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

November 17, 2009

MATERIALS LABORATORY FACTUAL REPORT Report No. 08-121

A. ACCIDENT

Place	:	Weaverville, California
Date	:	August 5, 2008
Vehicle	:	Sikorsky S-61N, N612AZ
NTSB No.	:	LAX08PA259
Investigator	:	Mike Hauf (AS-40)

B. COMPONENTS EXAMINED

Pieces of the fuel control units (FCUs) from the Number 1 (left) and Number 2 (right) General Electric CT58-140 turbo shaft engines that included the aspirator assembly; filter assembly; spool and sleeve portion of the pressure regulating valve (PRV); cylinder adapter; thread plug; and particles collected from the PRV; and an exemplar piece of a collector can that was submitted by Carson Helicopter Services Inc.

C. DETAILS OF THE EXAMINATION

Figure 1 shows photographs of pieces from the FCUs that include the filter assembly; spool and sleeve portion of the PRV assembly; cylinder adapter; thread plug; and particles collected from the PRV. Pieces of the FCU labeled number 1 engine were disassembled from FCU part number (P/N) 725725-6, serial number (S/N) 72835BR. Pieces of the FCU labeled number 2 engine were disassembled from FCU part number (P/N) 725725-5, serial number (S/N) 49882. Figure 2 shows a diagram of a portion of the FCU assembly. Figure 3 shows a diagram of the aspirator assembly.

Design of the Fuel Filter Assembly

The filter assembly comprises a two-section screen-type 40-micron filter (a main screen and a servo screen), body, and a thread plug. The body of the fuel filter assembly was made from a metal casting. For the purpose of this report the main screen will be referred to as the removable-cartridge filter and the servo screen will be referred to as the permanent filter. Figure 4 shows a photograph of the removable-cartridge and permanent filters from the number 1 engine. The removable-cartridge filter assembly was made from perforated sheet stock that was formed into a cylinder. The sheet was manufactured with nominal 0.1-inch diameter holes and the ends of the sheet were attached to a ring portion. The bore of the removable-cartridge filter contained two layers of wire screen, referred to as the inner and outer screens. The diameter of the wire for the inner screen was smaller compared to the diameter of the wire for the outer screen. The ends of the sheet stock and wire screens were brazed to the rings. The permanent filter also contained two layers of wire screen (referred to as the inner screen and the outer screen). The diameter of the wire for the inner screen was smaller compared to the diameter of the wire for the outer screen. According to a representative from General Electric, the manufacturer of the FCU, the smaller diameter inner screen is specified as a 40-micrometer filter, 325 x 325 mesh x 0.0014-inch diameter wire, and wires are spaced apart to create an opening between 0.0019 inch and 0.0021 inch.[1] The larger diameter outer wire screen is a 50 x 50 mesh x 0.0095-inch diameter wire and is used as a structural support for the smaller diameter inner screen. The ends of the wire screens for the permanent filter also were brazed to the body of the fuel filter assembly.

Design of the Spool and Sleeve Portion of the Pressure Regulating Valve (PRV)

The two main purposes of the PRV are to maintain a constant pressure drop or differential across the main metering valve and to bypass the unused or excess fuel flow from the fuel pump not required by the engine combustor and the control servo. The PRV contains a spool and sleeve portion. The spool was manufactured with four circumferential balance grooves and a smaller diameter groove at the diaphragm end of the spool. When the PRV is in the assembled condition, the spool portion slides within the bore of the sleeve.

Design of the Aspirator Assembly

Schematics of the aspirator assembly are shown in figures 2 and 3. The position adjusting screw portion is manufactured from tube stock. The position adjusting screw at one end contained an external thread and the other end contained a circumferential internal square groove. The external thread portion is to be attached to the mating internal threads on the temperature sensor housing. The position adjusting screw and housing were manufactured with several drilled holes to accommodate a retaining wire. A position adjusting screw is attached to the temperature housing and the ends of the retaining wire are inserted into the alignment holes of the adjusting screw and housing. The retaining wire locks the position of the position adjusting screw relative to the housing. The temperature sensor bellows assembly is inserted into the end of the position adjusting screw that contains the circumferential internal square groove. A spring is inserted into the temperature sensor bellows assembly, and a retainer is inserted into the bore of the position adjusting screw until the retainer is positioned slightly deeper than the circumferential internal square groove. An internal retaining ring is inserted into the circumferential internal square groove. In the installed condition, the spring applies pressure to the retainer. The internal retaining ring prevents the retainer from sliding out of the position adjusting screw.

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[1] The conversions are as follows: 325 mesh=0.0017 inch=44 microns. Also, 50 mesh=0.0117 inch=297 microns.

Number 1 Engine FCU Filter Initial Inspection with Light and Magnifying Glass

Figure 4 shows a photograph of the removable-cartridge and permanent filters from the number 1 engine. Fiber optic light was inserted inside each screen filter. When viewed from the outside, light was visible and passed through each screen filter.

The GE Aircraft Engines Maintenance Manual for the CT58 Turbo Shaft Engine 73-20-1, dated “Jul 31/03”, section “C. Inspection/Check” provides guidance on when to reduce the filter inspection/cleaning time interval. According to the manual, the optimum filter inspection/cleaning time interval can be established by consistently finding 50 percent or less of the available filter area plugged[2] when inspected. In other words, the interval for inspection/cleaning can remain the same/unchanged provided that plugging of the screen filter is 50% or less of the available open area. Each filter is inspected separately by placing a small light inside the filter element and then visually inspecting the element with a 10X power glass. The following guidelines are to be used in establishing optimum filter inspection/cleaning intervals:

(a) Consistent plugging of 40-60 percent of available open area. No change in procedure required.
(b) Consistent plugging of 61-70 percent of available open area. Recommend 20% reduction in inspection/cleaning interval. (e.g., current cleaning interval = 100 hours, reduce to 80 hours or less.)
(c) Consistent plugging of more than 71 percent of available area. Reduce inspection/cleaning interval by 40%
(d) Consistent plugging of less than 40% percent of the available open area. The operator may program an increase in the inspection/cleaning interval. Do not exceed 20% of the inspection/cleaning interval on any increase.

Fiber optic light was inserted inside a screen filter. When viewed from outside the screen with a 12.5X glass, the available open areas were estimated by the amount of light that passed the inner 40 micrometer screen. The estimate takes into account the available open areas all around the circumference of the filter. The permanent and removable filters were inspected separately (disassembled from each other). The table below indicates the estimated plugging of available open area on the inner screen portion of each filter (areas that did not permit passage of light).

	Item	Estimated Plugging of Available Open Area[3]
#1 Engine	Permanent Screen Filter	10%
	Removable Screen Filter	25%

[2] Plugging in this report is defined as follows: interstices in the filter occluded by assemblages of particles (e.g. cake) such that light transmitted from a high-intensity flexible light guide will not pass through.
[3] Estimated plugging is expressed in percent, where 100% indicates the available open area on the inner screen portion of a filter is completely blocked with foreign material and 0% indicates the inner screen portion of a filter has no foreign material blockage.

According to the guidelines in the maintenance manual, the screen filters for the number 1 engine do not require a change in inspection/cleaning time interval.

During the fiber optic light examination, a sample of particles was removed with carbon double-sided adhesive tape from an isolated area on the inner face of each screen filter for analysis. There was no visible change in the amount of light that passed through each screen after samples were removed for analysis. A description of how the sample particles were removed and the analysis of those particles are discussed in the next section titled “Number 1 Engine FCU Filter Inspection with Binocular Microscope and SEM”.

Number 1 Engine FCU Filter Inspection with Binocular Microscope and SEM

Bench binocular microscope examination of the exterior portion of the removable-cartridge filter revealed that the straight rod-like and curled fibers extended through the open cavities of the inner and outer wire screen, see figures 5 and 6. The inner wire screen also contained irregular block-like particles that were trapped within the cavities of the screen.

The removable-cartridge filter assembly was inserted into the chamber of a scanning electron microscope (SEM). The SEM examination confirmed that irregular block-like particles were embedded within the cavities of the inner screen and that straight and curled fibers extended through the inner and outer screens. The size of the opening for the inner and outer wire screen was measured. For the outer screen, the open distance between parallel wires typically measured approximately 250 micrometers (0.01 inch). For the inner screen, the open distance between parallel wires typically measured approximately 50 micrometers (0.002 inch). The dimensions of both screens are consistent with the nominal size indicated by the FCU manufacturer. Energy dispersive spectroscopy (EDS) analysis of the wall portion of the cartridge filter produced a spectrum that contained a major elemental peak of iron and minor elemental peaks of chromium and nickel, typical for stainless steel. EDS spectrum of the wire screens showed the same elemental peaks. EDS spectrum of the braze material between the ring portions and the wire screen contained elemental peaks of silver and cadmium. Appendix 1 shows the EDS spectra of the screen filter base metal and the braze metal.

A piece of 0.3-inch wide carbon double-sided adhesive tape was inserted into the bore of the removable-cartridge filter assembly and pressed against the inner screen. The tape was then peeled from the filter. Tape was peeled in a single event (no repeated application) and from one isolated area of the inner screen. Particles from the inner screen were found adhering to the tape. The same procedure was following for each screen filter. A significant amount of particles remained on the inner screen of each filter in the corresponding area where particles were removed for analysis, as observed by fiber optic light examination. The amount of light that passed through the isolated area where the sample particles were removed appeared similar to the amount of light that passed through the same area before the particles were removed for analysis. SEM photograph of typical particles that were peeled from the inner filter is shown in figure 7. The adhesive surface of the tape retained irregular block-like particles, straight and curled fibers that were consistent with the size and shape of the particles that were visible within the 0.1-inch holes of the removable-cartridge filter. The length and width of the irregular block-like particles measured as large as 120 micrometers (0.005 inch), when measured either lengthwise or widthwise. The size of a few irregular block-like particles was smaller than 20 micrometers (0.0008 inch), when measured either along the length, width, and thickness. When looking at various straight rod-like fibers, the following typical diameter sizes were encountered and were measured approximately: 5 micrometer, 10 micrometer, 20 micrometer and 40 micrometer. The length of the straight fibers measured as long as 400 micrometer (0.016 inch), whereas, the length of the curled fibers measured as long as 600 micrometers (0.024 inch). Appendix 1 shows the EDS spectra of eight particles labeled particles “1” through “8” in figure 7 that were randomly selected for analysis. The EDS spectrum of “straight rod-like (particle 1)” in Appendix 1 was consistent with a silicate glass fiber such as E-glass.

Figure 8 shows a photograph of a portion of the permanent filter when viewed from the exterior face. This permanent filter contained an inner and outer wire screen. The diameter of the wire and distance between the wires for the inner screen was smaller compared to those for the outer screen. For the outer screen, the open distance between parallel wires measured approximately 125 micrometers (0.005 inch). For the inner screen, the open distance between parallel wires measured approximately 45 micrometers (0.002 inch), within the range specified by the manufacturer. Carbon adhesive tape was placed in the bore of the permanent filter. The tape was peeled from the inner screen and particles were found adhering to the tape. SEM examination of the surface of the carbon adhesive tape revealed straight and curled fibers, and irregular block-like particles that were similar to those found in the inner screen of the removable-cartridge filter. The quantity of fibers and irregular block-like particles found on the inner screen was much less than that found on the inner screen of the removable-cartridge filter. The EDS spectra of various fibers and particles that were embedded within the openings of the inner screen from the permanent filter were similar to those from the inner screen of the removable-cartridge filter.

Number 1 Engine FCU Pressure Regulating Valve (PRV) Inspection

According to the Airworthiness Group Chairman's factual report, the PRV from the left engine’s FCU (number 1 engine) was examined at Hamilton Sundstrand at which time its spool and sleeve assembly were separated from each other using an arbor press (very little force was required). No evidence of contamination was observed in the spool’s balance grooves and, other than soot, the sleeve appeared clean. Linear scratches were observed on the spool and according to Hamilton Sundstrand these scratches looked like a normal wear pattern. Witness marks of coked fuel were seen on the outer diameter of the spool that matched the opening of the metering windows in the sleeve. The Airworthiness Group submitted the PRV assembly (spool and sleeve) to the National Transportation Safety Board Materials Laboratory for metallurgical examination.

Figure 9 shows a photograph of the as-received spool portion of PRV from the number 1 engine. The spool portion contained four circumferential balance grooves. Figure 10 shows a higher magnification of two of the four circumferential balance grooves.

Visual examination of the spool's balance grooves with the unaided eye revealed no evidence of particle contamination. Bench binocular microscope and SEM examination of the spool portion from the PRV from the number 1 engine revealed each of the four circumferential balance grooves contained between two and three fragments of straight rod-like fibers. Figure 11 shows a photograph of two straight rod-like particles that were found in one of the four circumferential balance groove portions of the spool. The typical length of a straight rod-like fiber measured approximately 60 micrometers (0.0024 inch) and the typical diameter measured approximately 10 micrometers (0.0004 inch). EDS analysis of a straight fiber produced a spectrum that contained major elemental peaks of silicon, aluminum and calcium with minor elemental peaks of magnesium, carbon, and oxygen, consistent with a silicate glass fiber such as E-glass, and similar to the EDS spectrum of the fiber labeled “straight rod-like fiber (particle 1)” in Appendix 1 of the particle removed with tape from the removable cartridge filter of fuel control in the number 1 engine.

The surface of the spool in areas outside of the circumferential balance grooves (larger diameter portion) contained minor scoring marks that were oriented parallel to the length of the spool. The width of the score marks measured between 6 and 12 micrometers. The depth of several score marks when viewed at the corner edges of the larger diameter portion measured between 4 and 6 micrometers. EDS analysis of the surface of the spool produced a spectrum that contained a major elemental peak of iron and minor elemental peaks of chromium and nickel, consistent with 440C martensitic stainless steel material specified in HS engineering drawings for the spool and sleeve. The EDS spectrum of the score marks on the surface of the spool was similar to those on the surface of the spool, consistent with 440C steel. No evidence of materials that were foreign to the base metal was found in the score marks.

A saw cut was made through the length of the sleeve to expose the inner surface. The inner surface also contained minor scoring marks that were oriented parallel to the length of the spool. The scoring marks appeared less severe compared to those on the surface of the spool. The width of the score marks measured less than 1 micrometer. The depth of the scoring mark appeared similar to the width of a score mark. EDS analysis of the inner surface of the sleeve contained a major elemental peak of chromium, and minor elemental peaks of iron and manganese, consistent with the inner surface having been coated with chromium. EDS spectrum of the score marks that were located on the inner surface of the sleeve was similar to areas located outside of the score marks. No evidence of materials that were foreign to the base metal was found in the score marks.

During the process of removing the spool from its sleeve assembly using an arbor press at Hamilton Sundstrand, particles fell off of the PRV assembly. These particles were collected and placed on a cylindrical aluminum "stub". (Reference Airworthiness Group Chairman's Factual Report). The as-received stub with the collected particles is shown in figure 1. SEM examination of the stub revealed particles of similar shape and size to those extracted from the inner screen of the removable-cartridge filter. The EDS spectrum of the particles on the stub were similar to the EDS spectrum of the particles from the inner screen of the cartridge filter, with the exception that EDS spectrum from a fragment in figure 12 showed a major elemental peak of fluorine and carbon. The EDS spectrum of the fluorine-carbon particle is labeled particle 9 in Appendix 1. The fragment in figure 12 appears to be fractured into two major pieces. The total length and total width of the two fluorine-carbon fragments measured as large as 450 micrometers (0.018 inches) in either orientation of measure.

Number 1 Engine Cylinder Adapter and Thread Plug

The cylinder adapter and thread plug from the number 1 engine, both shown in figure 1, contained no evidence of a crack.

Number 1 Engine Upper Half Assembly of the FCU

The number 1 engine upper half assembly of the FCU was submitted for examination (photograph is shown on the upper right corner in figure 1 and in figure 13). The aspirator assembly and position adjusting screw was attached to this assembly. The inner wall of this assembly in the general area indicated by arrow "W" in figure 13 was covered with dry black soot deposit. A sample of soot deposit was removed with carbon double sided adhesive tape. EDS analysis of the sample produced a spectrum that contained major elemental peaks of silicon, carbon, and oxygen.

Examination of the aspirator assembly revealed that the temperature sensor bellows assembly, spring, spring retainer cap (an aluminum alloy), internal retainer ring, and external end cap (dust cover) were not submitted to the Safety Board Materials Laboratory. The wall of the position adjusting screw for the temperature sensor bellows assembly was specified as aluminum alloy 7075 and was to be heat-treated to the T6 condition. The position adjusting screw was attached to the housing portion of the aspirator assembly. Bench binocular microscope examination of the open end of the position adjusting screw revealed a fracture on the inner face that extended all around the position adjusting screw in the area between the inside corner of the inner circumferential square groove and the open end of the tube (see figure 13). SEM examination of the position adjusting screw revealed the circumferential fracture contained intergranular globular features and showed no evidence of fatigue cracking (see figure 13). Examination of the prepared and etched section revealed a microstructure that contained solid solution melting at the grain boundaries consistent with an overheated aluminum alloy (see figure 14).

Number 2 Engine FCU Filter Initial Inspection with Light and Magnifying Glass

Figure 15 shows a photograph of the permanent and removable filters from the number 2 engine. When viewed from outside the screen filters (after the screen filters were disassembled from each other) with a 12.5X glass, the available open areas were estimated by the amount of light that passed the inner 40 micrometer screen. The table below indicates the estimated plugging of available open area on the inner screen portion of each screen filter (areas that did not permit passage of light).

	Item	Estimated Plugging of Available Open Area
#2 Engine	Permanent Screen Filter	20%
	Removable Screen Filter	50%

According to the guidelines in the maintenance manual, the permanent and removable screen filters from the number 2 engine do not require a change in inspection/cleaning time interval.

During the fiber optic light examination, a sample of particles was removed with carbon double-sided adhesive tape from an isolated area on the inner face of each screen filter for analysis. There was no visible change in the amount of light that passed through each screen after samples were removed for analysis. The method of particle removal used was the same as that described in the section titled “Number 1 Engine FCU Filter Inspection with Binocular Microscope and SEM”.

Number 2 Engine FCU Filter Assembly Inspection

A piece of 0.3-inch wide carbon double-sided adhesive tape was inserted into the bore of the removable-cartridge filter assembly in the number 2 engine and pressed against the inner screen. The tape was then peeled from the inner screen. Particles from the inner screen were found adhering to the carbon tape (photograph not shown). Particles also were removed with carbon adhesive tape from the inner wire screen portion of the permanent filter of fuel control in the number 2 engine. Figure 16 shows an SEM photograph of typical particles that were extricated with carbon adhesive tape from the inner screen of the permanent filter. SEM examination of the carbon tapes revealed the inner screens for the removable cartridge and permanent filters contained irregular block-like particles, straight and curled fibers, that appeared similar to and more numerous than those found in the inner screen of the removable-cartridge filter and permanent filter from the number 1 engine.

Number 2 Engine FCU Pressure Regulating Valve (PRV) Inspection

According to the Airworthiness Group Chairman's factual report, the PRV from the right engine’s FCU (number 2 engine) was examined at Hamilton Sundstrand. Prior to separating the spool from the sleeve, the remaining dry, hardened seals were cleaned out of their grooves and disposed. An arbor press was used to separate the spool from the sleeve with very little force required. Small pieces of black material, which fell off of the PRV assembly during separation, were collected. The material was submitted on a cylindrical aluminum "stub" (reference figure 1) to the National Transportation Safety Board Materials Laboratory for metallurgical examination. No erosion was observed on the metering end of the spools outer surface. The Airworthiness Group also submitted the PRV assembly (spool and sleeve) to the National Transportation Safety Board Materials Laboratory for metallurgical examination.

Figure 17 shows a photograph of the as-received spool portion of the PRV from the number 2 engine. Figure 18 shows a photograph of two of the four circumferential balance grooves from the spool portion. Visual examination of the spool's balance grooves with the naked eye revealed no evidence of particle contamination. SEM examination of the spool portion from the PRV of the number 2 engine revealed one area in one circumferential balance groove contained fragments of curled fibers. Figure 19 shows a photograph of the curled fiber particles. The typical thickness of the fibers measured 20 micrometers (0.0008 inch) maximum. EDS analysis of a curled fiber produced a spectrum that contained major elemental peaks of carbon and oxygen; similar to the EDS spectrum labeled “particle 8” in Appendix 1. No evidence of straight rod-like particles was found in the groove portions of the spool. Figures 19 and 20 show photographs of a portion of the longitudinal scoring marks that were found on the surface of the spool between the circumferential balance grooves. The score marks appeared more severe (e.g., wider and deeper) compared to those on the surface of the spool from PRV in the number 1 engine. The width of the more severe score marks measured between 8 and 20 micrometers. The depth of several score marks when viewed at the edge of a land measured between 4 and 11 micrometers.

A saw cut was made through the length of the sleeve from the number 2 engine to expose the inner surface. The inner surface contained minor score marks that were oriented parallel to the length of the spool. The width and depth of the scoring marks appeared to be smaller compared to those on the surface of the spool but larger compared to those on the surface of the sleeve for the number 1 engine.

EDS analysis of the outer and inner surfaces of the spool and sleeve each produced a spectrum with elements that are consistent with the 440C martensitic stainless steel material specified in the HS engineering drawings for the spool and sleeve. EDS analysis of the score marks on the inner surfaces of the spool and sleeve also showed elemental peaks consistent with 440C steel.

Figure 1 shows a photograph of the as-received cylindrical aluminum "stub". SEM examination of the stub revealed particles that appeared similar to and more numerous than those found in the stub from the number 1 engine, see figure 21. Additionally, the stub from the number 2 engine contained hair-like fibers that were attached to a flat-backing material, as shown in figure 22, that were not found in the stub from the number 1 engine. The hair-like fibers that extended from a flat-backing material were not present in the wire screens and stub of the number 1 engine. EDS analysis of the hair-like fibers, labeled particle 10 hair-like fibers in Appendix 1, produced a spectrum that contained a major elemental peak of silicon and minor elemental peaks of carbon, oxygen, sulfur, calcium, and zinc. EDS spectrum of the flat-backing material, labeled particle 10 flat-backing material portion in Appendix 1, showed a major peak of carbon and a minor peak of oxygen.

Number 2 Engine Cylinder Adapter and Thread Plug

The cylinder adapter and thread plug from the number 2 engine contained no evidence of a crack.

Dimension of the Spool and Sleeves for the PRV of Number 1 and 2 Engines

The outside diameter of the spool and inside diameter of the sleeve was measured with a micrometer before the saw cutting operation. The measured and specified values for the diameter of the spool and sleeve are shown in Table 1. The outside diameter of the spool at the land portion (between the balance grooves) for the number 1 engine measured approximately 0.3771 inch, within the range specified in Hamilton Sunstrand (HS) spool engineering drawing 543461. The outside diameter of the spool between the balance grooves for the number 2 engine measured between approximately 0.3770 and 0.3771 inch, within the specified range. The inside diameter of the sleeve measured between 0.3776 and 0.3778 inch, within the range specified in HS sleeve engineering drawing 734913. The clearance between the spool and sleeve was calculated to be between 0.0004 inch (10 micrometer) and 0.0008 inch (20 micrometer). The spool and sleeve portions showed no evidence of a crack.

Table 1. Dimensions

	Spool Outside Diameter (inch)		Sleeve Inside Diameter (inch)	
	Specified	Measured	Specified	Measured
Engine 1	0.3770-0.3772	0.3771	0.3776-0.3778	0.3776-0.3778
Engine 2	0.3770-0.3772	0.3770-0.3771	0.3776-0.3778	0.3776-0.3778

Number 2 Engine Inlet Temperature (T2) Sensing System

Examination of the aspirator assembly revealed that the temperature sensor bellows assembly, spring, spring retainer cap (an aluminum alloy), internal retainer ring, and external end cap (dust cover) were not submitted. As indicated earlier, the wall of the position adjusting screw for the temperature sensor bellows assembly was specified as aluminum alloy 7075 and was to be heat-treated to the T6 condition. The position adjusting screw was attached to the housing portion of the aspirator assembly. The exterior face of the round non-thread end portion of the position adjusting screw exhibited a dent in the area indicated by an unmarked arrow in figure 23. The dent was visible from the inner surface of the position adjusting screw. When looking into the open end of the position adjusting screw, the wall showed evidence of deformation (i.e., was not round). The inner and outer face of the position adjusting screw was covered with soot. Bench binocular microscope examination of the open end of the position adjusting screw revealed a fracture on the inner face that extended all around the position adjusting screw in the area between the inside corner of the inner circumferential square groove and the open end of the tube (see figure 24). The position adjusting screw was disassembled from the housing and ultrasonic cleaned with a commercial detergent. SEM examination of the position adjusting screw revealed micro-cracks on the inner and outer surfaces of the wall. The circumferential fracture contained intergranular globular features, showed no evidence of fatigue cracking (see figure 24), and appeared similar to the intergranular globular fracture features found in the fractured position adjusting screw for the number 1 FCU. A radial-longitudinal metallurgical cross-section was made through the wall of the position adjusting screw for the number 2 FCU. Examination of the prepared and etched section revealed a microstructure that contained solid solution melting at the grain boundaries consistent with an overheated aluminum alloy (see figure 25).

Examination of the housing for the temperature sensor bellows assembly revealed the port near the position adjusting screw was covered with a layer of dry black soot. The surface of the dry black soot contained many pieces of white transparent-like glass fibers. Samples of the dry black soot and fibers were removed with carbon adhesive tape. EDS analysis of the black soot layer produced a spectrum that contained a major peak of silicon and minor peaks of carbon and oxygen. The EDS spectrum of a white transparent-like glass fiber produced a spectrum that contained elemental peaks similar to the EDS labeled “straight fiber (particle 1)” in Appendix 1. Dry black soot deposit and glass fibers were not found inside the “T2 Air Out” and “T2 Air In” ports of the temperature sensor housing. In comparison, the ports for “T1 Air Out” and “T1 Air In”, and the port for the position adjusting screw in the housing for the temperature sensor bellows assembly in number 1 FCU contained no evidence of dry black soot and no evidence of white transparent-like glass fibers.

According to representative from General Electric Aviation, Lynn Controls Engineering, a dust cover is to be installed over the position adjusting screw. As indicated earlier, a dust cover was not submitted with the parts from the fuel control. For comparison purpose, an exemplar dust cover was submitted (photograph not shown). The wall of the exemplar dust cover contained visible cross weave glass fibers. Fragments that resembled the size of the dust cover were found on the outer face of the housing for the temperature sensor bellows assembly in an area near the gasket side. Bench binocular microscope examination of the fragments revealed fibers with a cross-weave pattern consistent with exemplar dust cover. The fracture faces of the fragments showed no evidence of crack arrest marks.

Exemplar Piece of a Collector Can

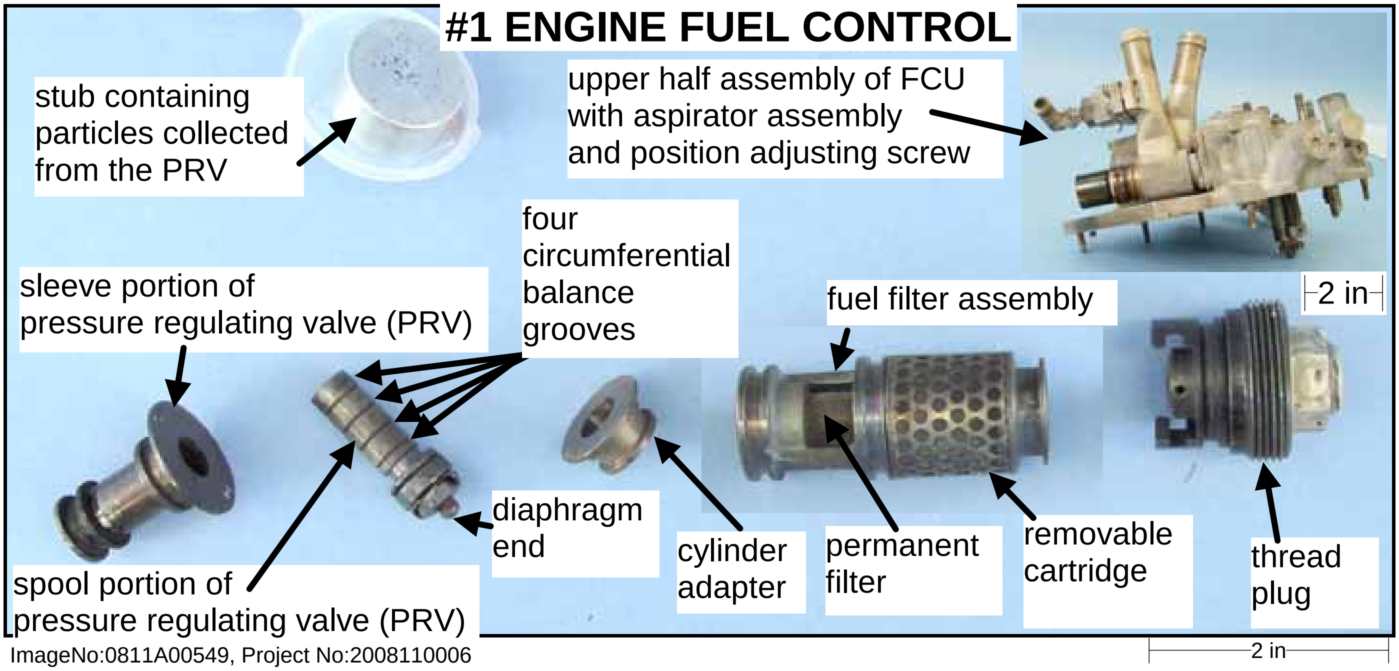
Pressurized fuel is supplied from each fuel tank via two electrically operated fuel booster pumps through a mixing chamber, fuel manifold, airframe fuel filter, and then to the engine fuel supply system. The forward and the aft fuel tanks each contain a fiberglass collector can, which houses the two fuel booster pumps. (reference Airworthiness Group Chairman's Factual Report)

Carson Helicopter Services Incorporated submitted a sample of the wall portion from a collector can. The piece measured approximately 4 inch by 4 inch; appeared light green, translucent-like, and contained cross weave fibers, consistent with fiberglass. At the Safety Board Materials Laboratory, a small piece at the corner of the sample was bent with pliers until the corner piece separated from the larger pieces. Figure 26 shows a photograph of the submitted piece after a corner piece was removed for examination. SEM examination of the fractured corner piece revealed the wall contained a cross weave pattern of straight rod fibers, oriented 90 degrees to each other in a polymer matrix. For comparison purpose, Table 1 provides a description summary of particles that were found in the spool circumferential balance groove portions of the PRV for the number 1 and 2 engines and fiber sample found in the exemplar collector can. The diameter of the straight rod fibers from the collector tank measured between 8 and 10 micrometers, similar to the diameter of the fibers found in all four circumferential balance groove portions of the spool from PRV in the number 1 engine. EDS analysis of a straight rod fiber from the collector can produced a spectrum the contained major elemental peaks of silicon, aluminum and calcium with minor element of magnesium, oxygen, carbon, consistent with silicate glass fiber such as E-glass.

Frank P. Zakar
Senior Metallurgist

Table 1. Description of Particles						
Engine	Part Description	Type of Particles Found	Where Found	Approx. Diameter/ Thickness (μm)	Approx. Length (μm)	EDS Elemental Peaks
1	Spool Portion of PRV	Straight Rod-like	Between 2 and 3 particles found in each balance groove portion of the spool	10	Several broken particles, each 60 μm	Major Elemental Peaks: Si, Al, Ca Minor Elemental Peaks: Fe, Mg, C, O
2	Spool Portion of PRV	Curled	Particles found in one area of one balance groove portion of the spool	20	length varied	Major Elemental Peaks: C, O
-	Exemplar fiberglass wall portion from collector can submitted by Carson Helicopter Services Inc.	Straight rod-like fibers found in wall portion of collector can	Fracture surface produced in the laboratory	Between 8 and 10	continuous	Major Elemental Peaks: Si, Al, Ca Minor Elemental Peaks: Mg, C, O

Note: μm is an abbreviation for micro-meters
EDS is an abbreviation for energy dispersive spectroscopy



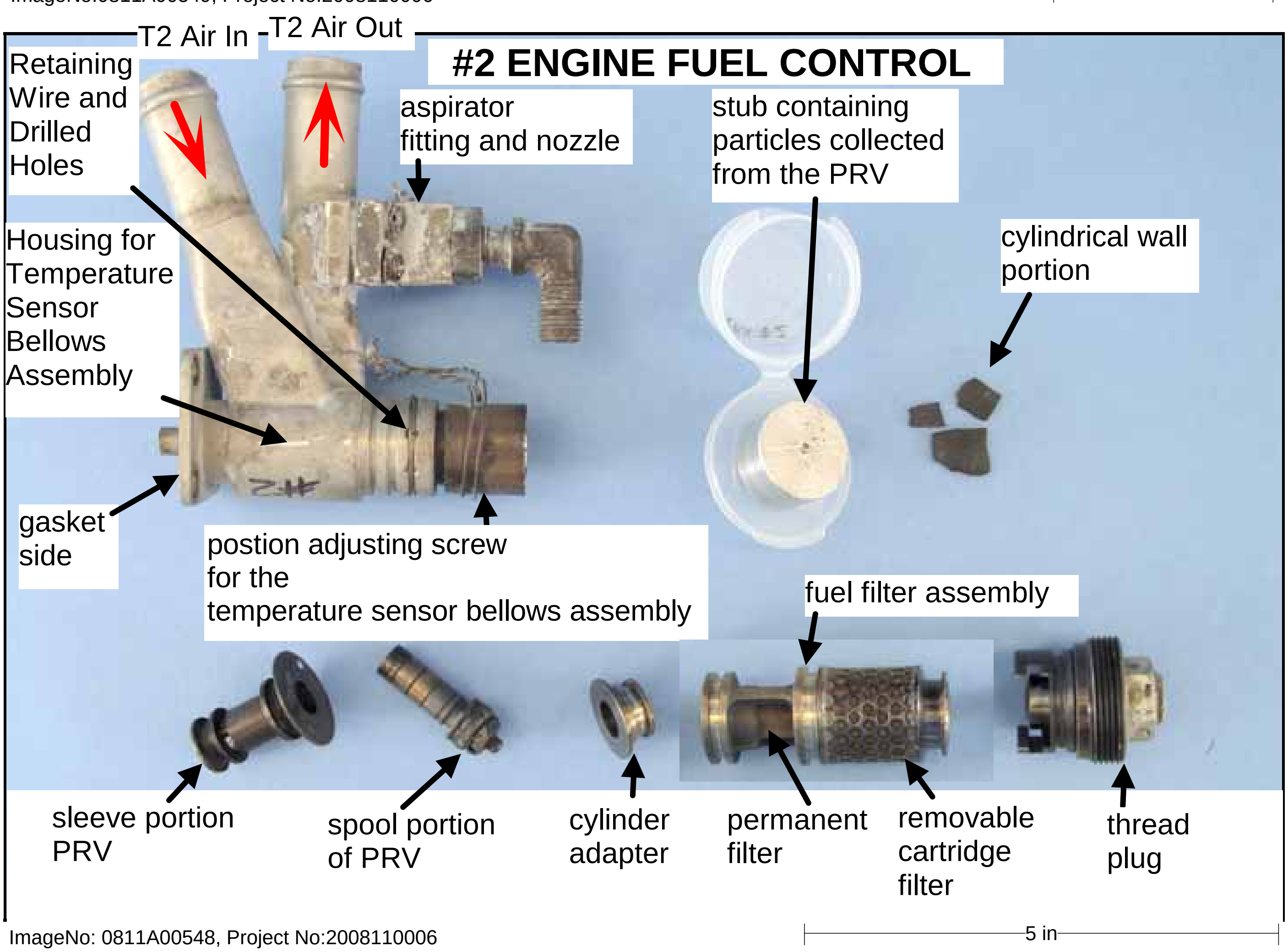


Figure 1. As-received pieces from fuel control of the number 1 engine (upper photograph) and the number 2 engine (lower photograph).

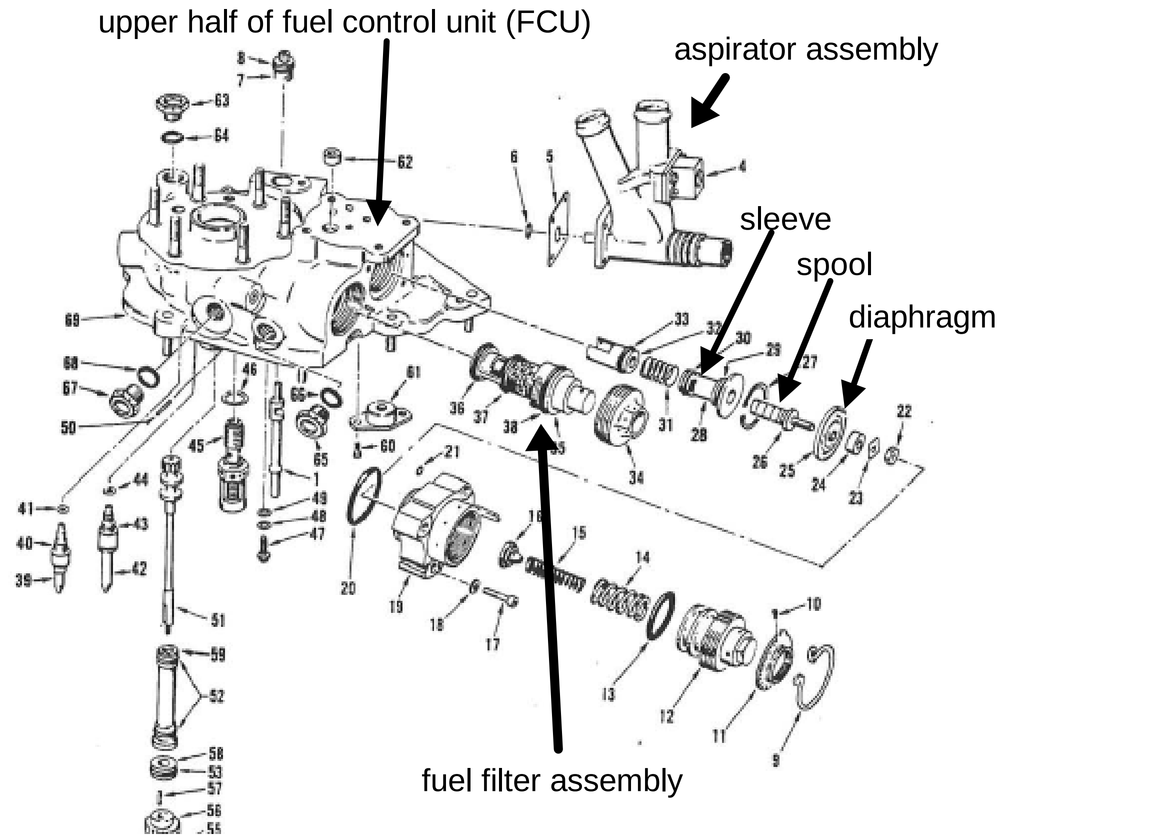


Figure 2. Diagram of a portion of the fuel control unit showing the aspirator assembly and fuel filter assembly.

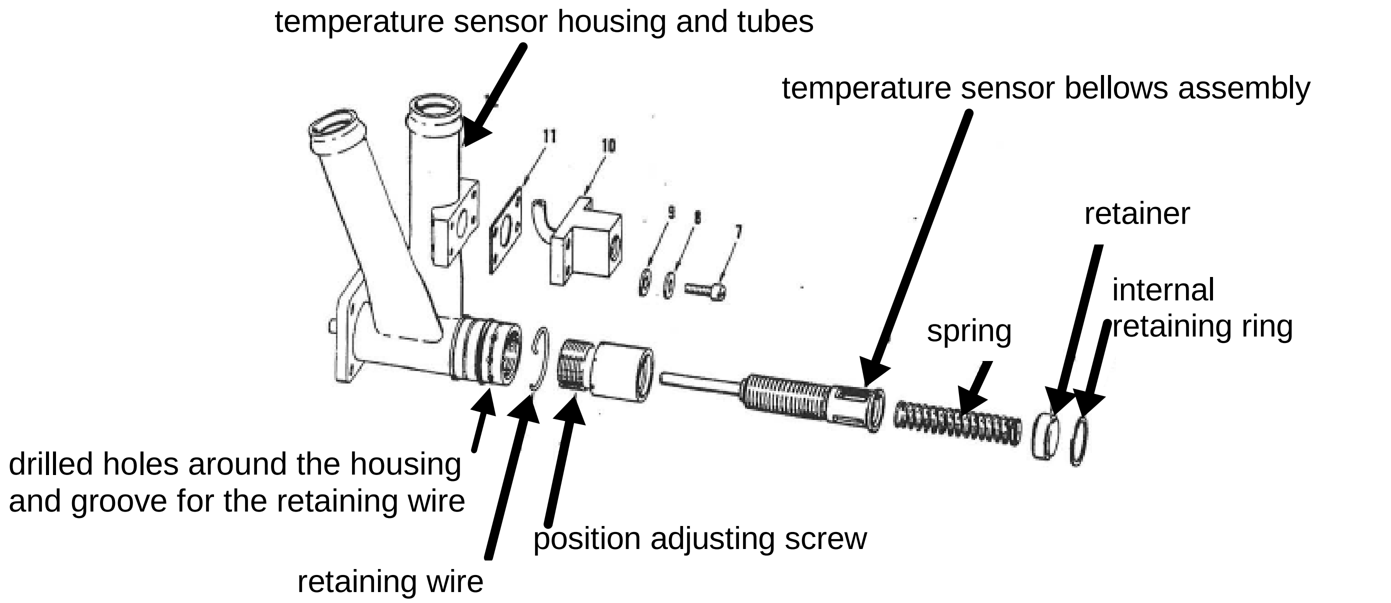


Figure 3. Diagram of the aspirator assembly showing greater detail than shown in figure 1.

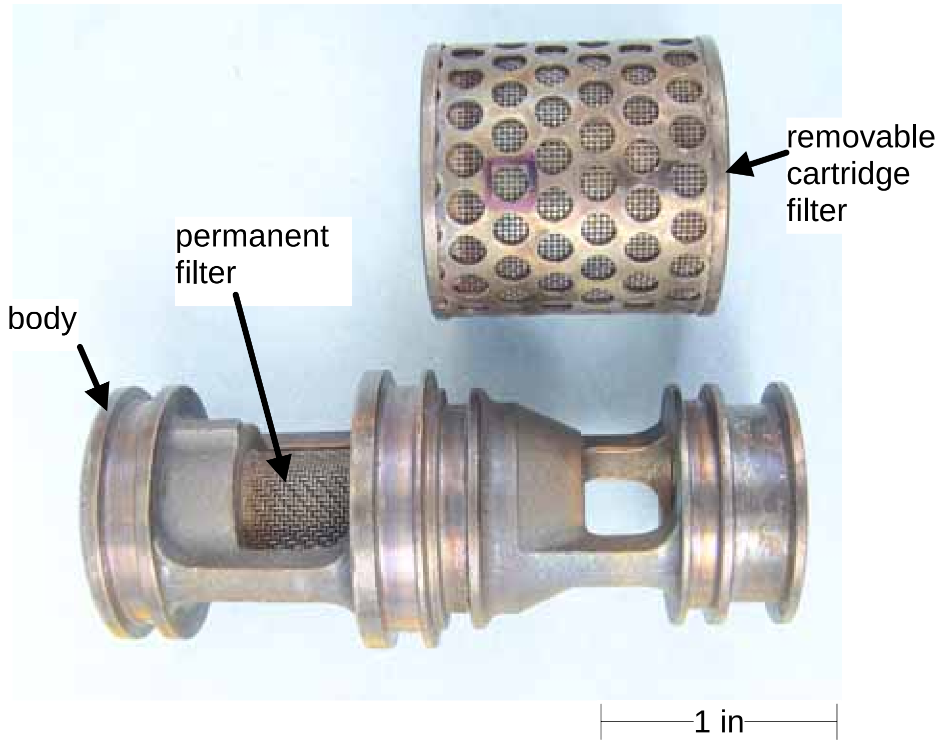
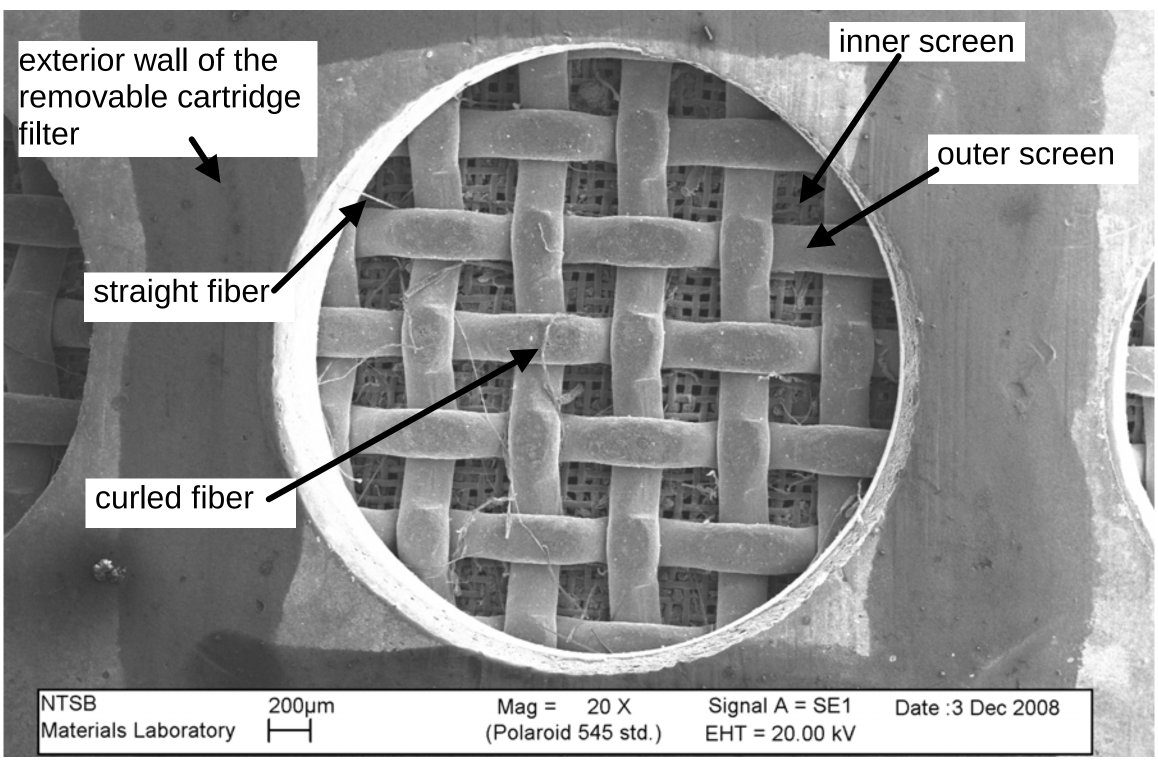
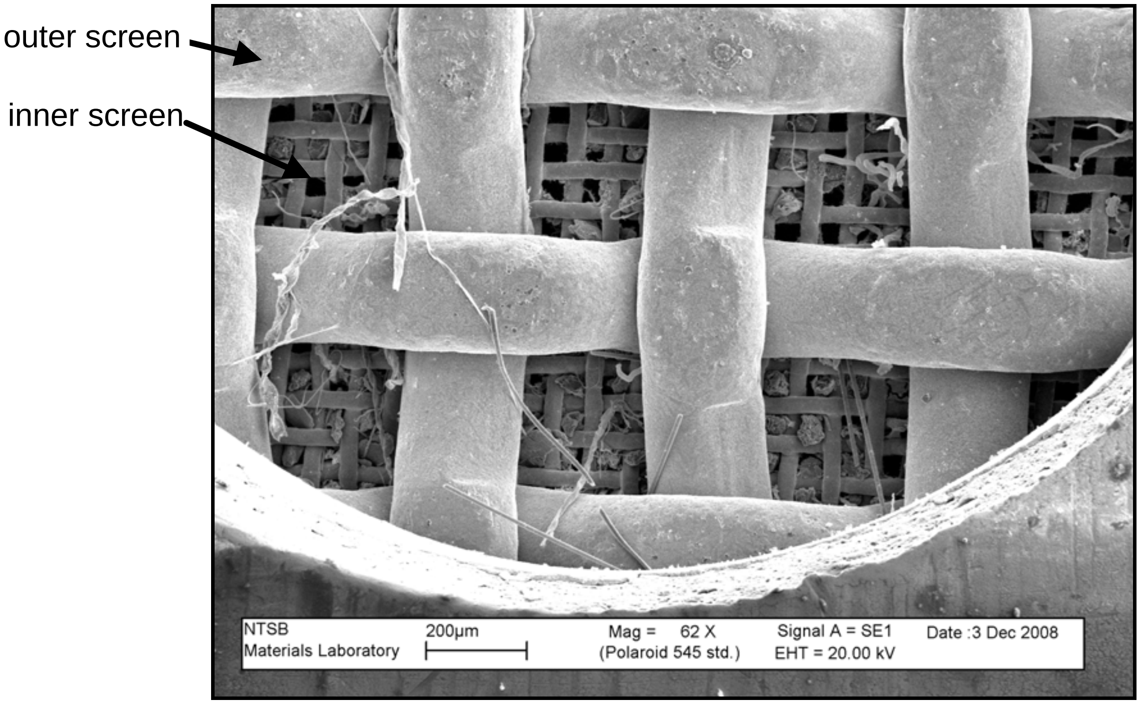


Figure 4. Photograph of the fuel filter assembly from the number 1 engine after the cartridge filter assembly was disassembled from the body.



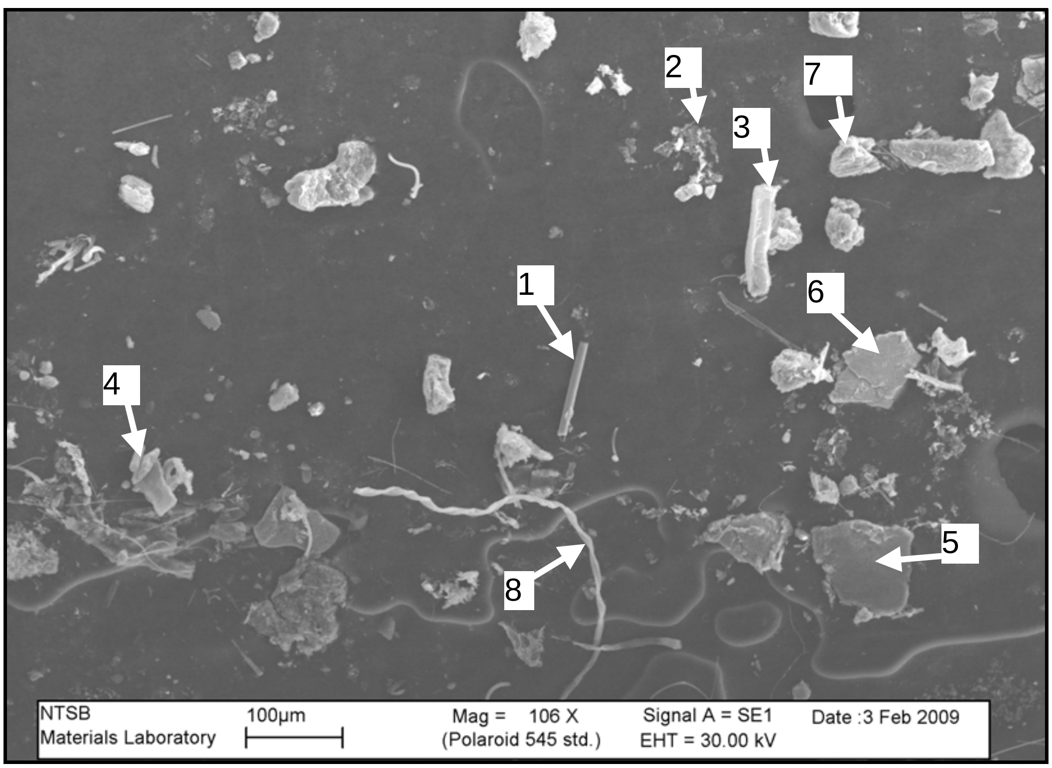
ImageNo:0902A00114

Figure 5. Scanning electron microscope (SEM) photograph of a portion of the external face of the removable cartridge filter for fuel control in the number 1 engine. This view shows one of the holes in the wall of the cartridge filter. The bore of the cartridge filter contained two layers of wire screen (referred as the inner and outer screens).



ImageNo:0902A00084, Project No:2008110006

Figure 6. Higher magnification SEM photograph of a portion of the removable cartridge filter for fuel control in the number engine that was shown in figure 5. This view shows particles embedded in the inner and outer screens.



ImageNo:0902A00099

Figure 7. SEM photograph of typical particles that were removed with carbon adhesive tape from the inner screen portion of the removable-cartridge filter from fuel control in the number 1 engine. Background is carbon adhesive tape. EDS spectrum of the particles arrowed "1" through "8" is shown in Appendix 1.

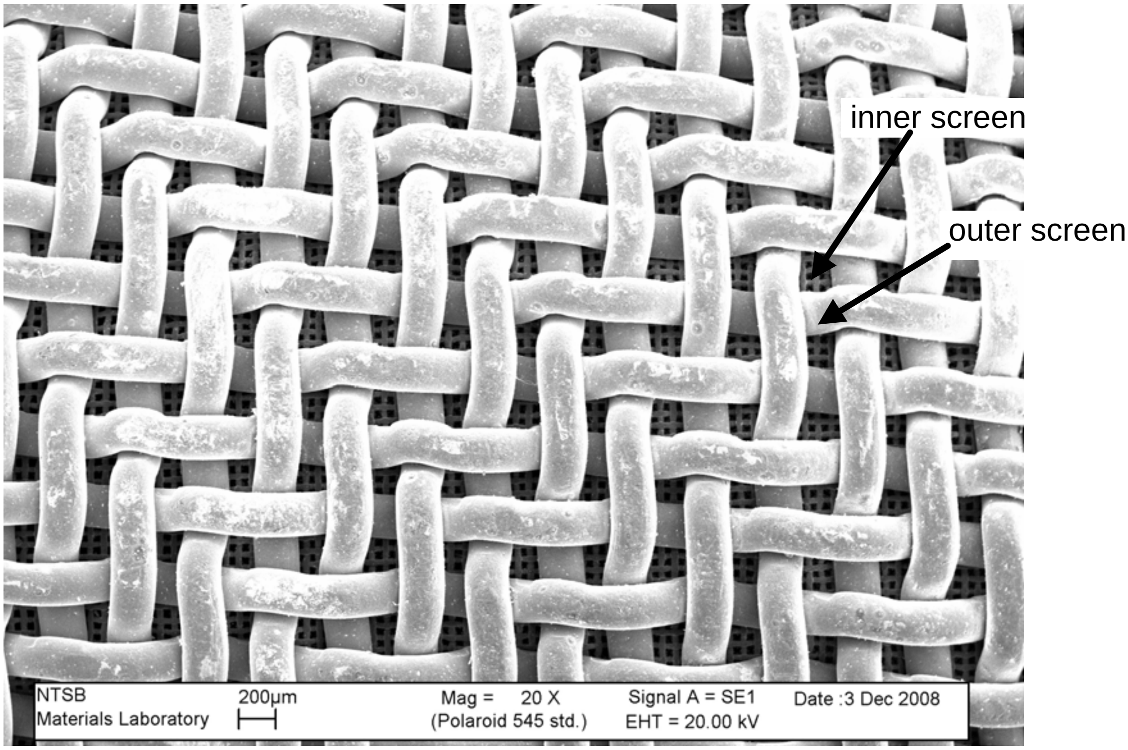


Figure 8. SEM photograph of a portion of permanent filter from fuel filter engine 1 showing the outer and inner wire screens.

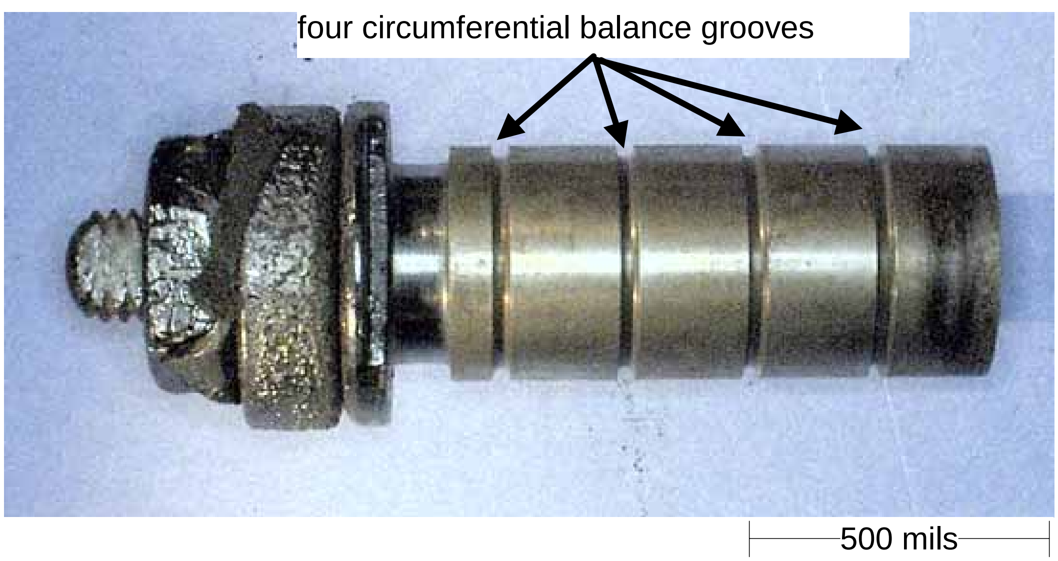


Figure 9. Photograph of the spool portion of PRV in the number 1 engine. The position of the circumferential balance grooves are indicated in the photograph.

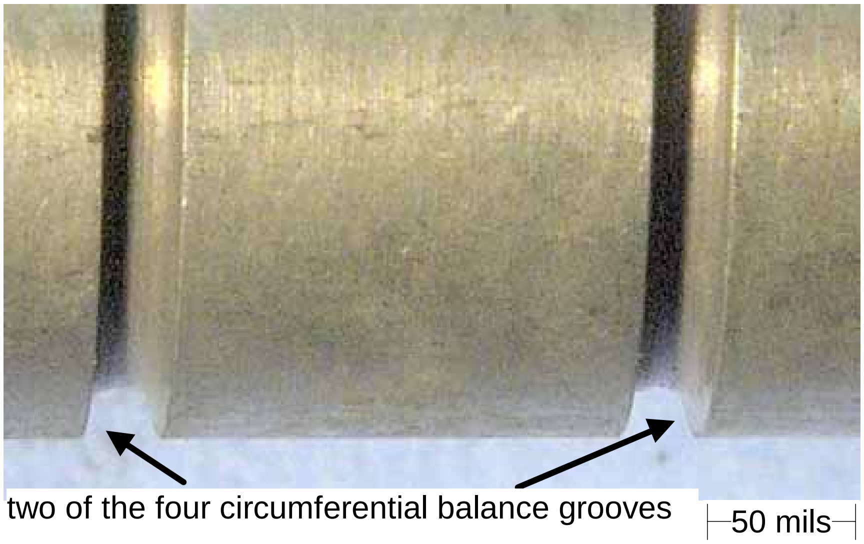


Figure 10. Close-up photograph of two of the four circumferential balance groove portions from the spool of PRV in the number 1 engine.

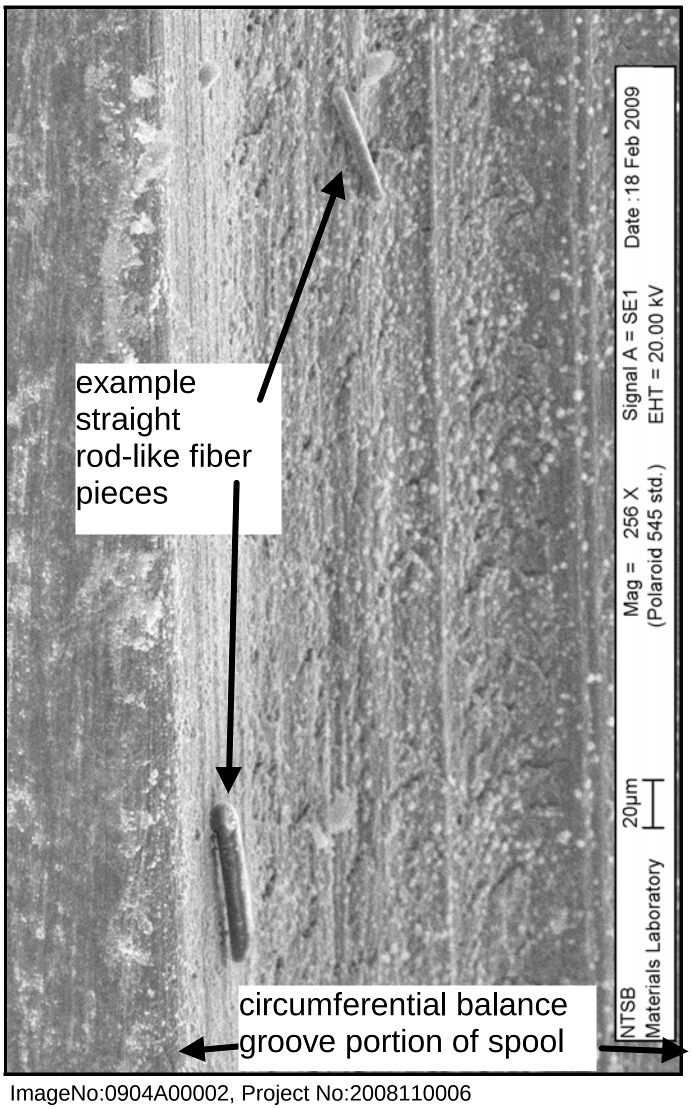
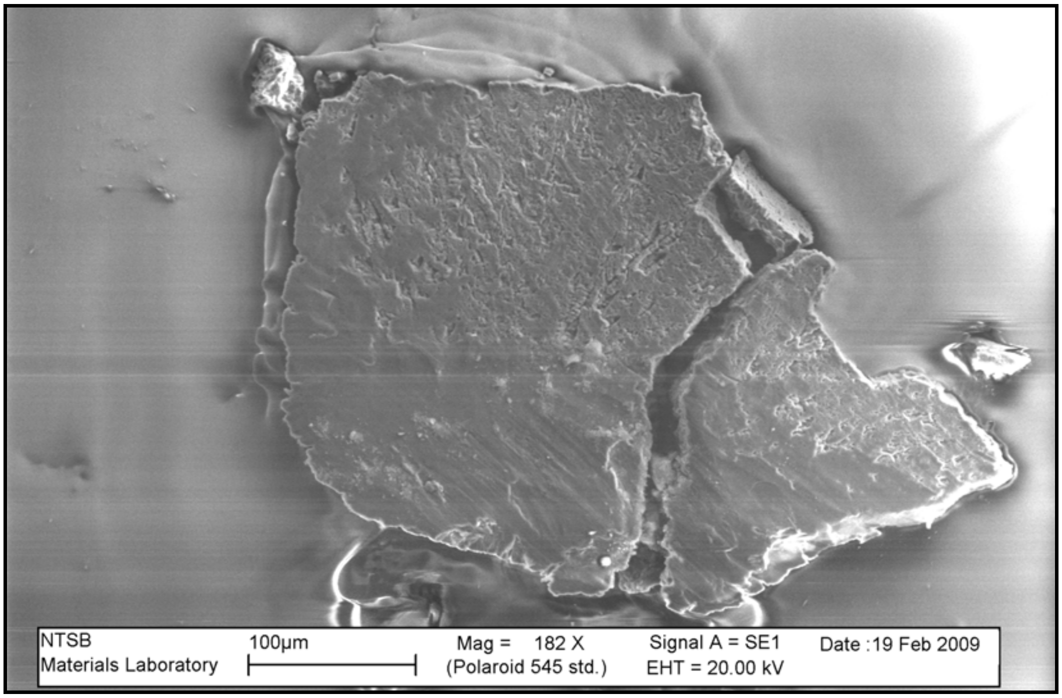


Figure 11. SEM photograph of a portion of a circumferential balance groove from the spool of PRV in the number 1 engine. This view shows two straight rod-like fibers located in the circumferential balance groove.



ImageNo:0904A00016, Project No:2008110006

Figure 12. SEM photograph of one of the particles found on the stub for PRV engine 1. The particle fractured into two major pieces. The EDS spectrum from this particle contained elemental peaks of fluorine and carbon.

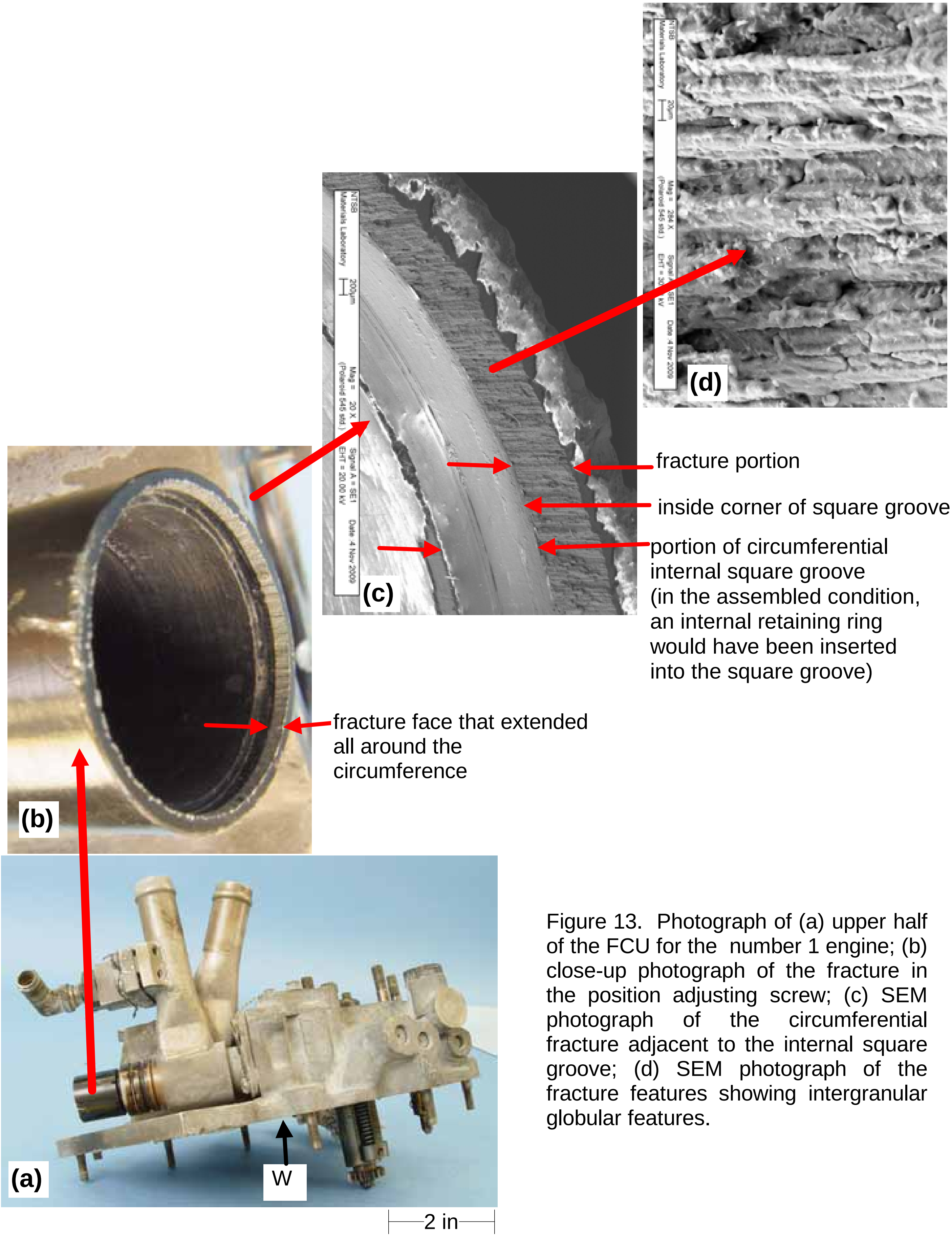


Figure 13. Photograph of (a) upper half of the FCU for the number 1 engine; (b) close-up photograph of the fracture in the position adjusting screw; (c) SEM photograph of the circumferential fracture adjacent to the internal square groove; (d) SEM photograph of the fracture features showing intergranular globular features.

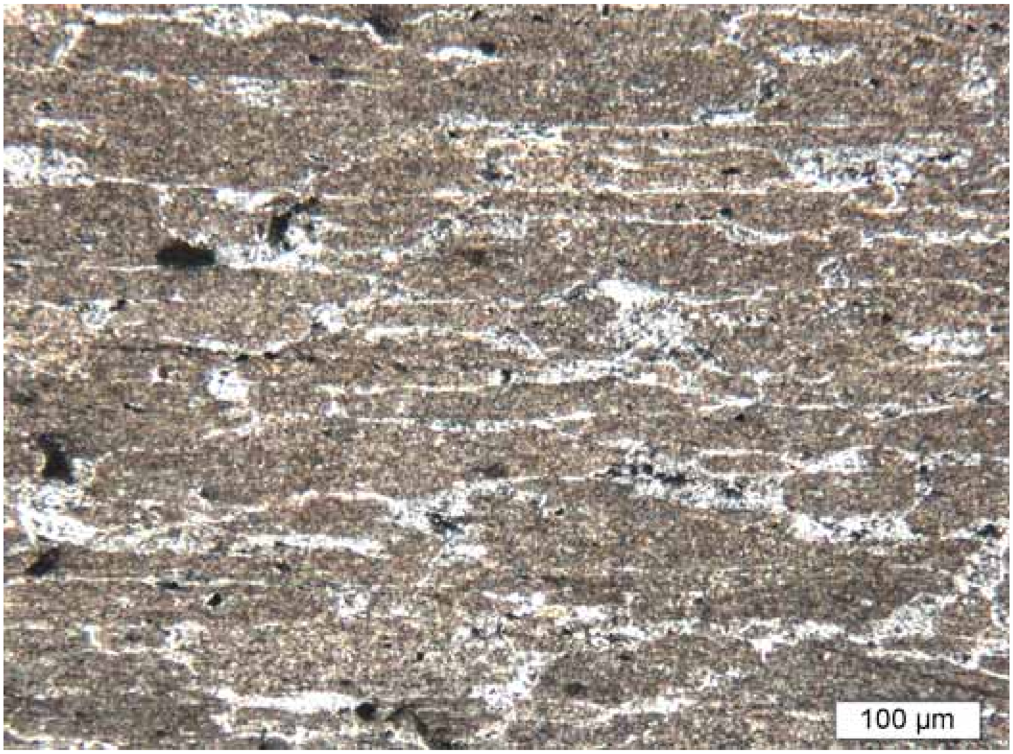


Figure 14. Longitudinal-radial section of the wall portion of the position adjusting screw. The microstructure shows an overheated aluminum alloy. Etched with Keller's reagent.

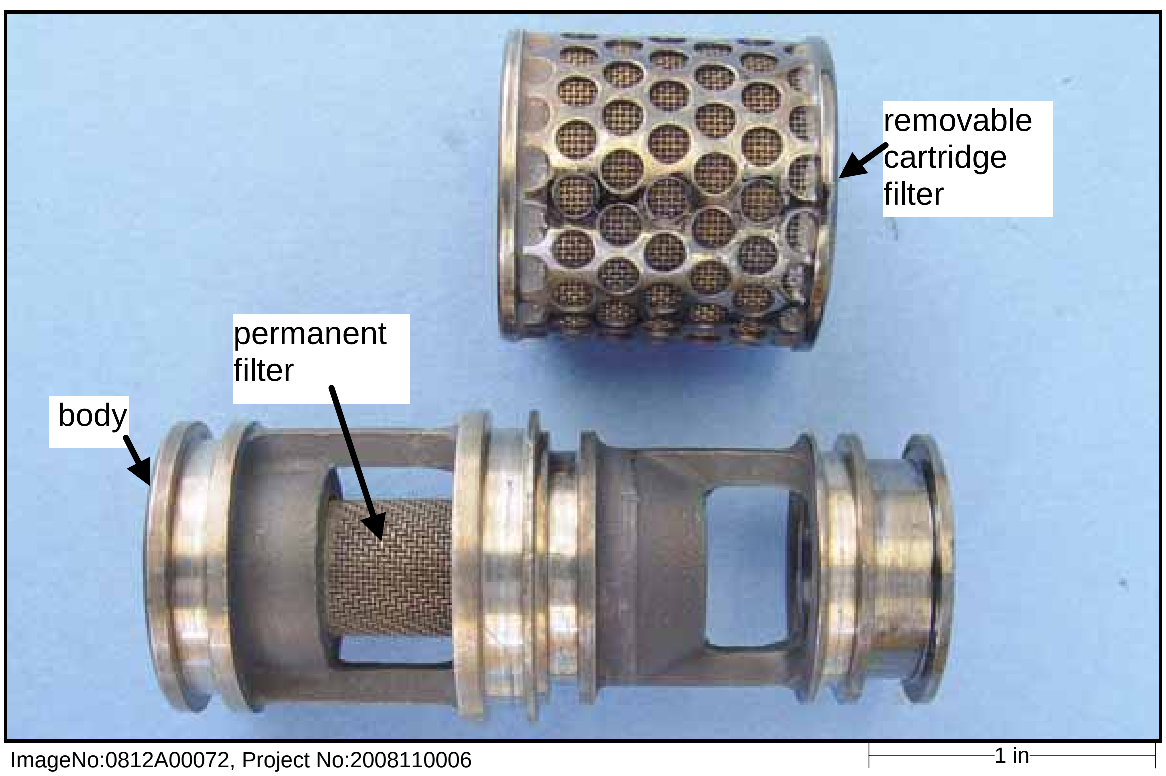
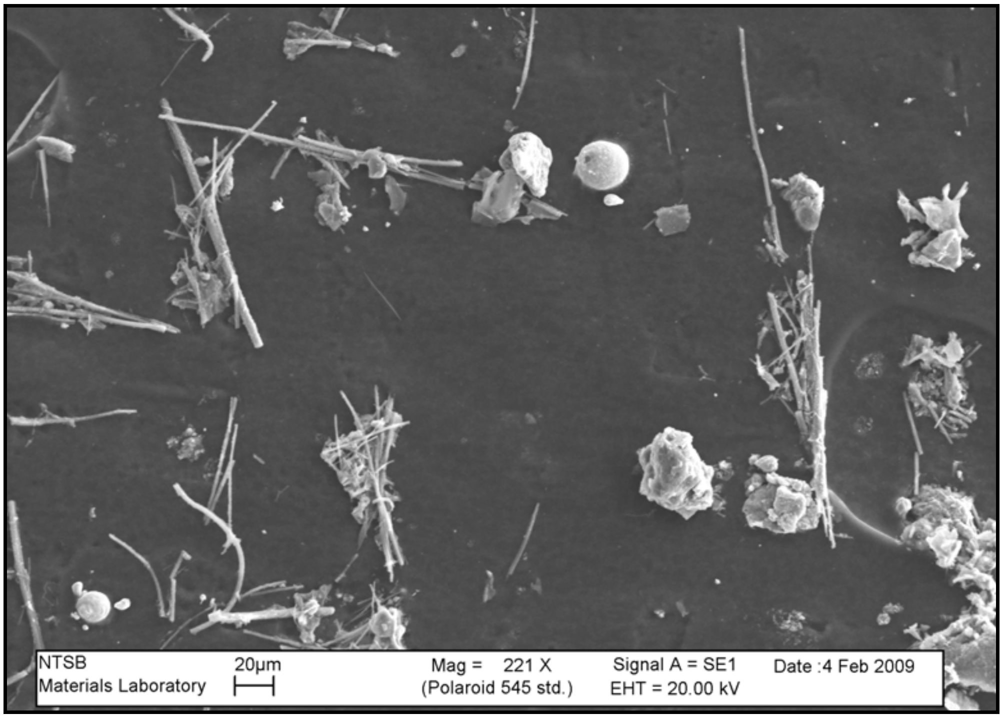


Figure 15. Photograph of the fuel filter assembly from the number 2 engine after the cartridge filter assembly was disassembled from the body.



ImageNo:0902A00105, Project No:2008110006

Figure 16. SEM photograph of particles that were removed from the permanent filter of fuel control in the number 2 engine. Background is carbon adhesive tape.

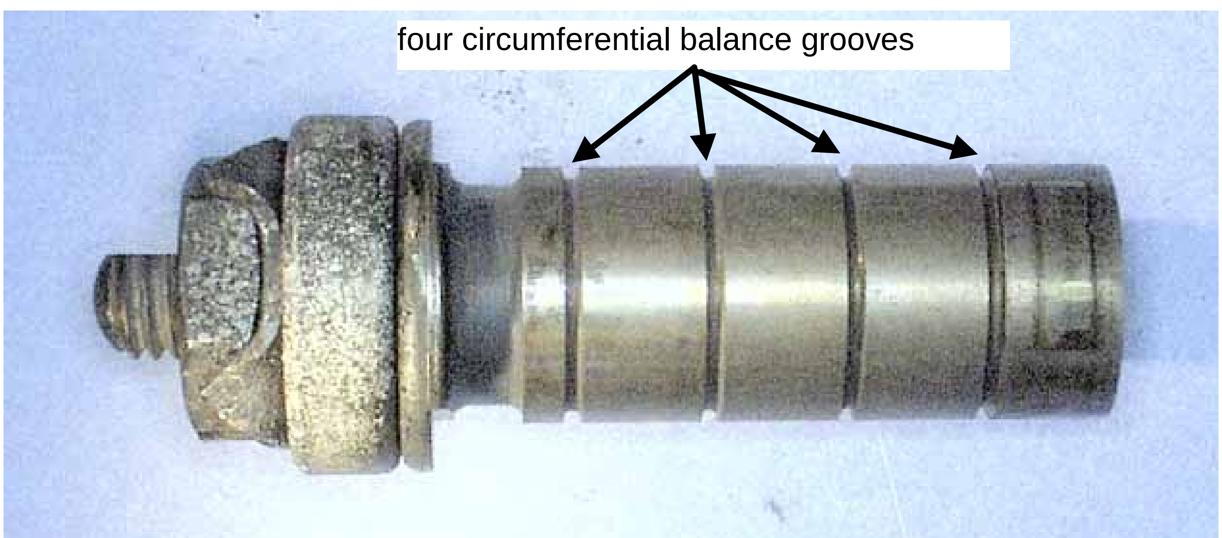


Figure 17. Photograph of the spool portion of PRV in the number 2 engine. The position of the circumferential balance grooves are indicated in the photograph.

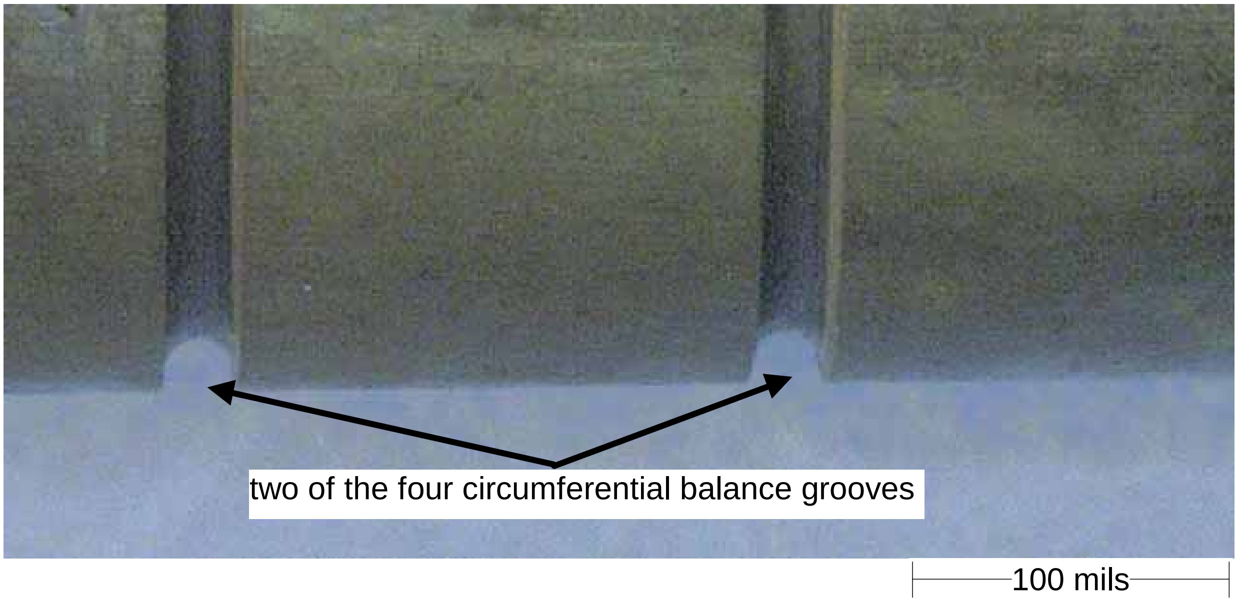


Figure 18. Close-up photograph of two of the four circumferential balance groove portions from the spool of PRV in the number 2 engine.

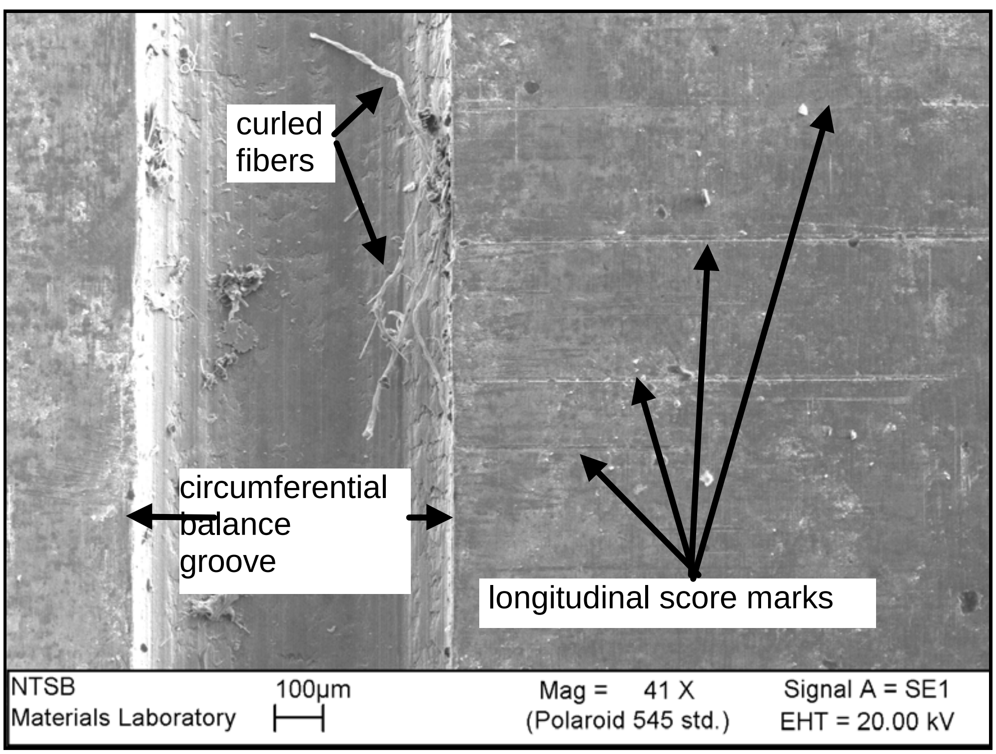
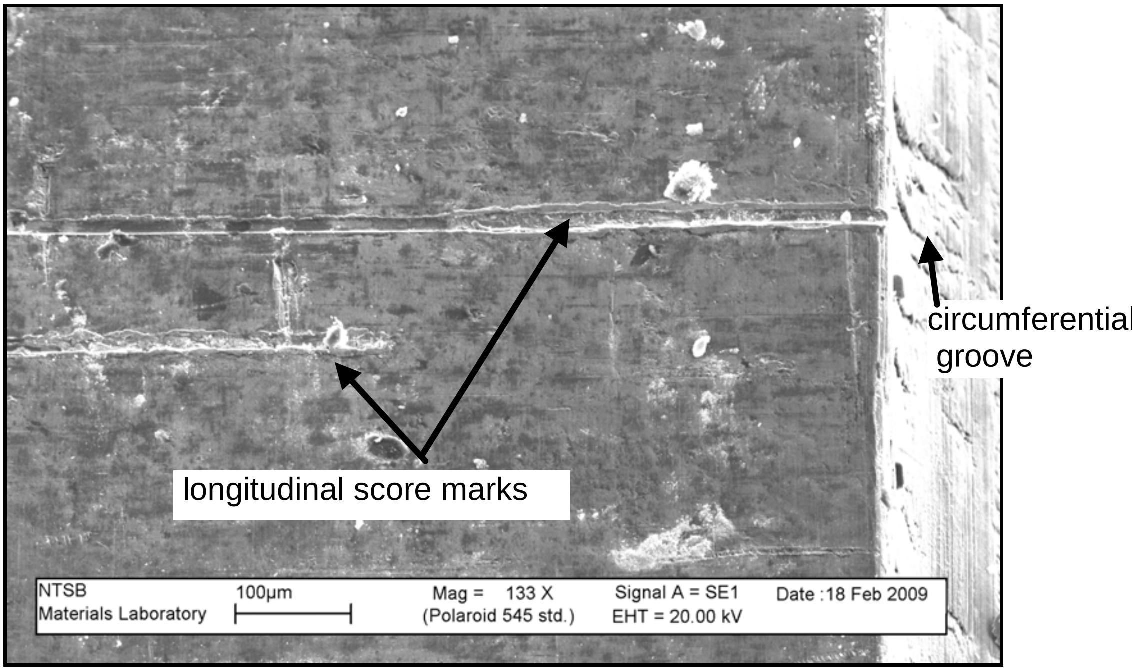
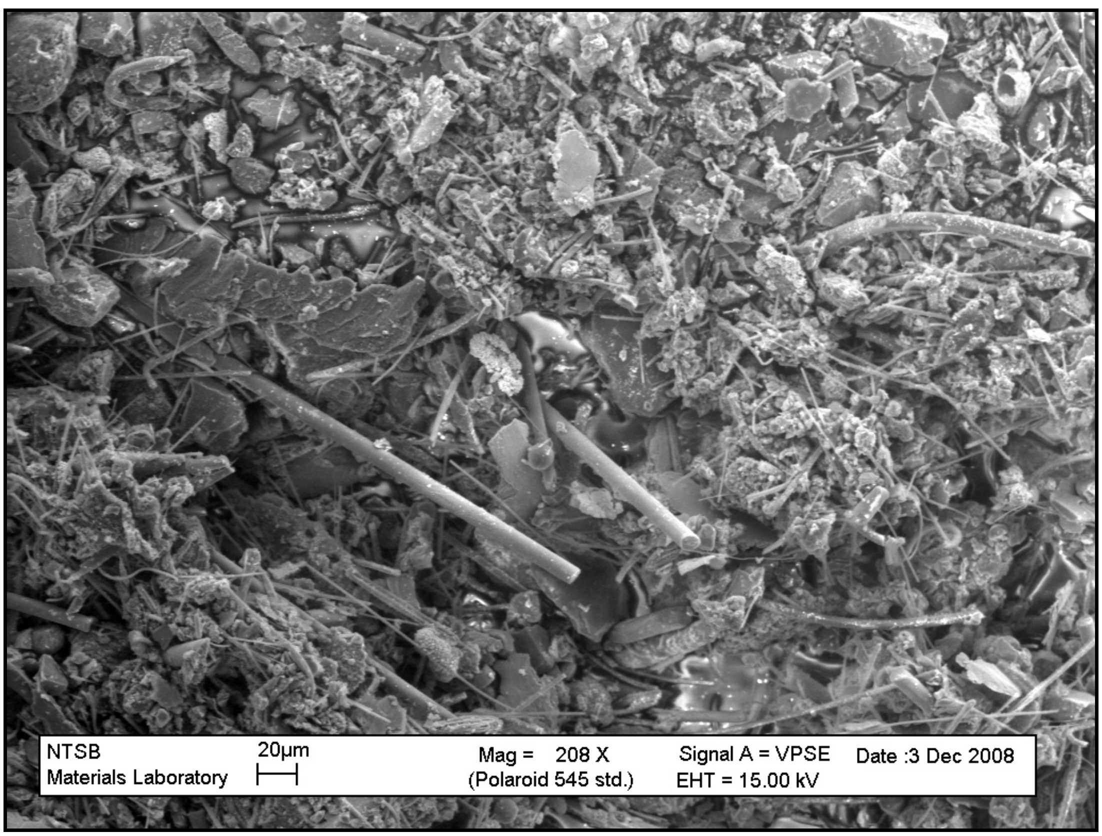


Figure 19. SEM photograph of a portion of the pool from the PRV in the number 2 engine showing one of the circumferential balance grooves. This view shows fibers within the groove in an area located adjacent to the spool surface. The surface also contained several longitudinal score marks that extend from the circumferential balance groove.



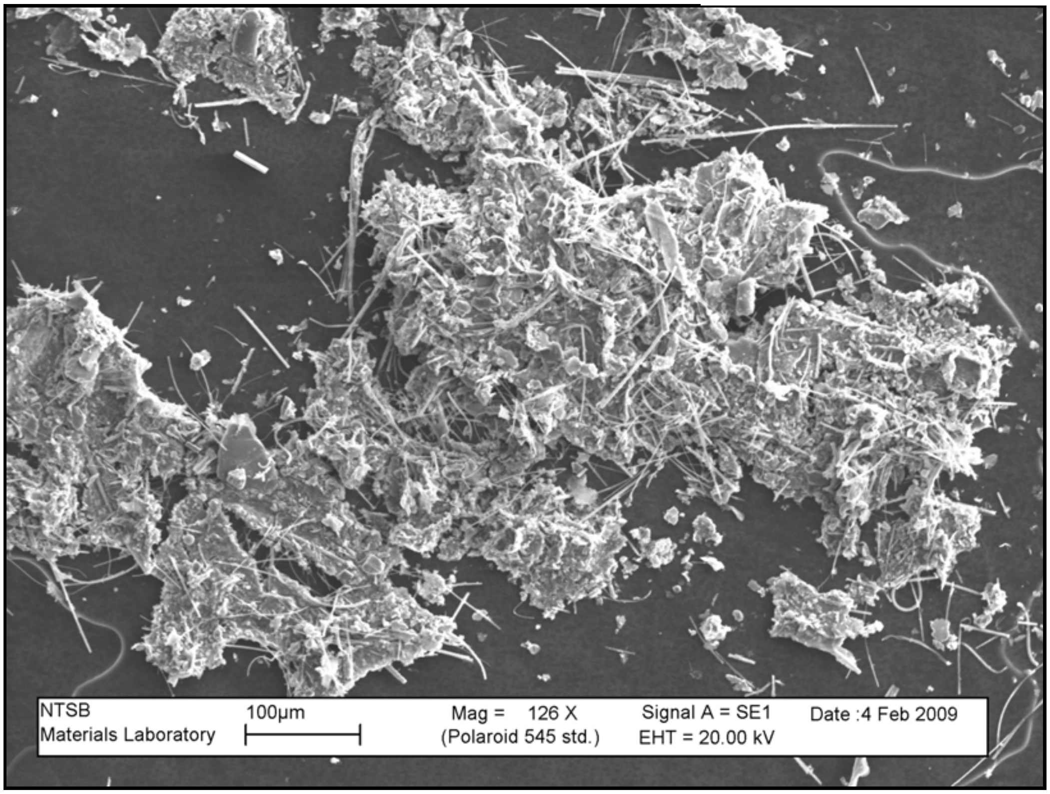
ImageNo: 0904A00007, Project No:2008110006

Figure 20. SEM photograph of a portion of the pool from the PRV in the number 2 engine showing one of the circumferential balance grooves. A longitudinal score mark extended from the circumeferential balance groove.



ImageNo: 0902A00094, Project No:2008110006

Figure 21. SEM photograph of particles found on the as-received stub that contained particled collected from PRV of the number 2 engine. The particles are embedded in adhesive bonded tape.



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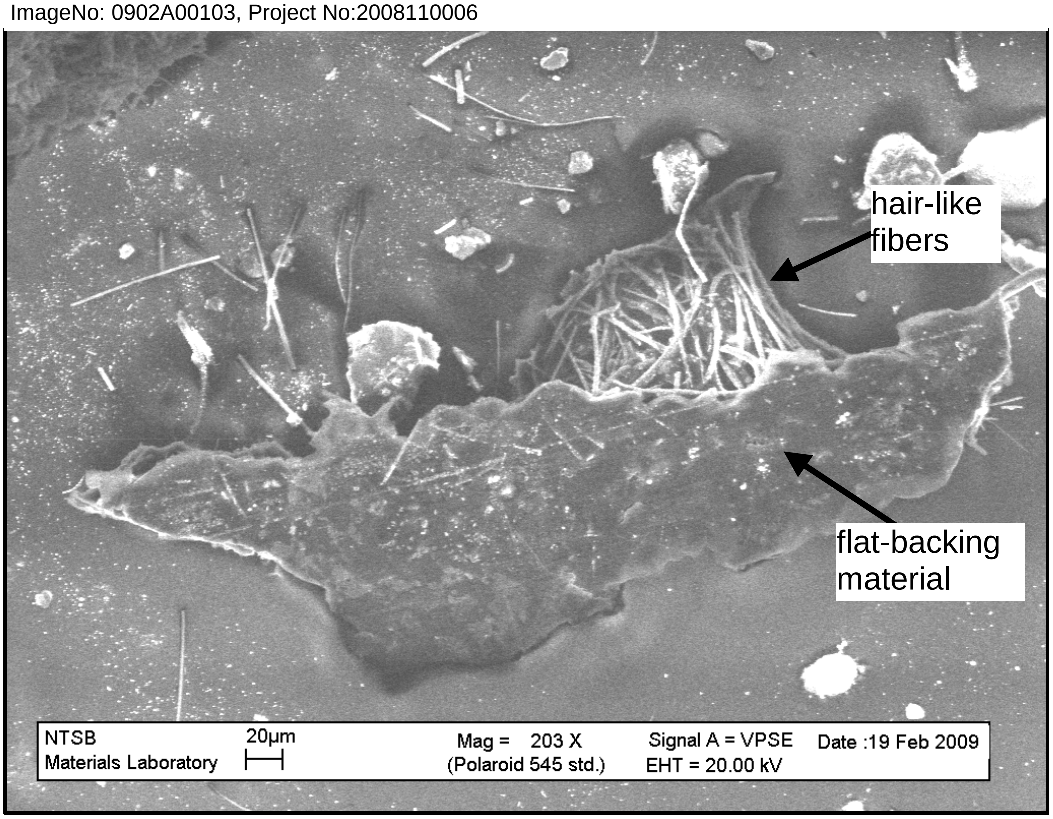
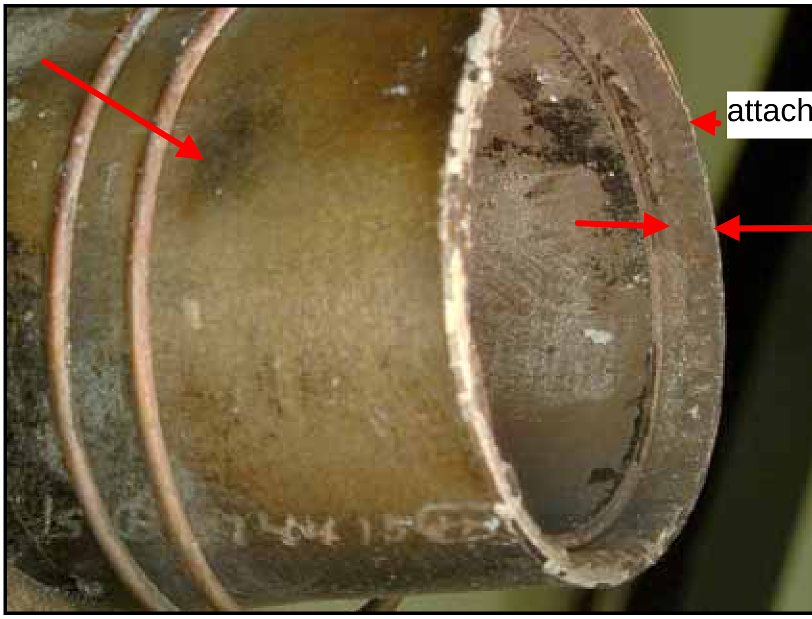


ImageNo:0903A00028, Project No:2008110006

Figure 22. SEM photograph of particles on the stub from PRV of the number 2 engine (upper side of page) and a slighty higher magnification view one of the same particles after it was turned over to reveal the hidden back side. The majority of the particles appear to have a flat-backing material with hair-like fibers extending from the flat-backing material portion.



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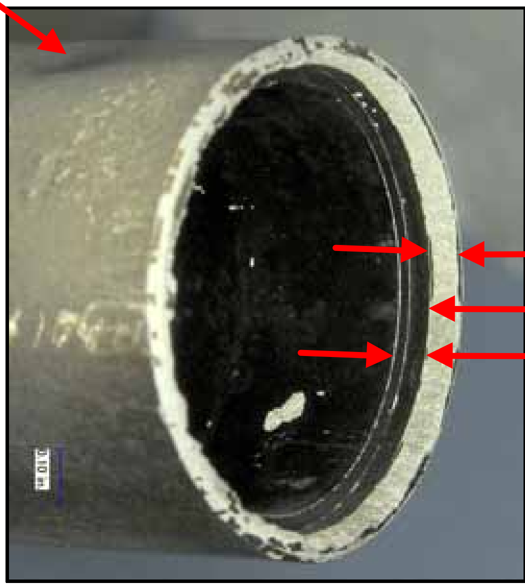

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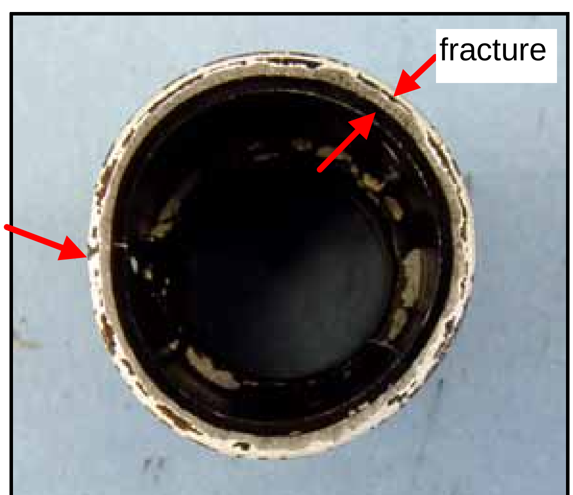
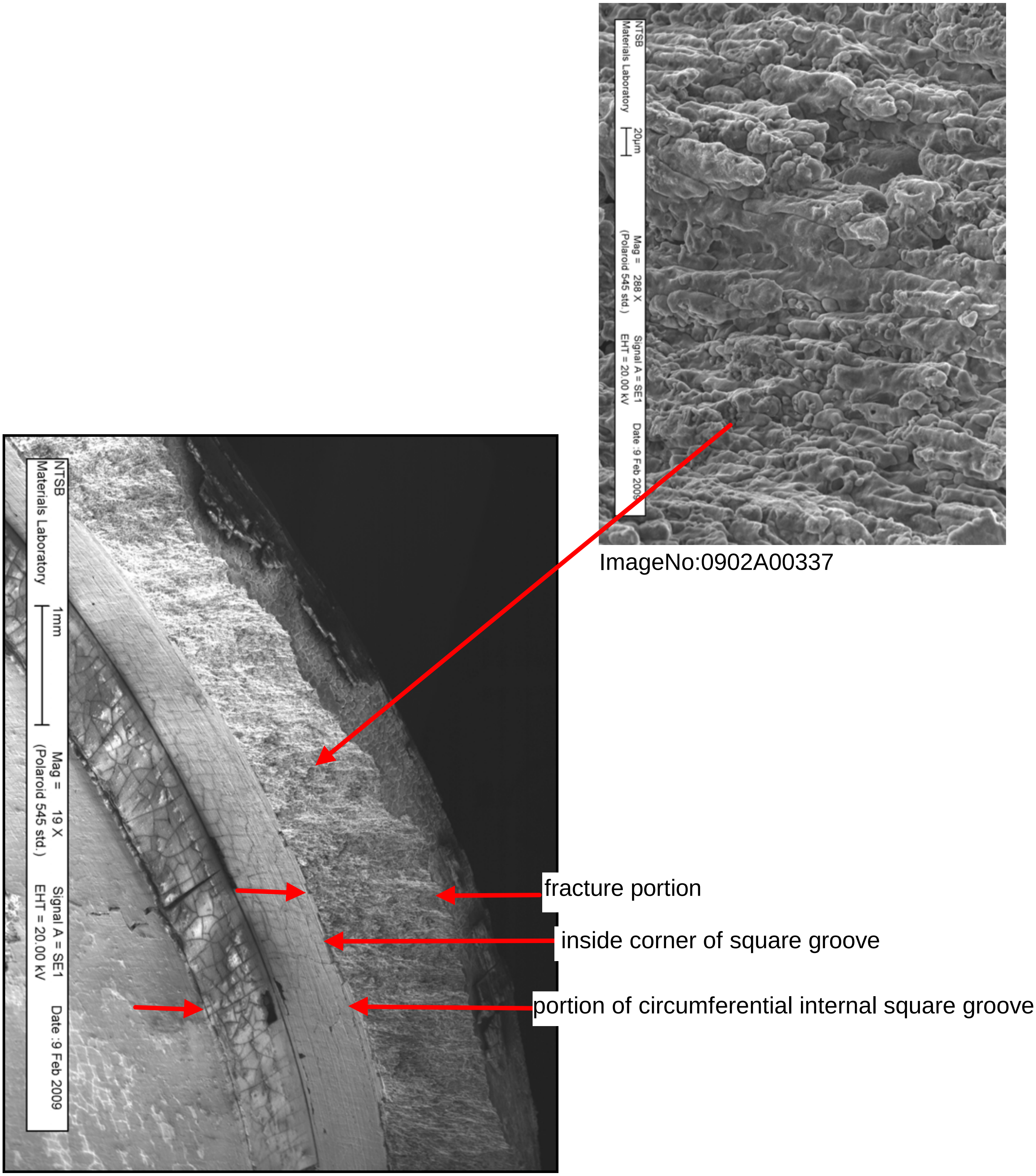


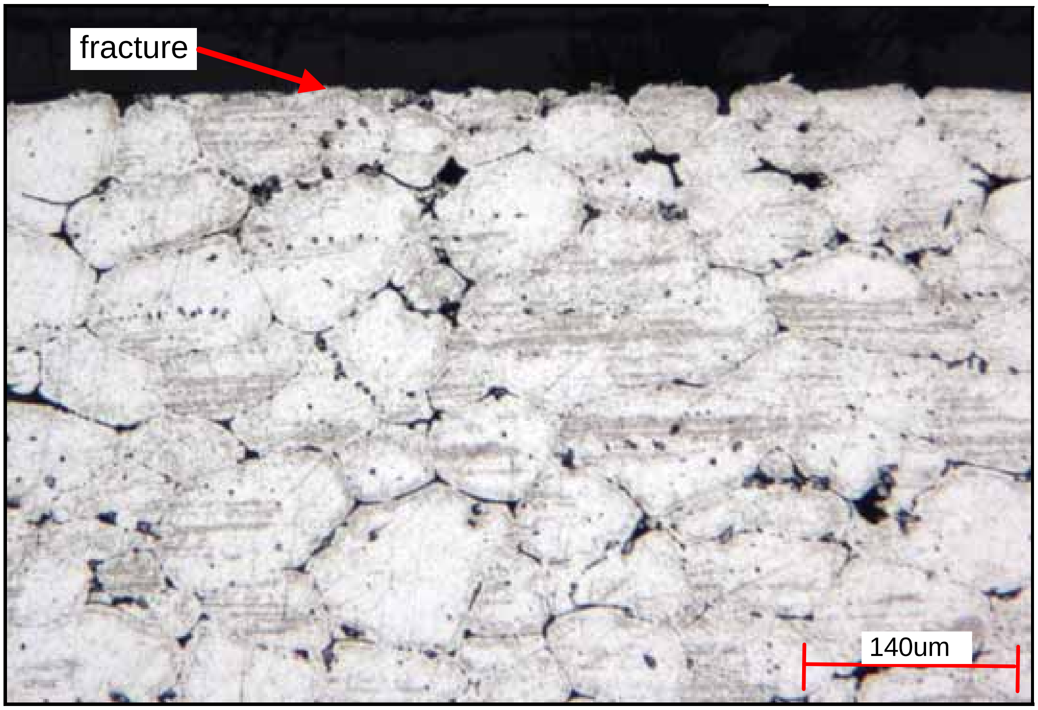
ImageNo:0902A00225, Project N 500 mils

Figure 23. View of the position adjusting screw for the temperature sensor bellows assembly in the number 2 engine, in the as-received condition (upper photograph); side view after disassembly and ultrasonic cleaned with detergent (center photograph); and view looking into the position adjusting screw (bottom photograph). Note the dent in the area indicated by an unmarked arrow. In the assembled condition, an internal retaining ring would have been inserted into the square groove.



ImageNo:0902A00248, Project No:2008110006

Figure 24. SEM photographs of a portion of the position adjusting screw for the temperature sensor bellows assembly (lower left corner of page) and a higher SEM photograph of the fracture face (upper right corner of page). In the assembled condition, an internal retaining ring would have been inserted into the square groove.



ImageNo: 0904A00029, Project No:2008110006

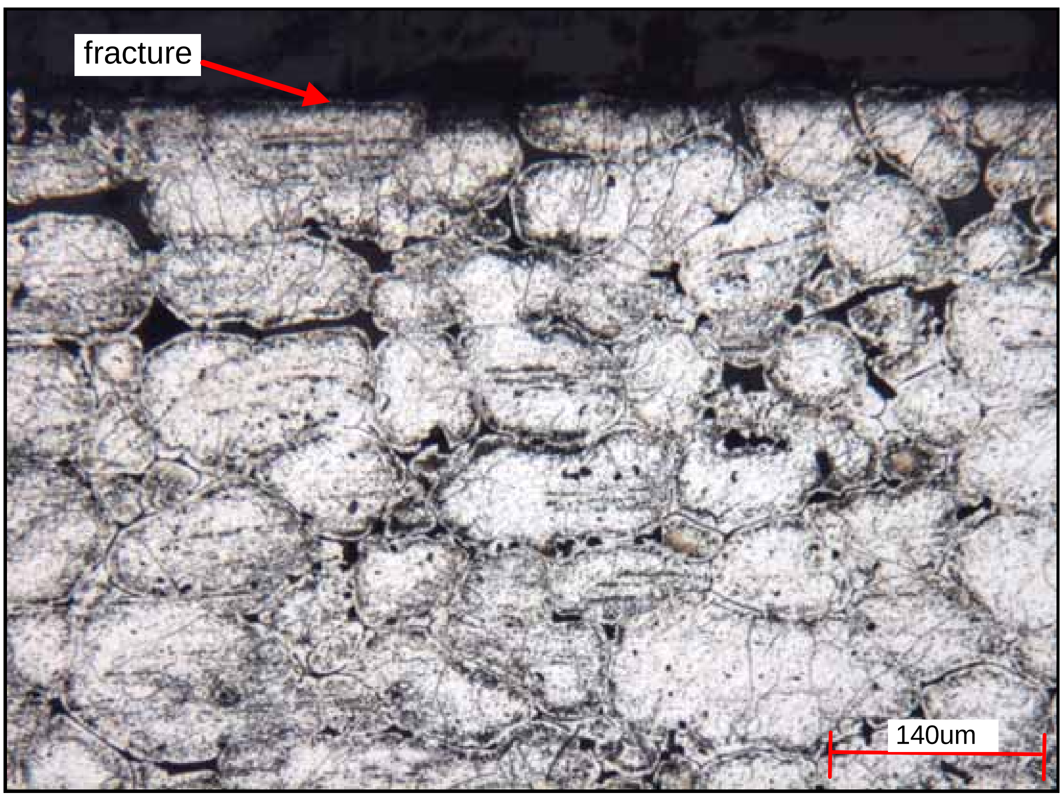


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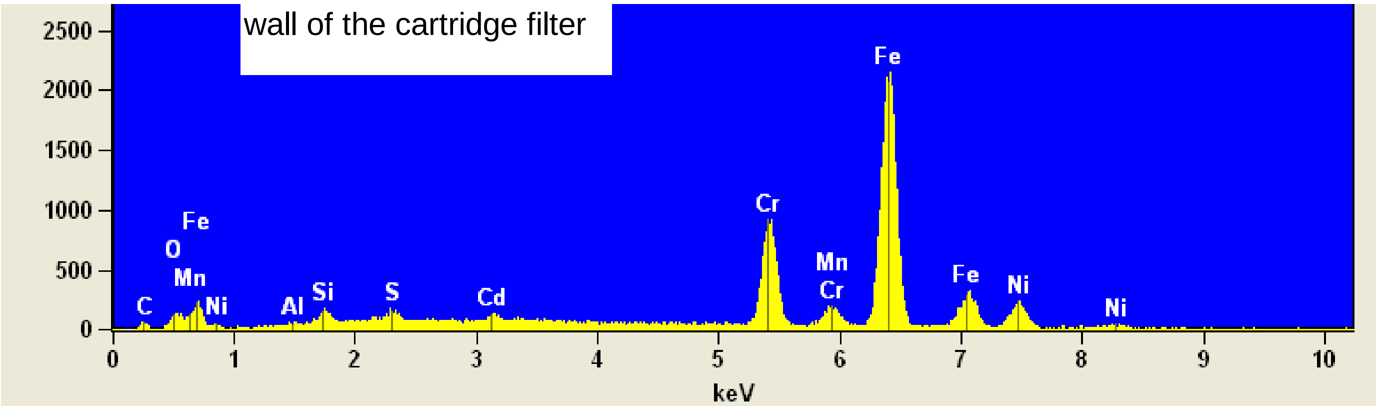
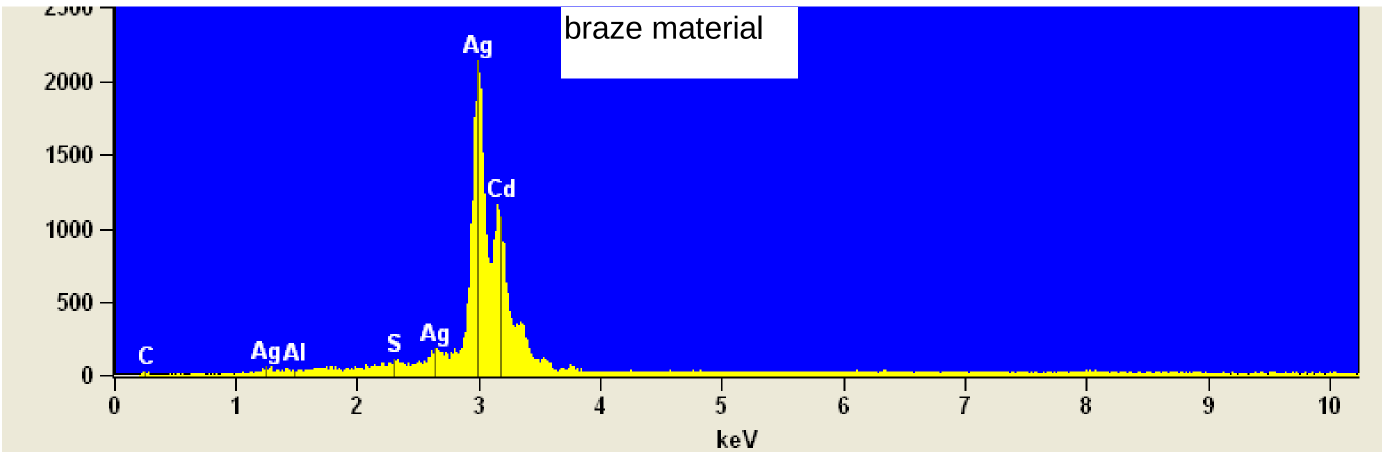
Figure 25. Longitudinal-radial section of the wall portion of the position adjusting screw from the temperature sensor bellows assembly. The microstructure shows an overheated aluminum alloy with solid solution melting at the grain boundaries. The two photographs were taken in an area that was located near each other and adjacent to the fracture face. The area shown on the bottom photograph was etched for a longer period of time compared to the area on the upper photograph. Etched with Keller's reagent.

Figure 26. Photograph of the fiberglass wall portion from an exemplar collector can that was submitted by Carson Helicopter Services Incorporated. A piece from the lower right corner was fractured at the Safety Board Materials Laboratory for examination.

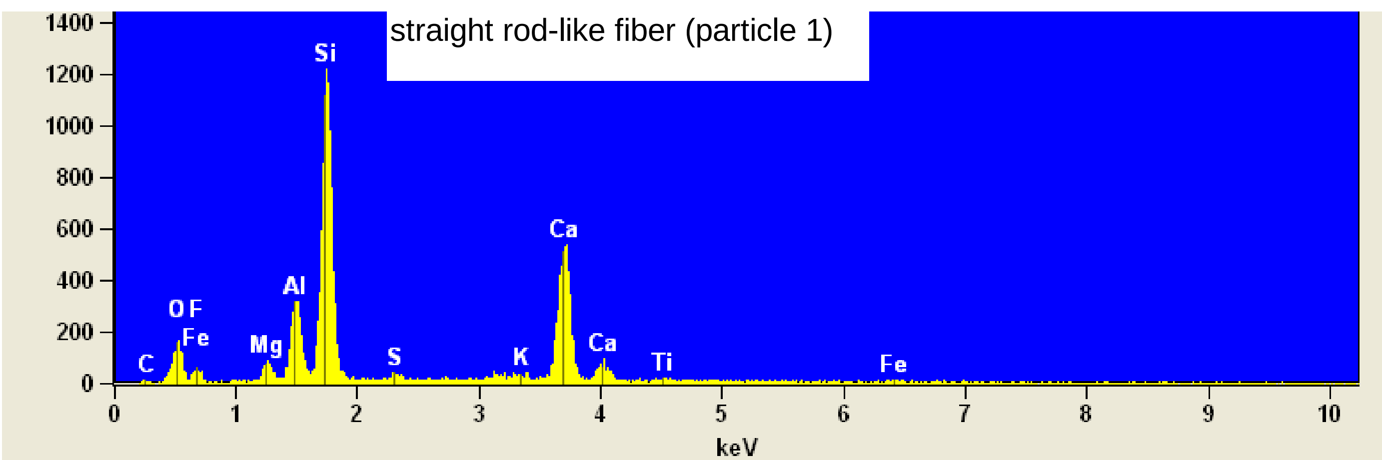
APPENDIX 1



EDS spectrum of the wall from the removable-cartridge filter contained major elemental peaks of iron, chromium, and nickel, and minor elemental peaks of carbon, oxygen, aluminum, silicon, sulfur, and cadmium.

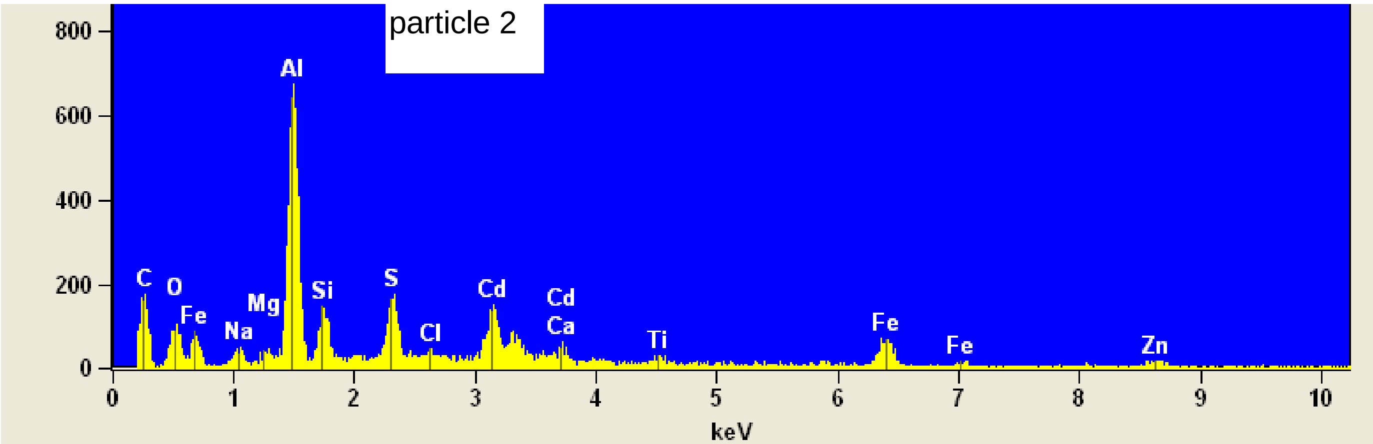


EDS spectrum of the wall of the braze material between the casting and screens contained major elemental peaks of silver and cadmium, and minor peaks of carbon and sulfur.

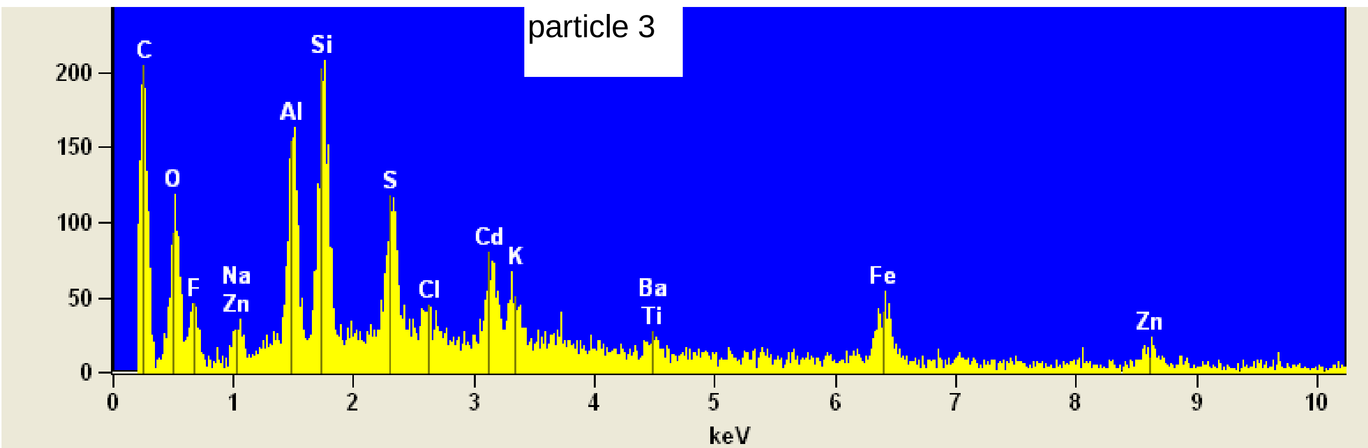


EDS spectrum of the straight rod-like fiber (particle 1 in figure 7) contained major elemental peaks of silicon, aluminum and calcium with minor elemental peaks of magnesium, carbon, and oxygen, consistent with a silicate glass fiber such as E-glass.

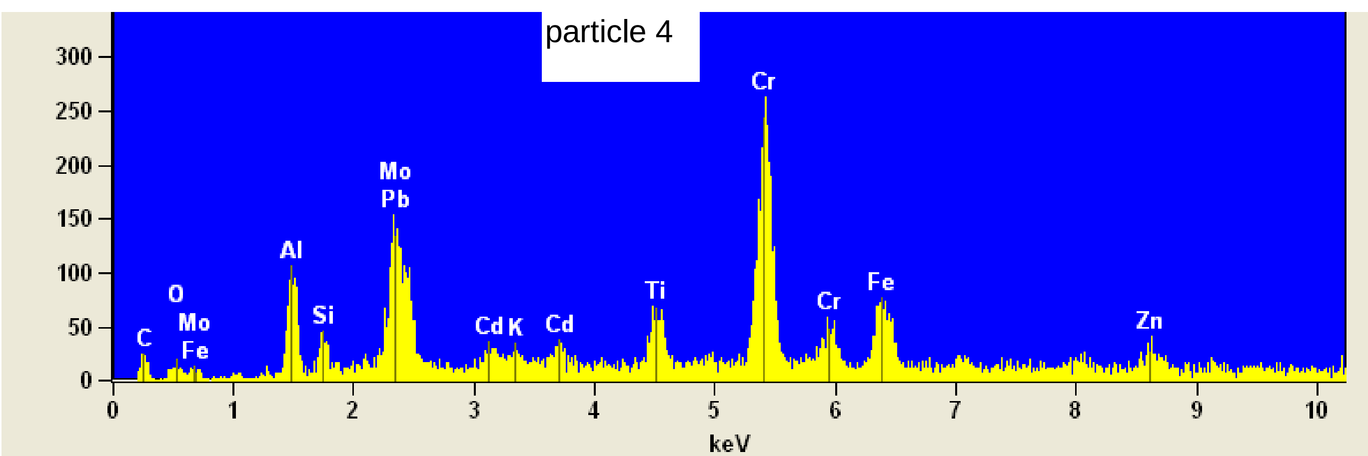
APPENDIX 1



EDS spectrum of particle 2 in figure 7 contained a major peak of aluminum and minor peaks of carbon, oxygen, iron, sodium, magnesium, silicon, sulfur, chlorine, cadmium, titanium, iron, and zinc.

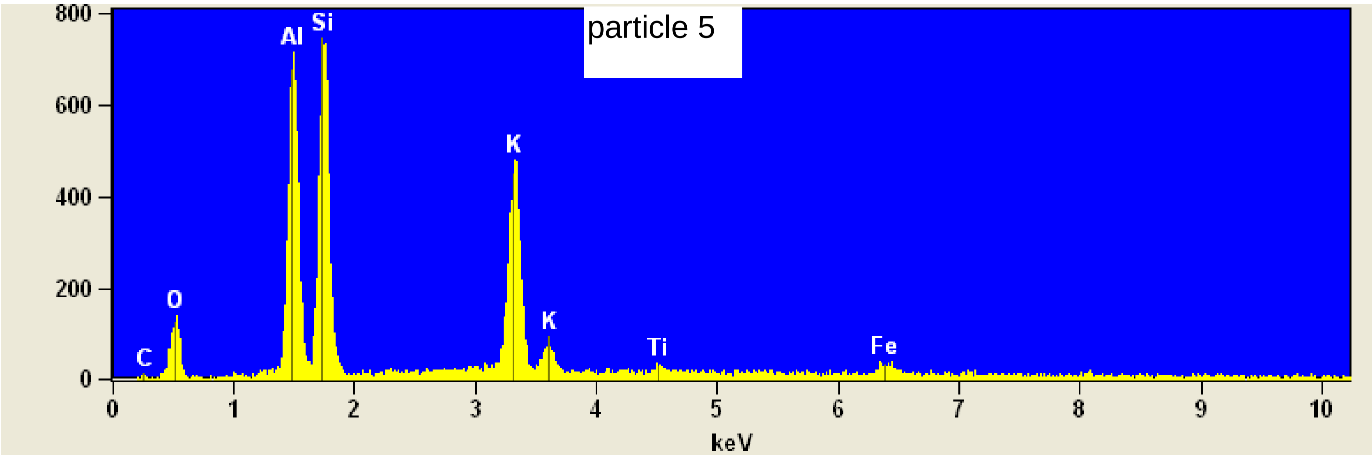


EDS spectrum of particle 3 in figure 7 contained major elemental peaks of silicon, aluminum, and carbon, and minor peaks of fluorine, sodium, zinc, sulfur, chorine, cadmium, potassium, titanium, iron and zinc.

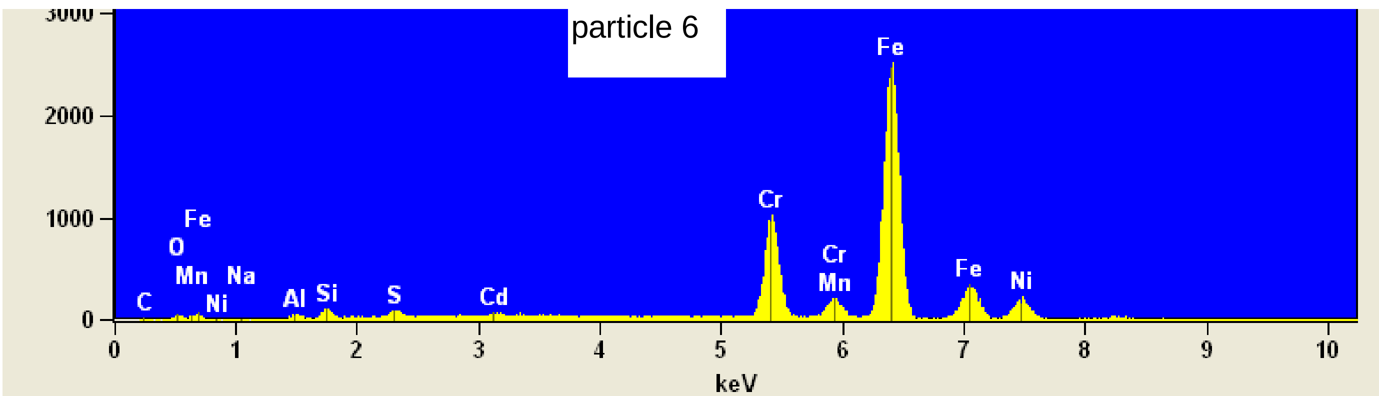


EDS spectrum of particle 4 in figure 7 contained element peaks of iron, nickel, chromium (present in the body of the filter assembly), and elemental peaks of lead, aluminum, silicon, zinc, titanium, carbon, cadmium, and potassium.

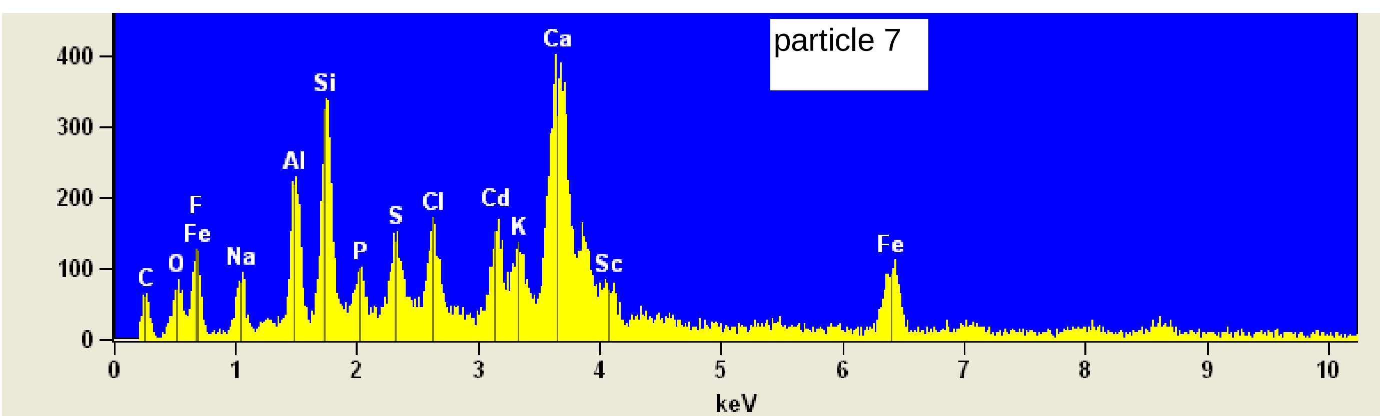
APPENDIX 1



EDS spectrum of particle 5 in figure 7 contained major elemental peaks of silicon, aluminum, and potassium (consistent with Feldspar) and minor elemental peaks of iron, carbon, and oxygen.

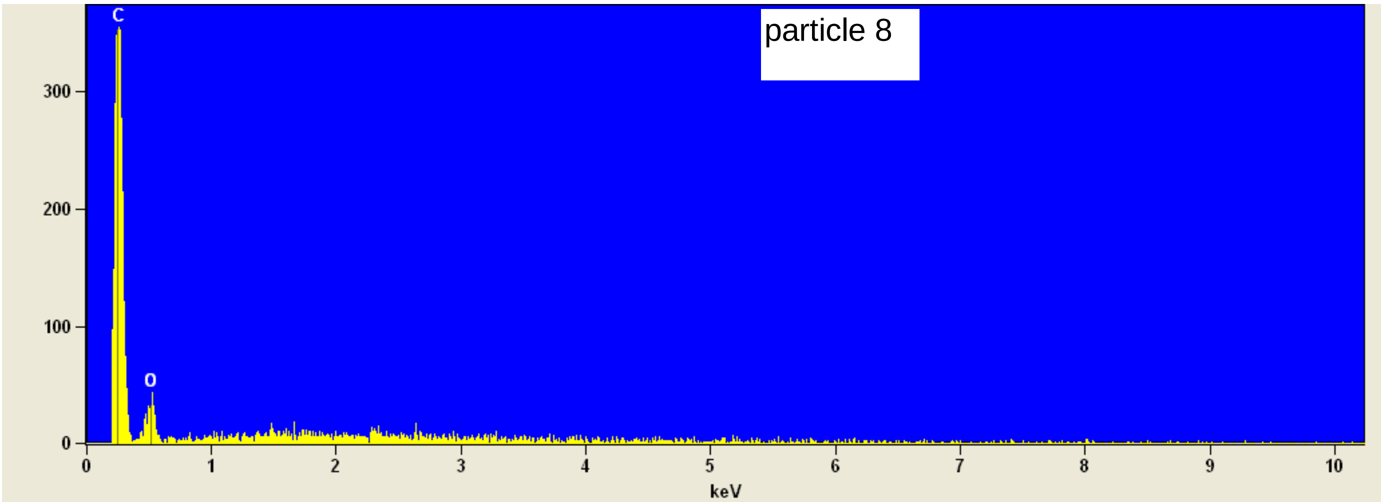


EDS spectrum of particle 6 in figure 7 contained major elemental peaks of iron, chromium, and nickel consistent with stainless steel, and minor elements of oxygen, aluminum, silicon, sulfur, and cadmium.

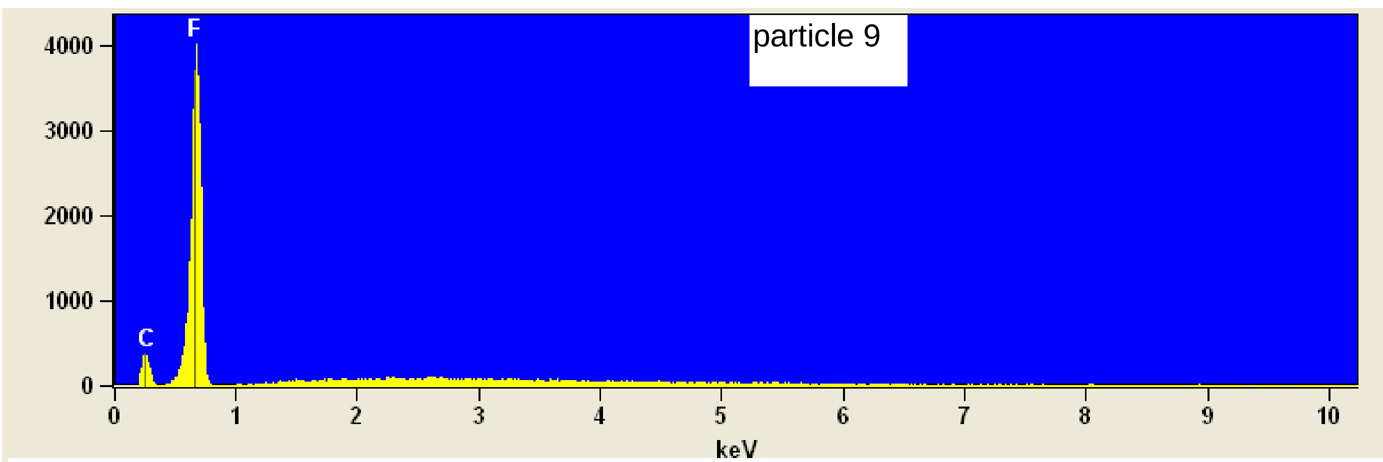


EDS spectrum of particle 7 in figure 7 contained the same elemental peaks as in particle 3 with the exception that the major elemental peaks in this particle were calcium, silicon, and aluminum.

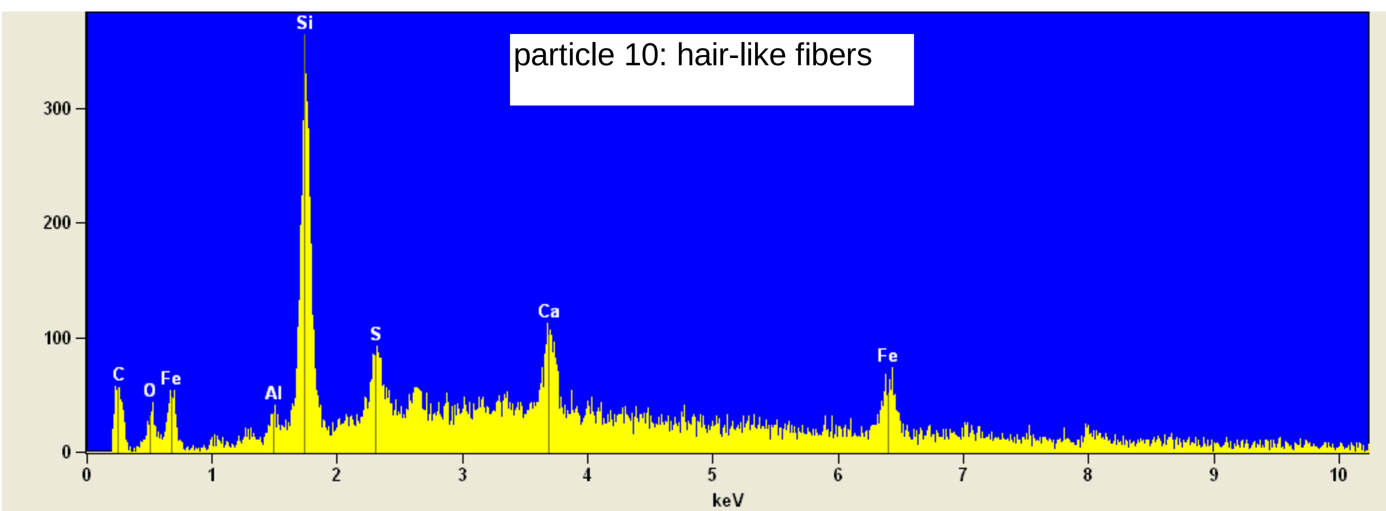
APPENDIX 1



EDS spectrum of particle 8 (curled fiber) in figure 7 contained a major elemental peak of carbon and a minor peak of oxygen.

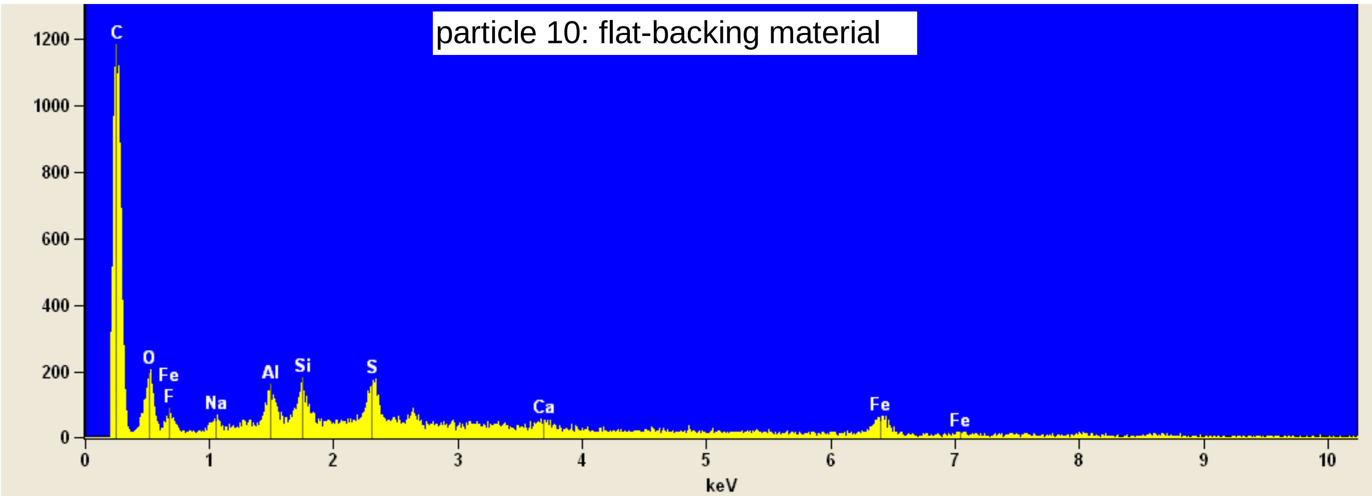


EDS spectrum of particle 9 in figure 7 contained a major elemental peak of fluorine and minor peak of carbon.

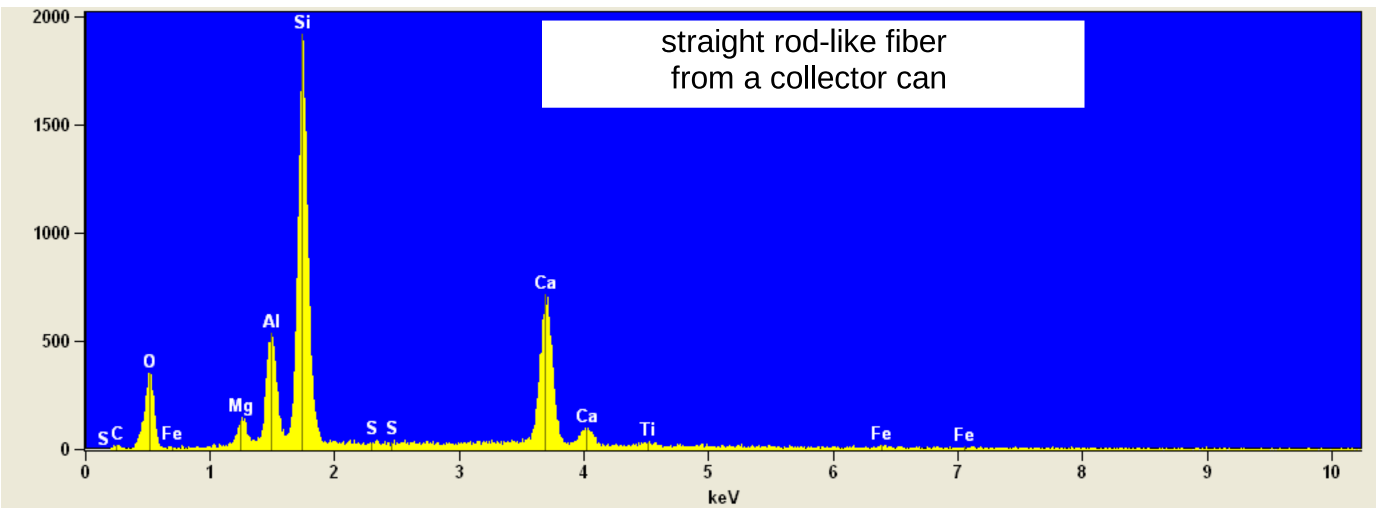


EDS spectrum of particle 10 in figure 7 in the area that contained hair-like fibers showed a major elemental peak of silicon and minor peaks of carbon, oxygen, aluminum, sulfur, calcium and iron.

APPENDIX 1



EDS spectrum of particle 10 in figure 7 in the area that contained a flat wall showed a major elemental peak of carbon and minor peaks of oxygen, fluorine, sodium, aluminum, silicon, sulfur, calcium. and iron.



EDS spectrum of a straight rod fiber from a collector can submitted by Carson Helicopter Services Incorporated showing major elemental peaks of silicon, aluminum, and calcium, and minor elemental peaks of magnesium, oxygen, and carbon.