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

December 9, 2009

MATERIALS LABORATORY FACTUAL REPORT Report No. 09-094

A. ACCIDENT

Place : Goode Army Airfield, Afghanistan
Date : August 19, 2009
Vehicle : Sikorsky S-61
NTSB No. : ENG09SA023
Investigator : Mike Hauf (AS-40)

B. COMPONENTS EXAMINED

Spool and sleeve portion of the pressure relief valve; rod portion of the pilot valve; three plastic bags and four plastic containers with cover that contained contamination particle(s) from several areas of the fuel control unit (FCU) on a model General Electric CT58 turbo shaft engine. The FCU reportedly was part number 725725-5, serial number 29172.

C. DETAILS OF THE EXAMINATION

A photograph of the as-received spool and sleeve portion of the pressure relief valve (PRV); the rod portion of the pilot valve; contamination particles from various portions of the FCU is shown in figure 1. The spool was received inserted in the sleeve portion of the PRV.

Sleeve Portion of the PRV

Bench binocular examination of the sleeve portion of the PRV before the spool was disassembled from the sleeve revealed the outer wall of the sleeve contained a particle, referred to as sample “1” in figure 2, which was embedded between the rubber O-ring and the housing near the bore at the metering end. Sample “1” was irregular and displayed a luster. This sample was removed with tweezers from the sleeve and placed on an aluminum stub that was covered with doubled-sided carbon adhesive tape. Scanning electron microscope (SEM) examination of sample “1” revealed a major portion of the fracture face contained smear (mechanical) damage. Figure 3 shows an SEM photograph of this sample. The areas of the fracture that contained no evidence of smear damage showed ductile dimple fracture features typical of overstress separation with no evidence of fatigue cracking. X-ray energy dispersive spectroscopy (EDS) analysis of sample “1” produced a spectrum that contained a major elemental peak of aluminum, and minor

elemental peaks of silicon, magnesium, iron, copper, carbon, and oxygen, consistent with an aluminum alloy, as shown in figure 2. The grade of the aluminum alloy was not determined. Table 1 provides a summary of the description, major elemental peaks that were found in the EDS spectrum, and size for sample 1. Table 1 also shows example(s) of materials that contain such element(s) and measured particle sizes. Particle sizes were reported in micrometers and converted to inches (shown in parentheses). Table 2 shows the conversion units for most of the particles that were measured in order of increasing size.

Spool Portion of the PRV

A spool portion contains four circumferential balance grooves, referred to as grooves "A" through "D" in figure 2. Groove "A" was located next to the diaphragm portion and groove "D" was located next to the metering end. The spool portion was pulled out of the sleeve in increments to expose one groove at a time. Each time a new groove was exposed, the spool was rotated and the complete circumference was examined with bench binocular microscope for evidence of particles. During the examination at the Safety Board Materials Laboratory, the spool was completely pulled out of the sleeve with no resistance and with no evidence of binding. Particle(s) from the spool were pulled out of the groove with doubled-sided carbon adhesive tape and, in turn, this tape was placed on an aluminum stub. Particle(s) were examined by SEM, analyzed by EDS, and the approximate length, width, thickness, and elements in the particle(s) was determined.

Examination of the spool revealed groove "A" contained one narrow particle referred as sample "2" in figure 2 and at higher magnification in figure 4. This particle was red. When the particle was removed from groove "A", the back side of the particle was found to be white. EDS spectrum of this sample contained a major elemental peak of chlorine and minor elemental peaks of titanium, iron, calcium, aluminum, silicon, carbon, and oxygen, as shown in figure 4, consistent with a non-metallic material. Groove "B" contained dust-like particles in one isolated area of the groove, see figure 5. EDS analysis was performed on two typical particles, referred to as samples "3" and "3B". EDS spectrums of these two particles are consistent with a non-metallic material. Groove "C" contained one narrow particle that exhibited a luster, referred to as sample "4A" in figure 6. Initially, this sample was thought to have fallen out of the spool during extraction because the sample was not visible on the tape surface. However, SEM examination of the tape in electron backscatter mode (ability to detect materials with greater density than the tape) revealed sample "4A" was imbedded within the tape, and had fractured into two pieces. Two other particles were found in the tape, referred to as samples "4B" and "4C" in figure 6, which were not visible in the groove during bench binocular microscope examination. Figures 6 shows SEM photographs of samples "4B" and "4C". Figure 7 shows the EDS spectrum of samples "4A", "4B", and "4C". Samples "4A", "4B", and "4C" are consistent with nickel, cadmium, and stainless steel, respectively. Table 1 provides a summary description of particle(s) that were found in each groove and approximate sizes of each particle. Groove "D" contained one fiber referred to as sample 5 in figure 8. The EDS spectrum of this particle showed a major peak of carbon consistent with a non-metallic material, see figure 8.

Areas outside of the grooves also were examined for evidence of particles. The reduced diameter portion of the spool in the area next to groove “A” contained one narrow particle referred to as sample 6 in figure 9. An EDS spectrum of this sample contained a major elemental peak of aluminum and minor peaks of silicon, zinc, iron, chromium, calcium, sulfur, oxygen, and carbon, consistent with an aluminum alloy. The grade of the aluminum alloy was not determined. The diaphragm is attached with a screw and nut to the spool. When looking into the bore of the spool from the metering end, the screw head was visible. Two particles were found embedded between the screw head and the bore of the spool, referred to as samples “7” and “8” in figure 10. EDS spectrums of samples “7” and “8” showed major elemental peaks of iron and chromium consistent with stainless steel. The EDS spectrum of sample “8” also contained minor elemental peaks of copper zinc, silver, tin, sulfur, aluminum, silicon, carbon and oxygen, consistent with materials typically found in bearing alloys. Table 1 provides a summary description of this sample and approximate size.

Dimension of the Spool and Sleeve

The outside diameter of the spool and inside diameter of the sleeve were measured with a micrometer. The measured and specified values for the diameter of the spool and sleeve are shown in the table labeled “Dimensions”. The outside diameter of the spool at the land portion (between the balance grooves) measured approximately 0.3770 inch, within the range specified in Hamilton Sunstrand (HS) spool engineering drawing 543461. The inside diameter of the sleeve measured approximately 0.3777 inch, within the range specified in HS sleeve engineering drawing 734913. The clearance between the spool and sleeve for an assembly that is within drawing tolerance was calculated to be between 0.0004 inch (10 micrometers) and 0.0008 inch (20 micrometer). The clearance between the spool and sleeve for the as-received assembly was calculated to be 0.0007 inches (18 micrometers). The spool and sleeve portions showed no evidence of a crack.

Dimensions			
Spool Outside Diameter (inch)		Sleeve Inside Diameter (inch)	
Specified	Measured	Specified	Measured
0.3770-0.3772	0.3770	0.3776-0.3778	0.3777

Particles Collected from Different Areas of the FCU

According to the Systems Group Chairman, contamination particles were found in various portions of the FCU during its examination at Columbia Helicopters, Inc. These particles were collected and placed in flexible plastic bags and rigid plastic containers, as show in figure 1. Plastic bag labeled “3D CAM particle” contained a cotton swab and a red particle at the bottom of the bag. For the purpose of this examination, the red particle was referred to as sample 9 in figure 11. Sample 9 was removed from the bag with tweezers and placed on an aluminum stub that was covered with doubled-sided carbon adhesive tape. When viewed with a bench binocular microscope, one side of sample 9 was red and the other side was white. Figure 11 shows a photograph of the red and white faces of sample 9 and EDS spectrum of this sample. EDS analysis of sample 9 produced a

spectrum that contained a major elemental peak of chlorine and minor peaks of titanium, sulfur, aluminum, silicon, oxygen and carbon, consistent with a non-metallic material. The approximate size of sample 9 is shown in table 1. The cotton swab showed no evidence of other particles.

Plastic bag labeled “Inside of NG Governor flyweight Cap” contained a cotton swab and a white narrow particle at the bottom of the bag. The white particle was referred to as sample 10 (photograph and EDS not shown). The EDS spectrum of sample 10 contained a major elemental peak of calcium, and minor peaks of silicon, aluminum, and carbon, consistent with a non-metallic material. The approximate size of the particle is shown in table 1.

Plastic bag labeled “Metal Particle Fine Filter Housing” contained a cotton swab. The tip of the cotton swab contained a particle, referred to as sample 11 (photograph and EDS not shown). EDS spectrum of sample 11 contained elemental peaks of carbon and oxygen, consistent with a non-metallic material. The approximate size of the particle is shown in table 1.

Four rigid clear plastic containers with a cover were submitted and they were labeled ““PRV”, “T2 servo end cap”, “lead lag screw end cap”, and “TV end cap”. The cover was removed from each container. Bench binocular microscope examination revealed each container contained several particles. Two typical particles (an irregular particle and a fiber) were selected from each container for examination and EDS analysis. The particles collected from container labeled “TV end cap” were referred to as samples 12A and 12B; samples collected from container labeled “lead lag screw end cap” were referred to as samples 13A and 13B; particles collected from container labeled “T2 servo end cap” were referred to as 14A and 14B, particles collected from container labeled “PRV” were referred to as samples 15A and 15B. Each sample was examined by an SEM and analyzed by EDS. Table 1 provides a summary of the particles that were selected, major elemental peaks that were found in each respective EDS spectrum, and approximate size of each selected particle. Photographs and EDS spectrums of the particles are not shown in this report. EDS spectrum from sample 13A was consistent with cadmium. EDS spectrums of the samples removed from the containers were consistent with non-metallic material.

Exemplar Plastic Sheets Submitted for Comparison

Two translucent plastic sheets were submitted by Columbia Helicopters Incorporated, as shown in figure 12. One sheet was pink throughout the thickness and the other sheet was yellow throughout the thickness, referred to as samples 16 and 17, respectively. Each sheet measured 8.5 inches by 11 inches. A representative from Columbia Helicopters Incorporated indicated the sheets are used as cleaning media for polishing and cleaning parts that are overhauled in their facility. The sheets are cut into smaller pieces when used as cleaning media. EDS analysis of a sample from each sheet produced a spectrum that contained major peaks of carbon and oxygen, as shown in figure 12.

Other Exemplar Pieces

For purpose of comparison between particles, the Safety Board Materials Laboratory performed EDS analysis on a broken fragment of a clear plastic container that housed one of the submitted particles referred to as sample 18; and reference vinyl material, referred to as sample 19. EDS analysis of the clear plastic fragment from the container that housed one of the submitted particles produced a spectrum that contained a major peak of carbon and oxygen, whereas, the vinyl material produced a spectrum that contained a major peak of chlorine, as shown in figure 13.

Pilot Valve

SEM examination of the pilot valve revealed the rod portions contained minor longitudinal score marks. The score marks measured as wide as 5 micrometer and the depth of the score marks was estimated to be as deep as the width (5 micrometer). EDS spectrum of the base metal produced a spectrum that contained major elemental peaks of iron, chromium, and nickel, consistent with stainless steel. The tip of a rod portion (left rod in figure 14) contained several deposits. The EDS spectrum of a deposit contained the same elemental peaks as the base metal as well as peaks of zinc, sulfur, and sodium. The EDS spectrum of the score marks (not shown) contained the same elemental peaks as the base metal for the pilot valve (score contained no transfer of foreign material).

Frank P. Zakar
Senior Metallurgist

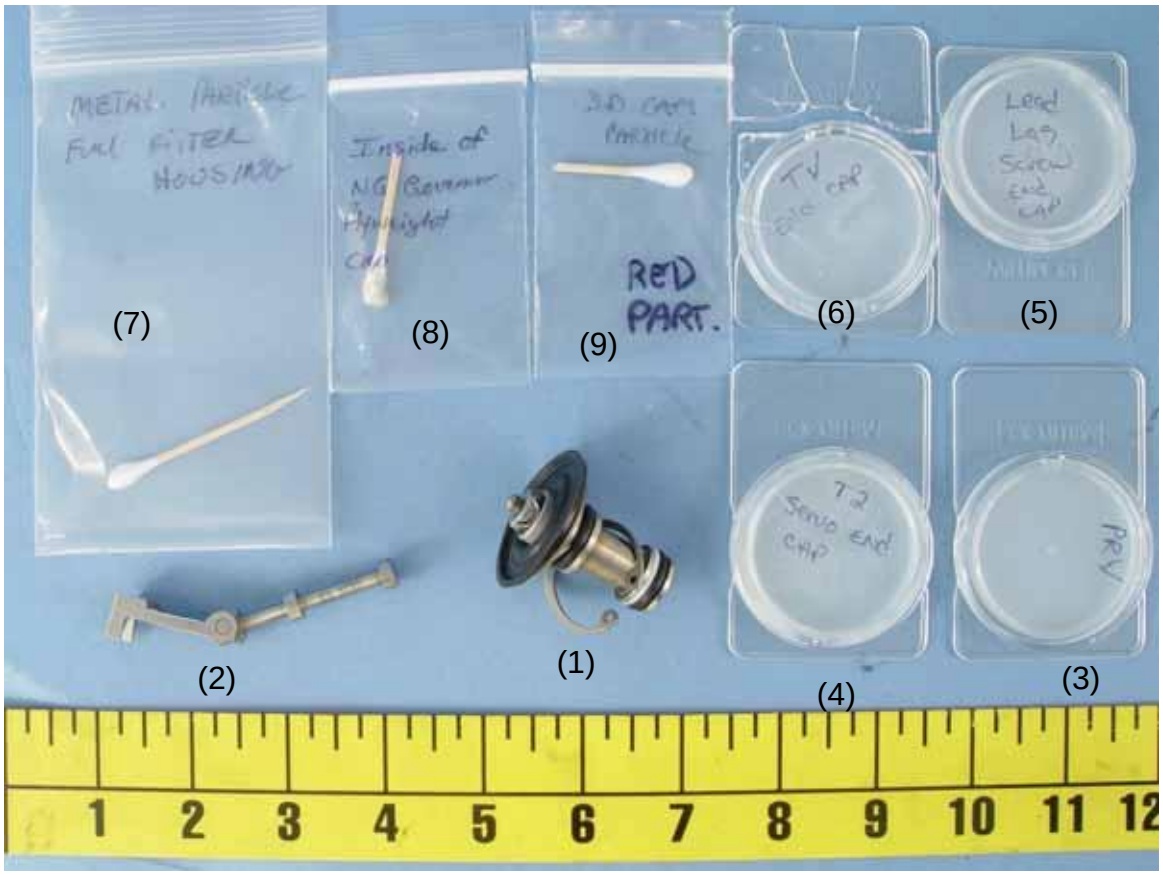


Figure 1. Photograph of the as-received (1) spool and sleeve portion of the pressure relief valve with retaining ring; (2) rod portion of the pilot valve; (3) specimen container with cover labeled “PRV”; (4) specimen container with cover labeled “T2 servo end cap”; (5) specimen container with cover labeled “lead lag screw end cap”; (6) specimen container with cover labeled “TV (throttle valve) end cap”; (7) specimen bag with cotton swab labeled “metal particle fuel filter housing”; (8) specimen bag with cotton swab labeled “inside of NG Governor flyweight cap”; and (9) specimen bag with cotton swab labeled “3D CAM particle” that contained a red particle that was freely moving within the bag. The numbers on this page were randomly selected to facilitate identification of the submitted pieces and do not correspond to sample numbers used later in this report.

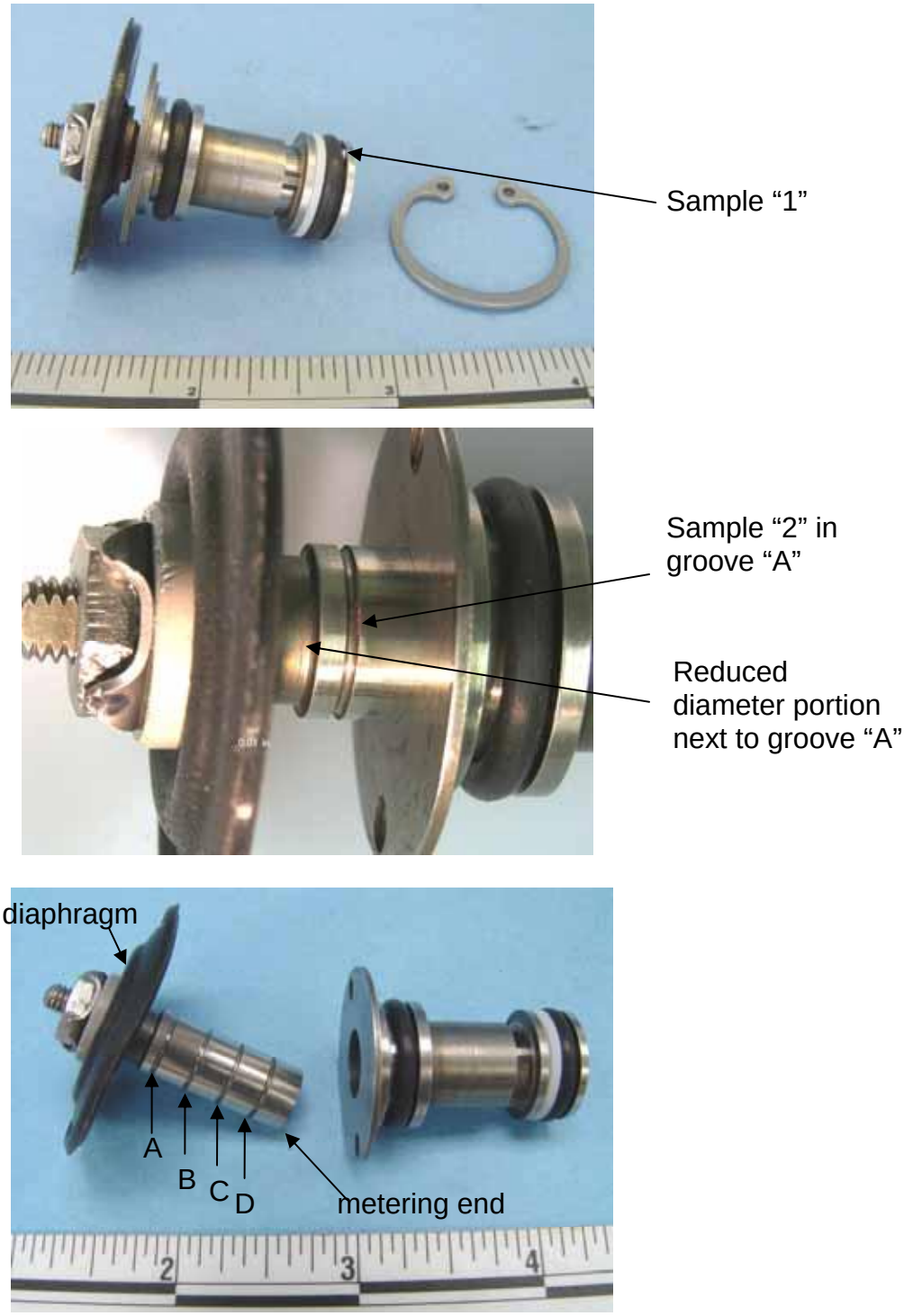
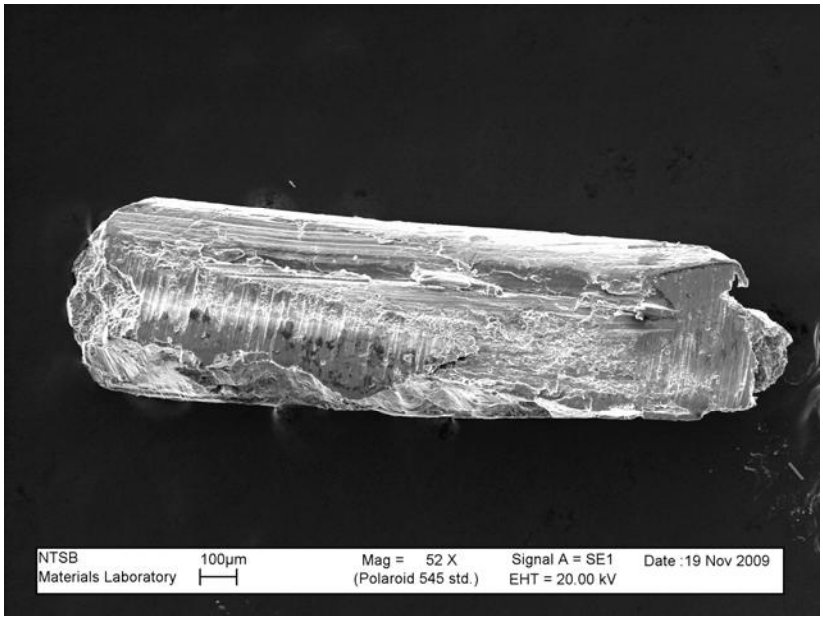


Figure 2. Photographs of the as-received spool portion that was inserted into the sleeve portion (top of page); spool partially removed from the sleeve portion showing a red particle that was attached to balance groove “A” (center of page); spool portion disassembled from the sleeve portion showing grooves labeled A” through “D” (bottom of page).



Sample 1

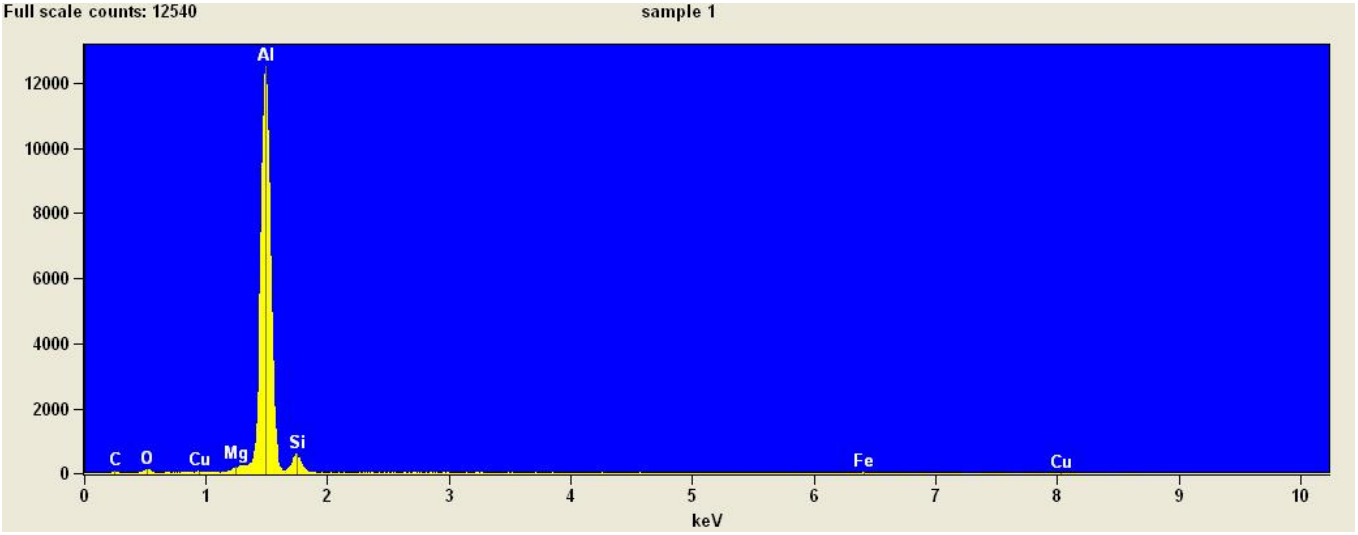


Figure 3. Scanning electron microscope (SEM) photograph of the particle referred to as sample "1" that was found on the outside surface of the sleeve in the area between the metering end of the sleeve and the rubber o-ring seal.

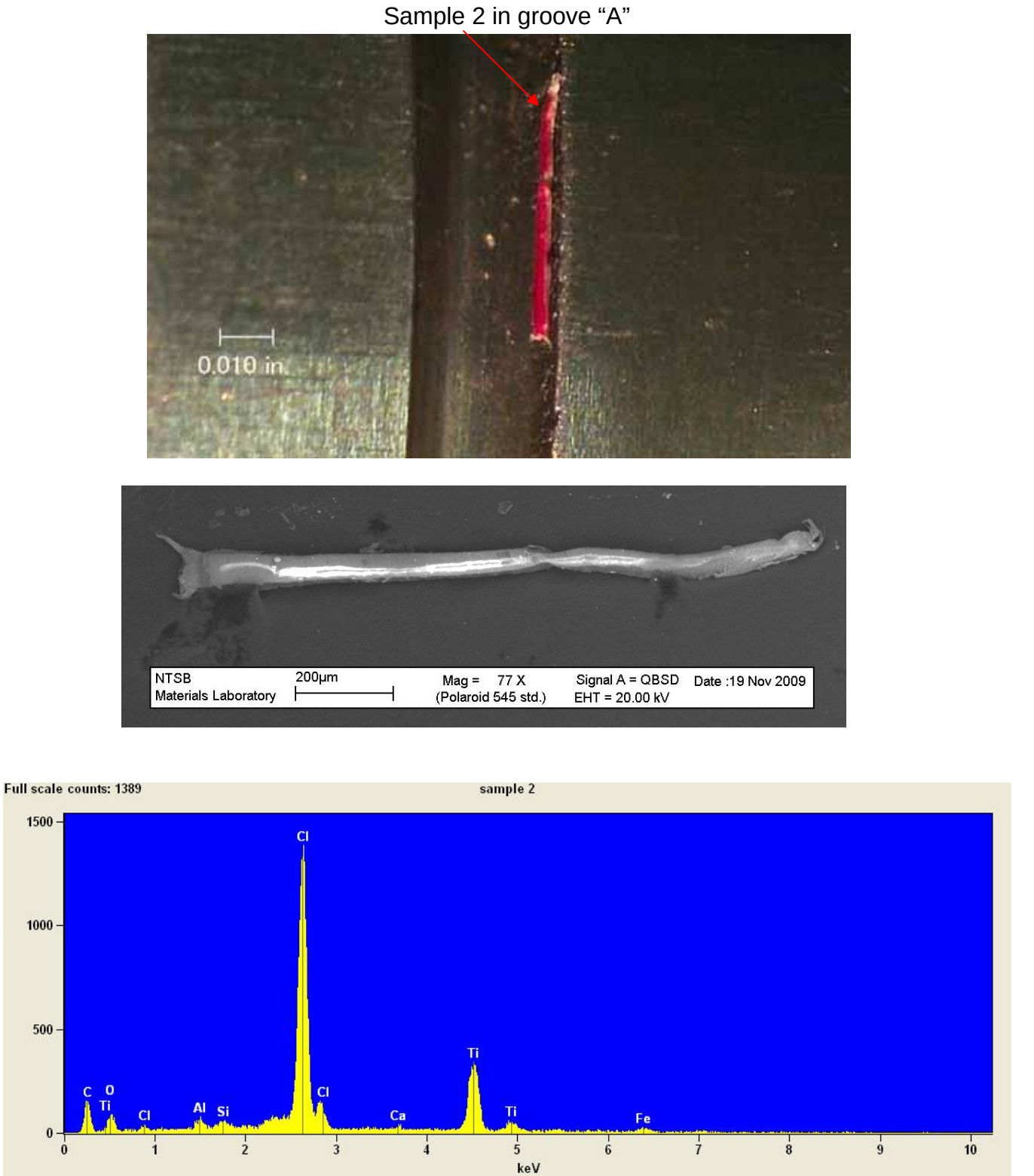
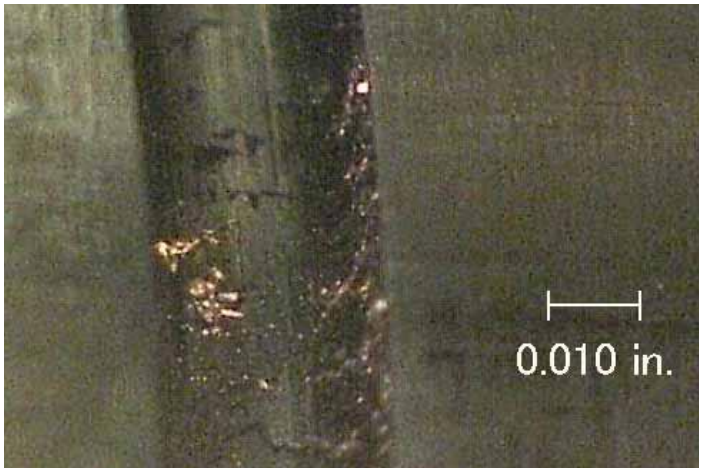
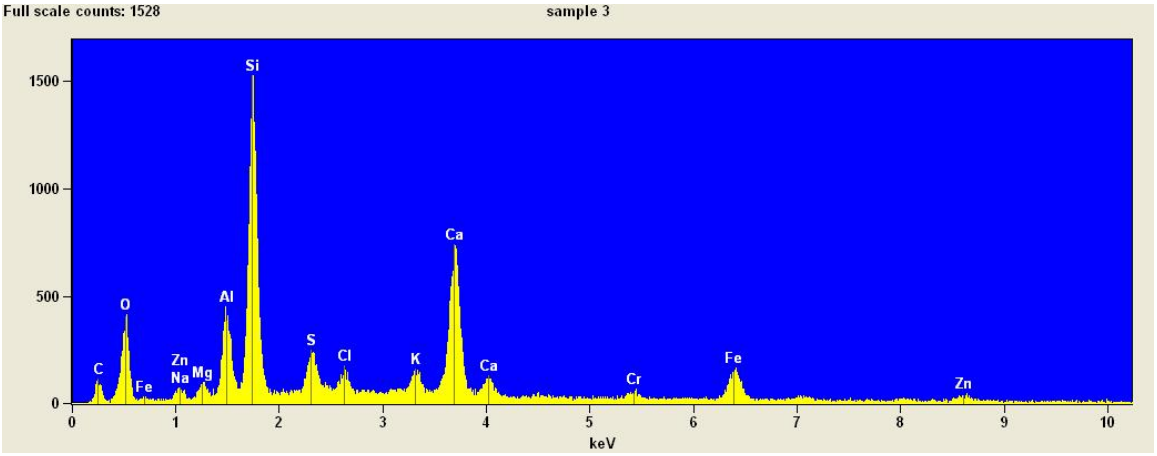


Figure 4. Photograph of the spool portion of the PRV in the area of groove “A” showing a red particle referred to as “sample 2” that was found in this groove (top of page). SEM photograph of the same particle (center of page) and EDS spectrum of the same particle (bottom of page).

Dust particles in groove “B”





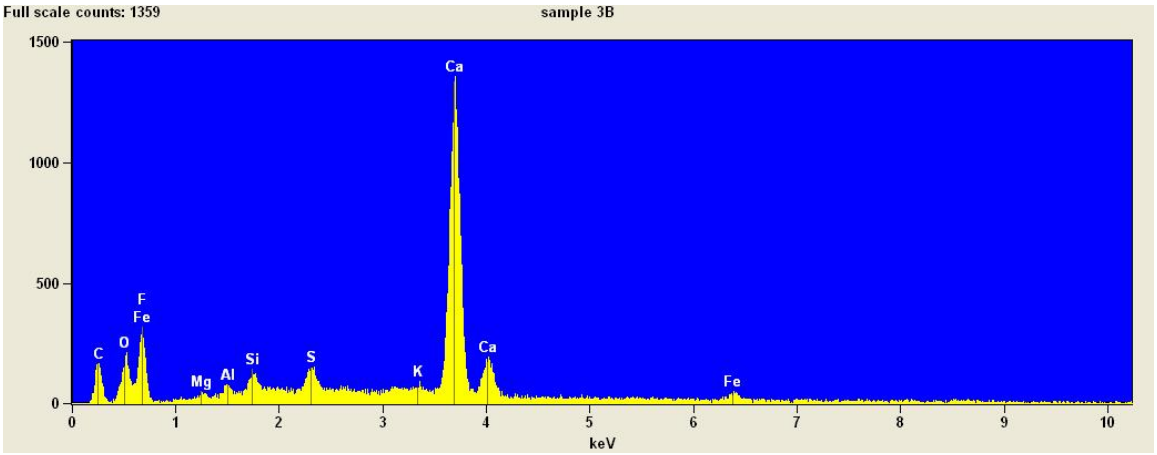


Figure 5. Photograph of the spool portion of the PRV in the area of groove “B” showing dust-like particles that were found in the groove (top of page). EDS spectrums from two typical dust-like particles referred to as sample “3” and “3B” are shown on the bottom of the page.

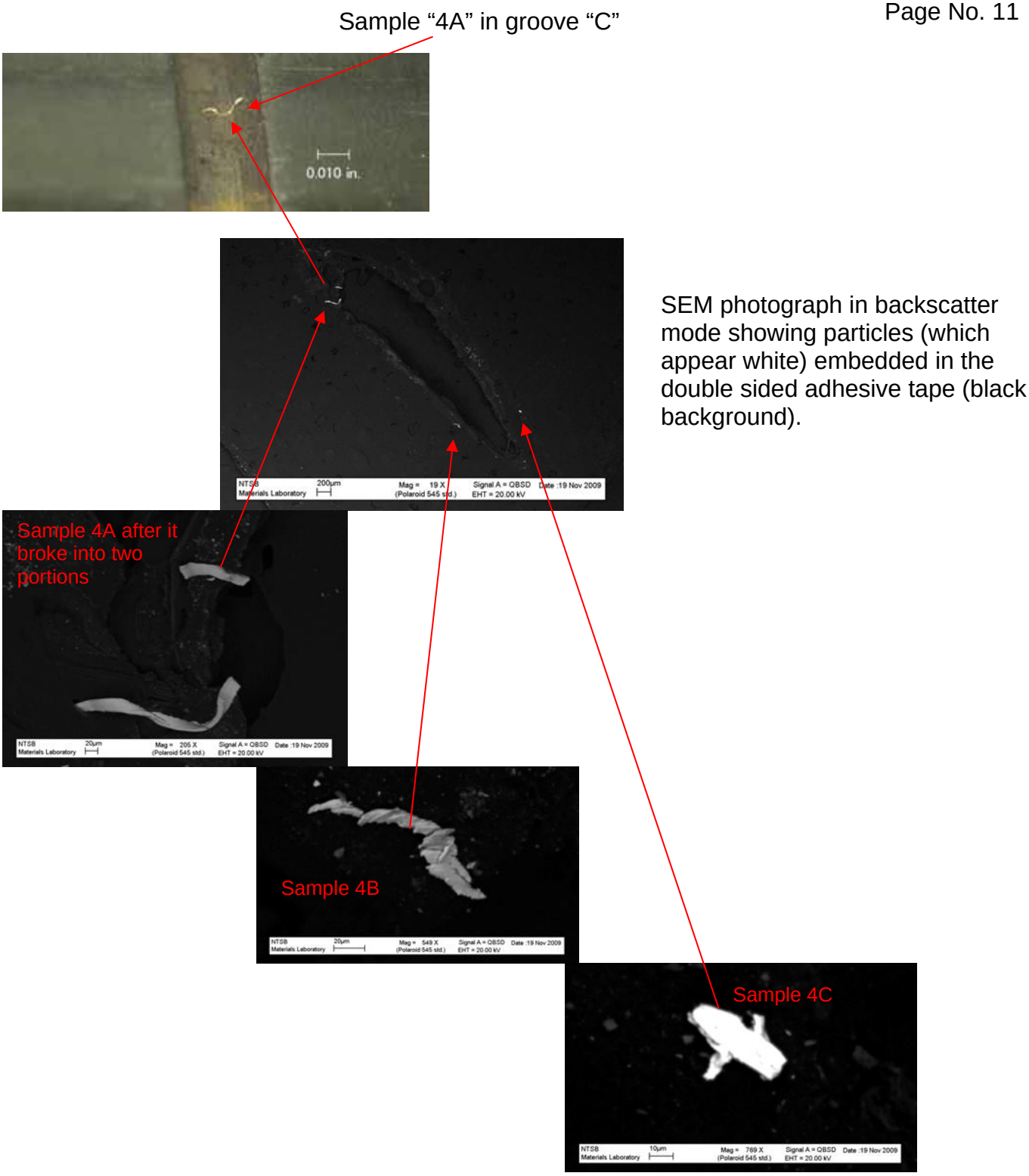


Figure 6. Photograph of narrow particle referred to as sample “4A” that was found in groove “C” of spool portion of the PRV (top of page). After removal with tape, sample “4A” fractured into two pieces. Follow-up examination of the tape with SEM in backscatter mode showed two additional particles (samples “4B” and “4C”) were picked up on the tape that were not visible with binocular microscope.

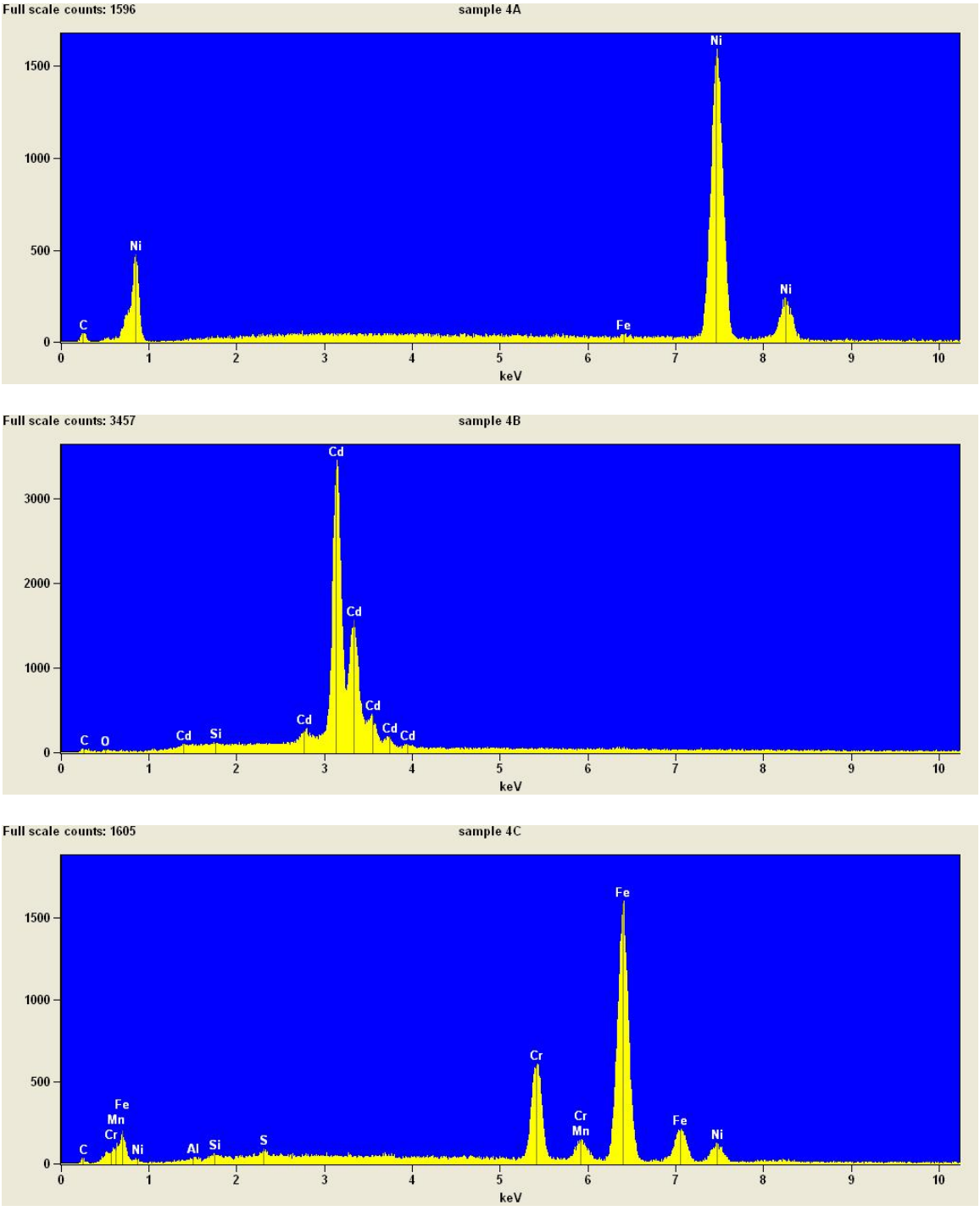


Figure 7. EDS spectrums of samples referred to as “4A”, “4B” and “4C”.

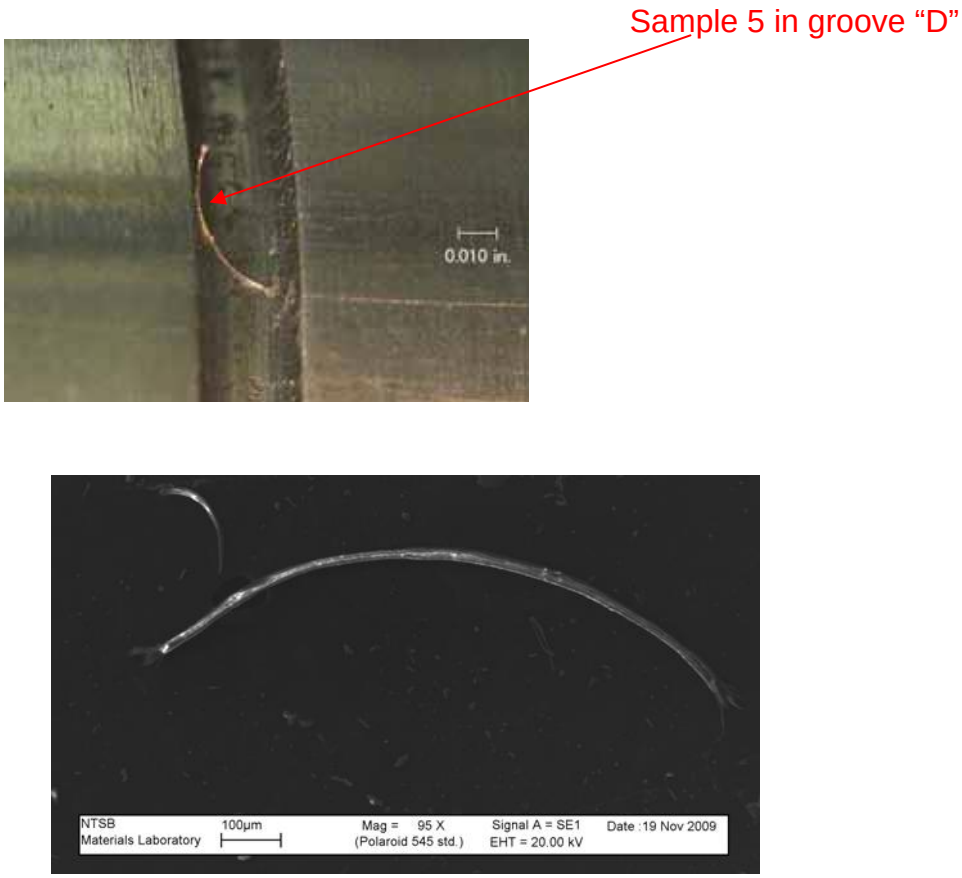


Figure 8. Photograph of the spool portion of the PRV in the area of groove “D” showing a fiber referred to as sample 5 (top of page). SEM photograph of the same particle (center of page) and EDS spectrum of sample 5 (bottom of page).

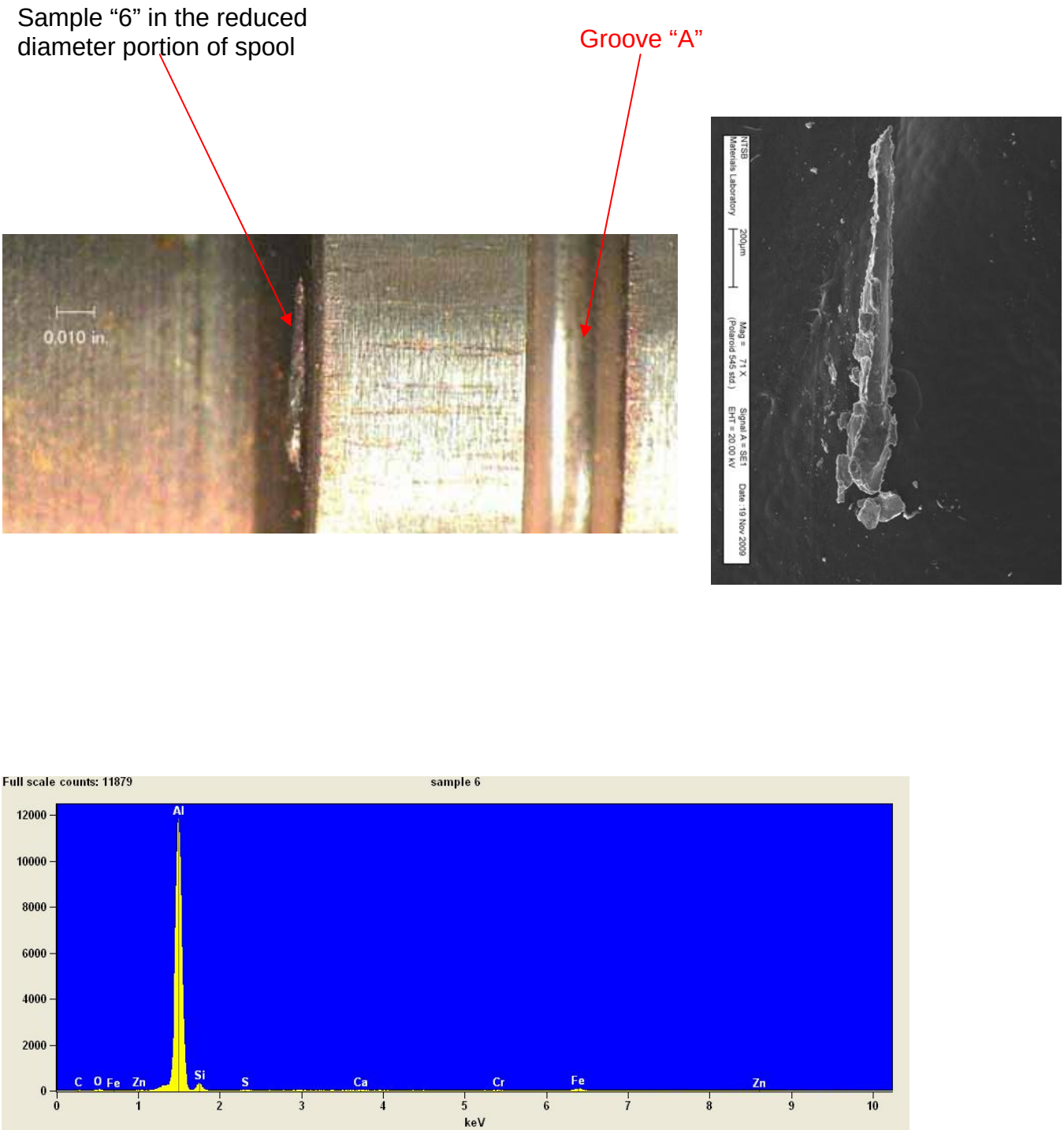
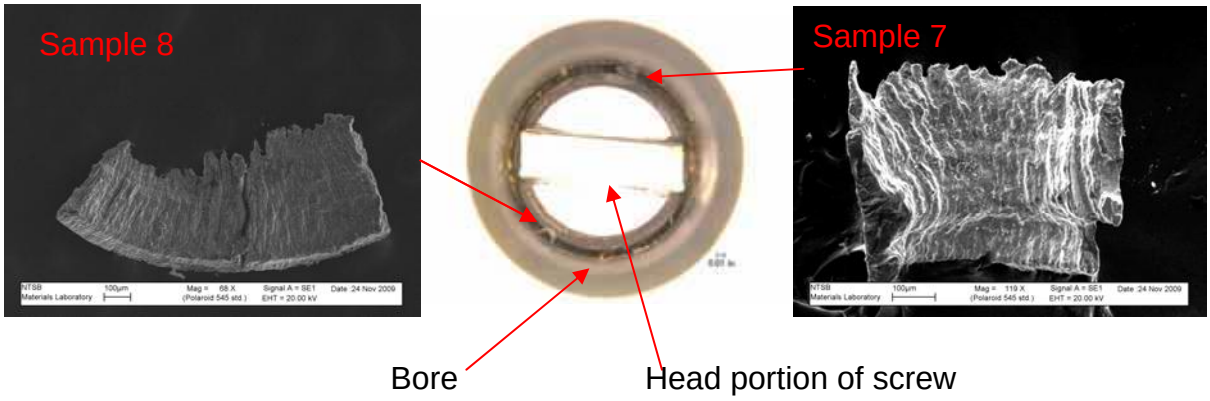
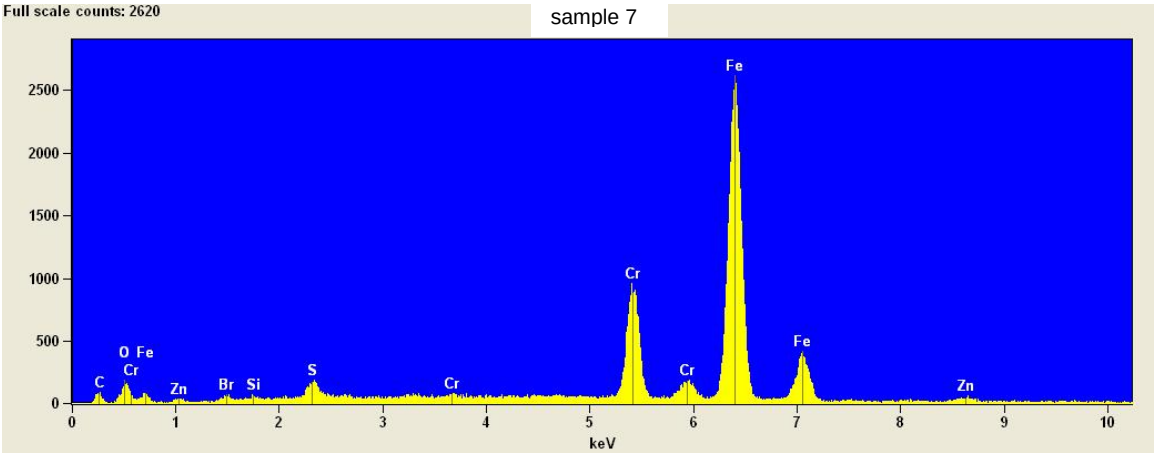


Figure 9. Photograph of a metal-like particle, referred to as sample “6”, that was found on the reduced diameter portion of the spool in the area located between the diaphragm and groove “A” (upper left corner of page); SEM photograph of the same particle (upper right corner); and EDS spectrum of the particle (bottom of page).





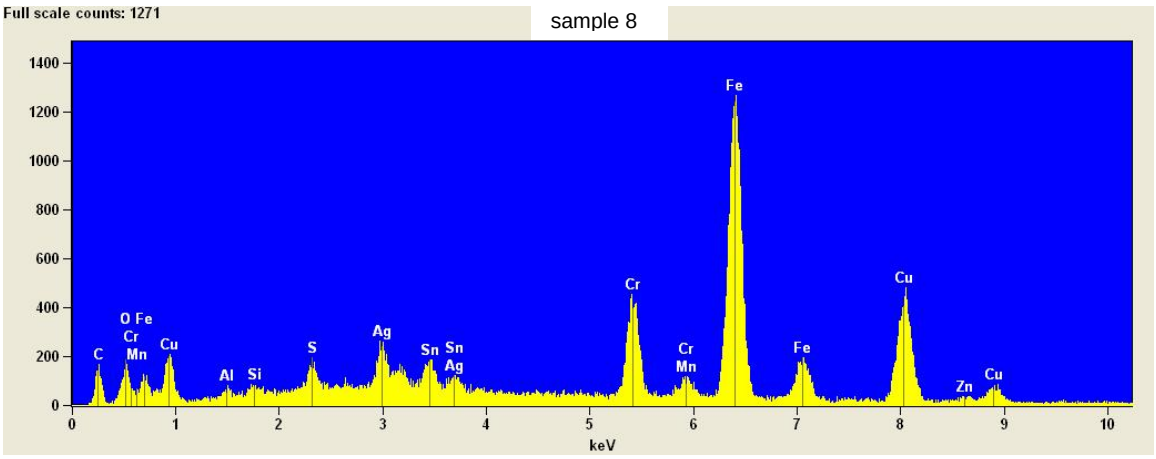
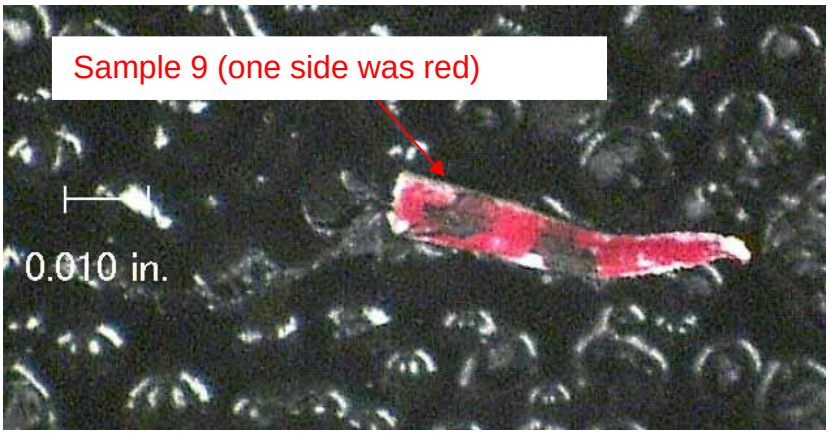
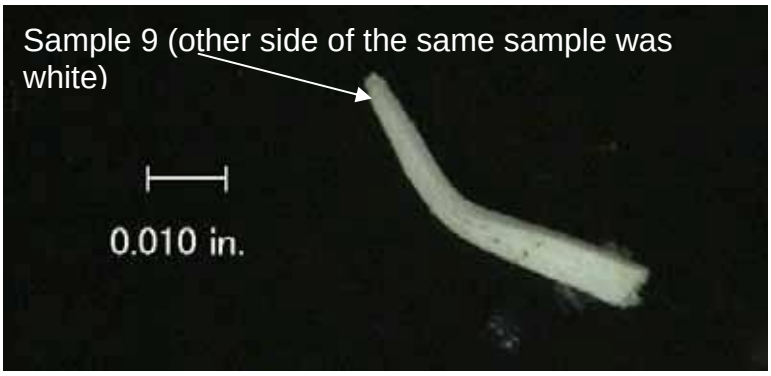


Figure 10. Photograph of the spool portion when looking into the bore and showing the head portion of the screw. Screw attaches the diaphragm to the spool. Particles referred to as sample 7 and 8 were found wedged between the head portion of the screw and the bore of the spool (top of page). EDS spectra of the two particles are shown at the bottom of the page.





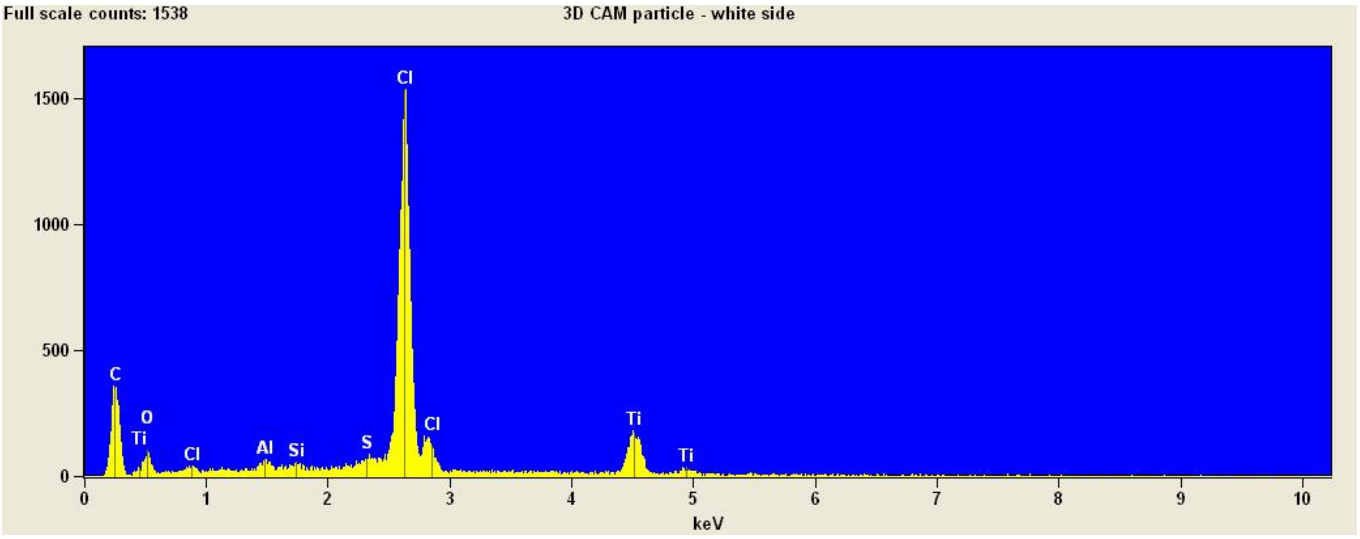
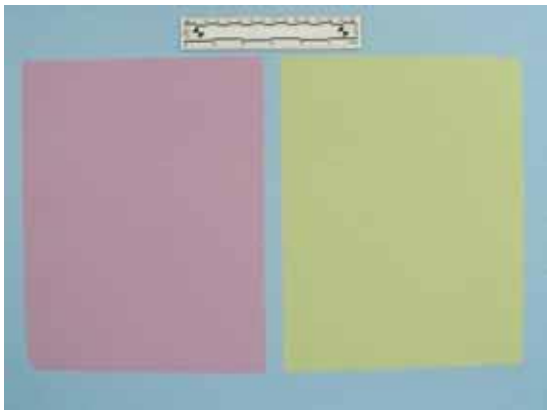
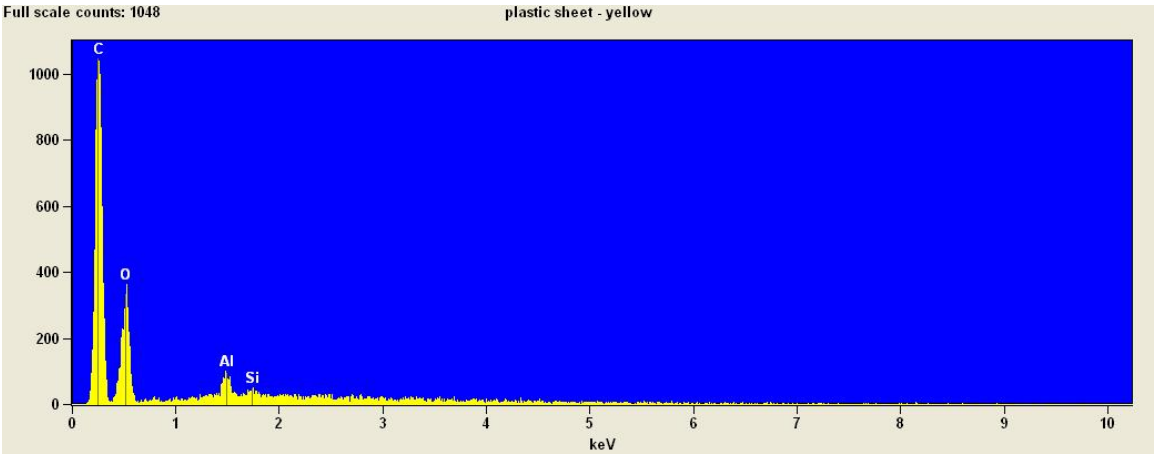


Figure 11. Flat and narrow red particle removed from bag labeled “3D CAM particle”, referred to as sample 9. One side of the sample was red (top of page) and the other side of the same particle was white (center of page). EDS spectrum of the particle is shown at the bottom of the page.





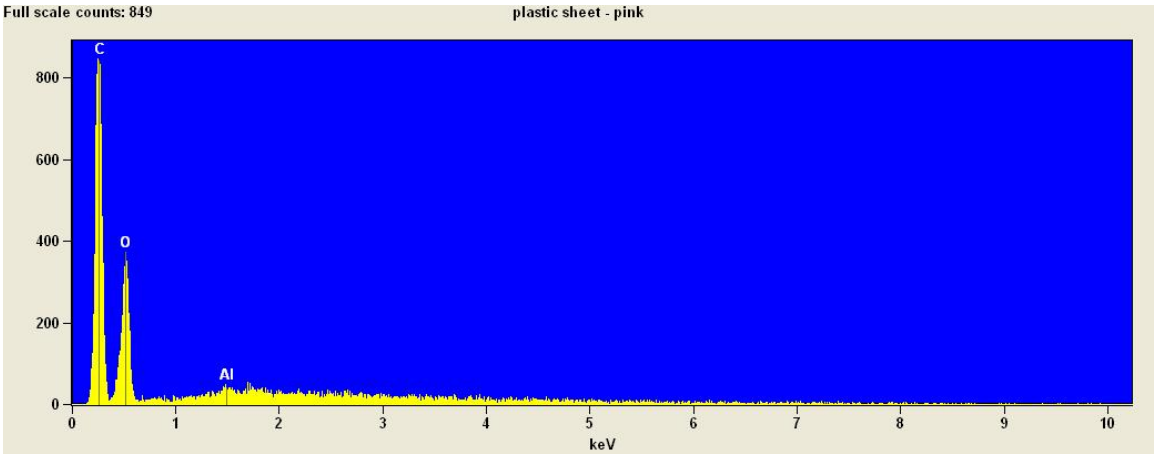


Figure 12. Photograph of exemplar pink plastic sheet, sample 16, and yellow plastic sheet, sample 17, (top of page) shown against a blue background. EDS spectrums of the two sheets are shown at the bottom of the page.

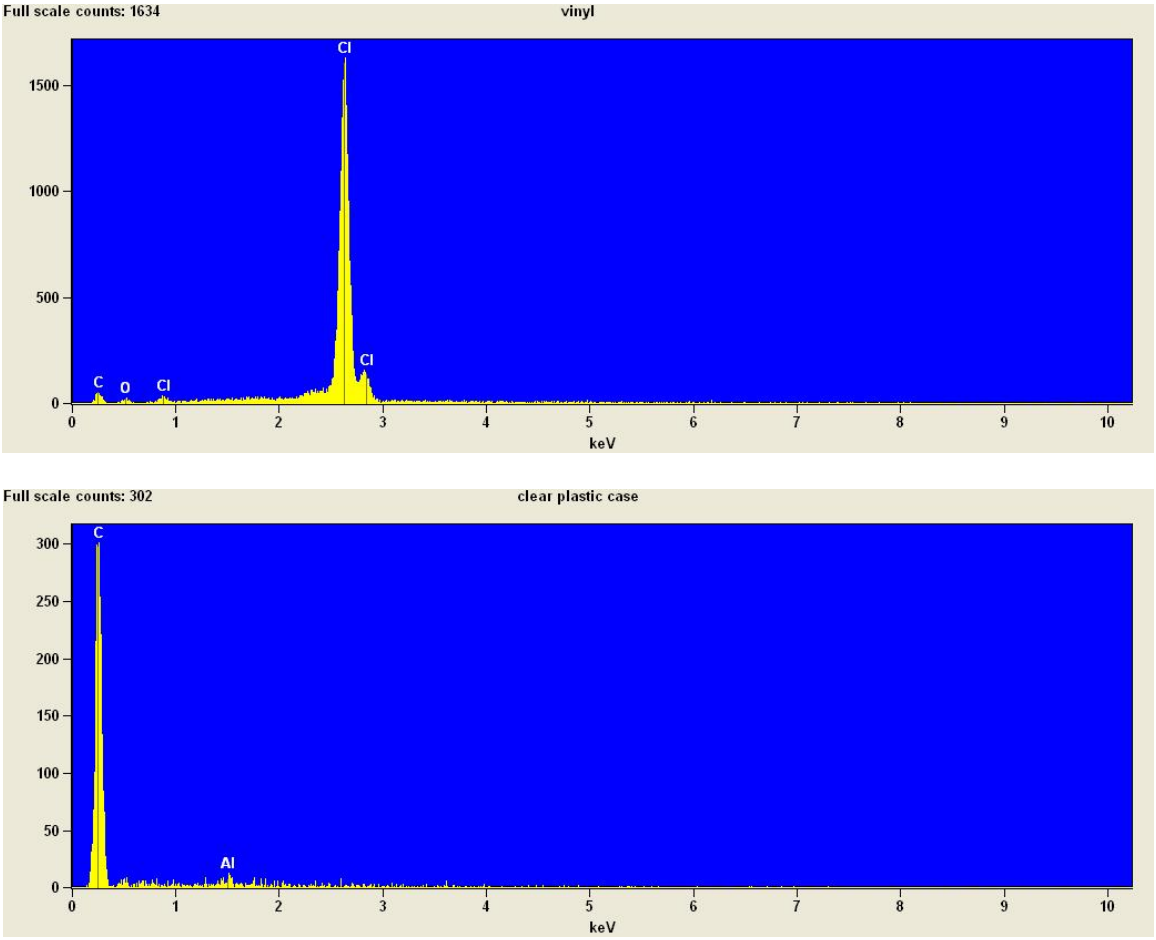
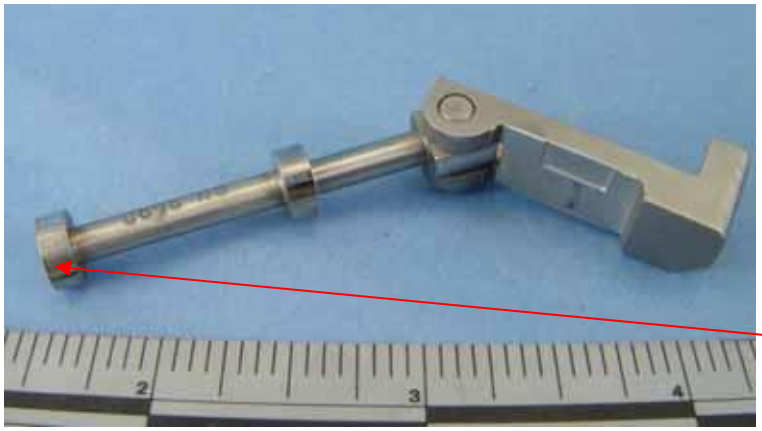
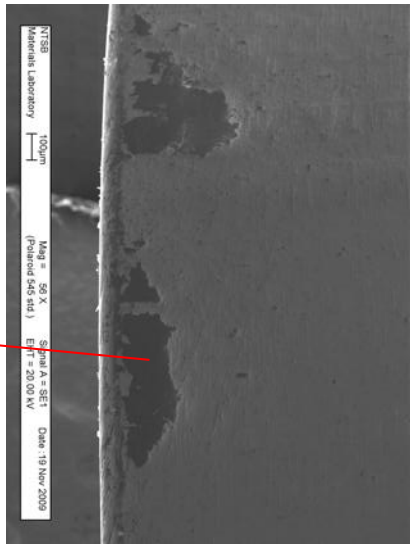


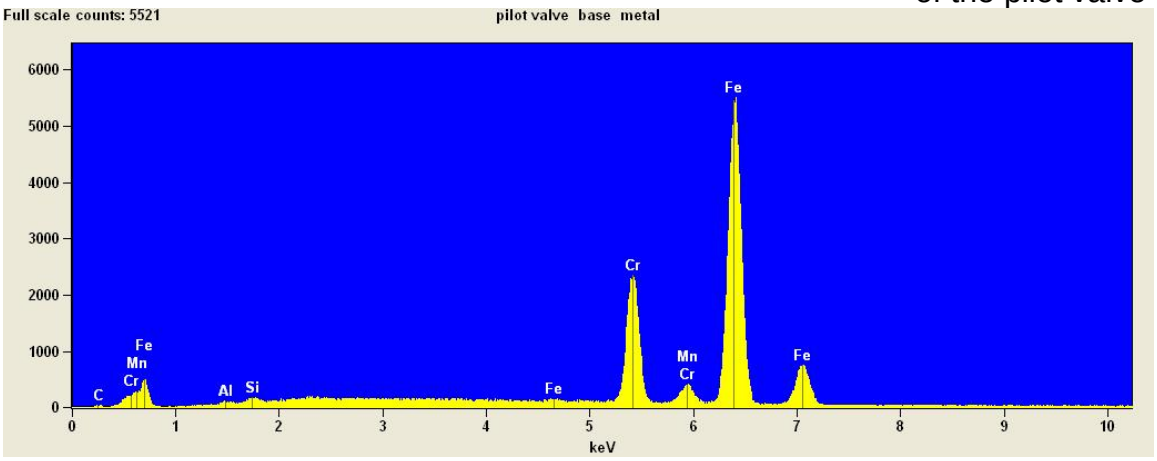
Figure 13. EDS spectrum of a reference vinyl material (top of page) and broken fragment from the clear plastic container (bottom of page).



Pilot Valve



Deposits at the rod portion of the pilot valve



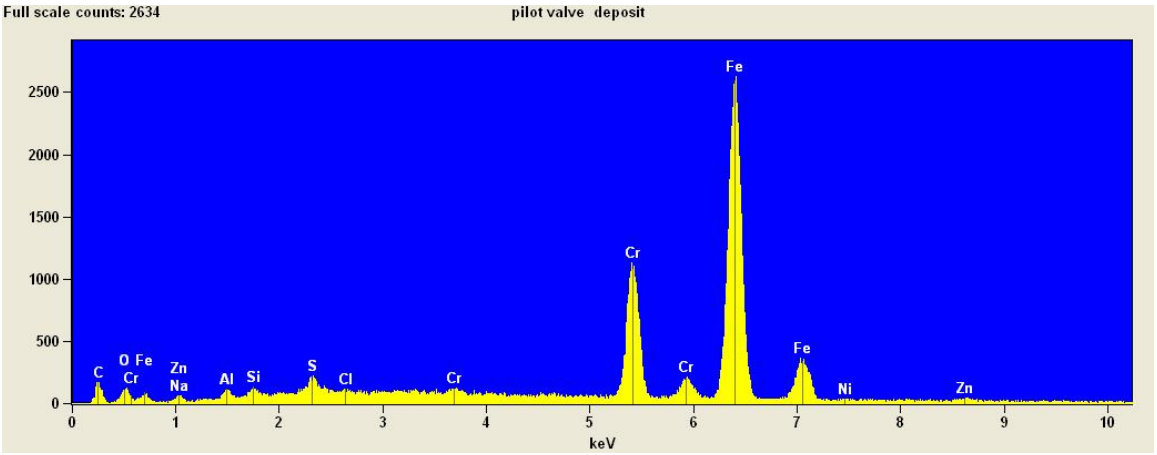


Figure 14. Photograph of the pilot valve (upper left corner); SEM photograph of a rod portion of the pilot valve showing a deposit (upper right corner); EDS spectrum of the base metal (center of page); and EDS spectrum of the deposit found on the rod portion (bottom of page).

Table 1. Description of Particles and Size							
Sample	**NTSB Sample No.**	**Description Of Particle**	**Major Elemental Peaks Found in the EDS Spectrum of the Particle**	**Consistent With Material Such as:**	**Size of Particle Measured in micrometers (converted to inches)**		
					Length, Approx	**Width, Approx**	**Thickness Max.**
One particle removed from the outer surface of the spool between rubber O-ring and the metering end of spool	1	Irregular, luster	Aluminum	Aluminum Alloy	1800 (0.07)	500 (0.02)	600 (0.023)
One particle found in balance groove “A” portion of the spool	2	Flat and narrow flexible particle, red on one side and white on the other side	Chlorine	Chlorinated Plastic such as Polyvinyl Chloride (PVC)	1300 (0.05)	80 (0.003)	80 (0.003)
Particles found in isolated area of groove “B” portion of the spool	3A	Irregular; Dust-like	Silicon, Calcium	Mineral	10 (0.0004)	10 (0.0004)	10 (0.0004)
	3B	Irregular; Dust-like	Calcium	Mineral	10 (0.0004)	10 (0.0004)	10 (0.0004)
Particles found in balance groove “C” portion of the spool	4A	Narrow, luster	Nickel	Nickel	380 (0.015)	20 (0.0008)	7 (0.0003)
	4B	Flat, irregular	Cadmium	Cadmium	132 (0.005)	20 (0.0008)	--
	4C	Flat, irregular	Iron, Chromium, Nickel	Stainless Steel	45 (0.002)	35 (0.0013)	--

One particle found in balance groove “D” portion of the spool	5	Fiber	Carbon, Oxygen	N-M Organic	1100 (0.043)	15 (0.0006)	15 (0.0006)
One particle found in reduced diameter portion of the spool in area next to groove “A”	6	Irregular, luster	Aluminum	Aluminum Alloy	1400 (0.06)	200 (0.008)	127 (0.005)
Particle found in bore of Spool, between head of screw and bore	7	Irregular, luster	Iron, Chromium	Stainless Steel	650 (0.03)	480 (0.019)	50 (0.002)
2nd particle found in bore of Spool, between head of screw and bore	8	Irregular, luster	Iron, Chromium and Copper, Silver, Tin, Zinc	Steel and/or Copper Bearing Alloy and/or Alloys with Plating	600 (0.023)	450 (0.018)	100 (0.004)
Bag labeled “3D CAM Particle” contained one red particle	9	Flat, narrow, and flexible; red on one side and white on the other side	Chlorine	Chlorinated Plastic Such as Polyvinyl-Chloride (PVC)	1000 (0.04)	180 (0.007)	80 (0.003)
Bag labeled “Inside of NG Governor flyweight Cap” contained one particle	10	Irregular, narrow, white	Calcium, Silicon, Aluminum, Carbon	N-M Organic	1800 (0.07)	130 (0.005)	--

Bag labeled "Metal Particle Fine Filter Housing" contained one particle	11	Irregular, dark	Carbon, Oxygen	N-M Organic	150 (0.006)	80 (0.003)	--
Container labeled "TV End Cap" contained several particles; Two particles were analyzed	12A	Irregular,	Carbon	N-M Organic	215 (0.008)	160 0.006)	--
	12B	Fiber, blue	Carbon, Oxygen	N-M Organic	2,300 (0.09)	20 (0.0008)	20 (0.0008)
Container labeled "Lead Lag Screw End Cap" contained several particles; two particles were analyzed	13A	Irregular	Cadmium	Cadmium	1,000 (0.04)	500 (0.02)	--
	13B	Fiber, yellow	Carbon, Oxygen	N-M Organic	1,600 (0.062)	20 (0.0008)	20 (0.0008)
Container labeled "T2 Servo end Caps" contained several particles; two particles were analyzed	14A	Irregular	Carbon, Oxygen, Sulfur	N-M Organic	150 (0.006)	20 (0.0008)	--
	14B	Fiber, blue	Carbon, Oxygen	N-M Organic	1,500 (0.06)	15 (0.0006)	20 (0.0008)

Container labeled "PRV" contained several particles; two particles were analyzed	15A	Irregular	Carbon, Oxygen	N-M Organic	88 (0.003)	60 (0.002)	--
	15B	Fiber	Carbon, Oxygen	N-M Organic	630 (0.02)	15 (0.0006)	15 (0.0006)
Exemplar plastic sheet, pink	16	Plastic sheet, Pink, Flexible	Carbon, Oxygen	Plastic	NA	NA	91 (0.0036)
Exemplar plastic sheet, yellow	17	Plastic sheet, Pink, Flexible	Carbon, Oxygen	Plastic	NA	NA	99 (0.0039)
Fragment of plastic container used for holding contaminant particles	18	Clear plastic, Rigid	Carbon, Oxygen	Plastic	NA	NA	NA
Reference Vinyl Material	19	Transparent, flexible	Chlorine	Vinyl	NA	NA	60 (0.002)

Note: -- indicates that the thickness of the particle was not measured. However, based on visual observation, the thickness for the particles was significantly less than (a small percentage of) the width.

N-M Organic indicates a non-metallic material that is organic

NA Not Applicable

Table 2. Unit Conversion for Sizes Commonly Found in this Report, Shown in Increasing Order		
Micrometer	**Inch**	**Millimeter**
1	0.000039	0.001
7	0.0003	
10	0.0004	0.01
15	0.0006	
20	0.0008	
35	0.0013	
60	0.002	
80	0.003	
100	0.004	0.1
132	0.005	
150	0.006	
180	0.007	
200	0.008	
380	0.015	
450	0.018	
480	0.019	
500	0.02	
600	0.023	
650	0.025	
1000	0.04	1
1100	0.043	
1300	0.05	
1500	0.06	
1600	0.062	
1800	0.07	
2300	0.09	

Note: 1 micrometer = 0.001 millimeter = .000001 meter