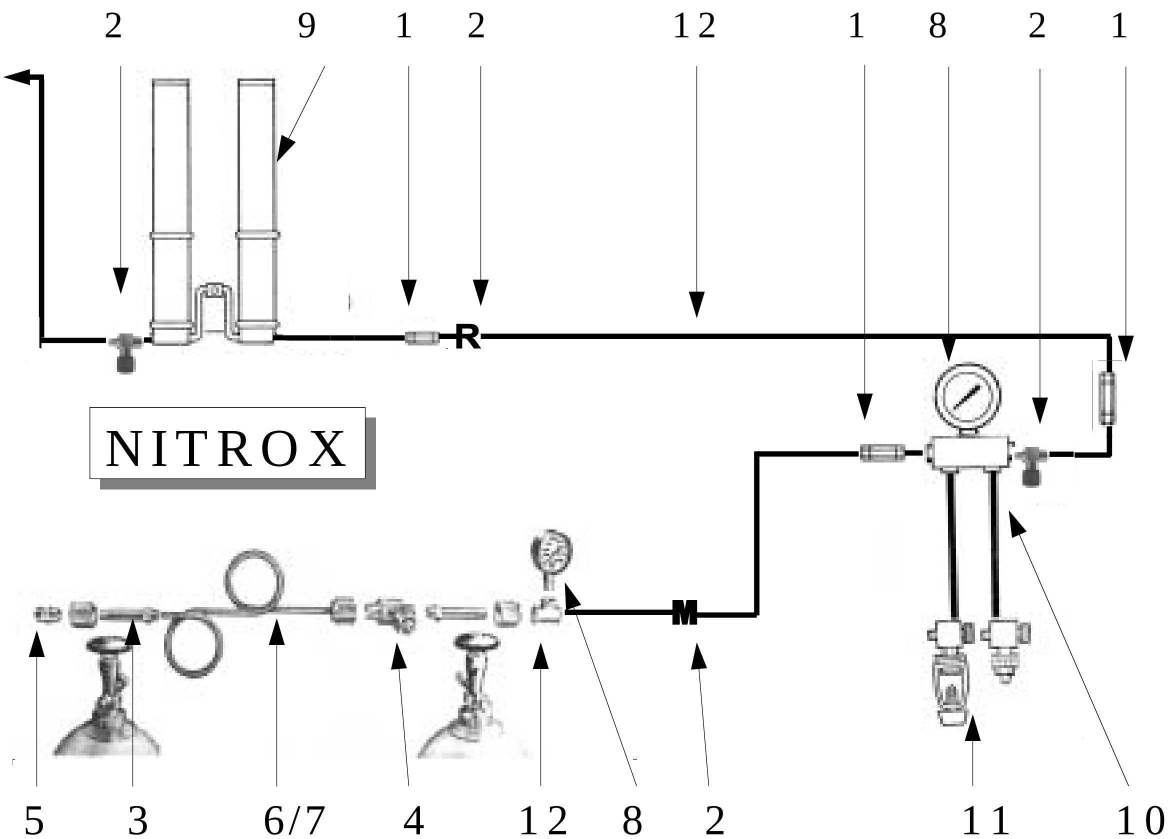
GAUGE PROTECTOR
2716 - FITS MOST 2.5” BOTTOM POST GAUGES

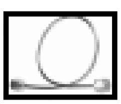


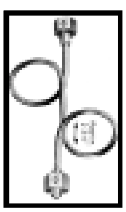




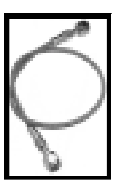





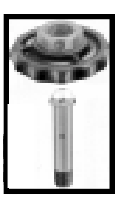
PIC #	DESCRIPTION	MATERIAL	MAX. P.S.I.	PART #
1	CHECK VALVE - 1/4” MNPT to 1/4” MNPT	STAINLESS STEEL	6000 PSI	2564
	CHECK VALVE - 1/4” FNPT to 1/4” FNPT	STAINLESS STEEL	6000 PSI	2566
	CHECK VALVE - 1/4” MNPT to 1/4” MNPT	BRASS	3000 PSI	2563
	CHECK VALVE - 1/4” MNPT to 1/4” FNPT	BRASS	3000 PSI	2565
	RESTRICTOR - 1/4” FNPT to 1/4” MNPT	STAINLESS STEEL	6000 PSI	2578
	MICRON FILTER - 1/4” MNPT to 1/4” MNPT	STAINLESS STEEL	6000 PSI	2567
2	LINE VALVE - 1/4”FNPT(inlet) to 1/4”MNPT	CHROME / BRASS	5000 PSI	2680
	PANEL VALVE -1/4”FNPT(inlet) to 1/4”MNPT	CHROME / BRASS	5000 PSI	2682
	METERING VALVE - 1/4” MNPT to 1/4”MNPT	STAINLESS STEEL	6000 PSI	2573
	METERING VALVE - 1/4” FNPT to 1/4” FNPT	STAINLESS STEEL	6000 PSI	2575
	1/4 TURN ON/OFF BALL VALVES	STAINLESS STEEL	6000 PSI	2686/8
3	AIR NUT / CGA 347	STAINLESS STEEL	5500 PSI	5002
	AIR NIPPLE 1/4”NPT x 3” LONG / CGA 347	STAINLESS STEEL	5500 PSI	5004
	AIR NUT / CGA 346	BRASS	3000 PSI	5006
	AIR NIPPLE 1/4”NPT x 2.25” LONG/ CGA346	BRASS	3000 PSI	5008
	AIR NUT / CGA 346	STAINLESS STEEL	5500 PSI	5010
	AIR NIPPLE 1/4”NPT x 2.25” LONG/ CGA346	STAINLESS STEEL	5500 PSI	5012
	OXYGEN NUT / CGA 540	BRASS	3000 PSI	5014
	OXYGEN NIPPLE 1/4” x 2.25”LONG/CGA540	BRASS	3000 PSI	5016
	OXYGEN NUT / CGA 540	STAINLESS STEEL	3000 PSI	5018
	OXYGEN NIPPLE 1/4” x 2.25”LONG/CGA540	STAINLESS STEEL	3000 PSI	5020
	HELIUM NUT & NIPPLE CGA	BRASS	3000 PSI	5021A
4	AIR TEE ADAPTER / CGA 346 (F to M & M)	BRASS	3000 PSI	5022
	AIR TEE ADAPTER / CGA 347 (F to M & M)	STAINLESS STEEL	5500 PSI	5023
	OXYGEN TEE ADAPTER / CGA 540(FtoM&M)	BRASS	3000PSI	5024
	OXYGEN TEE ADAPTER / CGA 540(FtoM&M)	STAINLESS STEEL	5500PSI	5025
5	AIR CGA-346 (VALVE to1/4”MNPT)ADAPTER	BRASS	3000 PSI	5026
	OXY.CGA-540(VALVEto1/4”MNPT)ADAPTER	BRASS	3000 PSI	5030
	AIR CGA-346 (VALVE to1/4”MNPT)ADAPTER	STAINLESS STEEL	3000PSI	5028
	OXY.CGA-540(VALVEto1/4”MNPT)ADAPTER	STAINLESS STEEL	5500PSI	5032







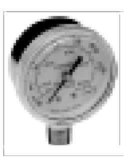
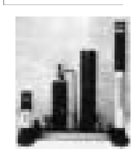




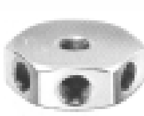
PIC #	DESCRIPTION	MATERIAL	MAX. P.S.I.	PART #
6	AIR PIGTAIL/ CGA-346 - 27" DOUBLE LOOP	COPPER	3000 PSI	5036
	AIR PIGTAIL/ CGA-346 - 18" SINGLE LOOP	CHROME/BRASS	3000 PSI	5038
	AIR PIGTAIL/ CGA-346 - 20" SINGLE LOOP	STAINLESS STEEL	5000 PSI	5040
	AIR PIGTAIL/ CGA-347 - 20" SINGLE LOOP	STAINLESS STEEL	5500 PSI	5042
	OXYGEN PIGTAIL/ CGA-540 - 27"DBL.LOOP	COPPER	3000 PSI	5044
	OXYGEN PIGTAIL/ CGA-540 - 18"SGL.LOOP	CHROME/BRASS	3000 PSI	5046
	OXYGEN PIGTAIL/ CGA-540 - 20"SGL.LOOP	STAINLESS STEEL	3000 PSI	5050
	FLEX-AIR PIGTAIL/CGA-346 - 36" BRAIDED	STAINLESS/TEFLON	3000 PSI	5054
	FLEX-AIR PIGTAIL/CGA-346 - 48" BRAIDED	STAINLESS/TEFLON	3000 PSI	5056
	FLEX-OXY.PIGTAIL/CGA-540 - 36" BRAIDED	STAINLESS/TEFLON	3000 PSI	5058
	FLEX-OXY.PIGTAIL/CGA-540 - 48" BRAIDED	STAINLESS/TEFLON	3000 PSI	5060
7	FLEX-HOSE1/4"FNPT to1/4"FNPT -24" BRAID	STAINLESS/TEFLON	3000 PSI	5062
	FLEX-HOSE1/4"FNPT to1/4"FNPT -36" BRAID	STAINLESS/TEFLON	3000 PSI	5064
	FLEX-HOSE1/4"FNPT to1/4"FNPT -48" BRAID	STAINLESS/TEFLON	3000 PSI	5066
	FLEX-HOSE1/4"MNPT to1/4"NPT-24"BRAID	STAINLESS/TEFLON	3000 PSI	5068
	FLEX-HOSE1/4"MNPT to1/4"NPT-36"BRAID	STAINLESS/TEFLON	3000 PSI	5070
	FLEX-HOSE1/4"MNPT to1/4"NPT-48"BRAID	STAINLESS/TEFLON	3000 PSI	5072
3	HAND TIGHT CONNECTOR FOR **OXYGEN** BOTTLES (CGA 540) NUT & NIPPLE	BRASS	3000 PSI	4050
	HAND TIGHT CONNECTOR FOR **AIR** BOTTLES (CGA 346) NUT & NIPPLE	BRASS	3000 PSI	4052
14	BACK PRESSURE REGULATOR – MAINTAINS FILTER CHAMBER PRESSURE AT 300-5000PSI (ADJUSTABLE) – 2-50 CFM FLOW - 1/4"NPT PORTS	ANODIZED ALUM. & STAINLESS STEEL	6000 PSI	5200



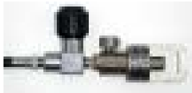
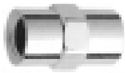
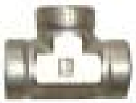
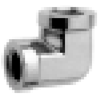
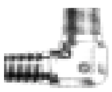
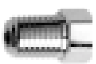
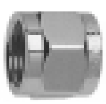
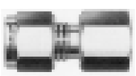
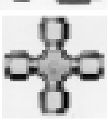
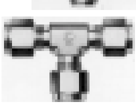
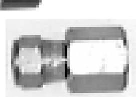
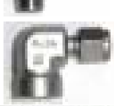






PIC #	DESCRIPTION	MATERIAL	MAX. P.S.I.	PART #
15	REDUCING REGULATOR – SETS FINAL PRESS. FOR FILL STATIONS – REGULATOR/VALVE TESTING – INPUT MAX - 6000PSI – OUTPUT 0 - 5000PSI	ANODIZED ALUM STAINLESS STEEL BRASS	6000PSI	5214
16	ADJUSTABLE PRESSURE RELIEF VALVE – 300 - 6000 PSI ADJUSTABLE – MAX. FLOW 100CFM@3000PSI – BUBBLE TIGHT/SIDE VENTING	ANODIZED ALUM. BRONZE	6000PSI	5218
10	PRESSURE SWITCH – 0 - 6000 PSI ADJUSTABLE – 5 AMP, 250 VOLT MAX, UL/CSA – SWITCH SPDT (N.O. & N.C.)	ANODIZED ALUM. BRASS STAINLESS STEEL VITON SEALS	6000PSI	5220
8	**DIGITAL PRESSURE GAUGE** – OXYGEN COMPATIBLE – 0-5000PSI DIRECT READ (2X OVER PRESSURE PROTECTION) – ACCURACY: +/-.25% FULL SCALE – AUTO SHUT-OFF, USER REPLACE BATT.	DELRIN STAINLESS STEEL	5000	2708 2708B
8	**LIQUID FILLED GAUGES**			
	0 - 5000 PSI (2.5”) BOTTOM POST -1/4”NPT	STAINLESS STEEL	5000PSI	2702
	0 - 5000 PSI (2.5”) BACK POST -1/4”NPT	STAINLESS STEEL	5000PSI	2720
	0 - 5000 PSI (2.5”) BACK, FLANGE MOUNT	STAINLESS STEEL	5000PSI	2703
	0 - 1000 PSI (2.5”) BOTTOM POST-1/4”NPT	STAINLESS STEEL	1000PSI	2715
	0 - 1000 PSI (2.5”) BACK POST -1/4”NPT	STAINLESS STEEL	1000PSI	2719
	0 - 600 PSI (2.5”) BOTTOM POST -1/4”NPT	STAINLESS STEEL	600PSI	2714
	0 - 600 PSI (2.5”) BACK POST -1/4”NPT	STAINLESS STEEL	600PSI	2718
	0 - 200 PSI (2.5”) BOTTOM POST -1/4”NPT	STAINLESS STEEL	200PSI	2712
	0 - 200 PSI (2.5”) BACK POST -1/4”NPT	STAINLESS STEEL	200PSI	2717
	GAUGE PROTECTOR FOR 2.5” B.MNT.	RUBBER	-	2716
8	**AIR FILLED GAUGES**			
	0 - 4000 PSI(2”)B.POST-**OXYGEN CLEANED**	BRASS/STEEL	4000PSI	2710
	0 - 6000 PSI (2”) BOTTOM POST - 1/4”NPT	BRASS/STEEL	6000PSI	2709
9	FILTER SYSTEMS AND INDIVIDUAL FILTER STACKS & ACCESSORIES - SEE PAGE 63 & 64 IN OUR CATALOG			
9	VISUAL MOISTURE /CARBON MONOXIDE INDICATOR - 1/4”FNPT, MOUNTS INLINE, DOWNSTREAM OF FILTER SYSTEM.	ANODIZED ALUMINUM	5000PSI	6000
	REPLACEMENT MOISTURE CARD			6002
	REPLACEMENT MOISTURE/CO CARD			6003
	1/4” TUBING-SEAMLESS GRADE 316	STAINLESS STEEL	5200 PSI	2580
	1/4” TUBING-WELDED GRADE 316	STAINLESS STEEL	5200 PSI	2582
	3/8” TUBING-SEAMLESS GRADE 316	STAINLESS STEEL	3500 PSI	2584
	MANIFOLD / MIXING BLOCKS			
	7 PORT (11” x 2”)-1/4”FNPT w/mount holes	ANODIZED ALUM.	5000 PSI	2570
	5 PORT (4.5”x 2”)-1/4”FNPT w/mount holes	ANODIZED ALUM.	5000 PSI	2568
	6 PORT (2” DIAM)-1/4”FNPT	BRASS	3000 PSI	2572
	6 PORT (2” DIAM)-1/4”FNPT	STAINLESS STEEL	6000 PSI	2574

	PIC #	DESCRIPTION	MATERIAL	MAX. P.S.I.	PART #
	11	FILL WHIPS SEE PAGES 57 & 58 IN OUR CATALOG FOR DETAILS			
		MALE TO MALE NIPPLE (1/4” MNPT)	CARBON STEEL	8000 PSI	2531
		MALE TO MALE NIPPLE (1/4” MNPT)	STAINLESS STEEL	7500 PSI	2531SS
		FEMALE TO FEMALE UNION (1/4” FNPT)	CARBON STEEL	6600 PSI	2533
		FEMALE TO FEMALE UNION (1/4” FNPT)	STAINLESS STEEL	6200 PSI	2533SS
		FEMALE TEE CONNECTORS (1/4” FNPT)	CARBON STEEL	6600 PSI	2535
		FEMALE TEE CONNECTORS (1/4” FNPT)	STAINLESS STEEL	6200 PSI	2535SS
		FEMALE ELBOW CONNECTORS(1/4”FNPT)	CARBON STEEL	8000 PSI	2528
		FEMALE ELBOW CONNECTORS(1/4”FNPT)	STAINLESS STEEL	7500 PSI	2528SS
		MALE ELBOW CONNECTORS(1/4”MNPT)	CARBON STEEL	8000 PSI	2529
		MALE ELBOW CONNECTORS(1/4”MNPT)	STAINLESS STEEL	7500 PSI	2529SS
		PIPE PLUG(1/4”MNPT)	CARBON STEEL	8000 PSI	2532
		PIPE PLUG(1/4”MNPT)	STAINLESS STEEL	7500 PSI	2532SS
		PIPE CAP (1/4”MNPT)	CARBON STEEL	6600 PSI	2530
		PIPE CAP (1/4”MNPT)	STAINLESS STEEL	6200 PSI	2530SS
		FEMALE (1/4”FNPT) TO TUBE 1/4”	CARBON STEEL	6600 PSI	2540
	12	FEMALE (1/4”FNPT) TO TUBE 1/4”	STAINLESS STEEL	6200 PSI	2540SS
		MALE (1/4”MNPT) TO TUBE 1/4”	CARBON STEEL	8000 PSI	2542
		MALE (1/4”MNPT) TO TUBE 1/4”	STAINLESS STEEL	7500 PSI	2542SS
		1/4” TUBE TO 1/4” TUBE UNION	CARBON STEEL	8000 PSI	2544
		1/4” TUBE TO 1/4” TUBE UNION	STAINLESS STEEL	7500 PSI	2544SS
		1/4” TUBE CROSS	CARBON STEEL	8000 PSI	2546
		1/4” TUBE CROSS	STAINLESS STEEL	7500 PSI	2546SS
		1/4” TUBE TEE	CARBON STEEL	8000 PSI	2548
		1/4” TUBE TEE	STAINLESS STEEL	7500 PSI	2548SS
		1/4” NUT OR FERULES ONLY	CARBON STEEL	8000 PSI	2550 /1
		1/4” NUT OR FERULES ONLY	STAINLESS STEEL	7500 PSI	2550/1SS
		A/N (HOSE) TO FEMALE 1/4”NPT ADAPTER	CARBON STEEL	8000 PSI	2552
		A/N (HOSE) TO FEMALE 1/4”NPT ADAPTER	STAINLESS STEEL	7500 PSI	2552SS
		A/N (HOSE) TO MALE 1/4”NPT ADAPTER	CARBON STEEL	8000 PSI	2554
		A/N (HOSE) TO MALE 1/4”NPT ADAPTER	STAINLESS STEEL	7500 PSI	2554SS
		MALE TO FEMALE ELBOW (1/4”NPT)	CARBON STEEL	8000 PSI	2534
		MALE TO FEMALE ELBOW (1/4”NPT)	STAINLESS STEEL	6500 PSI	2534SS
		MALE ELBOW(1/4”MNPT) TO TUBE 1/4”	CARBON STEEL	6500 PSI	2537
		MALE ELBOW(1/4”MNPT) TO TUBE 1/4”	STAINLESS STEEL	6000 PSI	2537SS
		FEMALE ELBOW(1/4”FNPT) TO TUBE 1/4”	CARBON STEEL	6500 PSI	2538
		FEMALE ELBOW(1/4”FNPT) TO TUBE 1/4”	STAINLESS STEEL	6000 PSI	2538SS
		STREET TEE(M,F,F)(1/4”NPT)	CARBON STEEL	6000 PSI	2536
		STREET TEE(M,F,F)(1/4”NPT)	STAINLESS STEEL	5600 PSI	2536SS

QUALITY BREAKTHROUGH THAT IS SETTING A NEW STANDARD FOR PURE BREATHING AIR

THE **PLUS AIR FILTER CARTRIDGES** PROVIDE MAXIMUM PURIFICATION FOR YOUR COMPRESSED AIR NEEDS THROUGH THESE UNIQUE FILTERING INNOVATIONS :

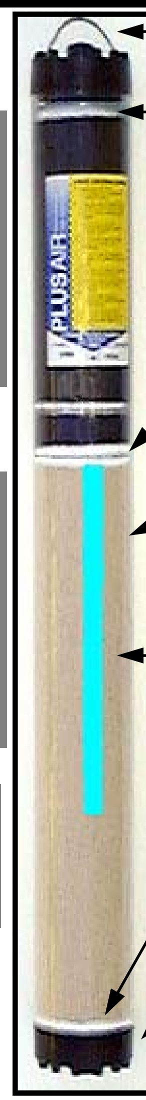
INSERT ROD............................STAINLESS ROD THROUGH-OUT FILTER ASSURES NO BREAKAGE OR FILTER SEPERATION
END CAPS.........................O-RING SEALED WITH "EASY PULL" HANDLE ON TOP
NO WOOL FELT PADS............PLUS AIR FILTERS USE ONLY 100% SYNTHETIC PADS FOR INCREASED MICRON FILTRATION.
BACKING-PLATES...............WE USE MULTIPLE NON CORROSIVE BACK PLATES AND PADS TO MAINTAIN EVEN PRESSURE ON THE SIDE WALLS THROUGHOUT THE LIFE OF THE FILTER.
AIR CHANNELING...................PERFORATED BACK-PLATES ASSURE THAT FILTERING OCCURS EVENLY ACROSS THE MEDIA BED AND DOES NOT CHANNEL DOWN THE SIDE WALL.
BETTER SEAL.....................O-RING SEALED END CAPS INSURE A SEAL WHICH WILL NOT CRACK &/OR SEPARATE FROM THE TUBE AS THE GLUED, & ELECTRONICALLY WELDED FILTERS CAN DO.
ACTIVE COMPRESSION.......STAINLESS STEEL SPRING ASSURES A TIGHT, EFFICIENT FILTERING MEDIA BED THROUGHOUT THE LIFE OF THE CARTRIDGE.
TRANSPARENT SHELL.........WITH COLOR CHANGING INDICATOR STRIP (MODELS WITH DESICCANT ONLY) TO INFORM YOU OF FILTRATION MEDIA CONDITION

IF YOU USE BAUER™ MAKO™OR L-FACTOR ™ REPLACE WITH...PLUS AIR

COMPARE AND SAVE

BAUER ™	PRICE	L-FACTOR ™	PRICE	A-PLUS PRICE
BC-106	$77.00	X22240	$58.35	FC-1801B.......$43.50
BC-274	$82.00	X22677	$60.00	FC-1503B.......$44.00
BC-275		X22627	$70.00	FC-1603B.......$44.00
BC-276	$82.00	X22247	$78.50	FC-1803B.......$59.50
58821	$77.00	X22240	$58.35	FC-1801B.......$43.50
58825	$82.00	X22677	$60.00	FC-1503B.......$44.00
58826		X22627	$70.00	FC-1603B.......$44.00
58827	$111.00	X22247	$78.50	FC-1803B.......$59.50

MAKO™	PRICE	L-FACTOR™	PRICE	A-PLUS PRICE
PC1201		X65220	$27.60	FC-1201M......$26.50
PC1501	$45.00	X65670	$27.40	FC-1501M......$26.50
PC1601		X65620	$28.95	FC-1601M......$26.50
PC1801	$55.00	X65240	$43.20	FC-1801M......$41.50
PD1203		X65227	$39.35	FC-1203M......$36.50
PD1503	$57.00	X65677	$46.05	FC-1503M......$41.00
PD1603		X65627	$46.95	FC-1603M......$41.50
PD1803	$80.00	X65247	$63.40	FC-1803M......$58.00



SEE OUR PRICE LIST FOR A COMPLETE LISTING OF FILTER REPLACEMENTS.

WE CUSTOM MANUFACTURE FILTERS TO MEET YOUR SPECIAL NEEDS. GIVE US A CALL AT 1-800-352-2360

PLUS- AIR PURIFICATION SYSTEMS ARE BUILT ACCORDING TO STRICT QUALITY STANDARDS AMONG SOME OF OUR FEATURES ARE:

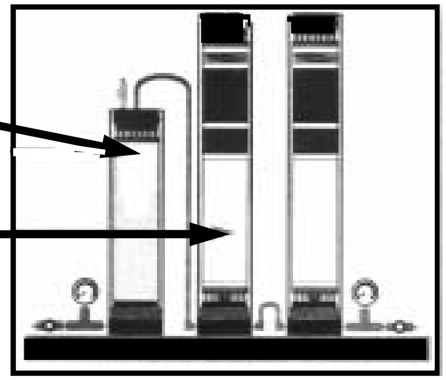
- -RELIEF VALVE SET TO YOUR SPECS
- -CHECK VALVE
- -PRESSURE GAUGE
- -PRESSURE VENT TO DEPRESSURIZE SYSTEM FOR CARTRIDGE CHANGES
- -PRESSURE MAINTAINING VALVE
- -COALESER FILTER AND DRAIN
- -VALVE FOR MECHANICAL SEPARATION OF OIL AND H_2O MISTS, WITH CONTAMINATION INDICATOR AS AN OPTION

ANODIZED EXTERIOR

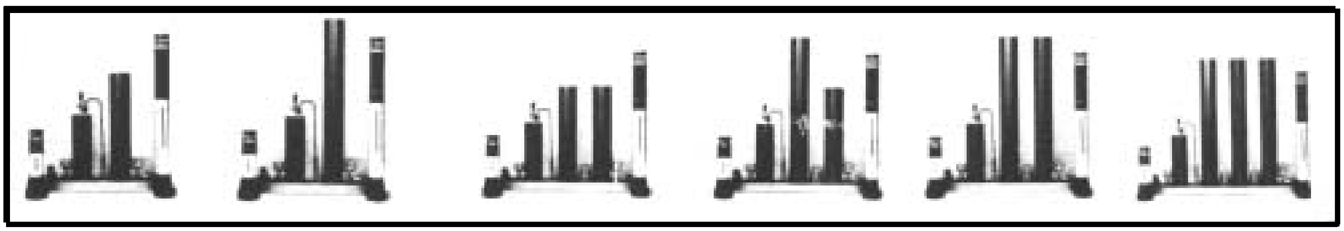
COALESCING SEPARATOR

EASY CHANGE FILTERS

RATED 5,000 PSI



THESE PURIFICATION SYSTEMS ARE BUILT TO THE FOLLOWING SPEC: MATERIALS - ALUMINUM 7075-T6511/6061-T6511, ANODIZED BLACK, WORKING PRESSURE - 5000PSI, BURST PRESSURE - 24,000 PSI, PORTS - STAINLESS STEEL 1/4 NPT FEMALE



FS-1	FS-2	FS-3	FS-4	FS-5	FS-6
* 12,000 CU/FT	* 22,000 CU/FT	* 28,000 CU/FT	* 41,000 CU/FT	*75,000 CU/FT	* 110,000 CU/FT

MODELS APPROX. PROCESSING CAPABILITY VARIES WITH TEMPERATURE AT DEW POINT, PRESSURE, & INNER-STAGE SEPARATION

CHAMBERS AND COMPONENTS

ANODIZED BLACK - STAINLESS FITTINGS INCLUDED
5,000 PSI WORKING PRESS

AP-1 - REPLACEMENT CARTRIDGE CHAMBER WITH STAINLESS STEEL CONNECTORS (A/N-6) TO 1/4 NPT - 6000 PSI - SHORT

AP-3 - REPLACEMENT CARTRIDGE CHAMBER WITH STAINLESS CONNECTORS (A/N - 6 TO 1/4 NPT) 6000 PSI - ACCEPTS MOST FILTER CARTRIDGE - TALL

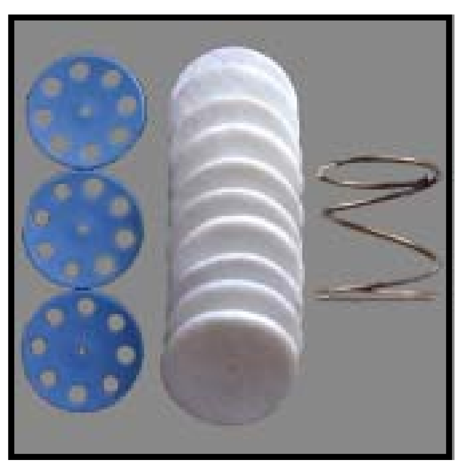
AP-6 - COALESCER UNIT, 6000PSI 40 CFM MAX, SEPARATES WATER AND OIL TO MICRONS

AP-7 - REPACKABLE FILTER CARTRIDGE. THIS STAINLESS STEEL CARTRIDGE CAN BE REPACKED INDEFINITELY WITH AIR PURIFICATION MEDIA PURCHASED IN BULK.

5990 - SYNTHETIC FELT PADS FOR AP-7 (12)

5991 - SPACERS FOR AP-7 (3 PER PACKAGE)

5992- FILTER TENSHION SPRING

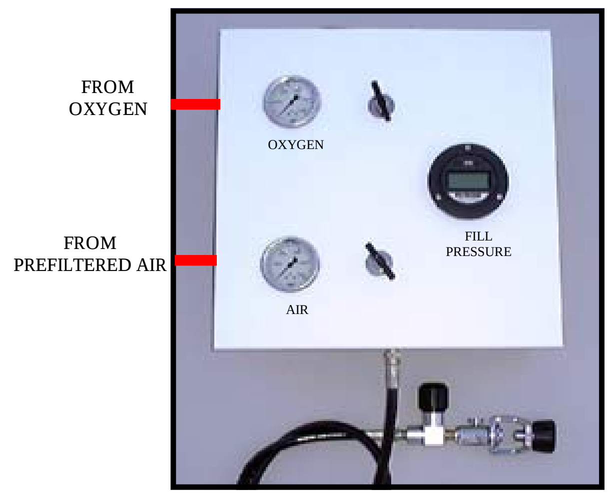


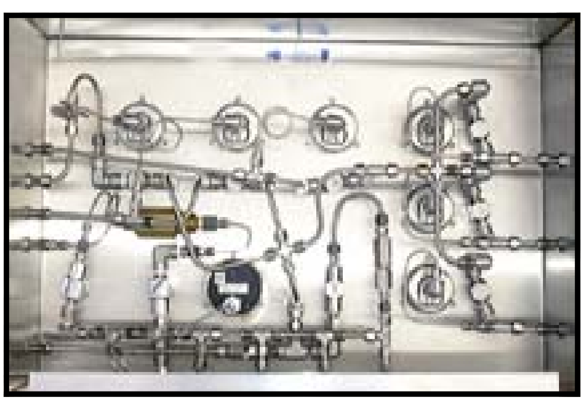
FOR THE MORE PROFESSIONAL DIVE STORE LOOK

STANDARD AIR PANEL INCLUDES:

1 - 4 inch filling pressure gauge
2 - bank pressure gauges
2 - panel mounted valves (standard)
1/4 turn valves available
4 - fill whip ports
2 - standard fill whips
other options on whips available
3 - high pressure ports for hook up to two air storage banks and direct compressor fill. (1/4fnpt or tube)

- MANY OTHER OPTIONS AVAILABLE - SEE PRICE LIST
- READY TO FLOW AIR - JUST HOOK UP COMPRESSOR & BANK LINES
- MADE FROM DURABLE, ATTRACTIVE, NON RUSTING KINGBOARD.
  WILL NOT CHIP, CRACK, FADE, RUST
- MOUNTS TO ANY WALL, SIDING, ETC. (BRACKETS INCLUDED)
- PANEL AVAILABLE IN GREY, WHITE, BLACK
- ALL STAINLESS STEEL TUBING AND CONNECTORS
- STAINLESS STEEL PANEL OPTION AVAILABLE

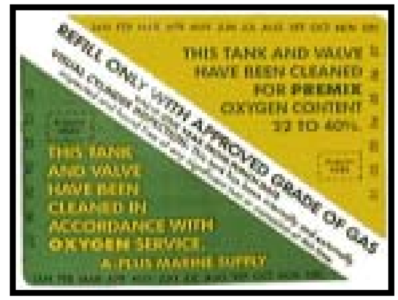




STANDARD NITROX PANEL INCLUDES:

- 1 - digital 0-5000psi gauge
  2x overpress. protected
  +/- .25% full scale accuracy
  auto shut off
  user replaced battery
  more accurate & durable than analog gauges
- 2 - metering valves
- 2 - fill whip ports
- 1 - standard fill whip
- 2 - stainless 0-6000psi check valves
- 2 - high pressure ports for oxygen and air hook up

TANK WRAP



INTERNAL TANK/
VALVE INSPECTION
STICKERS
V7018 -3"x4" STICKER
DESIGNATES USE FOR
BOTH EAN$_X$ OR OXYGEN

DECALS / TANK WRAP

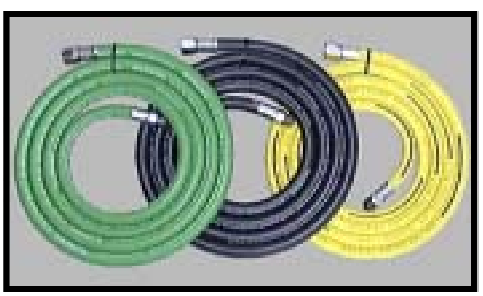
2694 - TANK WRAP YELLOW & GREEN - 23"x6"
V7012 - NITROX - 10" x 4"
V7014 - OXYGEN - 10" x 4"
V7015 - NITROX - 8" x 2"

TANK CONTENT SLATE

V7017 - SLATE WITH SILK SCREENED GAS CONTENTS, CORD-LOCKS AROUND TANK NECK. REUSABLE

CONTENT STICKER
V7016 - LABELS FOR GAS CONTENT - SIZE (1.5"x3") WILL ADHERE TO NECK OF TANK - COMES IN EASY TO DISPENSE ROLL. 500/ROLL

NITROX ONLY VALVE PROTECTOR
726OX - GREEN CAP FOR NITROX DESIGNATED CYLINDERS



7FT. REGULATOR HOSE
2809 - TECH REGULATOR HOSE - (3/8x24) THREADS
2803 - TECH REGULATOR HOSE - (1/2x20) THREADS

AVAIL. IN : BLACK , YELLOW , GREEN

2859V - VITON SHOP O- RING KIT
CONTAINS 17 OF THE MOST COMMON INDUSTRY USED ORINGS, ALONG W/SIZE CHART

OXYGEN COMPATIBLE VALVE KITS

V6050 - STANDARD K - VALVE
V6052 - OLD STYLE K - VALVE
V6054 - GENISIS VALVE
V6056 - GENERIC DIN VALVE

OXYGEN COMPATIBLE REGULATOR KITS

V6058	POSEIDON BALANCED	1st. STAGE
V6060	POSEIDON CYCLONE	2nd. STAGE
V6062	POSEIDON ODIN	2nd. STAGE
V6064	MAGNUM(YEAR)	1st. STAGE
V6066	MAGNUM(YEAR)	2nd. STAGE
V6068	BRUT(YEAR)	1st. STAGE
V6070	SCUBAPRO MK-5	1st. STAGE
V6072	SCUBAPRO MK-10	1st. STAGE
V6074	CONSHELF 14/SE/SE-2	1st. STAGE
V6076	CONSHELF 14/SE/SE-2	2nd. STAGE
V6078	DACOR 360	1st. STAGE

WE SUPPLY VITON O-RINGS AND KITS FOR MOST VALVES AND REGULATORS. THESE KITS ARE EXACT SIZES (INCLUDING METRIC), AND DUROMETER. NO MORE GUESS WORK.

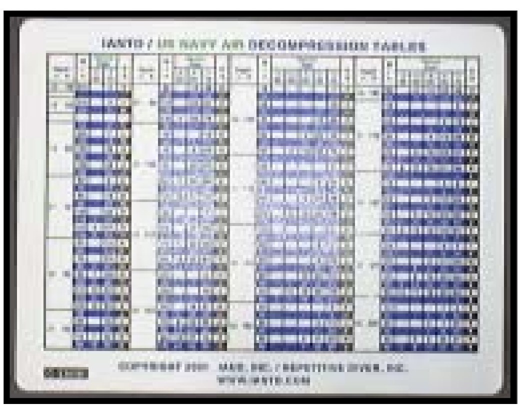
V7008 - OXYGEN ANALYZER

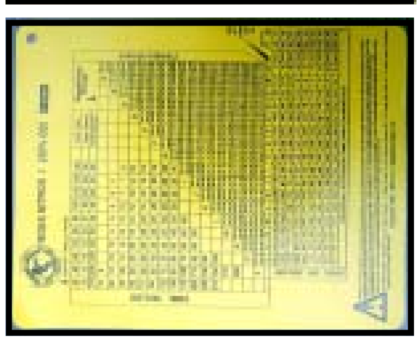
V7009 - FLOW METER
V7010 - REPLACEMENT SENSOR

OXYGEN COMPATIBLE LUBRICANT

2696 - 1/2 oz.
2697 - 2oz.
2698 - 1.0 oz.

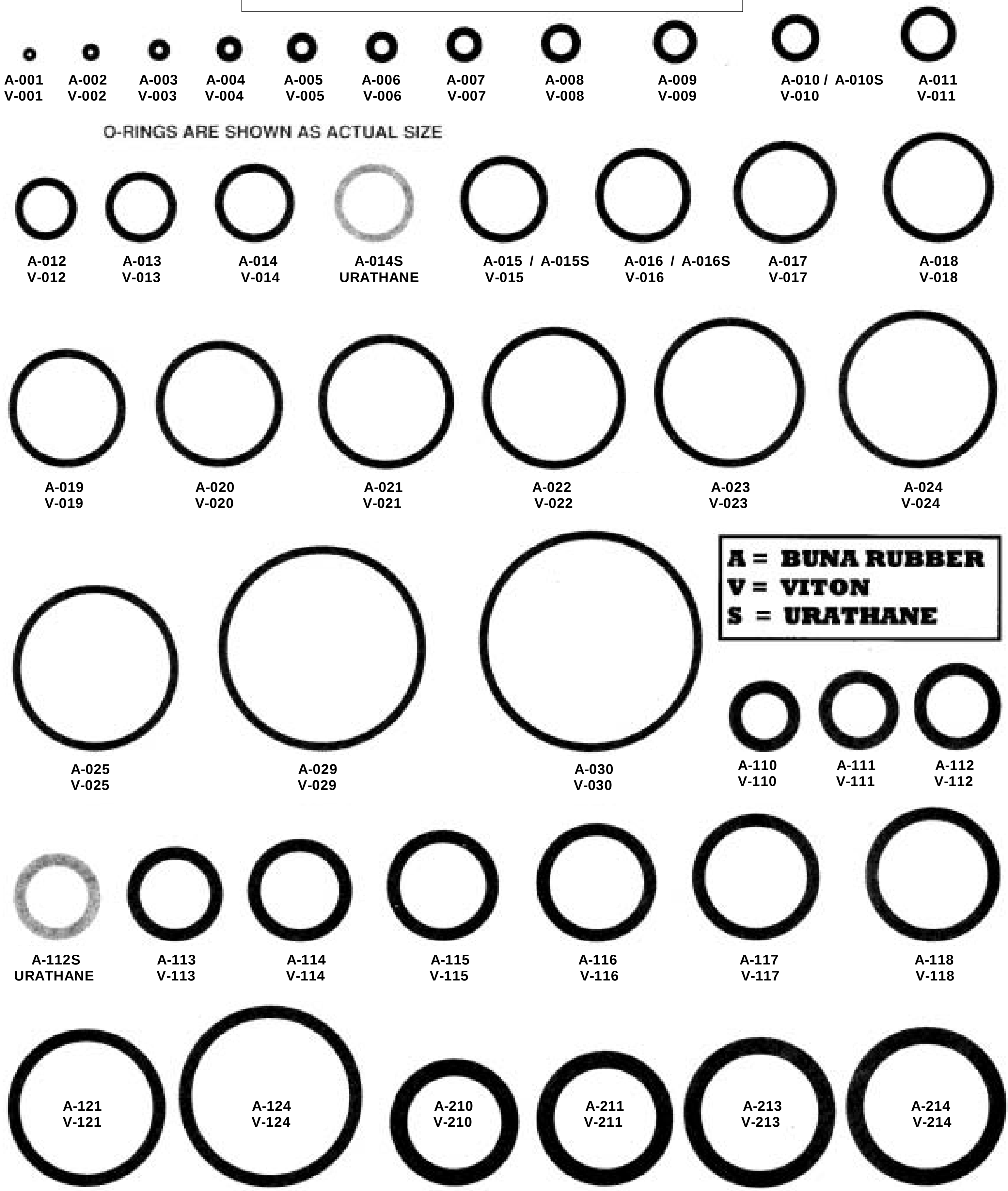
TABLES - WATERPROOF 7" x 9" FLEXIBLE/FOLDABLE





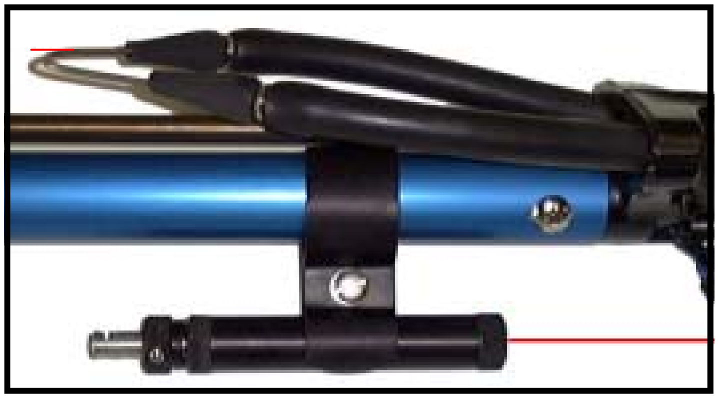
V7004 - US NAVY AIR TABLE - TO 190 FSW/58 MSW
V7000 - NITROX I TABLE (FSW/MSW)
V7002 - NITROX II TABLE - FSW/MSW
V7006 - NITROX EAD / MOD TABLE
V7008 - OTU / CNS OXYGEN TRACKING TABLE

O - RING SIZING CHART

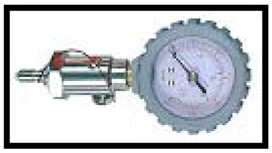


DUE TO THE SPACE AND SIZE LIMITATIONS WE HAVE PICTURED SOME OF THE MORE COMMON O - RINGS. PLEASE SEE OUR PRICE LIST FOR A COMPLETE LISTING OF O - RINGS WE CARRY, INCLUDING METRIC SIZES. SOME O - RINGS ARE COMPOSED OF A HIGHER DUROMETER (HARDER) MATERIAL. ALWAYS SEE MANUFACTURERS SPECS TO BE SURE OF TYPE & SIZE.

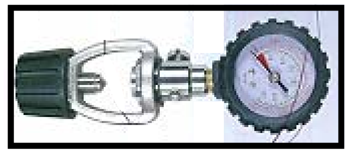
NEW LAST MINUTE ARRIVALS



LASER SIGHT FOR SPEAR GUNS—TWIST ON/OFF SWITCH, ALUMINUM CASING
310 - LASER SIGHT WITH WOOD GUN MOUNT
311 - LASER SIGHT WITH ROUND ALUMINUM BARREL GUN MOUNT



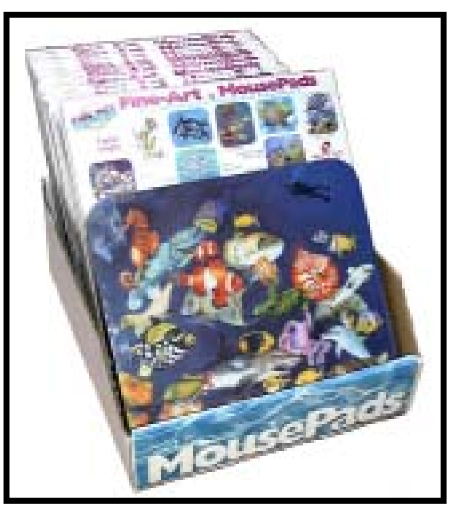
LOW PRESSURE CHECKER
3996 - COMES WITH BLEEDER, QUICK DISCONNECT & GAUGE PROTECTOR



TANK CHECKER
3997 - TANK CHECKER WITH BLEED AND RUBBER GAUGE BOOT

FILL YOKE
3999 - FILL YOKE WITH INTEGRATED ON/OFF VALVE AND BLEED SCREW

CROSS-OVER WHIP
3998 - AIR TRANSFER WHIP WITH TWO YOKES AND BLEED SCREW



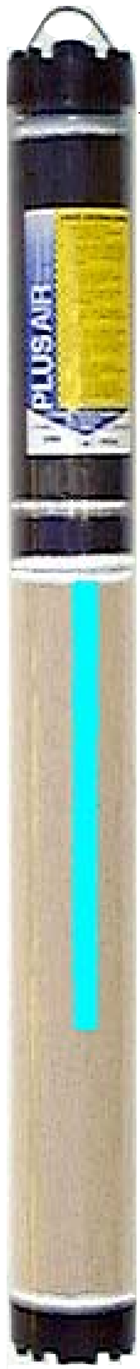
AQUATIC SCENE MOUSE PADS

890 - MOUSE PADS ASSORTED REEF AND FISH SCENES
FREE DISPLAY WITH 18 OR MORE UNITS

PLUS AIR

REPLACEMENT BREATHING AIR CARTRIDGES

TAKE A BREATH OF FRESH AIR



- LIFTING RING IS PROVIDED FOR EASY FILTER REMOVAL

O-RING SEAL

- OUR EXCLUSIVE O-RING SEALED END CAPS ENSURE A PERFECT SEAL, WHICH WILL NOT CRACK AND / OR SEPARATE FROM THE TUBE AS THE GLUED AND “SPIN WELDED” FILTERS CAN DO.
- INCREASED INTERNAL AIR FLOW AREAS TO REDUCE AIR SURGE.
- INTERNAL STAINLESS STEEL ROD FROM END TO END OF FILTER TO INSURE INTEGRITY
- TRANSPARENT CARTRIDGE SHELL, MADE OF RECYCLABLE PLASTIC, ALLOWS YOU TO INSPECT THE FILTER MEDIA.
- SYNTHETIC SEPARATION PADS BETWEEN THE FILTER MEDIA.
- PROPERLY SIZED CHEMICAL MEDIA PROVIDES CGA GRADE “E” OR BETTER AIR QUALITY AND OPTIMIZES THE CARTRIDGE LIFE.*
- MOISTURE INDICATOR CHANGES COLOR AS FILTER LIFE DIMINISHES, LEAVING NO GUESS WORK AS TO WHEN CARTRIDGE MUST BE CHANGED.
- EACH FILTER COMES PACKED AND VACUUM SEALED FOR LONG SHELF LIFE.
- MADE IN A TEMPERATURE AND HUMIDITY CONTROLLED ENVIRONMENT.
- MADE WITH 100% NON-CORROSIVE MATERIALS.
- BOTTOM FILTER ADAPTER IS THREADED INTO FILTER, UNLIKE MOST ADAPTERS WHICH ARE GLUED OR CLIPPED ON.

SEE OUR CATALOG AND PRICE LIST FOR THE PROPERLY MATCHED FILTERS FOR YOUR BREATHING AIR SYSTEM

DISTRIBUTED BY:

A - PLUS MARINE SUPPLY, INC.
800-352-2360 FAX (850) 934-3895
aplusmarine.com

* Air quality depends on many factors which are not necessarily controlled by the filters. To help insure consistent air quality have your air and air system checked at least as often as required by industry standards.

Attachment 3: Protocol for Disassembly and Testing to Determine a Root Cause of the DOT 3AL Cylinder Failure in Luraville, FL

Protocol for Disassembly and Testing to Determine a Root Cause of the DOT 3AL Cylinder Failure in Luraville, FL

This document provides a protocol for the disassembly, inspection and sampling for chemical and metallurgical analysis of supplied components involved in a fire during the filling of an aluminum SCUBA tank. The components requiring further analysis and disassembly/testing include an isolation valve, a fill whip, a fill valve and adapter, a cylinder valve and a fire-damaged aluminum cylinder.

The work outlined herein seeks to address two specific questions: 1) Was the cylinder valve that was located after the incident installed on the subject cylinder at the time of the incident, and, 2) What was the origin of the fire in question.

Objective:

Disassemble, inspect and document the condition and burn patterns associated with the equipment involved in the Luraville fire. Prepare samples for chemical and metallurgical analysis. During the disassembly, inspection, and sample collection ensure safeguards as outlined herein are present to preclude loss of critical information during the inspection and sampling process.

Develop a high level procedure/protocol that details the disassembly and documentation steps required for the equipment handling that proceeds in a direction from upstream to downstream (i.e., from the source of the supplied fill gas through to the failed cylinder).

Equipment for Inspection:

1) Gas supply system (not available for inspection by WHA)

2) Isolation valve that had been connected to a gas supply system at the inlet and to a flexible hose (fill whip) at the outlet. (Identified as Sherwood 6000 psig, stamped 4302)

3) Flexible hose (fill whip) (Parker Parflex 520N-4 SAE 100R8 ¼ W. P. 5000 psi PATENT # 4142554 – USE 55 SERIES FITTINGS 133118)

4) Fill valve between flexible hose and fill adapter (Identified as Sherwood 6000 psig, marking stamped 0503)

5) Fill Adapter (no specific identification, however it is consistent with a DIN filler with bleed port)

6) Cylinder Valve (Body casting shows THERMO. “Nitrox Use Only” is imprinted on an attached decal. Also the valve has a decal with 3000 indicated on it.)

7) Aluminum Cylinder (Markings are as follows: CTC/DOT-3AL3000-S30 UU02900LUXFER 9A87, Also, there are marks 9 $^{A8}{}_{21}$ 02)

Background:

There is a question as to whether the fill adapter and cylinder valve currently in our possession were actually installed on the failed cylinder at the time of the incident, since the fill adapter and cylinder valve assembly were reportedly found some distance away from the incident site several weeks after the event.

Goal:

Determine the origin of the ensuing fire. Confirm that the cylinder valve that was found after the incident was the actual valve installed on the cylinder at the time of the incident.

Inspection Issues:

It is understood that the cylinder valve assembly was recovered from outdoors in an open field after the incident. Due to the presence of debris that is visually consistent with mud/dirt on the cylinder valve assembly, selected areas of the fill valve, fill adapter, and cylinder valve must be carefully cleaned during the inspection to allow analysis of some underlying surface residues, fracture surfaces, and for documentation of component stampings. The cleaning process is expected to entail a careful (and selective) fluid flush with an appropriate solvent or distilled water with capture of the flushing fluid in a clean beaker and flush debris on laboratory filter paper.

Analysis techniques such as Energy Dispersive Spectroscopy (EDS) and Fourier Transform Infrared Spectroscopy (FTIR) will be used on either the “as received” component or on samples removed from the component. A list of samples currently expected for analysis is provided on pages 4 and 5.

The inspection and disassembly steps addressed herein include component removal from the adjacent hardware (i.e., isolation and fill valve removal from flex hose and fill adaptor) disassembly of the isolation and fill valve stems from their respective bodies and disassembly of the cylinder valve.

<u>Inspection will be documented as follows:</u>

Photographic and video recording will be employed to document the original configuration as well as all inspection work performed. A video microscope, stereo microscope, and boroscope will be employed as required. A video recording will be made of the boroscope images.

<u>Inspection guidelines:</u>

Incident hardware will be handled only by personnel attired in appropriate clean vinyl surgical gloves.

Specific details to be noted during the inspection include:

1) Determine and mark/scribe the exact position each valve seat with respect to “open/close”.

2) Determine the probable orientation of valves and attaching hardware just prior to and during the incident before dispersal by the event.

3) Inspection is to proceed from the gas supply side of the Sherwood isolation valve attached to the inlet of the fill whip, through the fill whip, then through the Sherwood fill valve, then through the filling adapter and finally through the cylinder valve (i.e., generally in an upstream to downstream direction).

<u>Specific details for each valve are as follows:</u>

Determine and mark the position of each valve handle affixed to the isolation and fill valves. Remove the isolation and fill valves from the flexhose. Photograph, videotape and boroscope both ends of the flexible hose as well as the inlet and outlet ports of these valves. If necessary, lightly wipe the outer surfaces of the fill valve in an attempt to reveal additional descriptive markings. Remove the valve knob and stem assemblies and document the condition of all internal components. Obtain and label samples from sites of interest for subsequent analysis by EDS or FTIR, as required.

For the fill adapter and attached cylinder valve, photograph, videotape and boroscope the inlet of the fill adapter and cylinder valve-to-cylinder port and then conduct the following general steps:

1) Determine and mark/scribe the position of the cylinder valve handle and the bleed screw on the fill adapter.

2) Obtain samples (as required) of residue from the outside of the cylinder valve to attempt to determine the presence of combustion residue, such as aluminum or aluminum oxide in subsequent laboratory testing.

3) Lightly wipe as needed selected outer surfaces of the valve and fill adapter to reveal any stampings covered by debris, and then remove the fill adapter from the valve. Capture any particles that may fall away during this removal process onto an appropriate container, such as a petri dish, for further analysis.

4) Document any observations regarding condition of the internal surfaces. Surfaces will be inspected with stereo and video microscope and documented with standard/magnified photographs.

5) Likewise, remove the valve knob and stem and finally, the relief device. Capture any particles that may fall away during this disassembly onto an appropriate container, such as a petri dish, for further analysis.

6) When documentation of the condition of the valve internal surfaces is completed, selectively spray (wash) the internal passages of the cylinder valve-to-cylinder port and the external fracture surfaces and threads to remove the dirt/mud-like debris that is adhering to these surfaces. (Note that the cylinder valve-to-cylinder interface is filled with debris). Capture the wash fluid in a beaker and the debris on filter paper for possible future analysis.

7) When the fill adapter and the various valve components are separated, subject selected components EDS or FTIR as required.

Although specific details regarding the inspection approach are provided in the above protocol, Wendell Hull & Associates, Inc. reserves the right to make real-time changes to the procedure, as required, during the actual inspection.

Analysis Interests:

Based on our preliminary analysis and visual inspections, the following is a partial list of items that will likely be subjected to EDS or FTIR analysis in an effort to identify combustion residues and/or materials. Other items may be identified for analysis during the actual inspection.

Energy Dispersive Spectroscopy (EDS):

1) Fracture surfaces on the outlet of the fill valve
2) Fracture surfaces on the inlet to the fill adapter
3) Residue on Cylinder Valve Body
4) Fracture surfaces on Cylinder Valve

5) Cylinder Valve-to-cylinder threads
6) Cylinder fragment

<u>Fourier Transform Infrared Spectroscopy (FTIR):</u>

1) Valve Seat or Seat Residue from Isolation valve
2) Valve Seat or Seat Residue from Fill Valve
3) Valve Seat or Seat Residue from fill adapter bleeder (if any)
4) Seal residue on fill adapter outlet port (currently attached to Cylinder Valve)
5) Valve Seat or Seat Residue from Cylinder Valve
6) Residue and/or liner material from the flexible hose inner surfaces

Attachment 4: Sign-in sheet for the WHA disassembly conducted on May 10, 2006

Sign-in (attendance)

Wendell Hull - Testing Protocol - May 10, 2006

Name	Company	e-mail / phone
Vincent Lopez	DOT PHMSA	vlopez@dot.gov 202-3
Andreas Kelly	Counsel - Thermovalves	akelly@sfklaw.com 30 995
RICHARD HARDER	THERMO VALVES	RHARDER@THERMOVAL
Jason Williams	USDOT / PHMSA	202-366-4455 Jason.Williams@dot.gov
WAYNE E CHANEY	USDOT / PHMSA	202 366-4700 wayne.chaney@dot.gov
William Barlen	Barlen + Associates, Inc.	BARLEN@optonline
Barry [illegible]	WHA	barry@wendellhull.
Nic Linley	WHA	nic@wendellhull.

Attachment 5: WHA disassembly notes and measurements

DOT Inspection

1) Thermo Valve

Broken fill adaptor >

Fractured

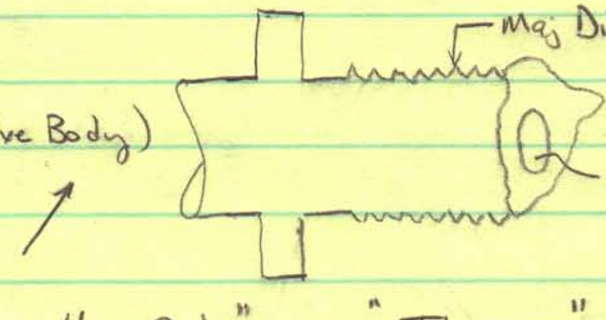
Dia ~ 0.2460 / 0.2465 / 0.2430

* Some Teflon tape protruding

Aluminum comb-like residue

Cylinder thread connection broken/burn residue + melt patterns

(Valve Body)



Maj Dia ~1.015" / 1.018 / 1.019 (Exemplar Valve ~1.026")

0.318" Dia (Also seeing burn-like residue and melt flow of metal)

"Nitrox Use Only" "Thermo" Stamped onto body

Noting aluminum-like combustion residue on valve exterior surfaces

Noting dirt in burst disc and on surfaces

Understand valve found in mud puddle "days" after incident

Disassembly

1. Upstream valve removed (fitting loose)
   S/m shows residue on end attached to hose inside fitting
2. Hose, boroscoped on end and no evidence of combustion residue
3. Valve (fire damaged) removed
   Fitting tight when removed
   Residue on exposed exterior surface but minimal debris inside

#1) Removed valve handle holding stem stationary

a) Jam Nut removed 5¼ turns > Stem and packing nut came out as assembly

b) Valve seat plug remained in valve and photographed with scribe marks on valve top/bonnet and seat plug

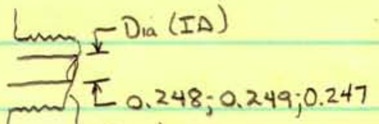
c) Valve seat plug in closed position w/o a large torque
Seat Stem turned 6 5/8 turns b/f letting go + coming out

Upstream fill valve (Date Code = 4302)

① Looks visually clean inside

② Removed packing residue from stem into petri dish

③ Seat is present but extruded & has much particulate residue on extruded surface (Not burned)



Downstream fill Valve (Date Code = 0503

① Scribed top of valve and removed handle

② Scribed nut/stem & removed nut/stem (~5 1/8 turns)

③ Scribed seat plug

Turned CW 1 5/8 turns b/f resistance

Turned CCW 6 3/4 turns b/f removal

⊛ Sample 2 - Downstream Fill Valve Seat Plug residue on side rim of seat plug

④ Seat is present & unburned

Fill Hose

Parker Parflex 520N-4 SAE 100R8 1/4 WP 5000 PSI

Patent #4142554 USE

⊛ Sample 3 > Teflon tape residue from downstream end of fill hose connection

Cylinder Valve Assembly

① Bleed Valve ~1/8 turn CW to tight   6 1/8 turn to remove (Check w/ Video)

Seat intact

Port generally clean

② Fill adaptor hand tight - removed by hand 3 1/8 turn to break loose

Combustion-like residue on tip end of adaptor where plugs into valve outlet

③ Removed residue from CV outlet

⊗ Sample 4

Photographed all with S/M

④ Fill Adaptor removed from CV adaptor > CV seal is intact

Noting mark (residue) w/ circular pattern on outer rim of CV adaptor - Mark aligns w/ CV outlet bleed port

⑤ Removed fill adaptor from CV outlet adapter

Oring is intact inside fitting

Aluminum-like residue in fitting & internal port

Appears Aluminum travelling toward upstream

⑥ Fill Adaptor & Bleed Valve

⊗ Sample 5 > Loose residue inside fill adaptor/bleed

⑦ Valve Disassembly

Scribed packing nut & stem

Valve stem would not turn CW and valve appears Closed (As Received)

Measuring breakaway torque on valve packing

>250 in-lbs ; Breakaway ~30 ft-lbs (~4 turns to remove)

Scribed seat plug and valve body (4 3/8 turns to remove seat plug)

⑧ Valve plug seat remains traumatized by heat
- The seat plug interface in valve body is significantly
fire washed w/ much melt-flow
- Melt flow also noted on C/V Inlet where threads are
damaged
- Noting a residue mass in the inlet bore of valve
⊗ Sample 6 > Had to chip w/ probe from ID surface
due to adherence to surface

⑨ Rupture Disc 5000 III S
Hamai Trade Mark

Attachment 6: FTIR and SEM/EDS Conducted at NASA-WSTF on May 11, 2006

FTIR Analysis Results:

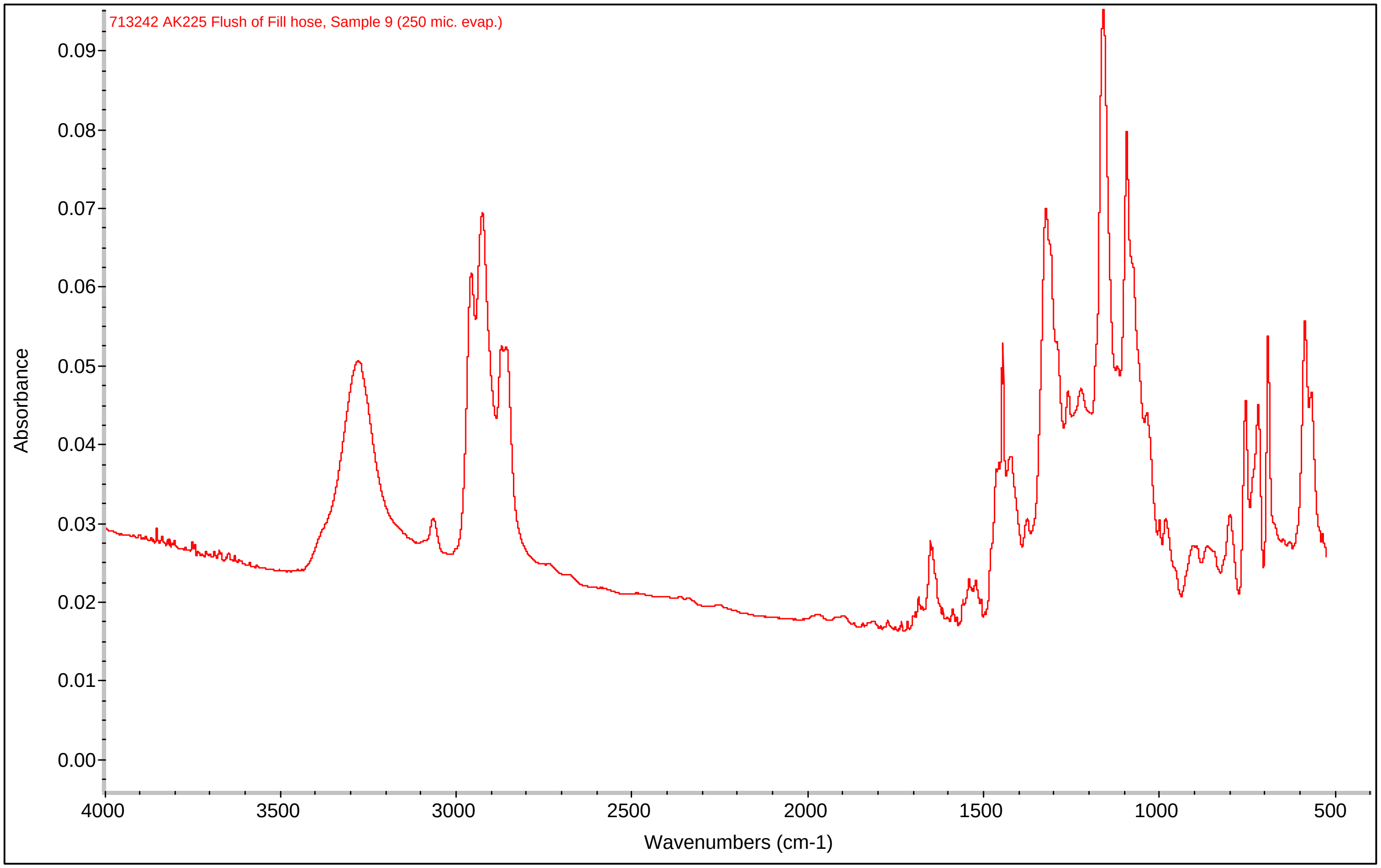
- Solvent Wash of the Flexible Hose
- Solvent Wash of the Interior Surfaces of the Upstream Fill Valve
- Solvent Wash of a Portion of the Bottom Surface of the Cylinder

SEM/EDS Analysis Results:

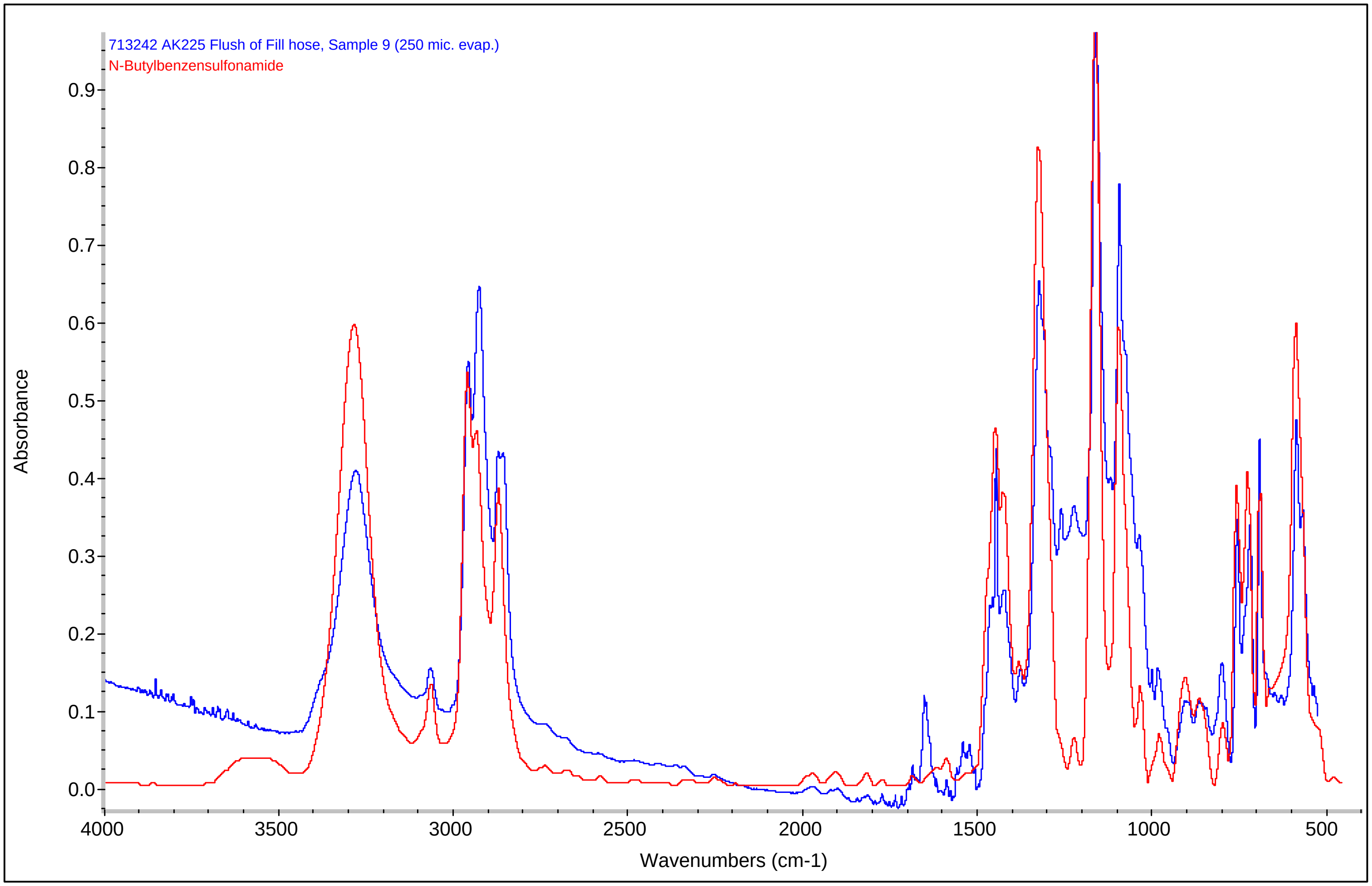
- Cylinder Valve Body Thread Residue
- Particulate Residue Removed from Cylinder Valve Inlet Bore
- Residue Removed from Cylinder Valve Outlet
- Downstream Fill Valve Fracture Surfaces
- Fill Valve Adaptor Fracture Surfaces
- Thread Root Comparison Features for Fill Valve and Adaptor

FTIR of Flexhose Residue

(Internal surface washed with AK225 Solvent)

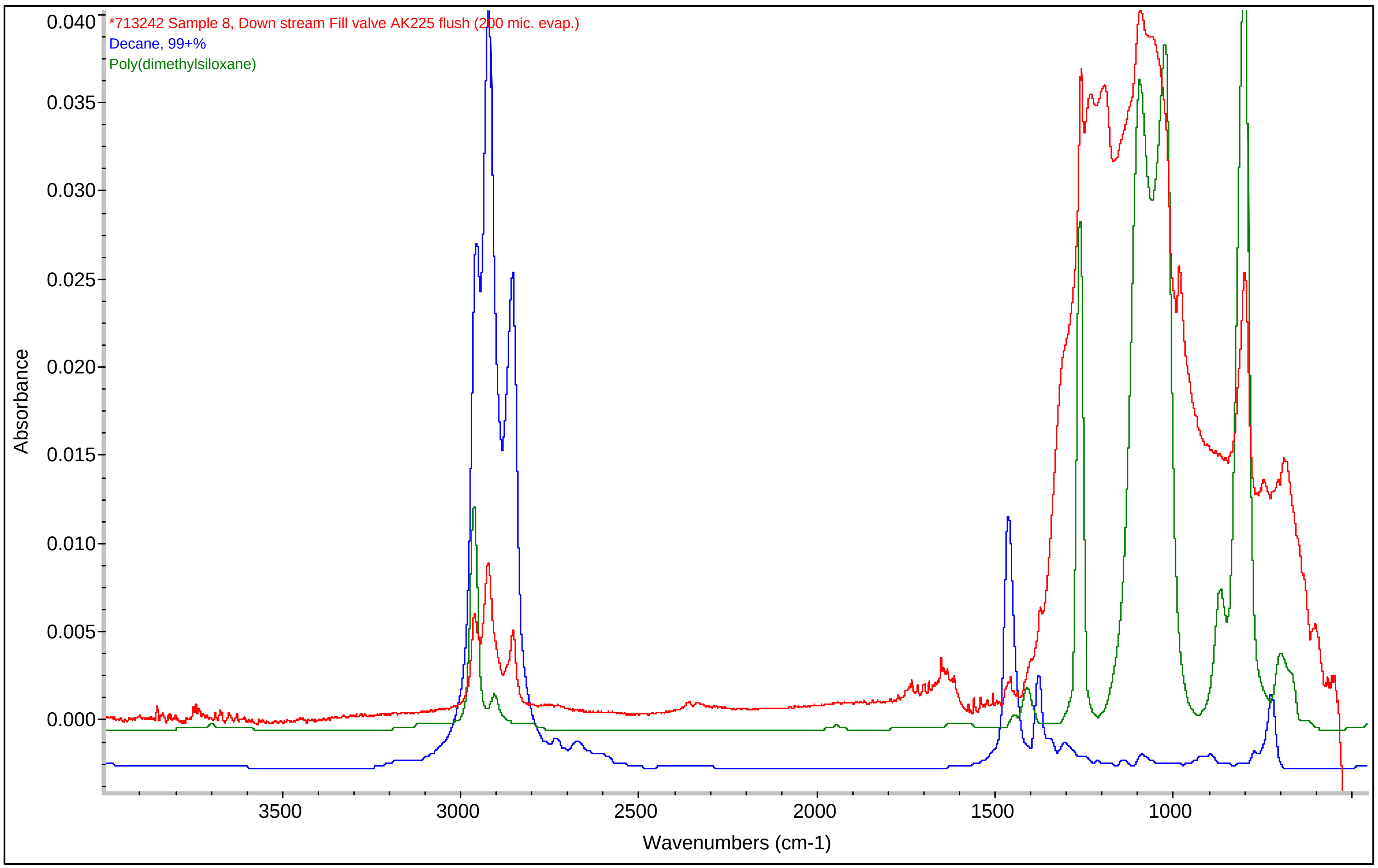


Comparison FTIR Spectra of Flexhose Flush and Typical Plasticizer



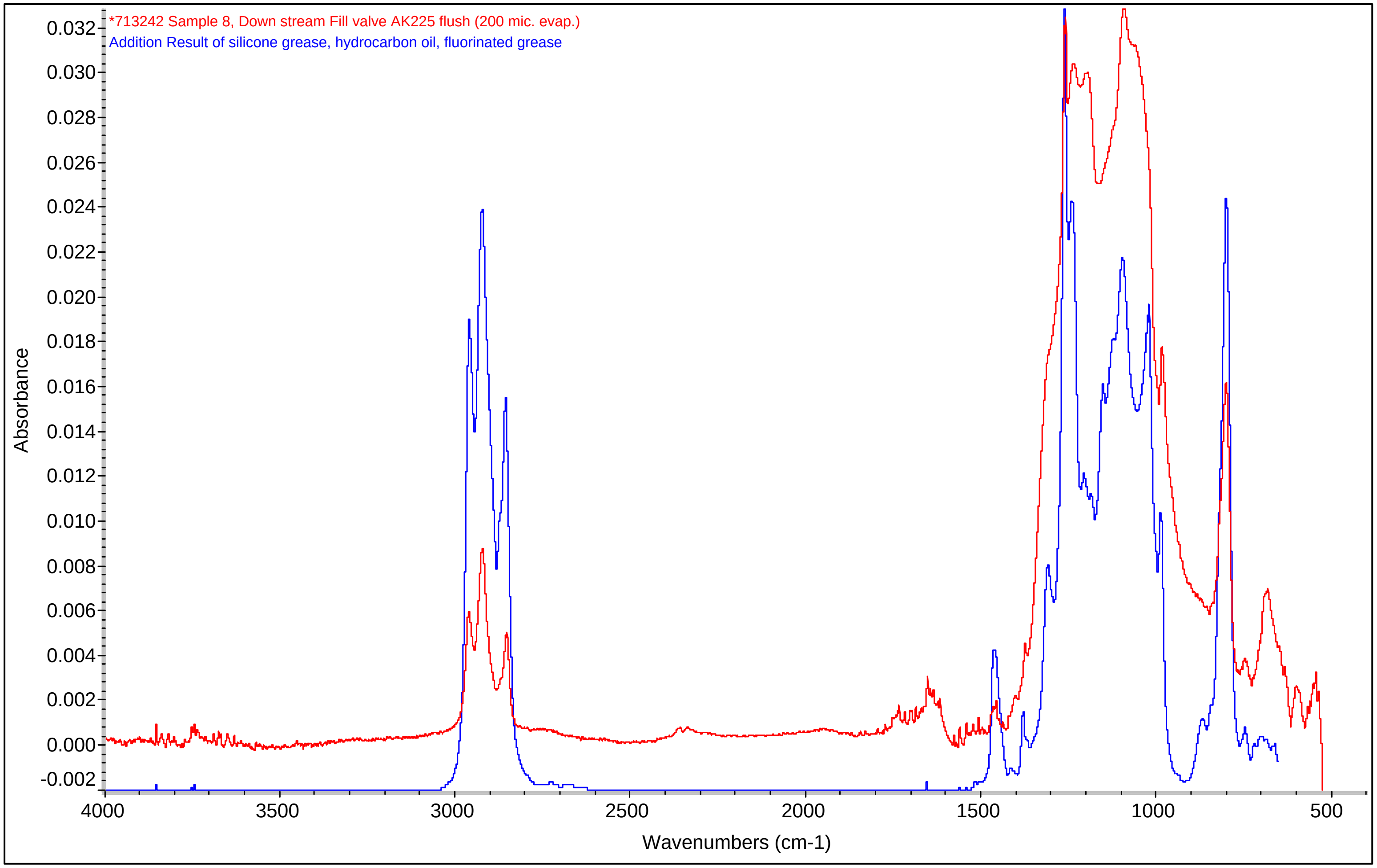
FTIR of Internal Surface of Upstream Fill Valve

(surface washed with AK225 solvent)

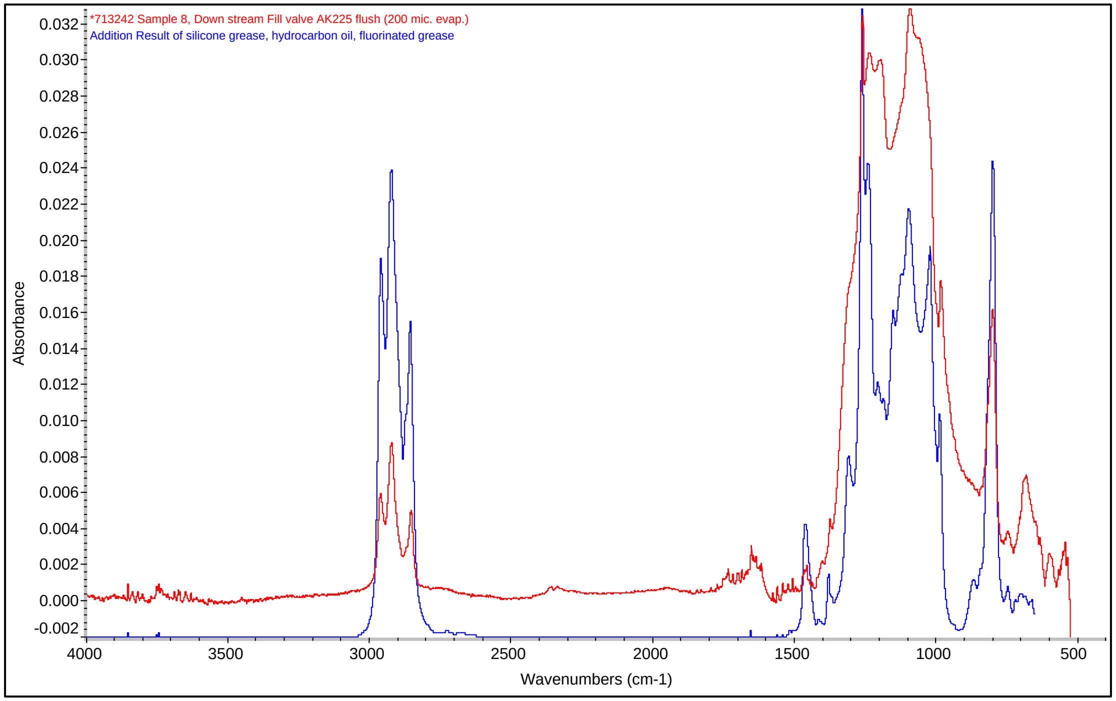


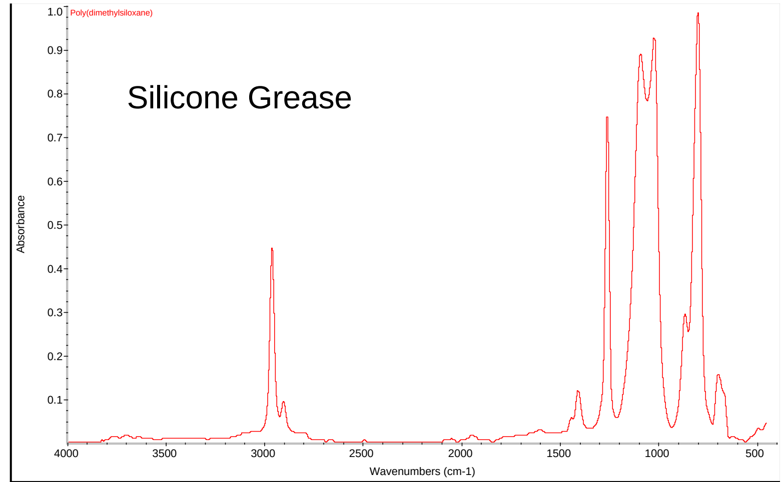
Comparison FTIR Spectra of Upstream Fill Valve and Lubricant Composite

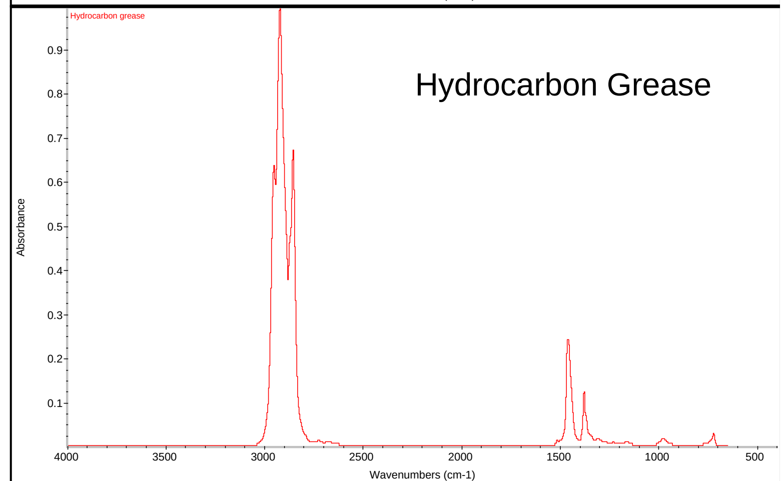
(Lubricant composite spectra comprised silicone oil, hydrocarbon oil, and fluorinated grease spectra added digitally)

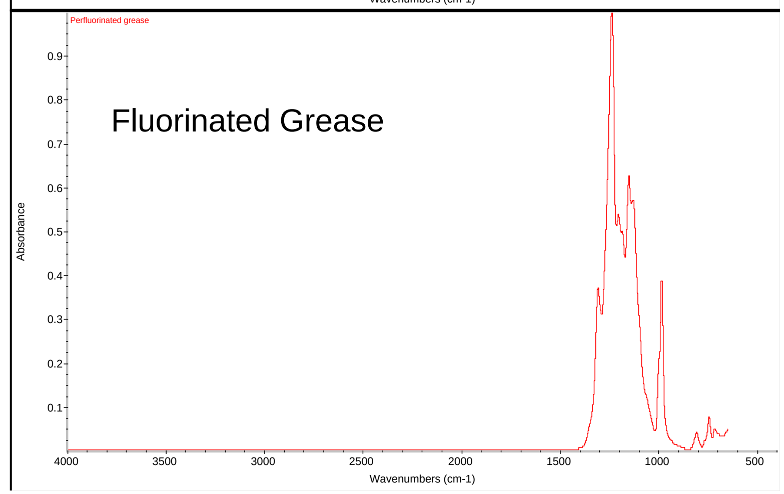


Upstream Fill Valve FTIR Spectra Compared to Grease Addition Spectra

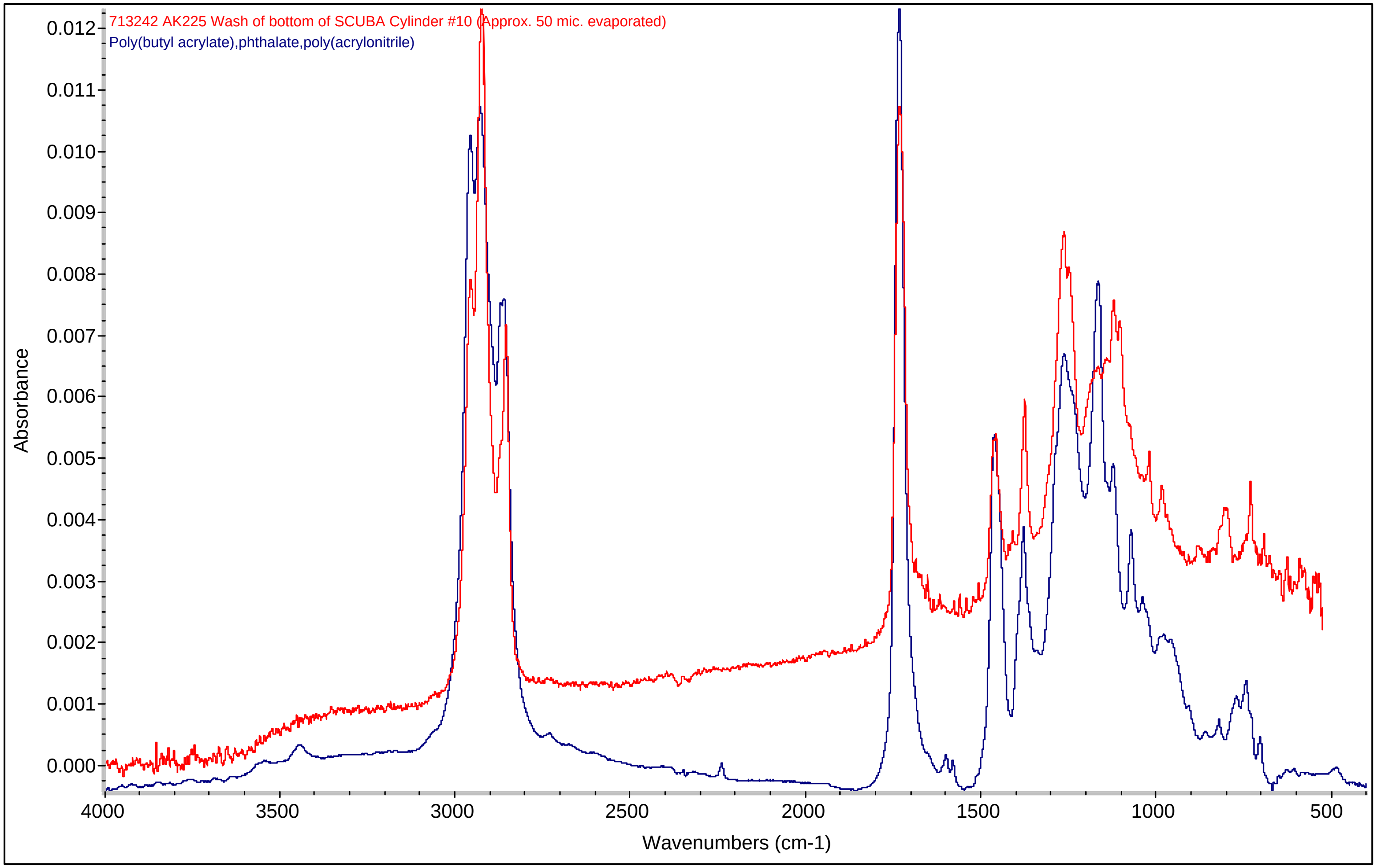




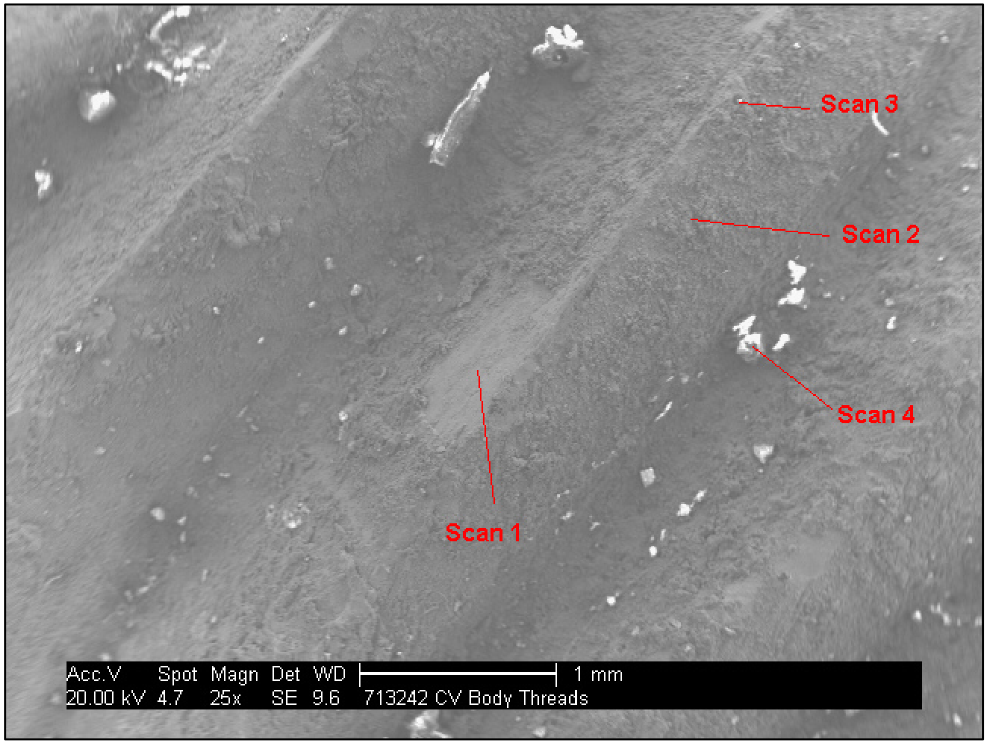


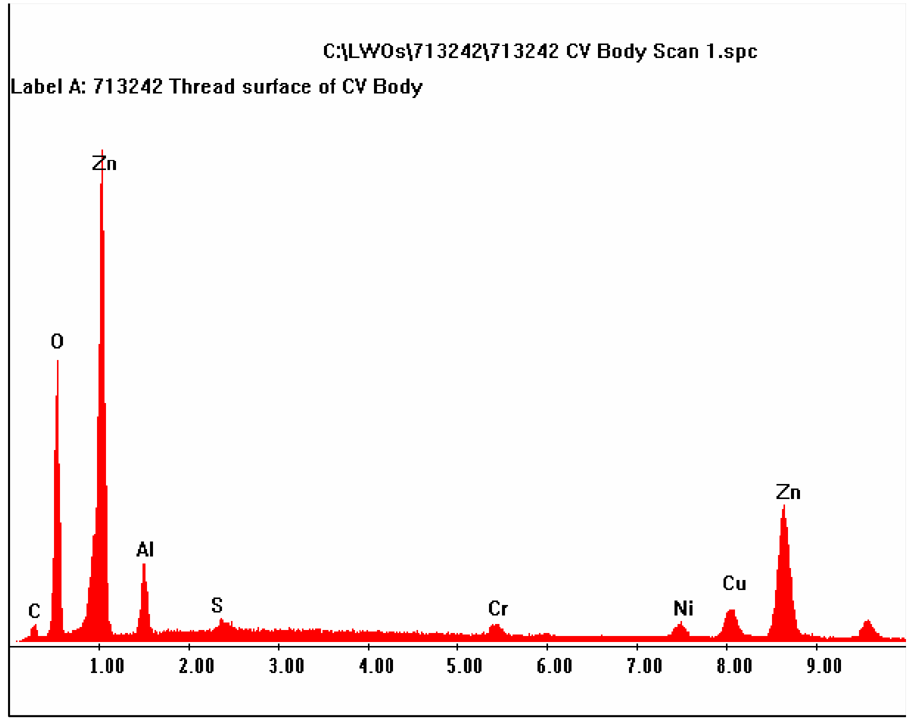


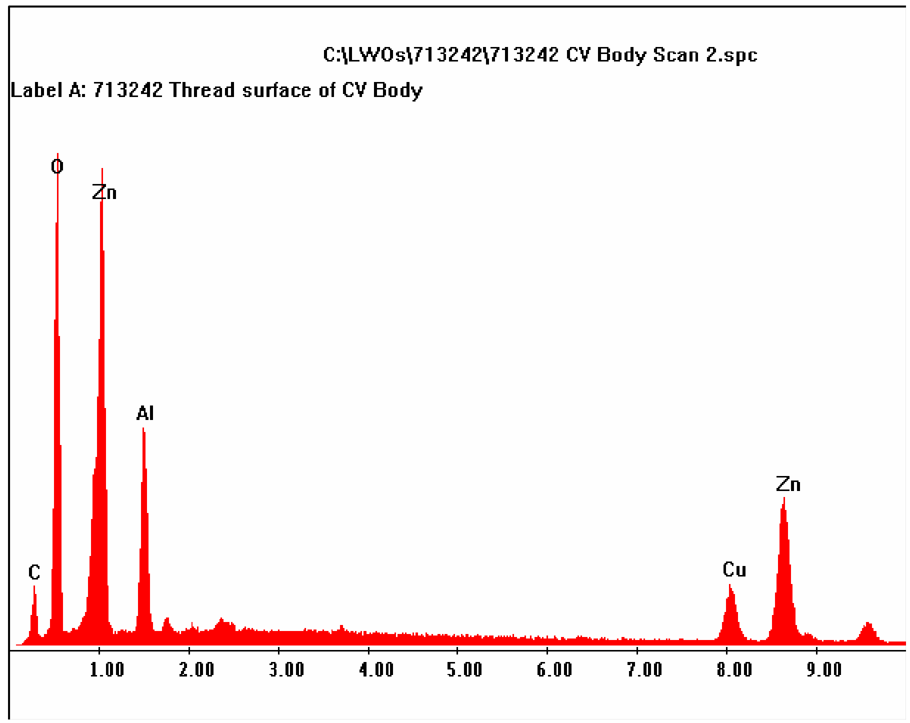
FTIR on Cylinder Internal Surface
(surface washed with AK225 solvent)



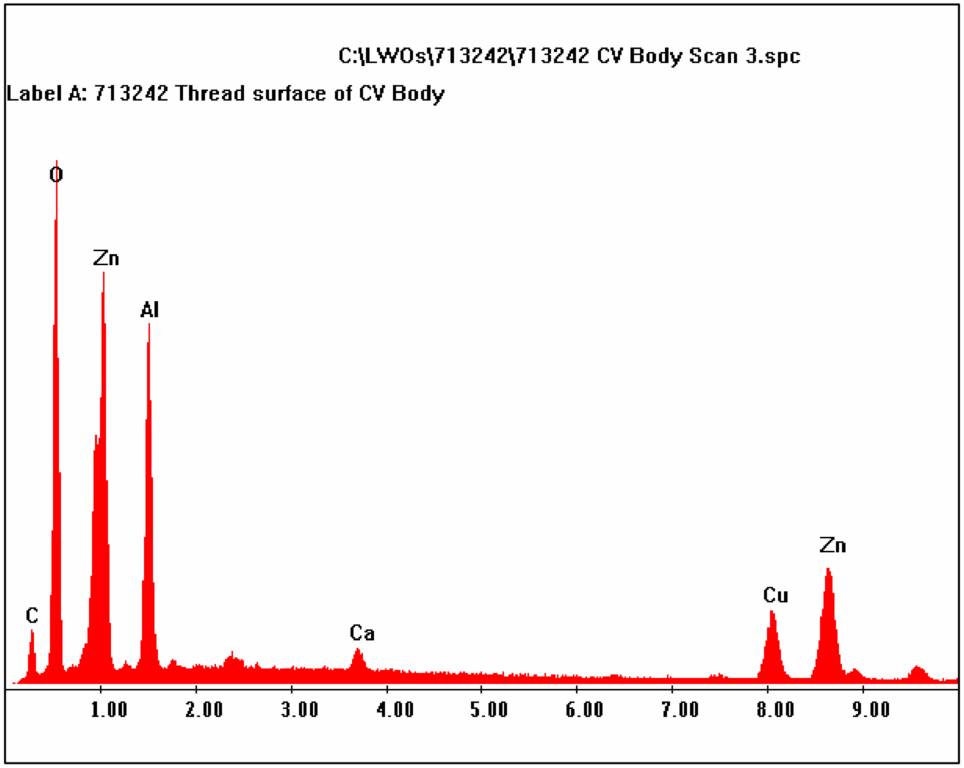
Cylinder Valve Body Thread Residue

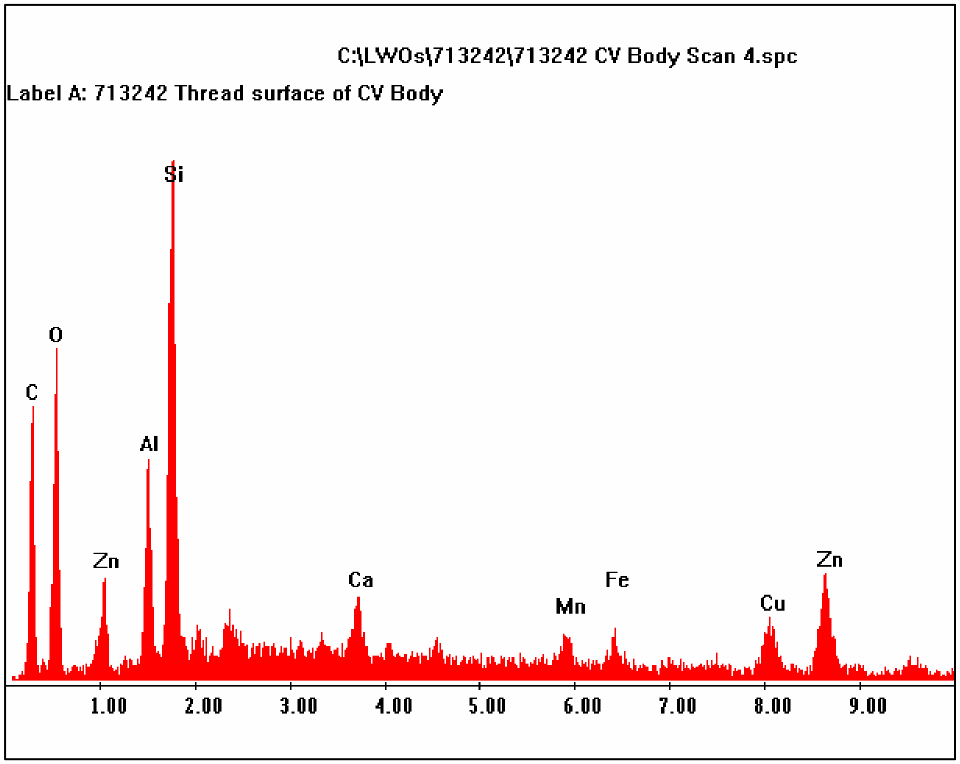




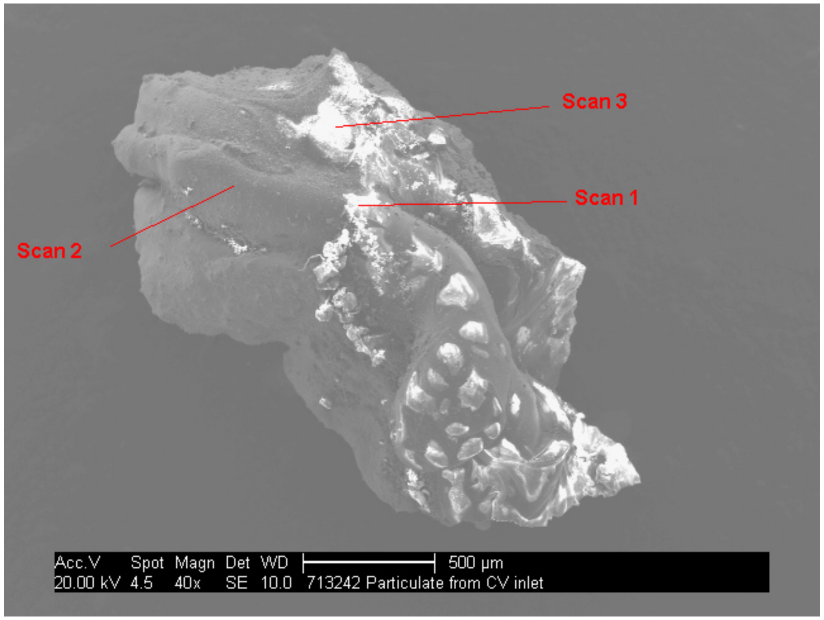


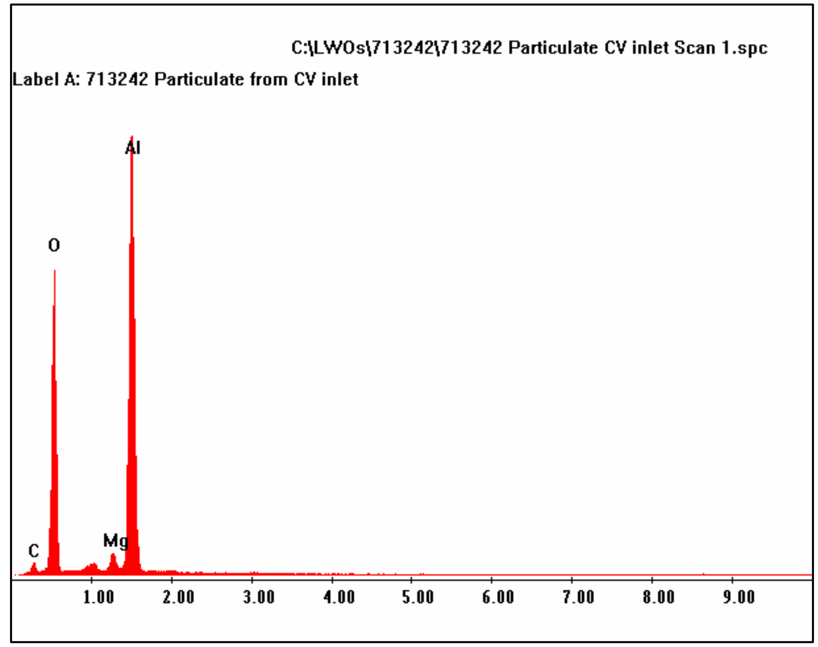
Cylinder Valve Body Thread Residue
(scans 3 and 4)

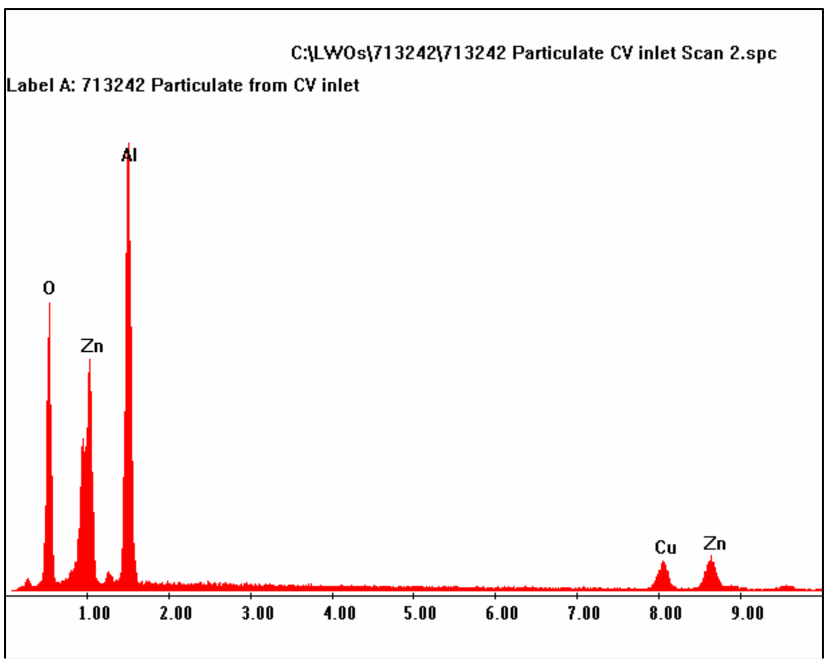


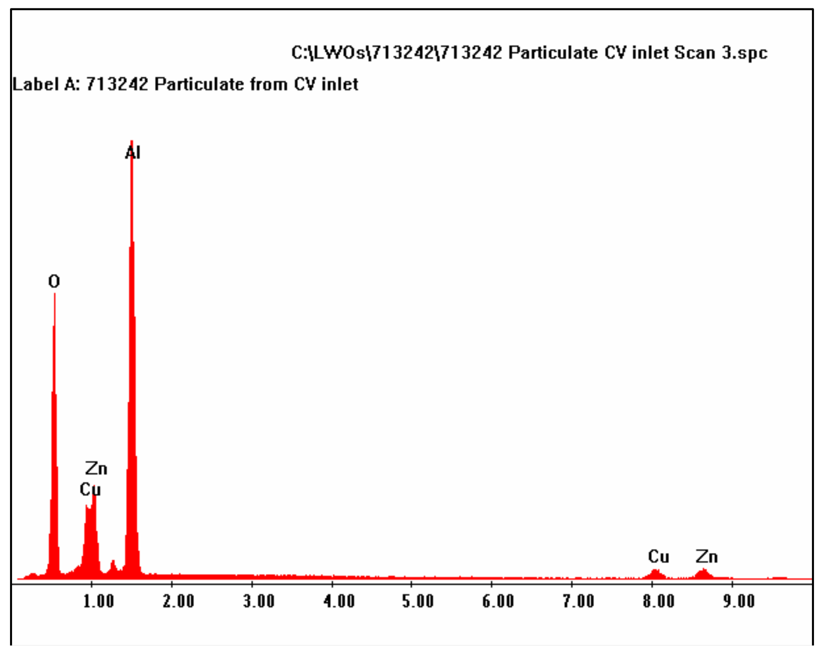


Particulate Residue Removed From Cylinder Valve Inlet Bore

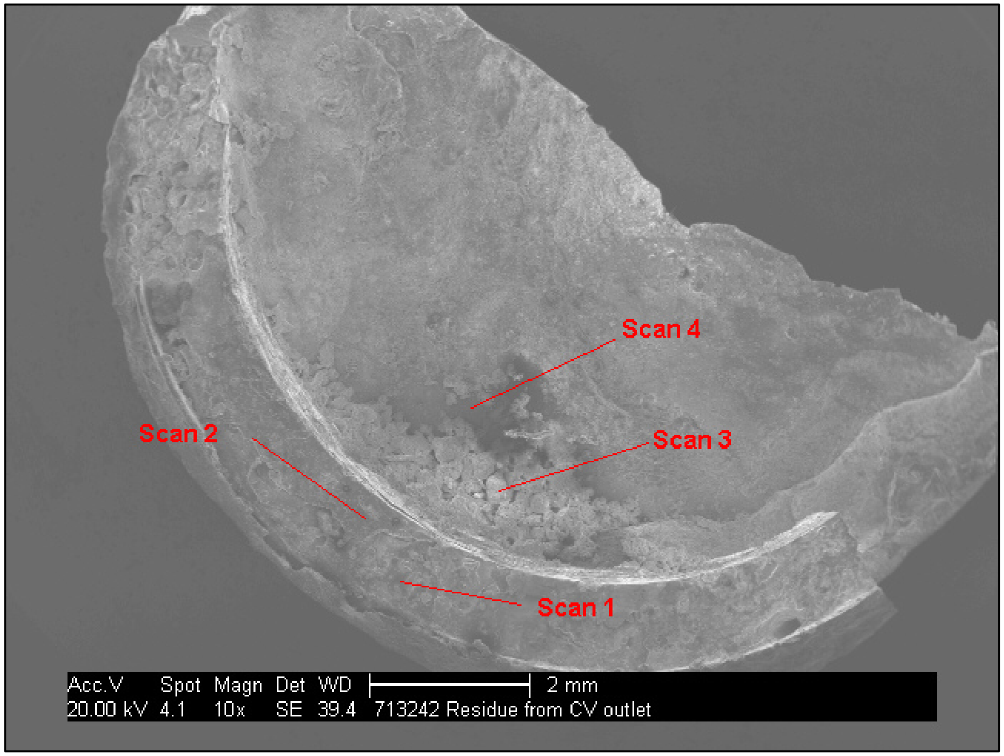


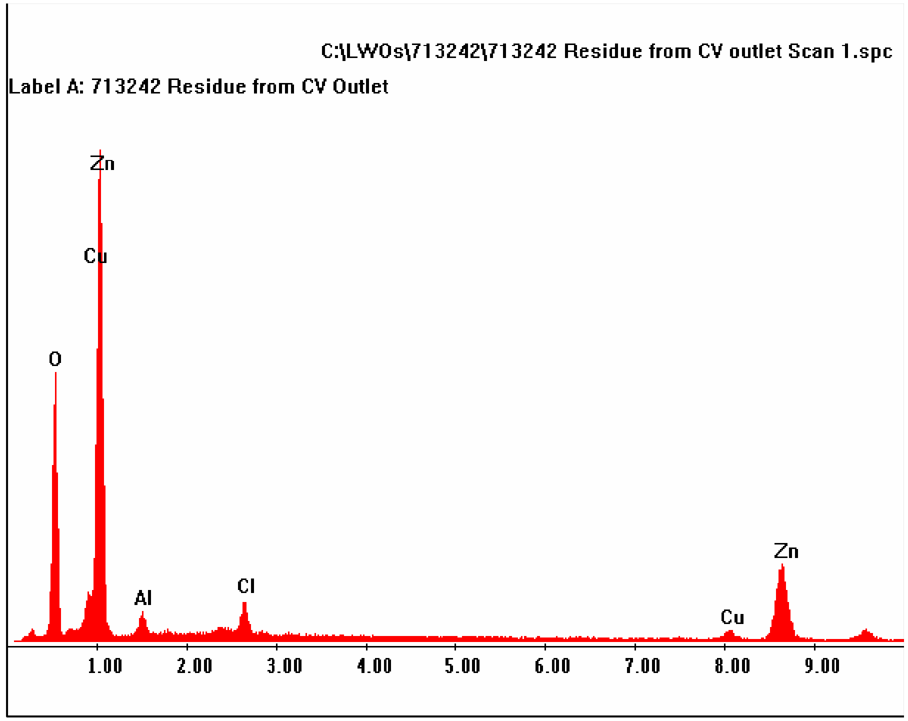


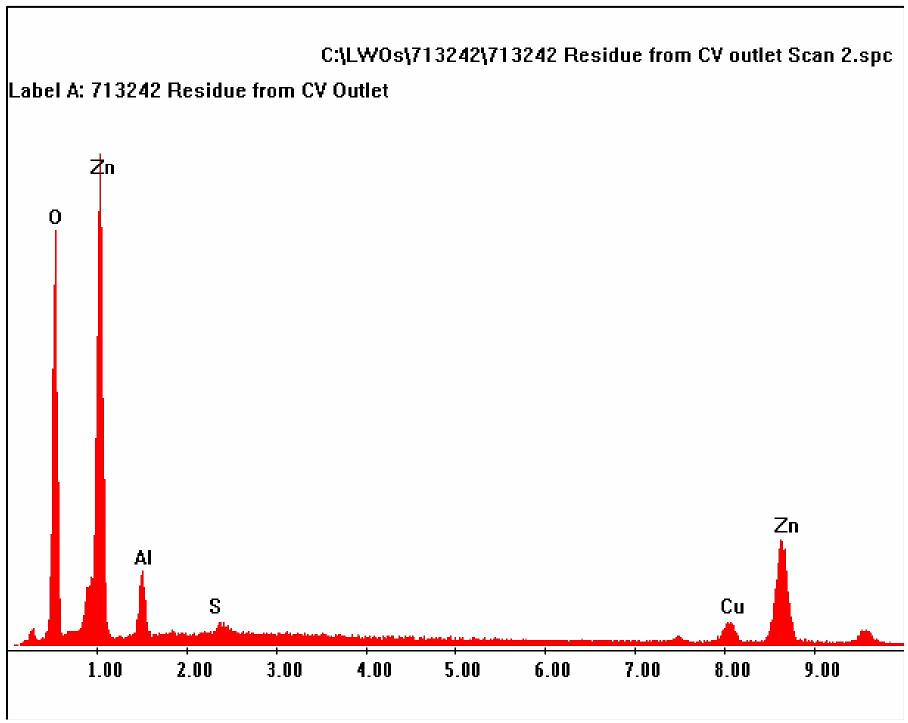




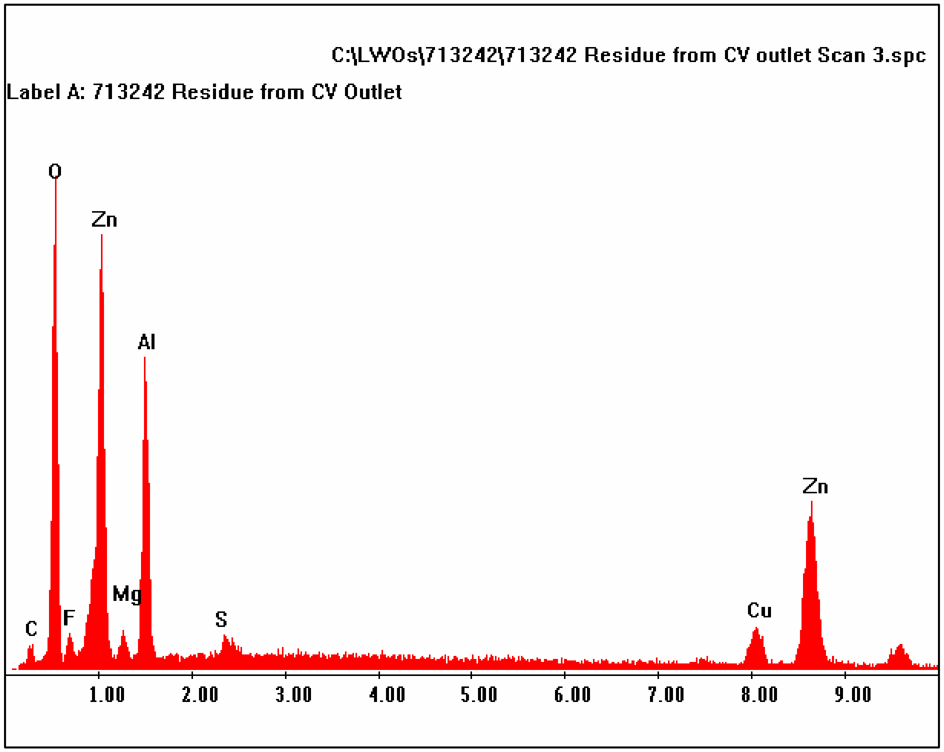
Residue Removed from Cylinder Valve Outlet

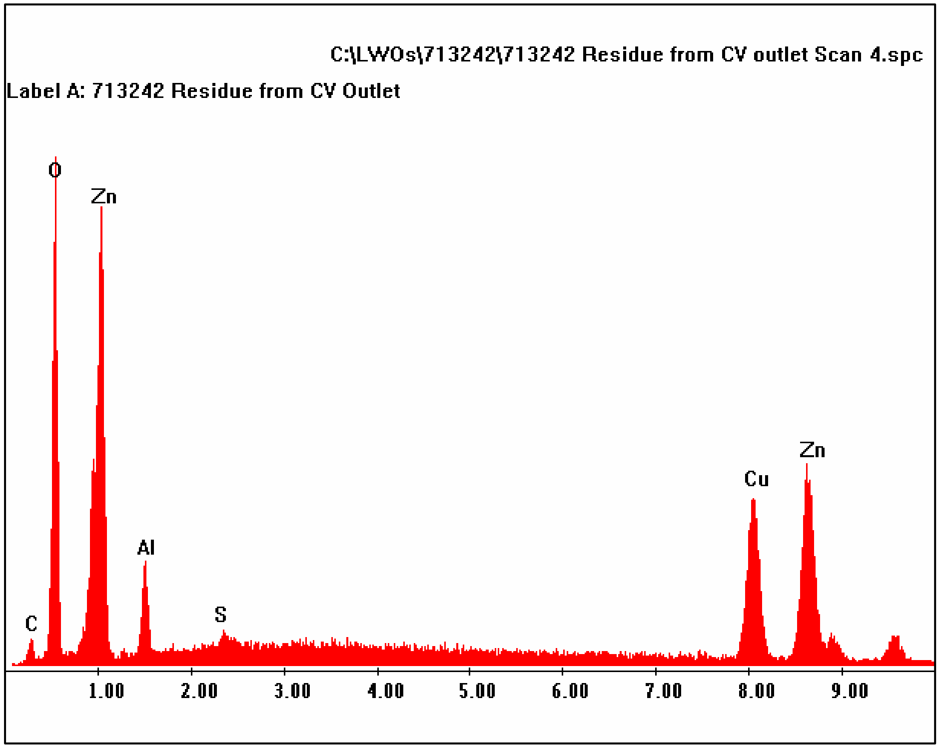




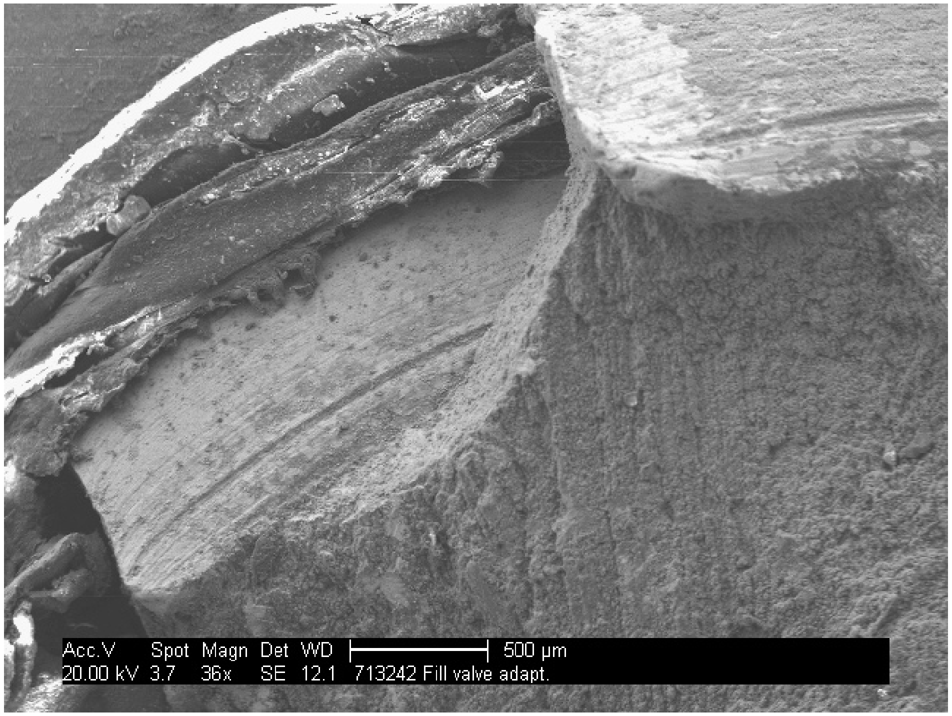


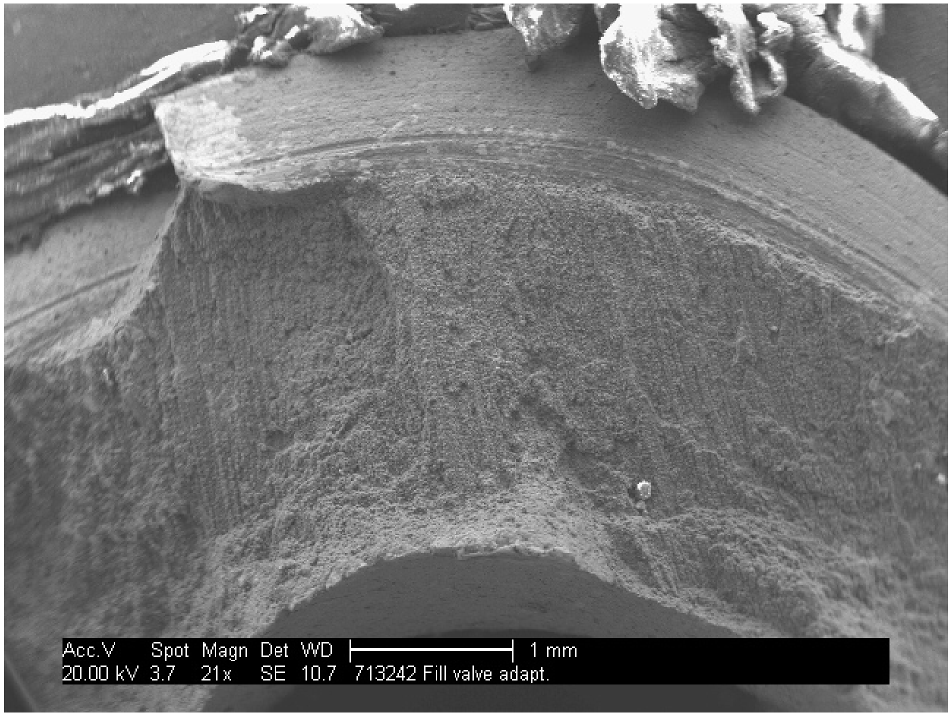
Residue Removed from Cylinder Valve Outlet
(scans 3 and 4)



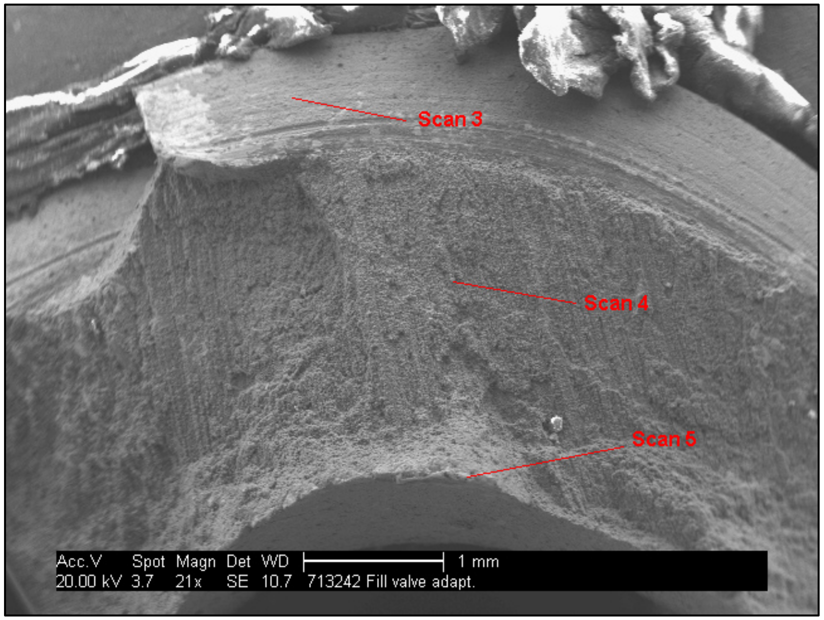


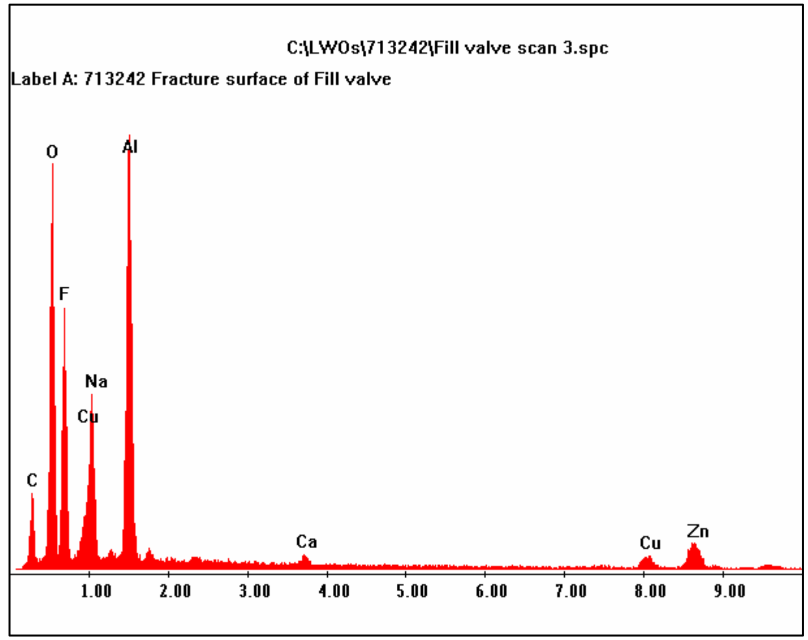
Fill Valve Adaptor Fracture Surface

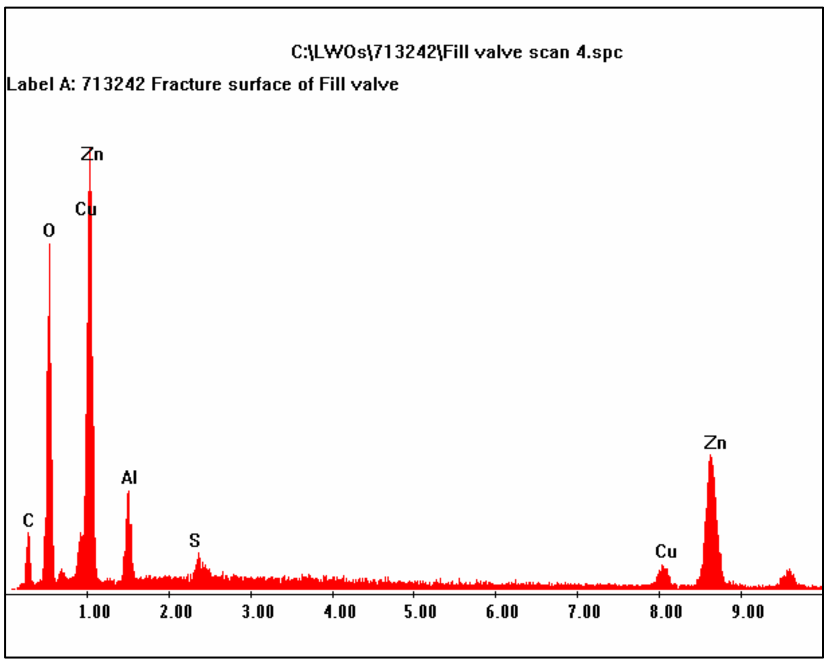


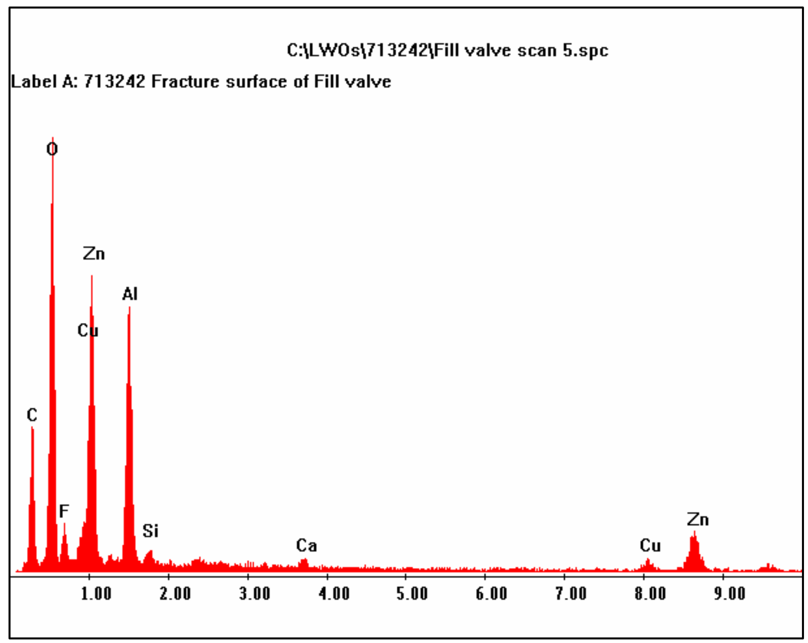


Fill Valve Adaptor Fracture Surface

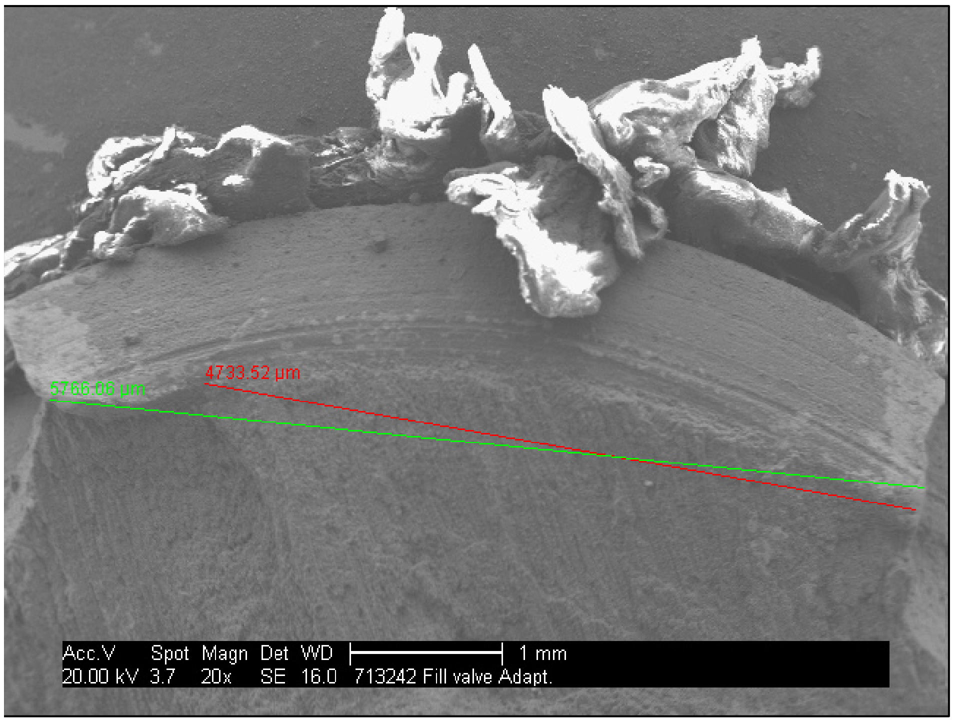




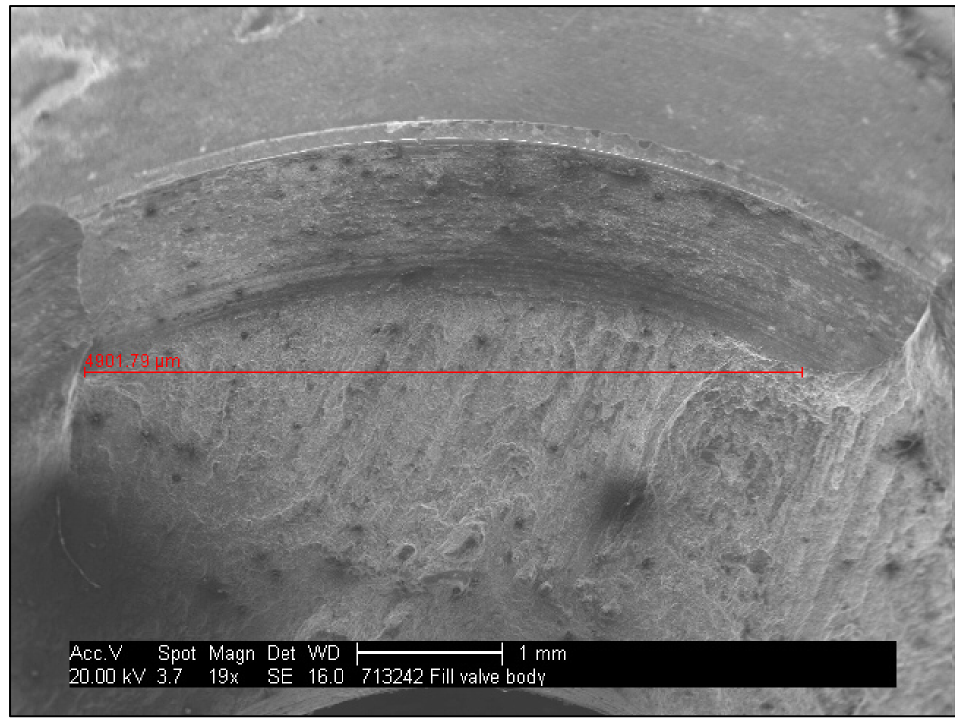




Thread Root Comparison

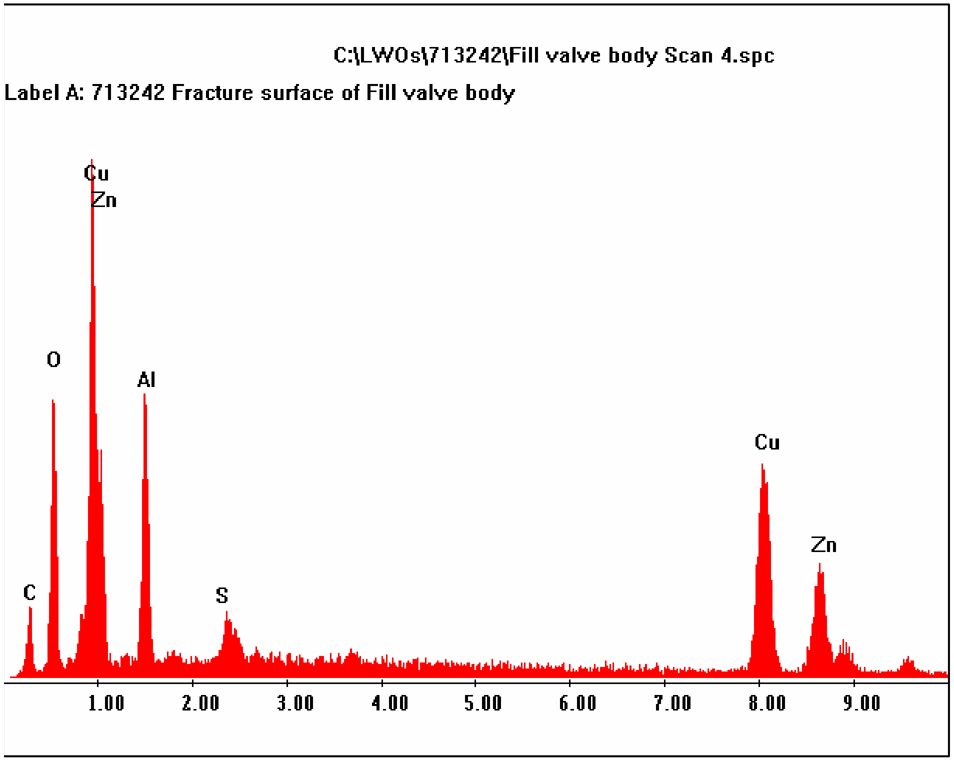


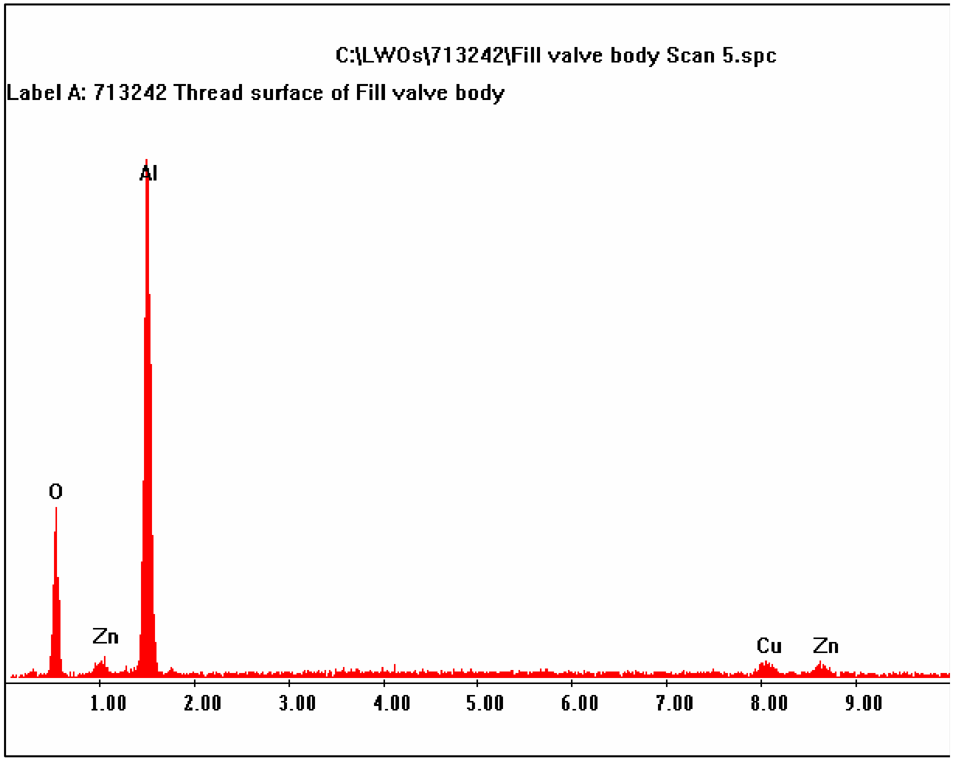
Fill Valve Adaptor Fracture



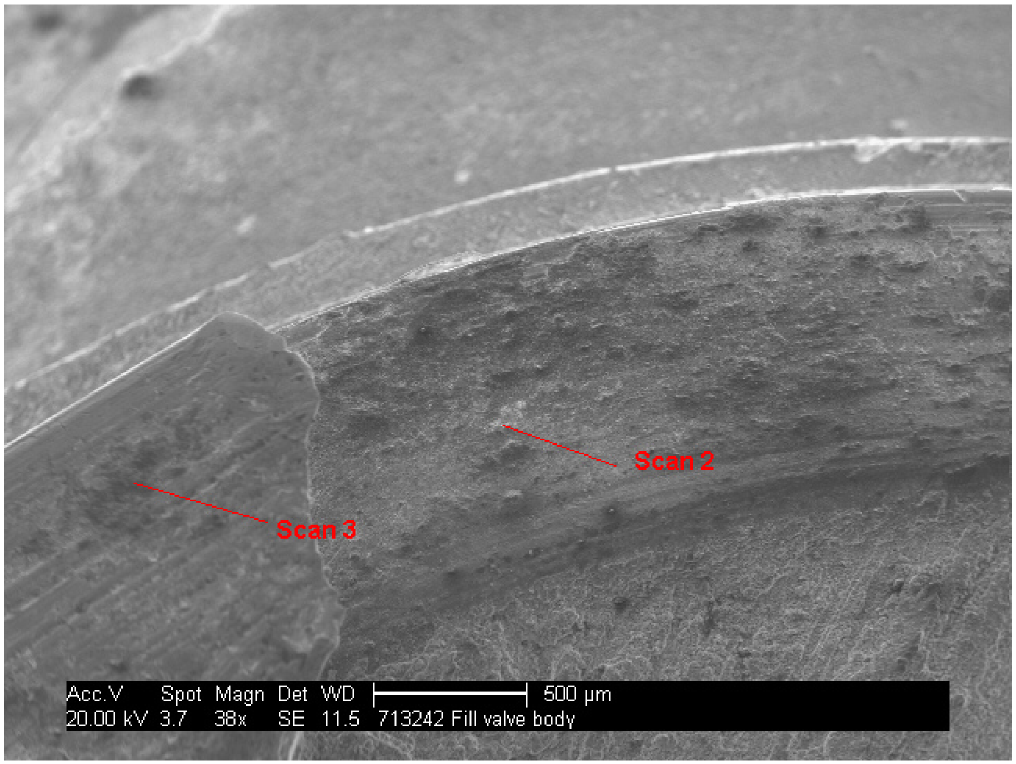
Fill Valve Body Fracture

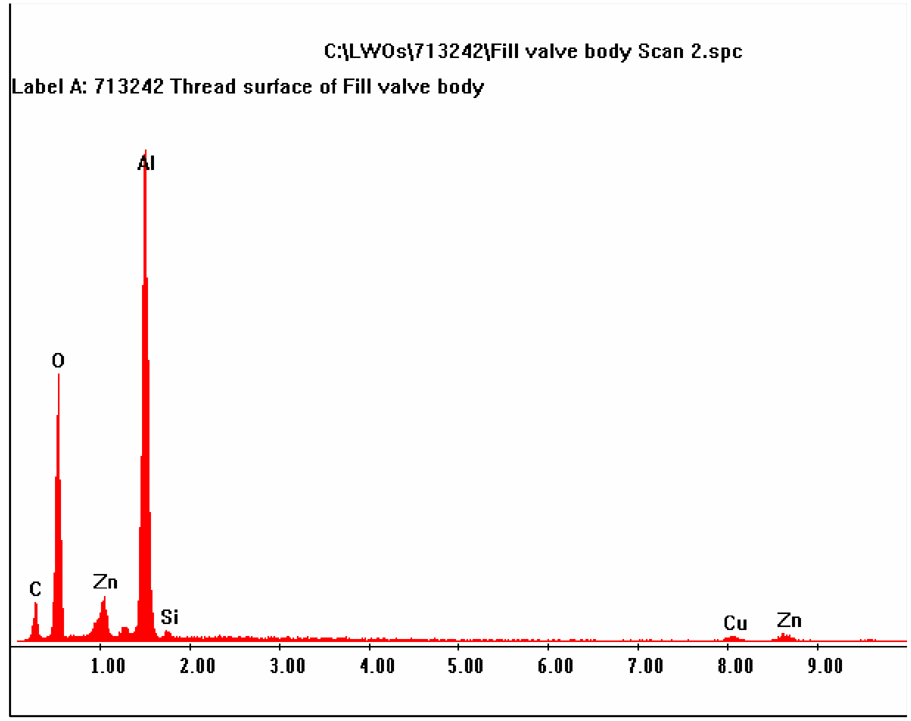
Fill Valve Body Fracture Surface

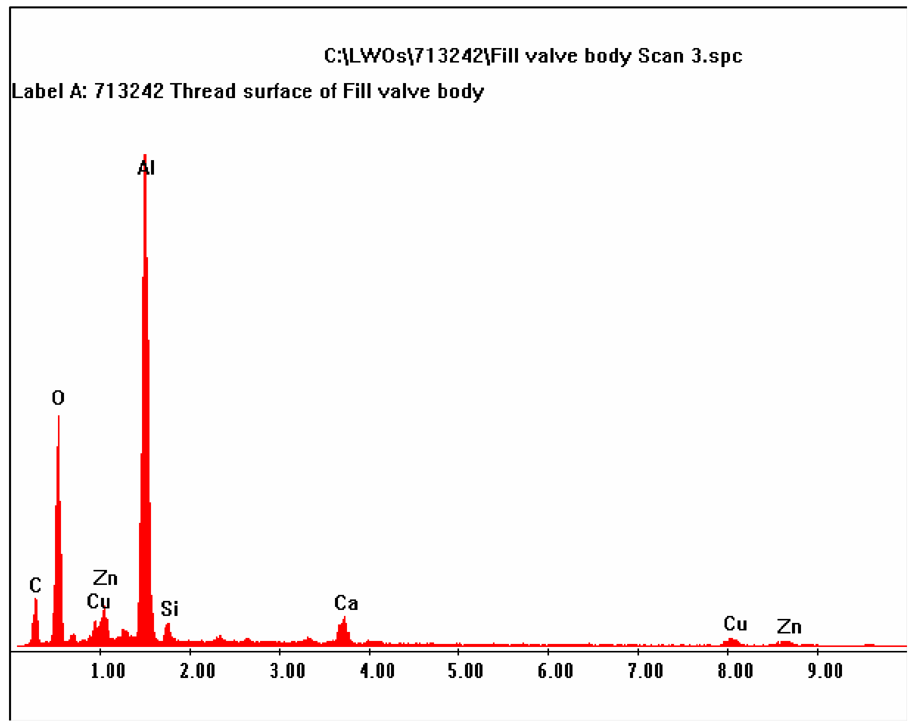




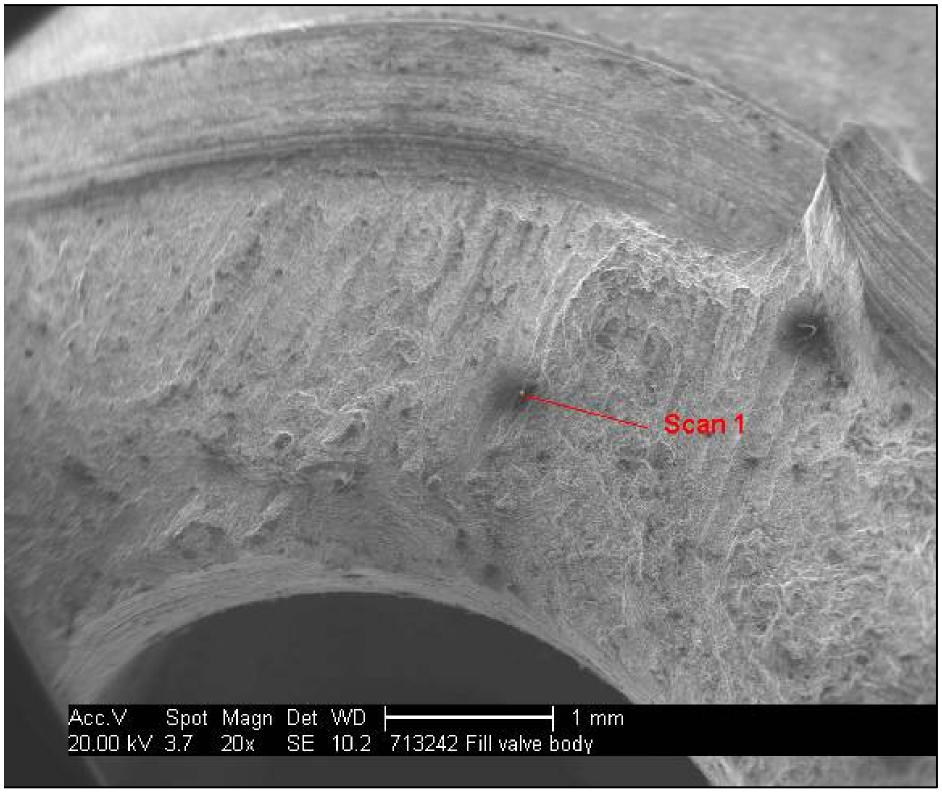
Fill Valve Body Fracture Surface

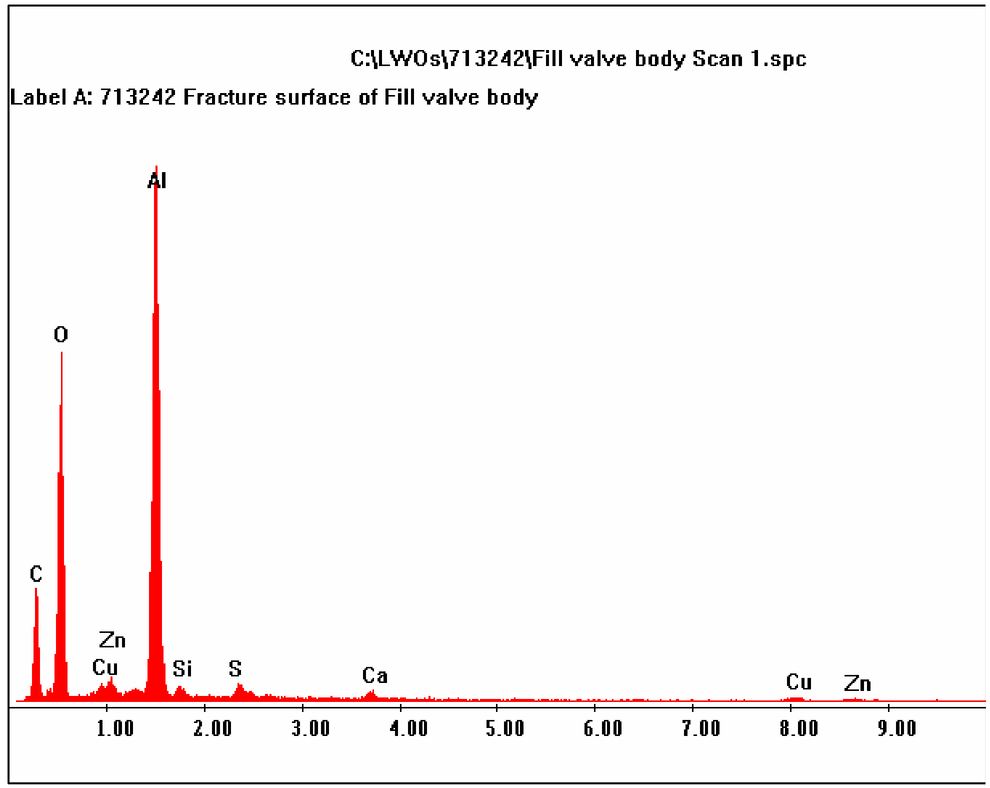






Fill Valve Body Thread Fracture





Fill Valve Adaptor Fracture Surface