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Materials Laboratory Flap Actuators Factual Report

by

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(38 Pages)

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
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MATERIALS LABORATORY FACTUAL REPORT

Report No. 09-050

A. ACCIDENT

Place	: Lubbock, Texas
Date	: January 27, 2009
Vehicle	: ATR 42, N902FX
NTSB No.	: CEN09MA142
Investigator	: Kristi Dunks, ASI-WPR

B. COMPONENTS EXAMINED

Flap actuators (4) with hydraulic lines and filters from the blue hydraulic system (2).

C. DETAILS OF THE EXAMINATION

Overall view of the flap actuators and hydraulic lines as received are shown in figures 1 to 4. The flap actuators had been disassembled under NTSB supervision at the flap actuator manufacturer's facility. The actuators and hydraulic lines showed evidence of soot deposits and discoloration consistent with exposure to heat and fire. The soot deposits, discoloration, and heat damage was greatest in the actuators from the right side of the airplane.

Each wing of the ATR-42 airplane has two flaps, and each flap is extended and retracted by rotating about 3 hinge points located below the wing surface. A hydraulic actuator is attached above the middle hinge point on each flap and controls the flap position. With flaps in the retracted position, the flap actuator is also fully retracted. At a flap position of 15 degrees (position for takeoff and approach), the flap actuator is extended 1.37 inches (34.7 millimeters). At a flap position of 30 degrees (position for landing), the flap actuator is extended 3.06 inches (77.7 millimeters). At a flap position of 45 degrees (position for emergencies), the flap actuator is extended 4.90 inches (124.4 millimeters).

An exploded view from the manufacturer's Component Maintenance Manual of the components that make up the flap actuator assembly is shown in figure 5. Selected components identified in figures 1 to 4 are also identified in figure 5. The flap actuator piston travels inside the housing. The forward and aft ends of the actuator have spherical bearings that attach to the adjacent structure. To extend the actuator, hydraulic fluid is pressurized through the left connector fitting (as viewed looking forward), through the pipe, and into the housing through a hole near the forward end of the housing. To retract the actuator, hydraulic fluid is pressurized through the right connector fitting (as viewed looking forward) and into the housing through a hole near the aft end of the housing.

C.1. Visual Examination

A visual examination was completed on the components shown in figures 1 to 4. To facilitate examination of the piston surfaces, the pistons were cleaned with ethanol and a soft rag during the examination.

C.1.a. Left Outboard Actuator and Hydraulic Lines

The left outboard actuator components are shown in figure 1. The left outboard actuator had the least amount of soot deposits and heat damage. The exterior surfaces of the hydraulic lines were blackened, and a black liquid dripped from the cut end of one line. The interior of the connector fittings were free of obstructions. The exterior of the pipe was blackened, and interior of the pipe was partially obstructed with black deposits near the notched end of the pipe.

A close view of the actuator housing is shown in figure 6. The forward end of the actuator housing exterior surface was blackened and tinted darker than the rest of the housing, and the data plate had separated from the housing. The interior of the housing was clear of deposits or discoloration.

The interior of the bushing appeared clean and clear of deposits. Portions of the interior surface within an 80 degree arc appeared polished consistent with sliding axial contact. The polished areas consisted of a semi-elliptical shape at the forward edge of the bushing, a circular area to the aft of the semi-elliptical area, and an area between the seals.

A close view of the piston is shown in figure 6. A polished circumferential mark approximately 0.05 inch wide was observed on the shaft approximately 1.47 inches from the aft end. The circumferential mark was up to 0.15 inch wide within a 70 degree arc with the aft edge of the mark located approximately 0.1 inch closer to the aft end. Slight longitudinal scratch marks were observed extending between 1.14 inches and 4.25 inches from the aft end of the piston. Some faint longitudinal marks extended up to 6.67 inches from the aft end of the piston. On the forward edge of the forward land, flat deformation of the corner was observed. A close view of this corner flat is shown in figure 7. In the land adjacent to the forward land, 10 longitudinal scratch marks were observed. A close view of five of these scratch marks is shown in figure 7.

Seals on the connector fittings, pipe, bushing, and piston appeared intact. Bearings at the ends of the actuator assembly moved freely.

C.1.b. Left Inboard Actuator and Hydraulic Lines

The left inboard actuator components are shown in figure 2. The left inboard actuator housing and hydraulic lines had similar levels of soot deposits as was observed on the left outboard actuator, but the piston also showed soot deposits. The exterior surfaces of the hydraulic lines were blackened, and a green liquid dripped from the fractured end of one line. The interior of the connector fittings were clear of deposits. The exterior of the pipe was blackened, and interior of the pipe was free of deposits.

A close view of the actuator housing is shown in figure 8. The forward end of the actuator housing exterior surface was blackened and tinted darker than the rest of the housing. A view of the interior of the housing is shown in figure 9. A thin gray deposit was observed on the surface at the forward end of the housing interior. The interior was rinsed with alcohol into a dish to collect the deposit, but the deposit disintegrated into many small pieces and was not recovered for analysis.

The interior of the bushing appeared clean and clear of deposits. Portions of the interior surface appeared polished consistent with sliding axial contact. The polished areas consisted of an area 0.3 inch wide and 0.1 inch deep at the forward edge of the bushing and an irregular shaped region up to 0.5 inch wide extending from the forward edge aft to the seals.

A close view of the piston is shown in figure 8. Black soot deposits were observed on the aft end of the piston within up to 4.5 inches from the aft end. A polished circumferential mark approximately 0.02 inch wide was observed on the shaft approximately 1.47 inches from the aft end. Slight longitudinal scratch marks were observed extending from 1.16 inches from the aft end to 4.30 inches from the aft end. Some faint longitudinal scratches ended at 3.85 inches from the aft end, and others appeared to extend up to 7.06 inches from the aft end. A slight discoloration and roughness was observed between 6.4 and 6.5 inches from the aft end. Faint longitudinal scratches were observed continuously extending over the area of discoloration and roughness consistent with the scratches occurring after the discoloration and roughness. A 0.06-inch long circumferential mark was observed at a location 2.05 inches from the aft end. A close view of the circumferential mark is shown in figure 10.

Seals on the connector fittings, pipe, and bushing appeared intact. Seals on the piston were intact, but expanded to a larger diameter. The spherical bearing at the forward end of the actuator assembly was stiff, but could be moved by hand. The spherical bearing at the aft end of the actuator assembly moved freely by hand.

C.1.c. Right Inboard Actuator and Hydraulic Lines

The right inboard actuator components are shown in figure 3. The right inboard actuator and hydraulic lines were darkened with soot deposits and heat tinting along their entire lengths. Green and black fluid was observed on the exterior surfaces of the hydraulic lines. Black deposits were observed on the interior of the connector fittings. The exterior of the pipe was blackened, and interior of the pipe was mostly obstructed with black deposits.

A close view of the actuator housing is shown in figure 11. The aft end of the actuator housing exterior surface was blackened and tinted darker than the rest of the housing. The interior surfaces were mostly covered with black deposits. Some green fluid was also observed on the interior surface of the housing.

A close view of the piston and bushing is shown in figure 11. The bushing was frozen on the piston against the stop flange on the piston. Black soot deposits were observed on the aft end of the piston within up to 1.1 inches from the aft end. The remainder of the piston surface was heat tinted. A dark-tinted circumferential mark approximately 0.06 inch wide was observed on the shaft approximately 1.48 inches from the aft end. Slight longitudinal scratch marks were observed extending from 1.18 inches from the aft end to 4.24 inches from the aft end. Some faint longitudinal scratches ended at 3.90 inches from the aft end. A cluster of longitudinal scratches approximately 0.10 to 0.20 inch long was observed on the shaft between 2.90 and 3.11 inches from the aft end of the piston. A close view of the aft end of the piston is shown in figure 12, and a closer view of the cluster of longitudinal scratches is shown in figure 13. Faint circumferential scratches appeared to coincide with the ends of the cluster of longitudinal scratches. The aft surface of the bushing was located 6.5 inches from the aft end of the piston. The forward corner of the forward land on the piston had a flat deformation similar to the corner flat observed on the forward land of the left outboard flap actuator piston.

Seals on the connector fittings were missing, and sooty deposits were observed in their place. Seals on the pipe were degraded, and material from the seals easily transferred off the seals when touched. Seals on the piston and bushing exterior were deformed with smooth surfaces consistent with deformation under high heat. Green seal material emanated from the aft side of the bushing. The spherical bearing at the forward end of the actuator assembly could not be moved by hand. The spherical bearing at the aft end of the actuator assembly moved freely by hand.

The structural pieces shown in figure 3 consisted of pieces of structure from the aft side of the actuator (smaller piece) and the forward side of the actuator (larger piece). Fractures on the aft structure piece had a speckled appearance with secondary cracking consistent with overstress fracture at high temperature. The forward structural piece also showed fractures with a speckled appearance and secondary cracks. Flowed metal and lamellar (woody) fracture features were also observed, all features consistent with overstress fracture at high temperature.

C.1.d. Right Outboard Actuator and Hydraulic Lines

The right outboard actuator components are shown in figure 4. The right outboard actuator and hydraulic lines were darkened with soot deposits and heat tinting along their entire lengths. Green fluid was observed dripping from the end of the shorter of the two lengths of hydraulic lines. Black deposits were observed on the interior of the connector fittings partly obstructing one fitting and completely obstructing the other fitting. The pipe was attached to the housing, and the exterior of the pipe was blackened.

A close view of the actuator housing is shown in figure 14. The actuator housing exterior surface was blackened and tinted brown relatively uniformly along its entire length. The interior surfaces were mostly covered with black, orange, and green deposits. Some green fluid was also observed on the interior surface of the housing. Views of deposits on the housing interior surfaces are shown in figures 15 and 16.

A close view of the piston and bushing is shown in figure 14. The bushing was frozen on the piston near the aft end of the piston. The distance between the forward end of the bushing and the stop flange on the piston was measured at 4 locations around the circumference of the piston, and at each location the distance measured was 5.412 inches. The length of the bushing measured 2.089 inches, and the aft end of the bushing was located 1.091 inches from the aft end of the piston. Black soot deposits were observed on the end of the piston aft of the bushing.

The piston was received sealed in a plastic bag. A green fluid was present on the surface of the piston shaft. Records show that when the flap actuator was examined at the manufacturer's facility, the green material had been a crystalline solid. After the piston was removed from the plastic bag for examination in the NTSB Materials Laboratory, the green fluid gradually began to recrystallize.

After samples of the green fluid were removed, the actuator piston was cleaned using alcohol to facilitate examination of the piston surface. Most of the piston shaft surfaces remained covered with a thin greenish gray film that covered most of the piston shaft surfaces and was not removed when cleaned using ethanol. Very faint longitudinal scratch marks were observed extending up to 7.04 inches from the aft end.

Seals on the connector fittings were missing, and sooty deposits were observed in their place. Seals on the piston and bushing had hazy crater-like and pitted surfaces consistent with exposure to high heat. Material from the forward seal on the piston was deformed over the forward land. Spherical bearings at the ends of the actuator assembly were outside of their housings, and both bearings could not be moved by hand. The aft spherical bearing was attached to a small structural piece.

The structural pieces shown in figure 4 consisted of pieces of structure from the aft side of the actuator (smaller piece) and the forward side of the actuator (larger piece). Fractures on both structural pieces showed areas of lamellar (woody) fracture features and features with a speckled appearance and secondary cracks, features consistent with overstress fracture at high temperature.

C.2. Dimensional Measurements

Each flap actuator piston was placed on V-blocks in an optical comparator, and the profile was viewed at 10 to 20 times magnification. While viewing the profile, each piston was displaced along the longitudinal axis along the exposed length of the piston shaft, then the piston was rotated approximately 90 degrees and scanned again. For the left outboard and left inboard actuators, the entire length of the piston shaft was scanned at 10 times magnification, and all four scans showed straight shafts without detectable deviations in straightness along the entire length of the shaft. For the right inboard and outboard pistons, the bushing covered portions of the shaft. However, the exposed portions of the shaft were scanned at 20 times magnification and showed no detectable deviations in straightness.

Using an inside micrometer, the inside diameter of the flap actuator housings were measured at a location approximately 4 inches forward of the aft end of the housing. Measurements aligned in the horizontal and vertical planes were taken. Results of the measurements are shown in table 1.

Table 1. Actuator Housing Inner Diameter Measurements

Actuator Housing	Inner Diameter (inch)	
	Horizontal	Vertical
Left Outboard	1.4909	1.4905
Left Inboard	1.4916	1.4909
Right Inboard	1.4916	1.4916
Right Outboard	1.4898	1.4916

The outer diameter of the piston shafts were measured at two positions approximately 90 degrees apart. The results of the piston diameter measurements are shown in table 2.

Table 2. Piston Shaft Outer Diameter Measurements

Piston	Outer Diameter (inch)	
	Position 1	Position 2
Left Outboard	1.2473	1.2473
Left Inboard	1.2471	1.2472
Right Inboard	1.2474	1.2474
Right Outboard	1.2474	1.2472

The inner diameters of the bushings were measured near the forward ends of the bushings. The bushings from the left outboard and left inboard actuators were intact, and for those bushings the inner diameters were measured with an inside micrometer at two positions located approximately 90 degrees apart. The bushing from the right outboard actuator had been cut to separate it from the piston, and for that bushing the diameter was measured using a SmartScope optical measurement device. The inner diameter of the bushing from the right inboard actuator was not measured. Results of the bushing inner diameter measurements are shown in table 3.

Table 3. Bushing Inner Diameter Measurements

Bushing	Inner Diameter (inch)	
	Position 1	Position 2
Left Outboard	1.279	1.249
Left Inboard	1.249	1.249
Right Inboard	---	---
Right Outboard	1.248	

C.3. CT Scans

Computed tomography (CT) scans of the flap actuator housings and pistons were completed at the Federal Bureau of Investigation Laboratory in Quantico, Virginia using a Hytec, Inc., FlashCT Radiographic Scanner model FCT-3200. The scans were reconstructed into 3D models, and slice-view images were obtained in two longitudinal planes intersecting near the longitudinal axis and one transverse plane near midspan. The slice-view images for the right outboard housing are shown in figure 17. The linearity of the housing sidewalls were checked for each housing, and no deviations from linearity were detected. However, given the resolution of the images and the gradients in pixel brightness in the housing interior, it is unlikely that any small deviations in linearity would be detected by this method.

C.4. Examination of Sectioned Components

The bushing from the right outboard piston was sectioned from the piston using an abrasive wheel cut-off saw. An overall view of the piston and bushing after cutting is shown in figure 18. The bushing interiors were mostly dull orange with green and black deposits. Original surface machining marks were observed in isolated areas. No polished areas consistent with wear were observed on the surfaces not covered in deposits. No evidence of galling or deformation of the bushing was observed. Interior seals of the bushing were degraded consistent with exposure to high heat.

In the area of the piston that had been under the bushing, patches of green deposits and reflective shaft surfaces were observed. Faint longitudinal scratches were observed extending through the reflective regions. A dark circumferential mark consistent with a seal contact area during heat exposure was observed up to 0.07 inch wide at a location 1.47 inches from the aft end of the shaft. A ring of green material was observed that had filled the corner between the shaft and the forward edge of the bushing. This green material was hard and broke apart when squeezed or poked with tweezers.

A sample of the green material was placed on an aluminum stub covered with carbon tape for analysis using energy dispersive x-ray spectroscopy (EDS). A typical EDS spectrum of the green material is shown in figure 19. A large peak of phosphorus was observed with smaller peaks of iron, chromium, nickel, copper, aluminum, silicon, oxygen, and carbon.

Using an abrasive wheel cut-off saw, the flap actuator housings were sectioned longitudinally along the length of the housing to expose the interior surfaces for close visual examination. Overall views of the interiors of the sectioned housings are shown in figures 20 to 23. The left outboard flap actuator housing was sectioned in approximately the vertical plane, while the remaining three actuator housings were sectioned in approximately the horizontal plane.

The interior surface of the left outboard flap actuator housing is shown in figure 20. The surface was reflective with manufacturing marks at 45 degree angles and no deposits along its entire length. The forward end up to 3.6 inches from the forward end of the actuator interior was more polished than the remainder of the surface with faint longitudinal scratches consistent with wear from piston displacement under normal actuation. A circumferential line was observed at a location 0.75 inch from the forward end of the interior, consistent with contact with the forward end of the piston middle seal in the retracted position.

Approximately 10 longitudinal scratch marks, each approximately 0.1 inch long, were observed on the lower portion of the left outboard flap actuator housing interior spread across both halves of the sectioned housing. A view of five of the scratch marks are shown in figure 24. The scratch marks were similar in appearance to those observed on the left outboard flap actuator piston land as shown in figure 7. The longitudinal scratch marks were located between 0.85 and 1.35 inches from the forward end of the housing interior. A nearly circumferential scratch mark, shown in figure 25, was also observed on the left outboard actuator housing interior. The nearly circumferential scratch was approximately 0.08 inches long located in the lower outboard quadrant of the housing interior and was 2.29 inches from the forward end of the housing interior.

An overall view of the left inboard flap actuator housing interior is shown in figure 21. A gray film was observed over much of the upper surface and parts of the lower surface at the forward end of the housing interior. Somewhat thicker greenish gray deposits were generally observed at the edges of the gray film. Faint longitudinal scratches were observed ending approximately 3.6 inches from the forward end of the housing interior.

The surfaces within the normal working area of the piston appeared less polished or worn than that of the left outboard housing interior. Faint circumferential scratches were observed on the lower half of the actuator housing interior at a location 1.33 inches from the interior forward end.

An overall view of the right inboard flap actuator housing interior is shown in figure 22. The interior was mostly covered with brown, gray, and black deposits. Faint longitudinal scratches were observed near the forward end of the actuator, but the ends were obscured by deposits.

An overall view of the right outboard flap actuator housing interior is shown in figure 23. Brown, green, gray, and black deposits covered nearly all of the interior surfaces. A light green gelatinous material was observed in the vicinity of the hydraulic fluid inlet hole for actuator retraction near the aft end of the housing interior. Similar-appearing light green material was observed in the threaded hole on the exterior of the housing where the inboard connector fitting had been attached. Black deposits were observed in the hydraulic fluid inlet hole for actuator extension at the forward end of the actuator housing interior.

Samples of deposits from the interior of the right outboard actuator housing were collected for examination using EDS. Using tweezers, samples were placed on aluminum stubs covered with carbon tape. Brown and green deposits from the interior surface, light green deposits from the hydraulic fluid inlet hole for retraction, and black deposits from the hydraulic fluid inlet hole for extension were collected. The brown and green deposits crumbled fairly easily when probed with tweezers. Beneath the brown and green deposits, a thin flat layer with a yellow brown reflective appearance was observed. The light green deposits from the retraction hole were gelatinous when probed by tweezers, but eventually solidified to an easily broken solid after time on the aluminum stub. The black deposit from the extension hole was a mix of fluid and particles. This sample was placed into an ethanol bath before mounting on the aluminum stub. When in ethanol, the deposit sample broke into smaller groups of fine particles that broke apart further when squeezed with tweezers. A small sample was recovered from the ethanol bath for EDS analysis.

Typical EDS spectra from the brown and green deposits and underlying thin flat yellow brown layers are shown in figures 26 and 27. The deposits typically showed a high peak of phosphorus with smaller peaks of iron, chromium, nickel, silicon, oxygen, and carbon. A small peak of calcium was detected on the surface of the brown and green layer and on the housing wall side of the thin yellow brown layer. The spectrum from the housing wall side of the thin yellow brown layer also showed smaller peaks for additional elements including titanium, cadmium, potassium, molybdenum, chlorine, aluminum, and sodium.

A typical EDS spectrum of the green deposit removed from the hydraulic fluid hole for actuator retraction is shown in figure 28. The spectrum showed a high peak of phosphorus with smaller peaks of iron, chromium, oxygen, and carbon.

A typical EDS spectrum of the black deposit removed from the hydraulic fluid hole for actuator extension is shown in figure 29. The spectrum showed a high peak of phosphorus with smaller peaks of iron, chromium, nickel, copper, zinc, calcium, potassium, aluminum, silicon, oxygen, and carbon.

C.5. Examination of Hydraulic Lines

Low-pressure compressed air was used to determine if the lengths of hydraulic lines had any obstructions that would completely restrict the flow of air through the lines. Air was introduced to the lines through an air pump needle that was inserted through the middle of a cone-shaped soft polymer plug such that the needle end of the air pump needle extended from the tip of the cone. The pointed end of the soft polymer cone was held by hand against the hydraulic line to provide the seal at that end of the line. The other end of the hydraulic line was inserted into a test tube to catch any outflow of material. In cases where both ends of the line were fractured, one end of the line was cut with a tube cutter to facilitate a good seal. In cases where a t-fitting was present, the t-fitting was disassembled as needed to allow testing of individual lengths of line.

Air was flowed through each hydraulic line piece from the left outboard flap actuator. Air flowed freely in all three pieces. Some semi-transparent black liquid discharged from the hydraulic line shown in the middle position in figure 1.

Air was flowed into both of the left inboard pieces. Air flowed through both hydraulic lines including line sections on either side of the t-fitting.

The section of hydraulic line from the right inboard flap actuator with the straight fitting was cut into 3 pieces and was separated at the fitting, creating 4 segments labeled RI-A to RI-D. Segment RI-A had air flow with some discharge of black deposits. No air flow was detected in segment RI-B. Segment RI-C had a transverse crack in the location of a bend. No air flow was detected from one end of segment RI-C to the crack, but air flow was detected between the other end of segment RI-C to the crack. Segment RI-D was a small approximately 1 inch long piece that was not tested for air flow.

The piece of hydraulic line from the right inboard flap actuator with the t-fitting was separated at the t-fitting. One piece of the line labeled segment RI-E had a black viscous discharge when air flowed through the line. The t-fitting was partly obstructed with black deposits. The remaining segment labeled segment RI-F had air flow with no discharge.

The three pieces of hydraulic line from the right outboard flap actuator were labeled RO-A to RO-C. Line RO-A had air flow, and solid material discharged from the end. Lines RO-B and RO-C had no air flow.

A wire was used to probe inside right outboard hydraulic line segments RO-B and RO-C to collect samples from the area of the obstruction. Samples collected from the lines were placed on an aluminum stub covered with carbon tape for EDS analysis. A sample of the black deposits that discharged from hydraulic line segment RO-A were similarly prepared for EDS analysis.

Results showing typical EDS spectra of deposits from the right outboard actuator hydraulic lines are shown in figures 30 to 32. All three samples showed a high peak of sulfur with smaller peaks of iron, chromium, nickel, silicon, aluminum, oxygen, and carbon.

Deposits were further examined with scanning electron microscopy (SEM) using backscattered electrons.[1] Bright colored particles with varying structure were observed within a darker gray matrix as shown in figures 33 to 35.

Figure 33 shows a typical bright particle with thin flat structure. A dashed line surrounds the particle shown in the backscattered SEM image in figure 33. The corresponding EDS spectrum for the thin flat particle is also shown in figure 33. EDS spectra typically showed a high peak of phosphorus with smaller peaks of iron, chromium, silicon, aluminum, oxygen, and carbon.

Figure 34 shows a typical bright particle with a higher aluminum peak in the EDS spectrum. A dashed line surrounds the particle shown in the backscattered SEM image in figure 34. The corresponding EDS spectrum for the particle is also shown in figure 34. EDS spectra typically showed high peaks of phosphorus and aluminum with smaller peaks of iron, oxygen, and carbon.

Figure 35 shows typical bright particles with facetted crystalline structures. The corresponding EDS spectrum for the facetted crystalline particles are also shown in figure 33. EDS spectra typically showed a high peak of phosphorus with smaller peaks of iron, chromium, silicon, aluminum, oxygen, and carbon.

C.6. Filters

Overall views of the inboard and outboard filters for the blue hydraulic system are shown in figures 36 and 37. The exterior surfaces of the filters appeared mostly clear of debris and deposits. However, isolated green deposits were observed on the inboard filter, and isolated black deposits were observed on the black filter.

A close view of the surface of the inboard filter is shown in figure 38. Arrows in figure 38 indicate locations of green deposits in this view. A sample of the green deposits were removed from the filter with tweezers. The deposits felt compressible and resilient when squeezed and poked with tweezers. The deposits were cleaned in an alcohol bath and then placed on an aluminum stub covered with carbon tape. A close view of one of the cleaned green deposits is shown in figure 39.

Typical EDS spectra for the green deposit in figure 39 are shown in figures 40 to 42. The overall EDS spectrum showed high peaks of calcium and carbon with smaller peaks of iron, nickel, barium, chlorine, sulfur, phosphorus, silicon, aluminum, magnesium, fluorine, oxygen, and carbon. In backscattered SEM images, the green deposit showed bright

[1] SEM images produced using backscattered electrons have contrast that is associated with atomic weight of the elements in the image. Materials with elements having higher atomic weights appear relatively lighter than others having elements with lower atomic weights.

particles in a darker matrix as shown in figure 43. A typical EDS spectrum in the darker matrix area showed primarily a high peak of calcium as shown in figure 41. A typical EDS spectrum of one of the brighter particles in the green deposit is shown in figure 42, where high peaks of silicon and aluminum with smaller peaks of iron, chromium, nickel, titanium, calcium, potassium, molybdenum, magnesium, sodium, oxygen, and carbon were observed.

A close view of the surface of the outboard filter is shown in figure 44. Some of the black deposits had a thin fibrous appearance while other deposits had a globular particulate appearance. Arrows in figure 44 indicate locations of black globular deposits in this view. A sample of the black globular deposits were removed from the filter with tweezers. The deposits were easily deformed when squeezed and poked with tweezers. The globular black deposits were cleaned in an alcohol bath and began to break apart into smaller particles. The cleaned globular black deposits were placed on an aluminum stub covered with carbon tape for EDS analysis.

A typical EDS spectrum of the black globular deposits is shown in figure 45. High peaks of phosphorus and potassium with smaller peaks of iron, chromium, nickel, manganese, silicon, sodium, oxygen, and carbon were observed. A backscattered electron SEM view of the black globular particle is shown in figure 46. Bright particles and medium gray particles were observed in the deposit. Figure 47 shows an EDS spectrum of one of the medium particles showing primarily a high peak of silicon. Typical EDS spectra of bright particles in the deposit are shown in figure 48. Most particles showed a high peak of iron with smaller peaks of chromium, nickel, and manganese as shown in the upper spectrum in figure 48. A few particles showed primarily peaks of silver and sulfur as shown in the lower spectrum in figure 48.

Matthew R. Fox
Senior Materials Engineer

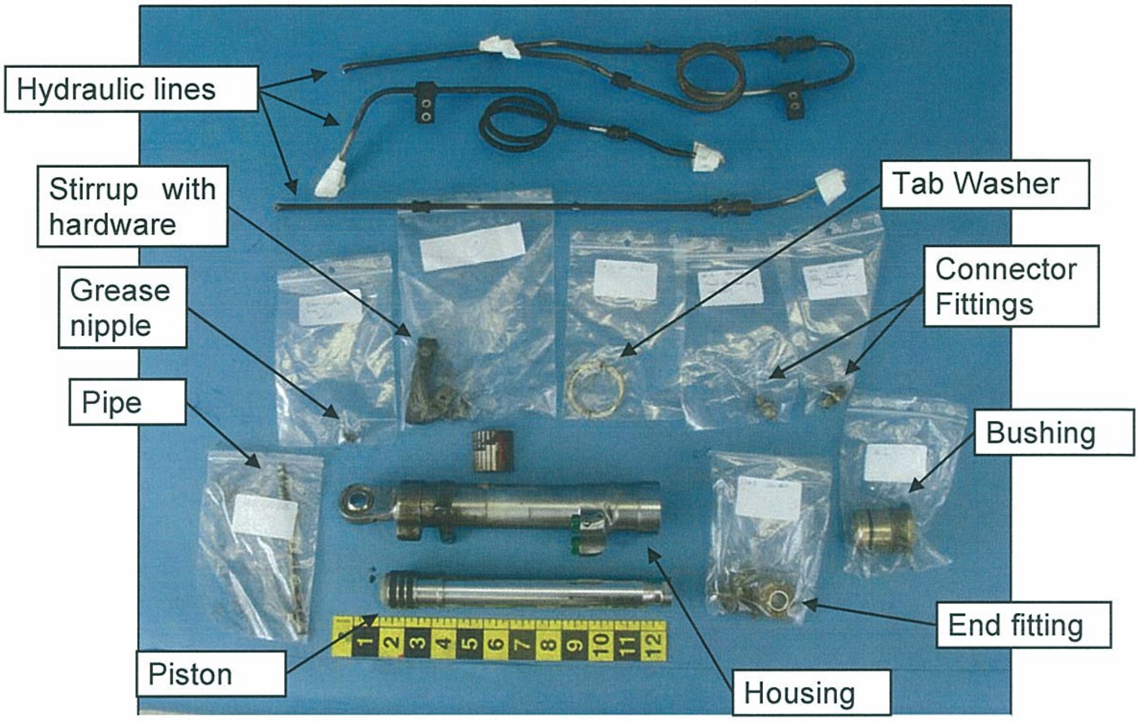


Figure 1. Overall view of the left outboard flap actuator and hydraulic lines.

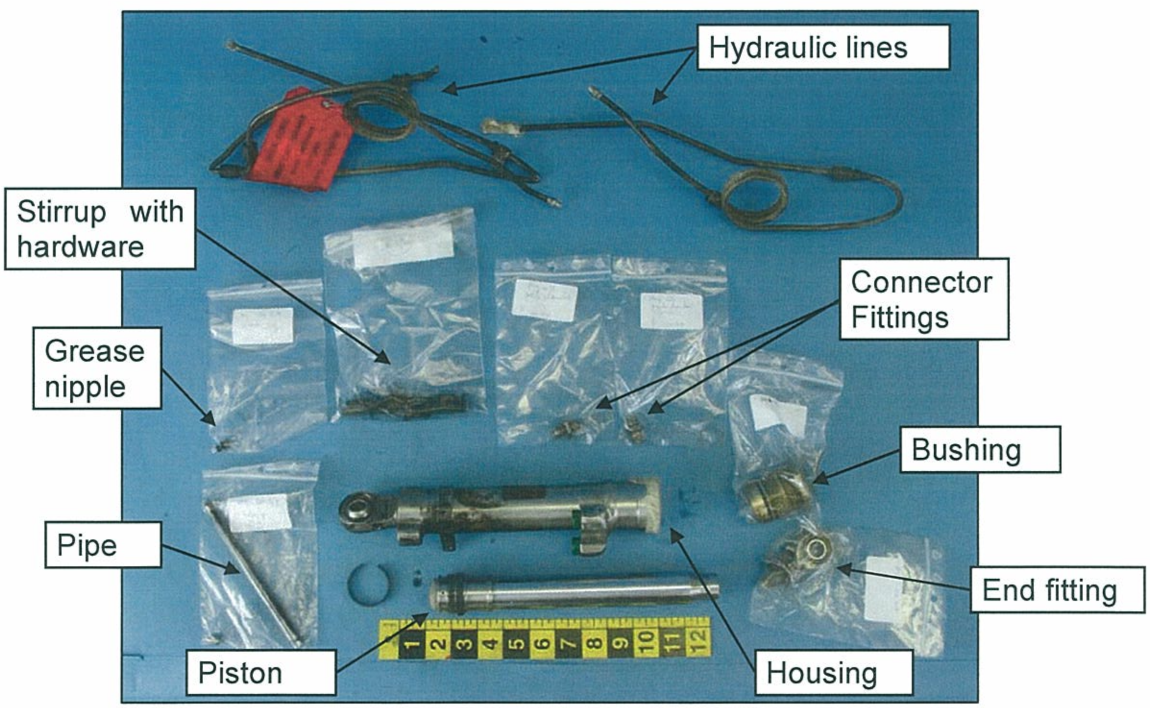


Figure 2. Overall view of the left inboard flap actuator and hydraulic lines.

Figure 3. Overall view of the right inboard flap actuator and hydraulic lines.

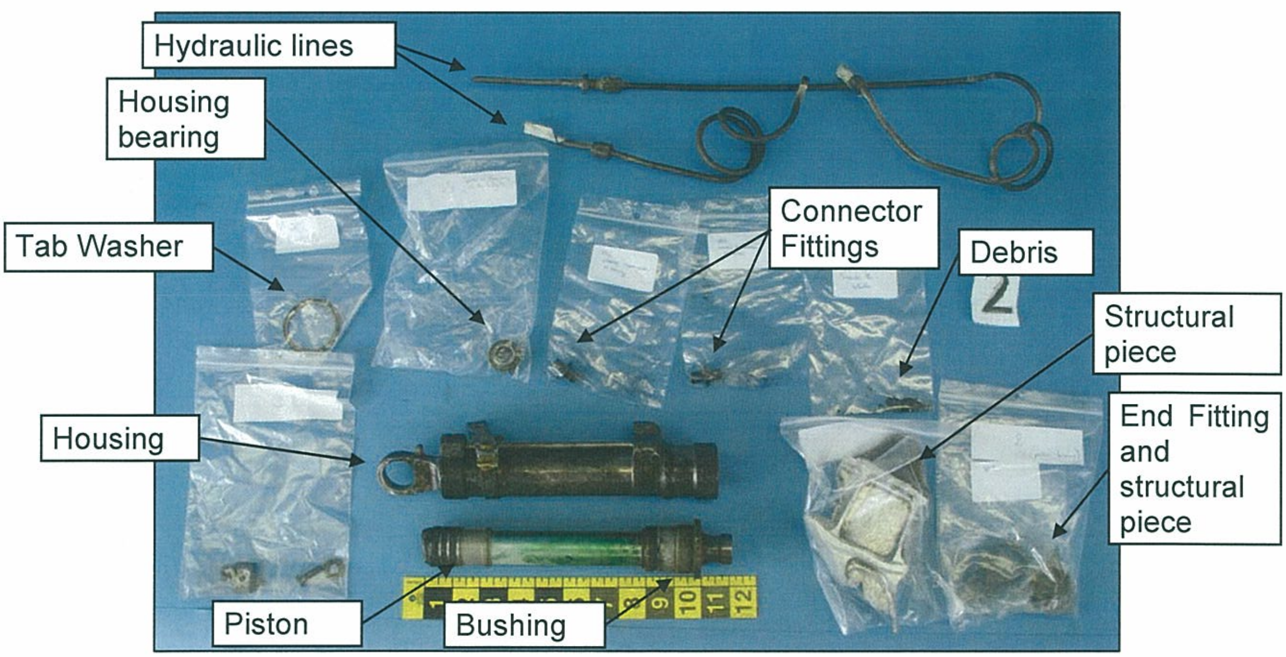


Figure 4. Overall view of the right outboard flap actuator and hydraulic lines.

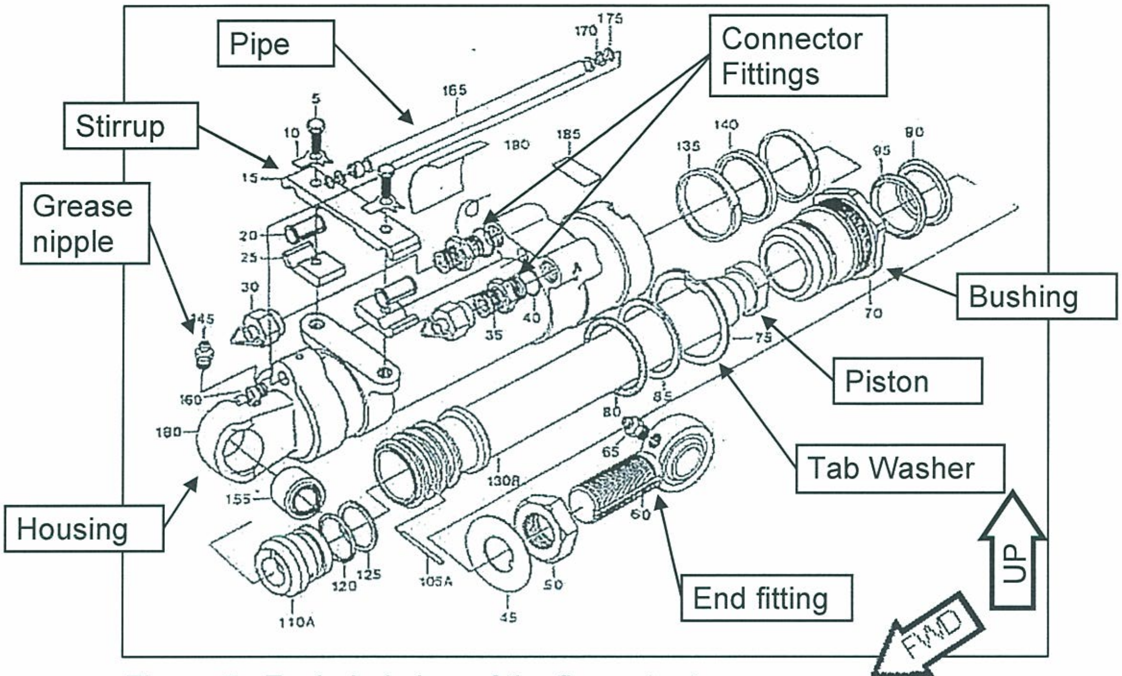


Figure 5. Exploded view of the flap actuator components.

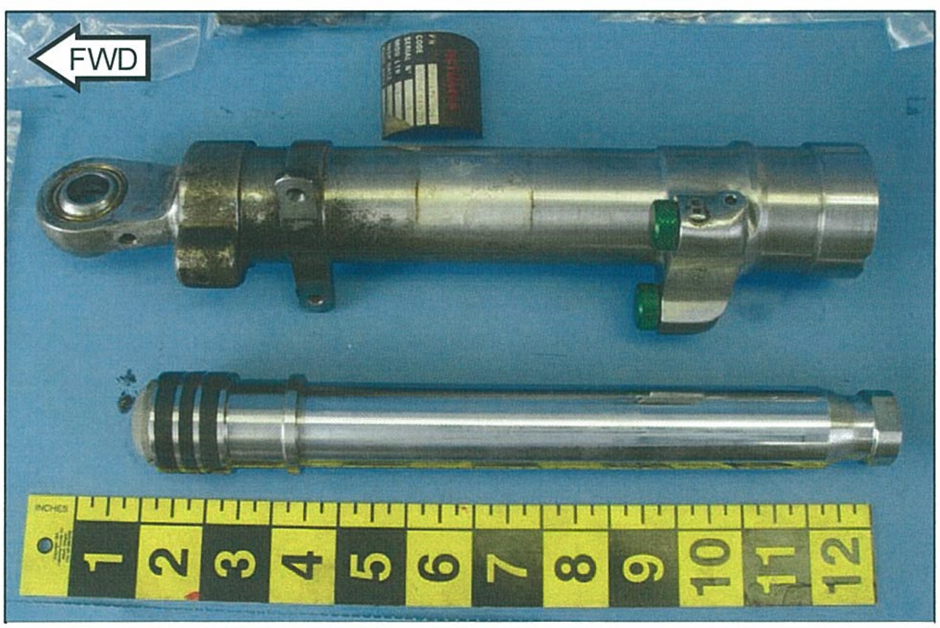
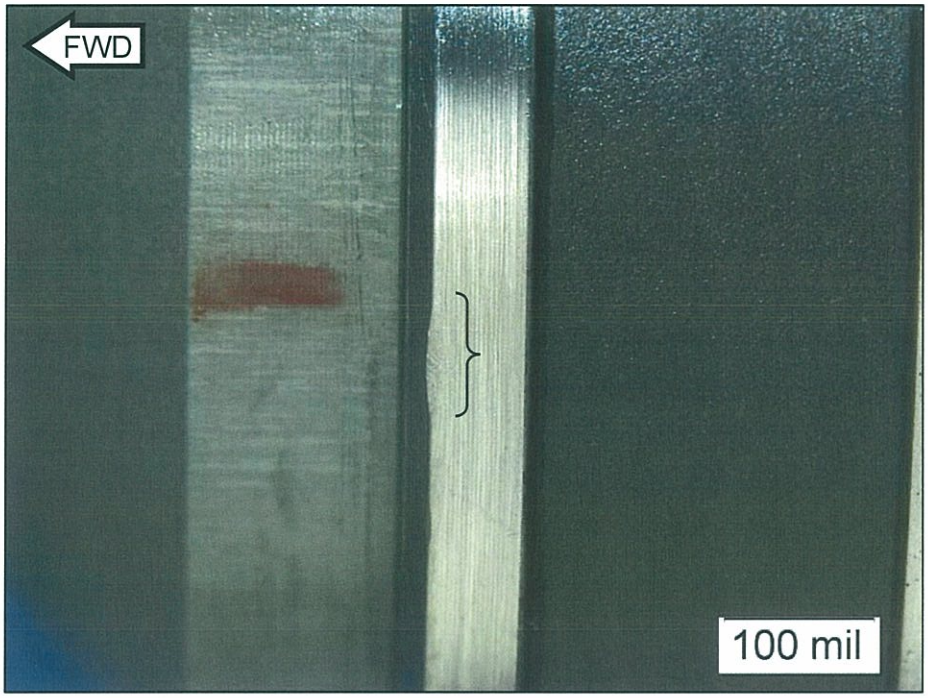


Figure 6. Close view of the left outboard flap actuator housing and piston.



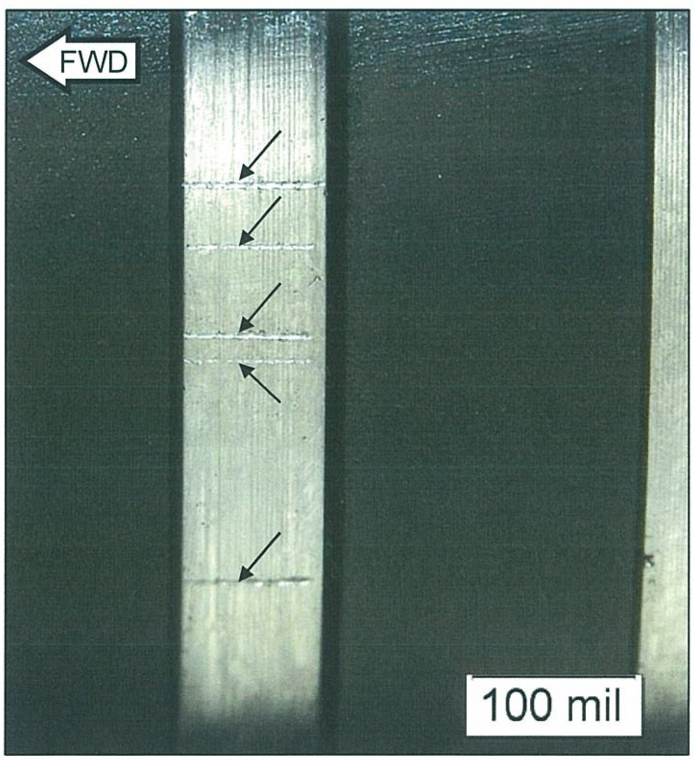


Figure 7. Close view of the forward land (above) and the forward middle land (left) on the left outboard actuator piston. An unlabeled bracket in the upper photo indicates a flat spot observed at the forward edge of the forward land, and unlabeled arrows in the left photo indicate longitudinal scratch marks on the land.

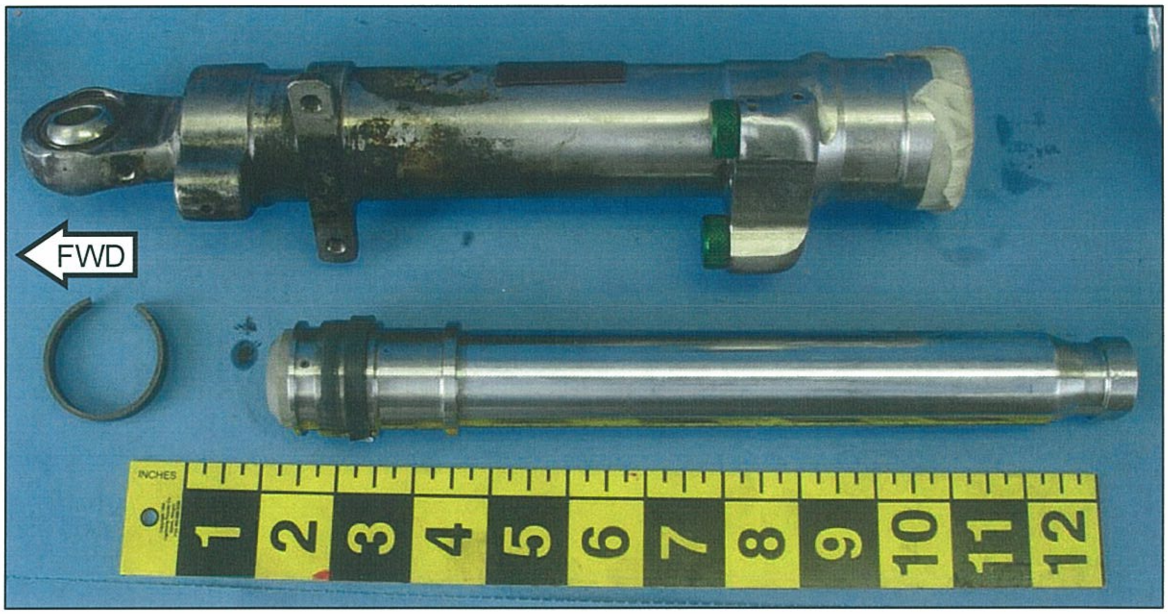


Figure 8. Close view of the left inboard flap actuator piston and housing.

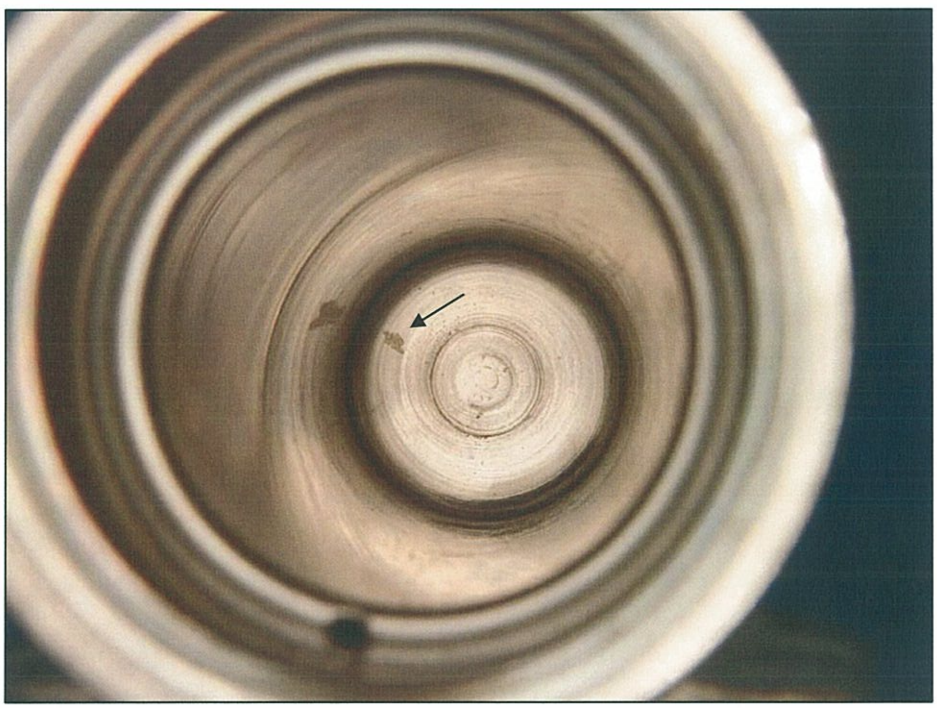


Figure 9. View of the interior of the left inboard flap actuator housing. An arrow indicates a thin gray deposit on the interior.

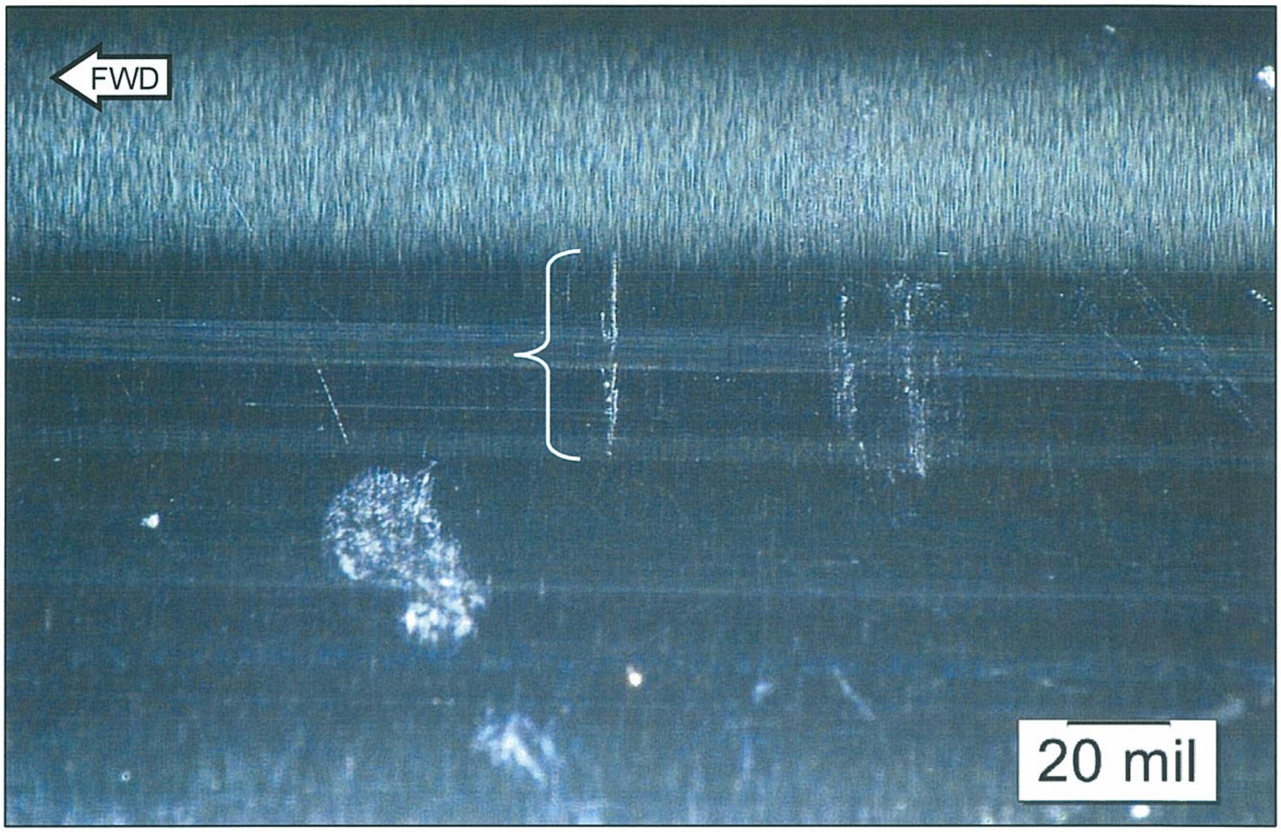


Figure 10. View of the right inboard flap actuator piston shaft surface near the aft end of the piston. An unlabeled bracket indicates a circumferential mark observed on the surface.

Figure 11. Close view of the right inboard flap actuator piston and housing with the bushing remaining in place on the piston.

Figure 12. Close view of the aft end of the right inboard flap actuator piston.

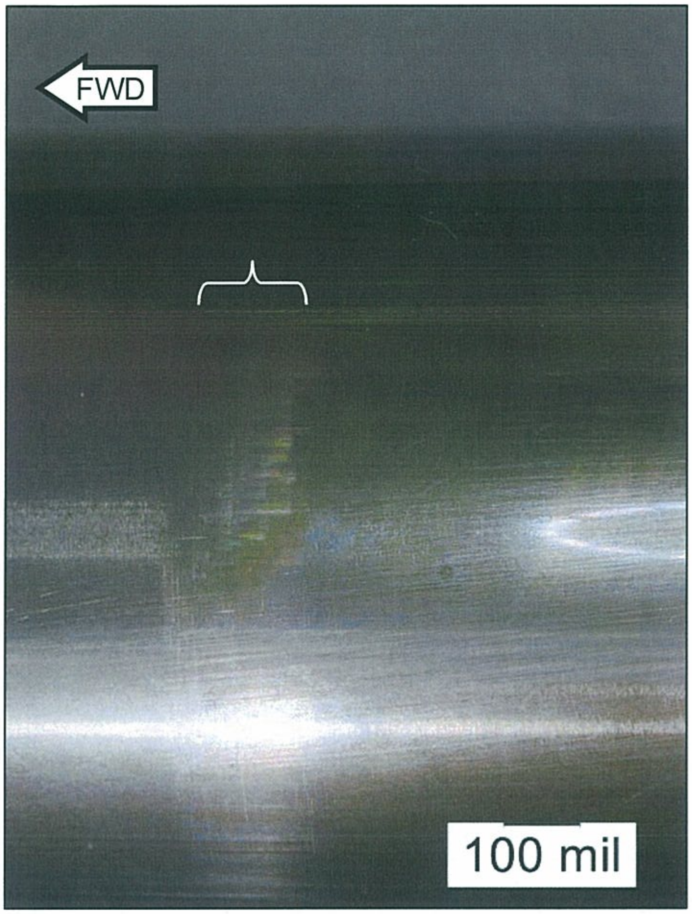


Figure 13. Close view of the right inboard flap actuator at a location approximately 3.1 inches from the aft end of the piston. An unlabeled bracket indicates a cluster of faint short longitudinal scratch marks and circumferential marks.

Figure 14. Close view of the right outboard flap actuator piston and housing.

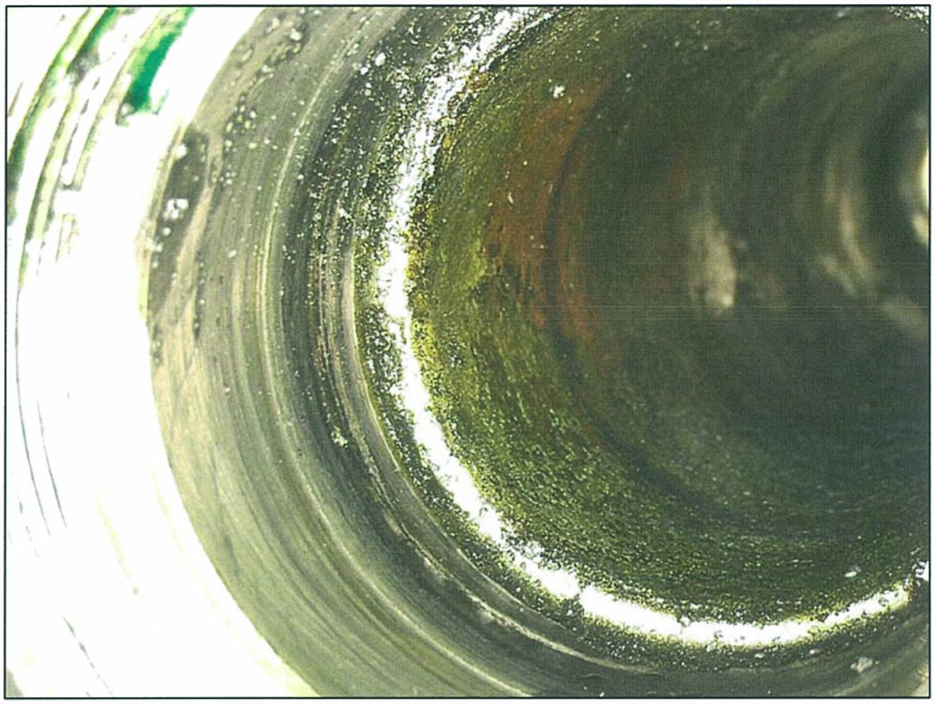


Figure 15. View of the interior of the right outboard flap actuator housing.

Figure 16. Closer view of deposits on the right outboard flap actuator housing interior.

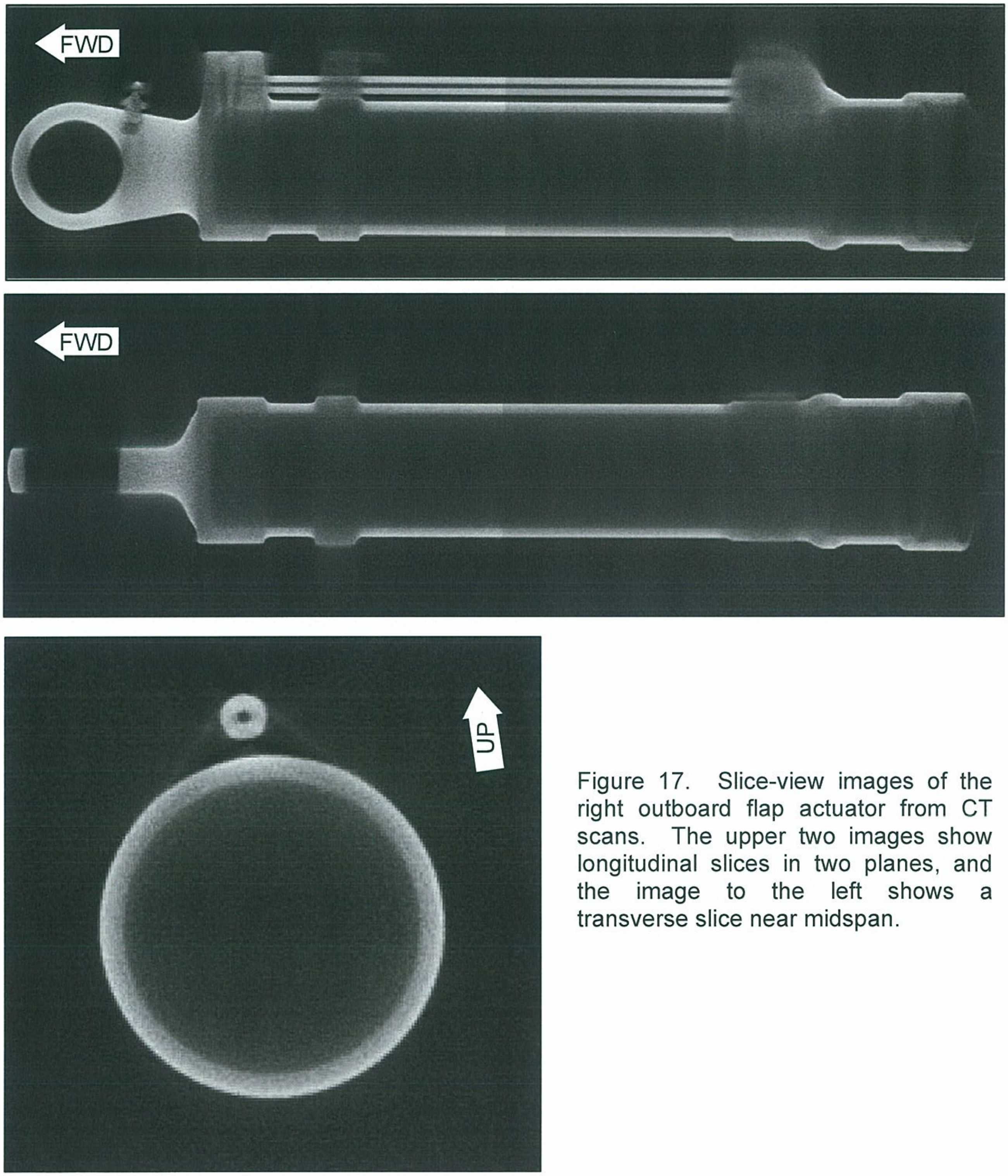


Figure 17. Slice-view images of the right outboard flap actuator from CT scans. The upper two images show longitudinal slices in two planes, and the image to the left shows a transverse slice near midspan.

Figure 19. Typical EDS spectrum of green material removed from the right outboard flap actuator piston adjacent to the location where the bushing had been before cutting.

Figure 18. Close view of the right outboard flap actuator piston and interior surfaces of the bushing after sectioning the bushing from the piston.

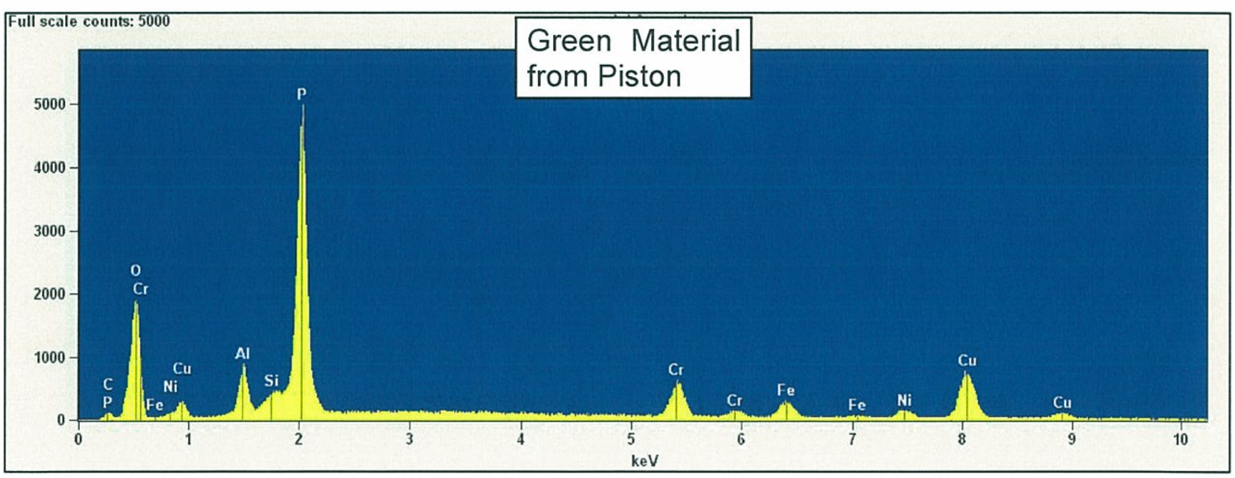


Figure 20. View of the left outboard flap actuator housing interior surface after sectioning.

Figure 21. View of the left inboard flap actuator housing interior surface after sectioning.

Figure 22. View of the right inboard flap actuator housing interior surface after sectioning.

Figure 23. View of the left outboard flap actuator housing interior surface after sectioning.

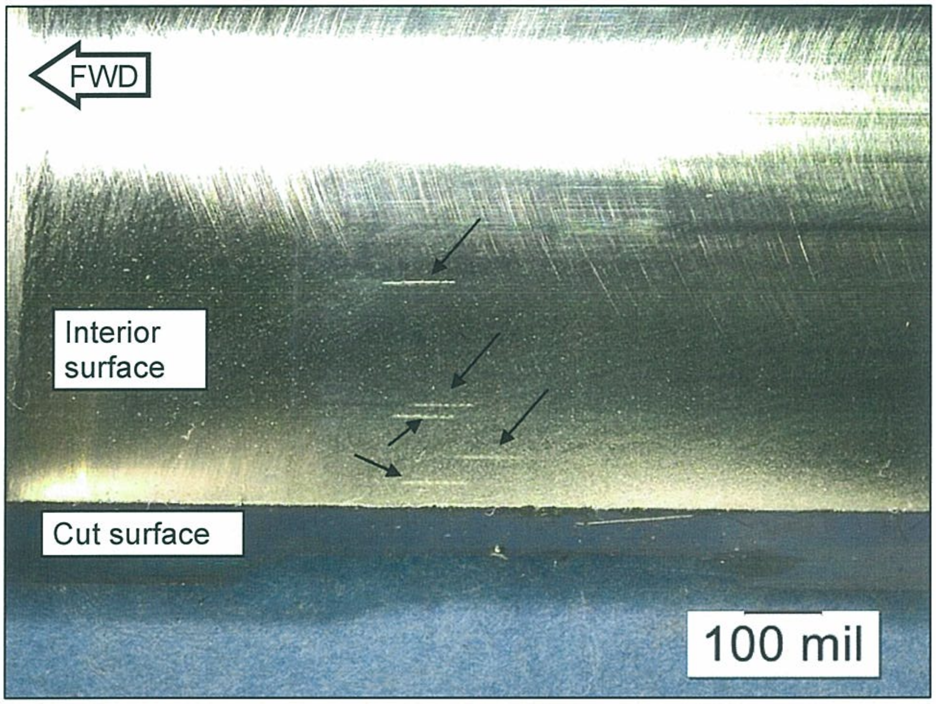


Figure 24. Five of the longitudinal marks, indicated with unlabeled arrows, observed on the interior of the left outboard housing.

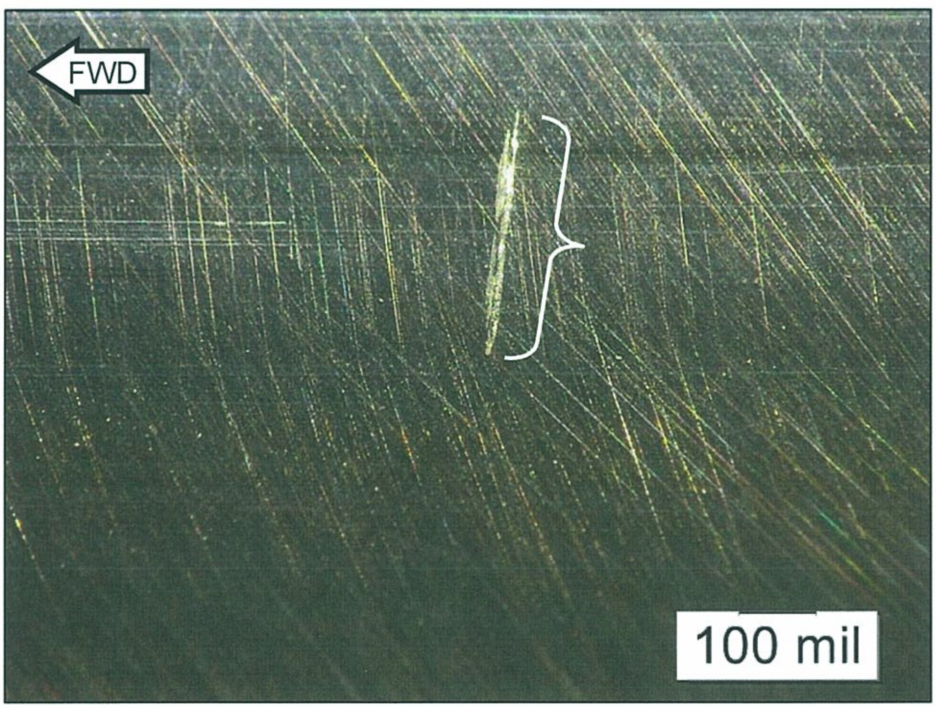


Figure 25. Nearly circumferential mark, indicated with an unlabeled bracket, observed on the interior of the left outboard housing.

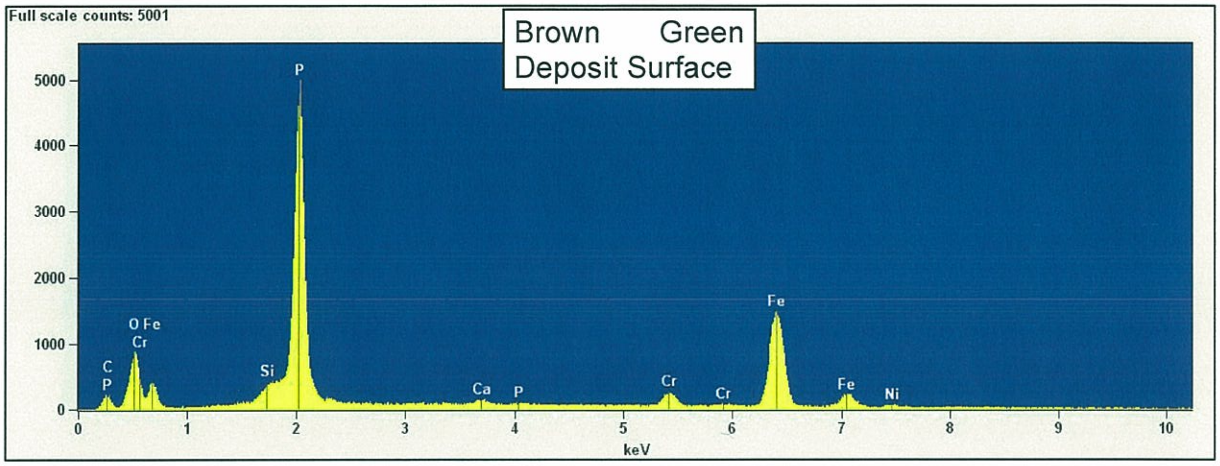


Figure 26. Typical EDS spectrum obtained from brown and green deposits removed from the interior surface of the right outboard flap actuator housing.

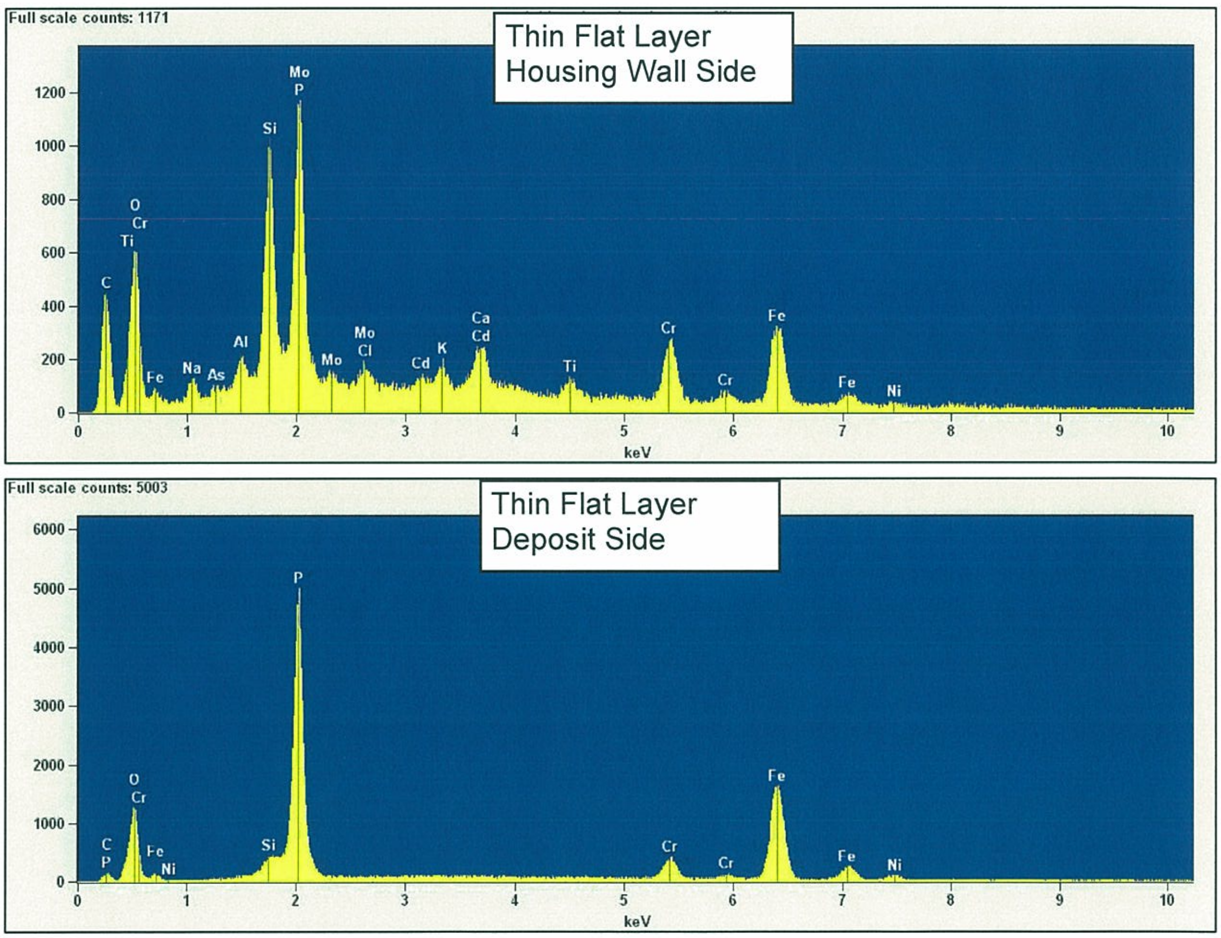


Figure 27. Typical EDS spectra of thin yellow-brown layers on the right outboard housing interior from surfaces mating to the housing wall (upper spectrum) and from the surface mating to deposits on the plate layers (lower spectrum).

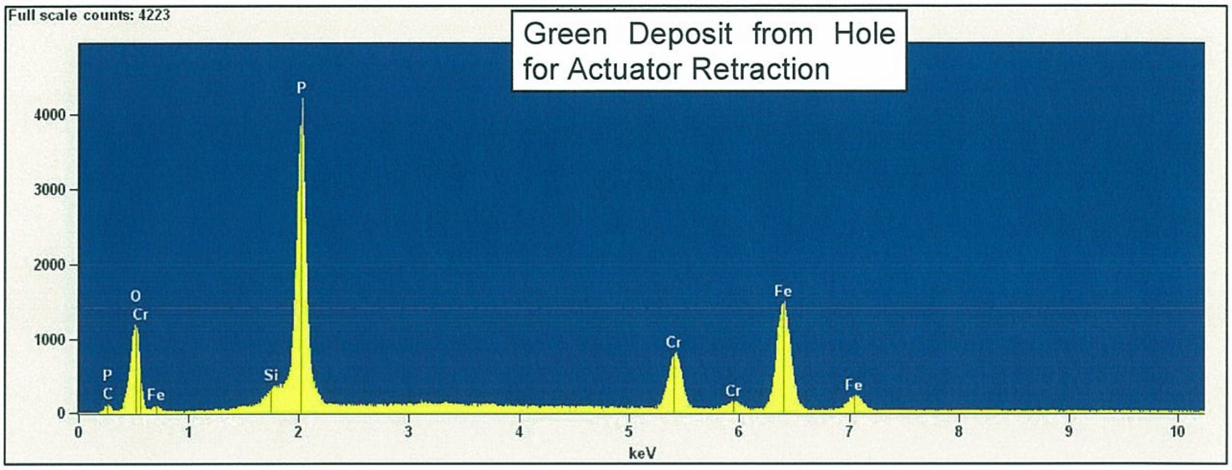


Figure 28. Typical EDS spectrum of green material removed from the hydraulic fluid hole for actuator retraction in the right outboard flap actuator housing interior.

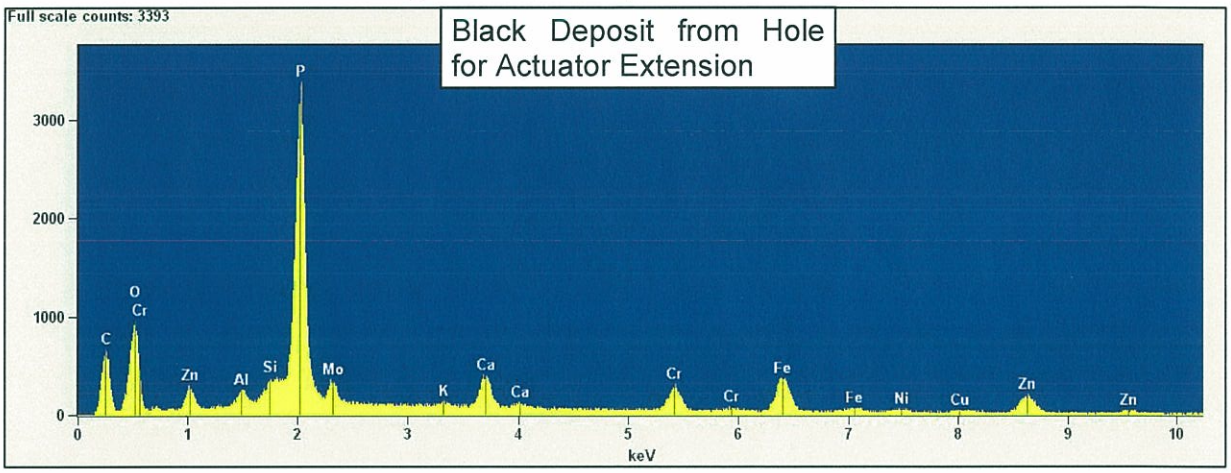


Figure 29. Typical EDS spectrum of black deposits removed from the hydraulic fluid hole for actuator extension in the right outboard flap actuator housing interior.

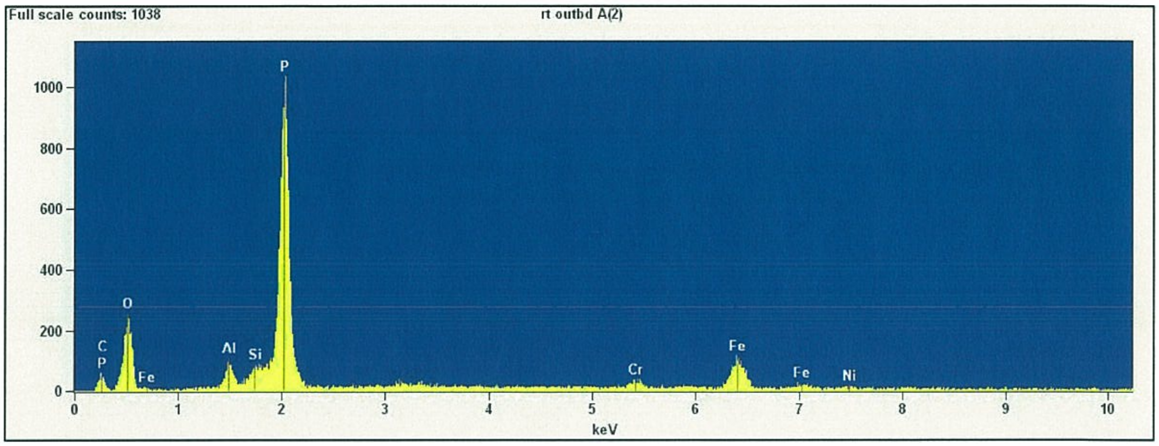


Figure 30. Typical EDS spectrum of deposits discharged from the right outboard hydraulic line RO-A.

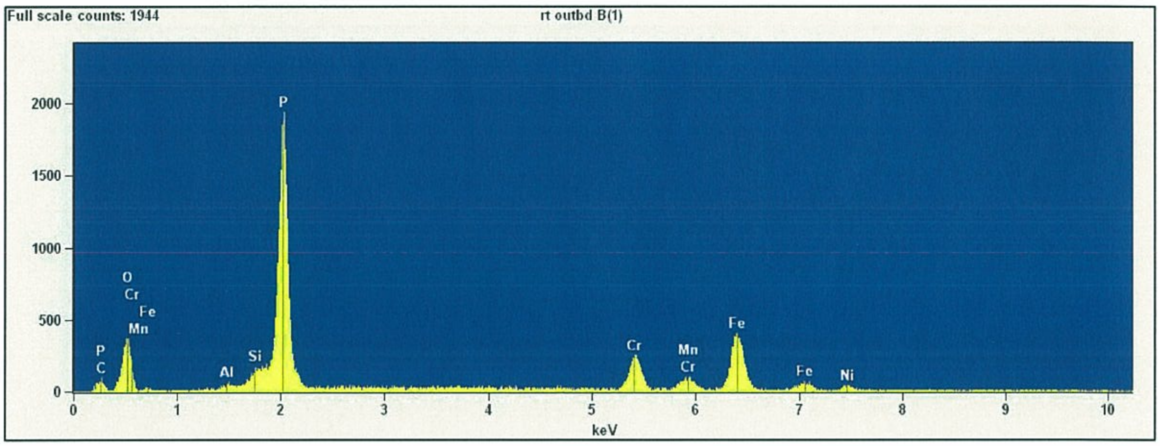


Figure 31. Typical EDS spectrum of deposits removed from the right outboard hydraulic line RO-B.

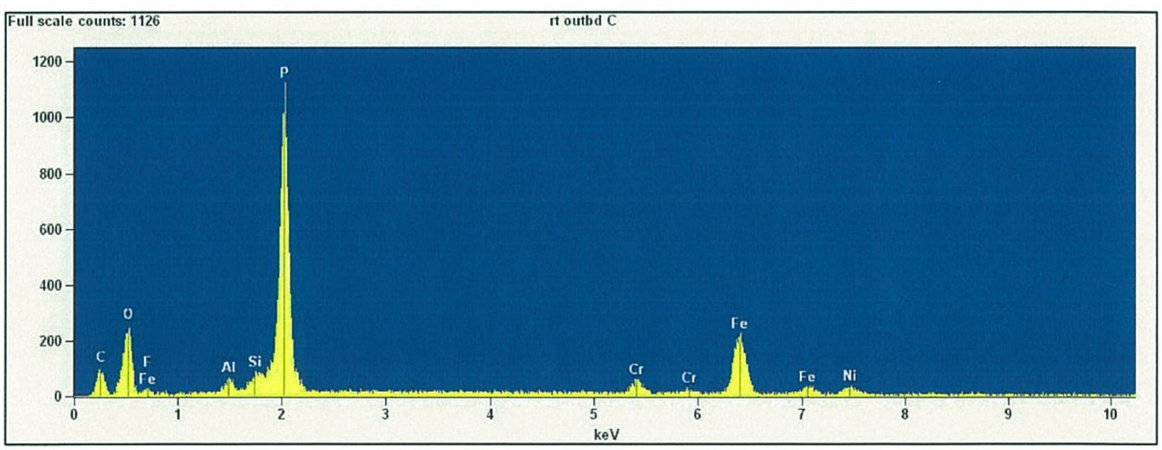
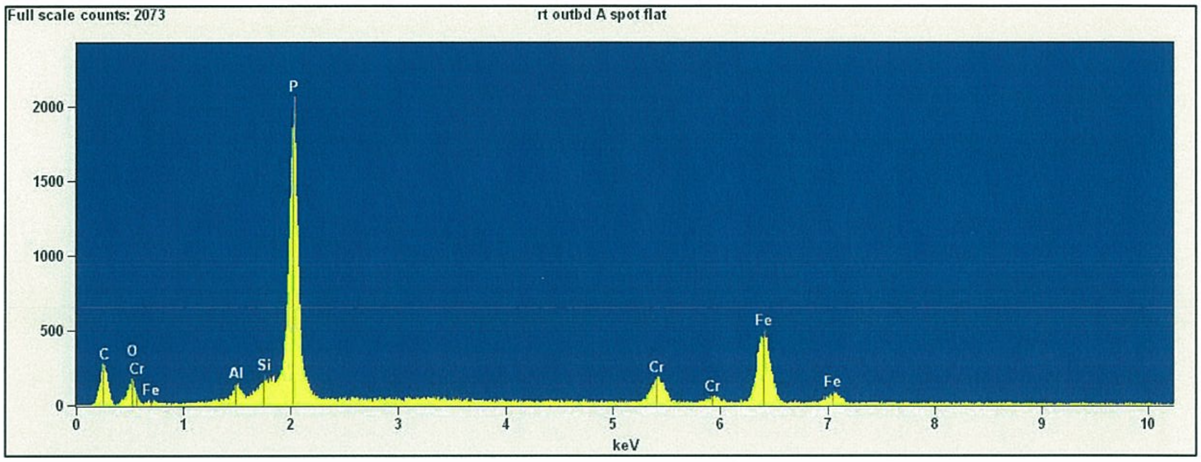


Figure 32. Typical EDS spectrum of deposits removed from the right outboard hydraulic line segment RO-C.



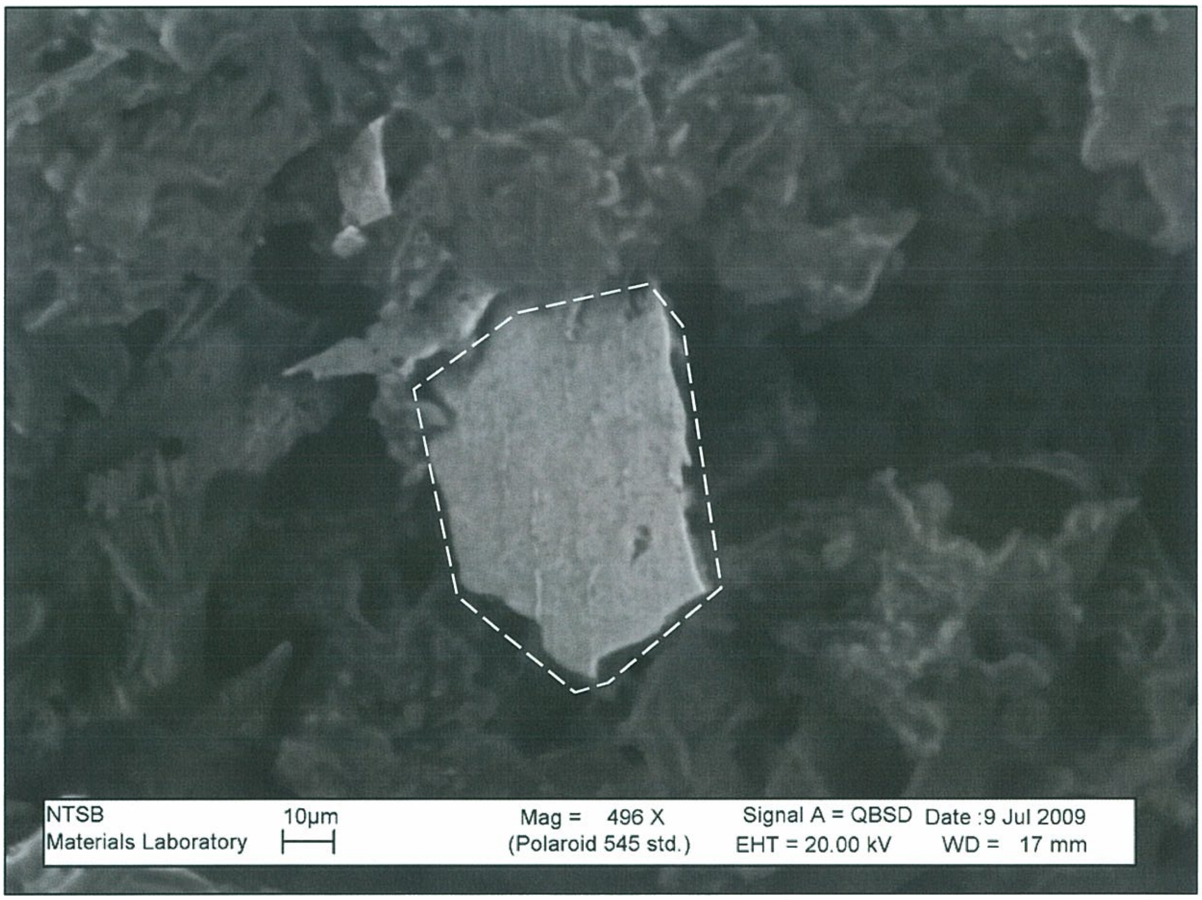


Figure 33. SEM view using backscattered electrons of a typical plate-like particle indicated with a dashed boundary line observed in deposits removed from the right outboard hydraulic lines and corresponding typical EDS spectrum of the plate-like deposits.

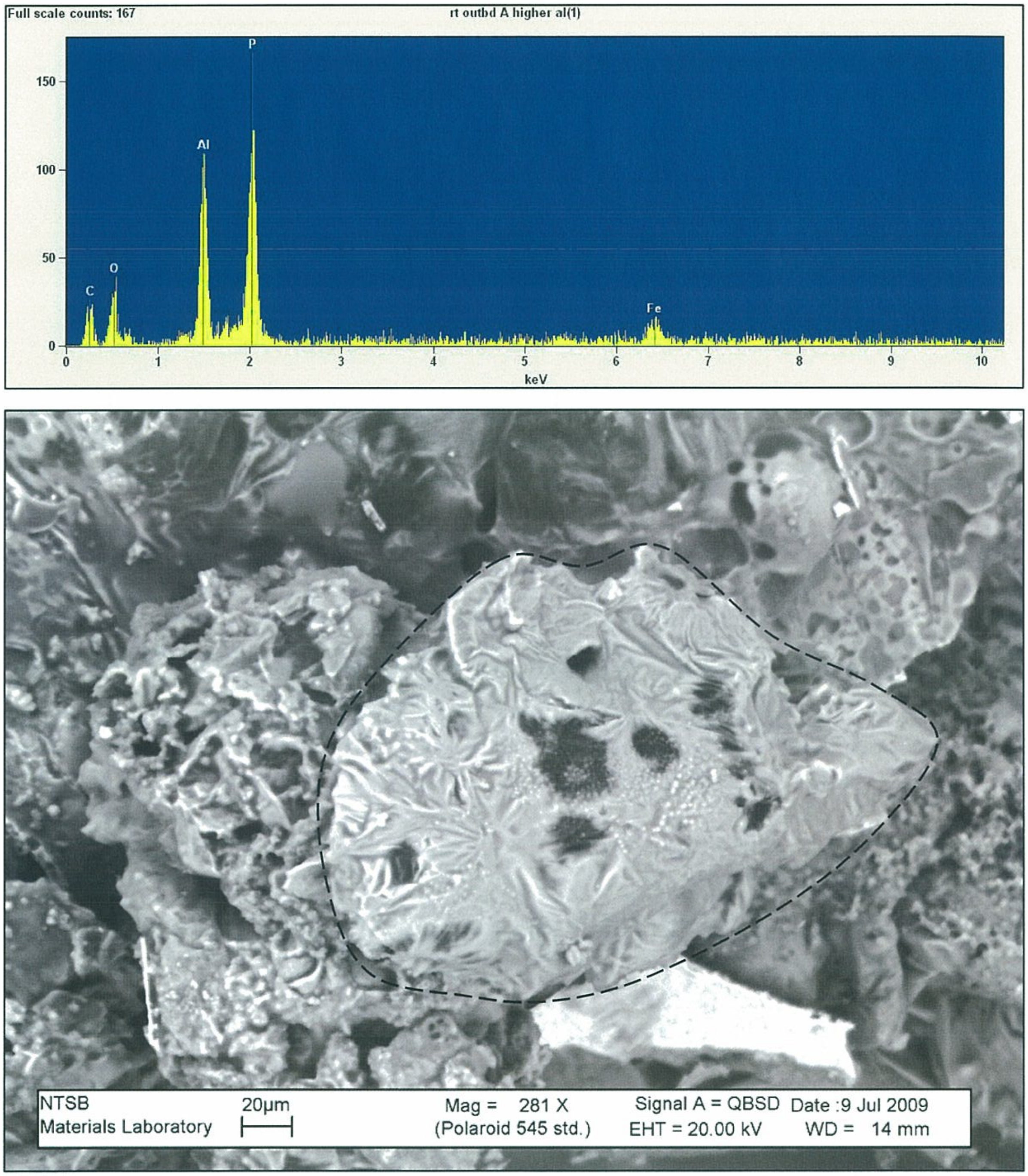
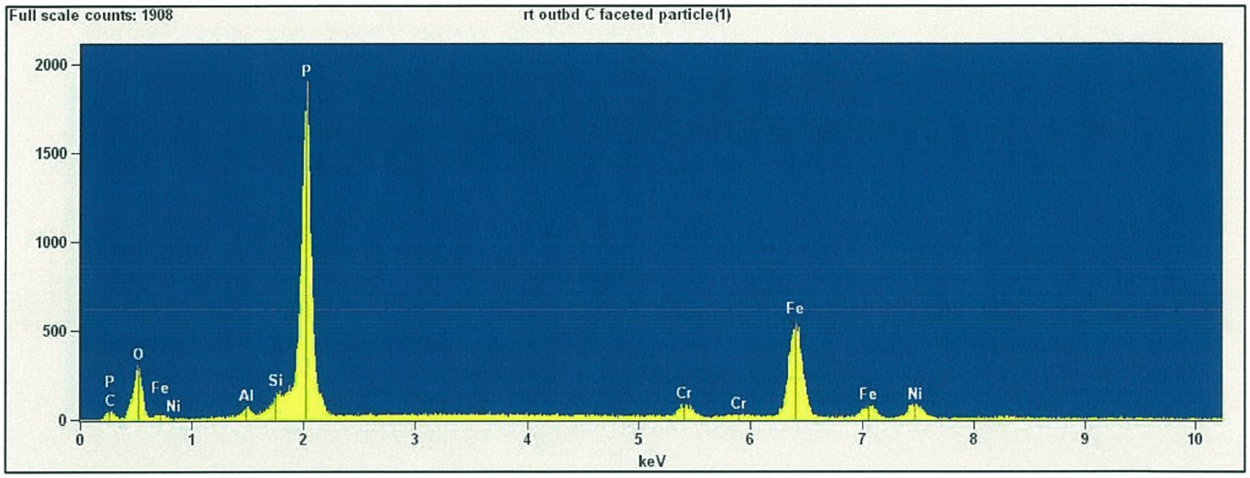


Figure 34. SEM view using backscattered electrons of a typical aluminum-rich particle indicated with a dashed boundary line observed in deposits removed from the right outboard hydraulic lines and corresponding typical EDS spectrum of the deposits showing a relatively high peak of aluminum in the spectrum.



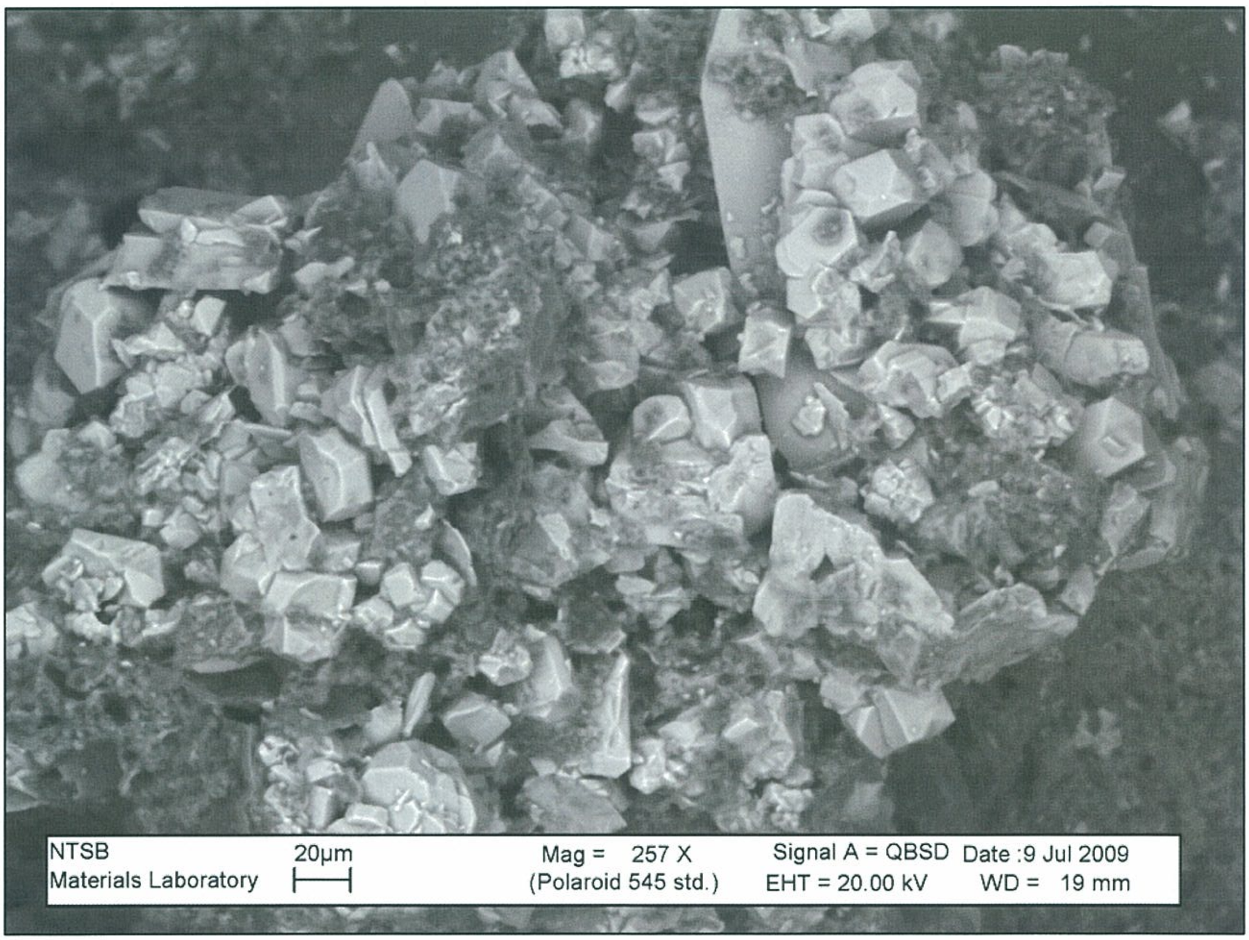


Figure 35. SEM view using backscattered electrons of a cluster of facetted crystalline particles observed in deposits removed from the right outboard hydraulic lines and corresponding typical EDS spectrum of the facetted crystalline deposits.

Figure 36. Overall view of the inboard filter from the blue hydraulic system.

Figure 37. Overall view of the outboard filter from the blue hydraulic system.

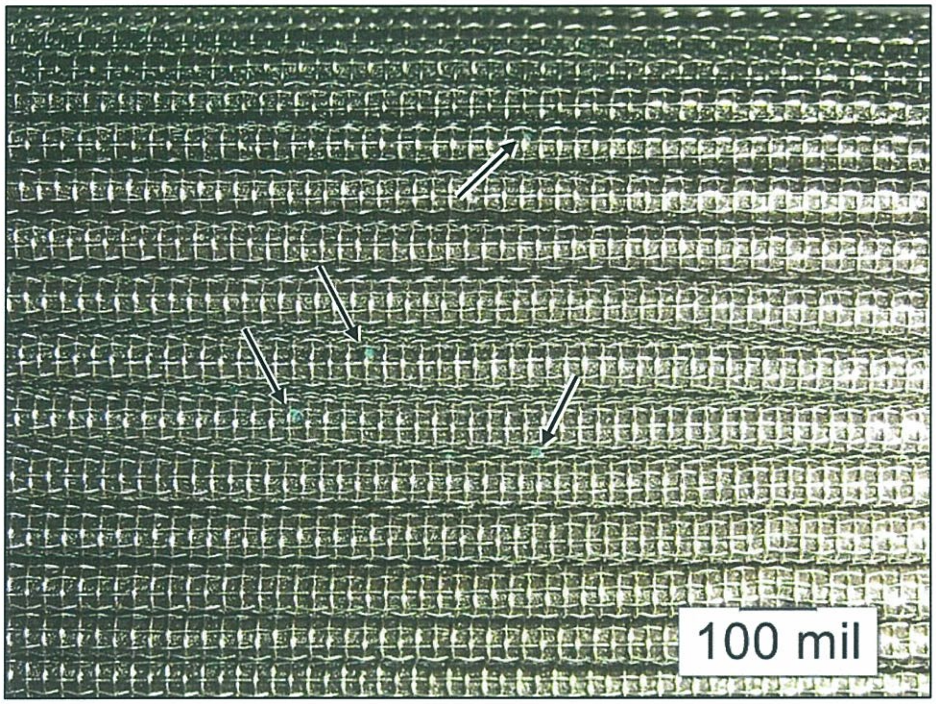


Figure 38. Close view of the inboard filter element from the blue hydraulic system. Arrows indicate green deposits in the filter.

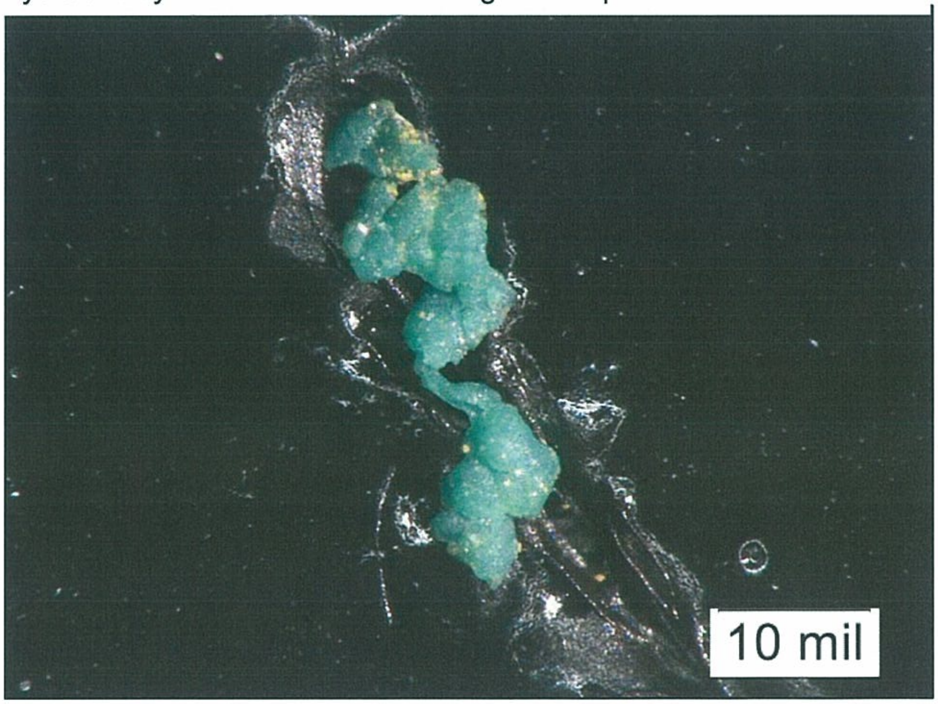


Figure 39. Close view of a green deposit removed from the inboard filter from the blue hydraulic system. The deposit is shown after cleaning in alcohol and placed on carbon tape for SEM examination.

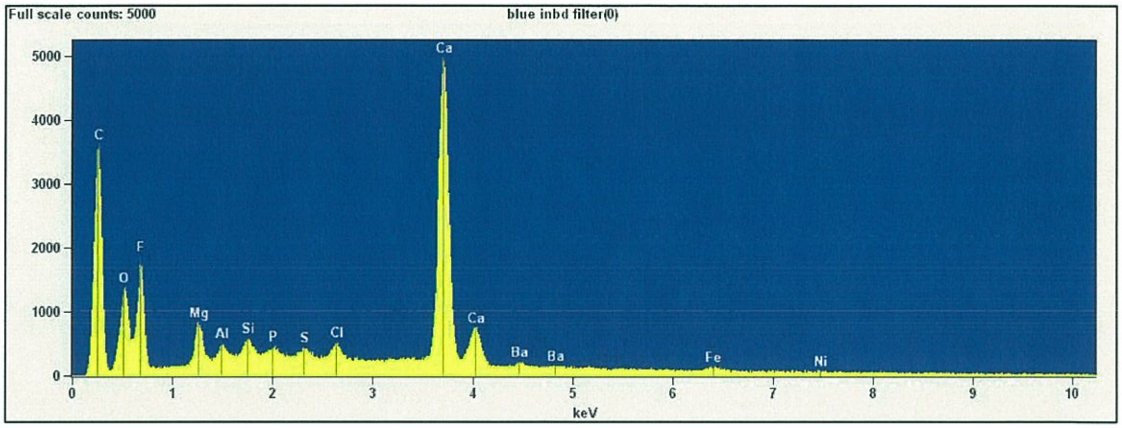


Figure 40. Overall EDS spectrum obtained from the green deposit shown in figure 38.

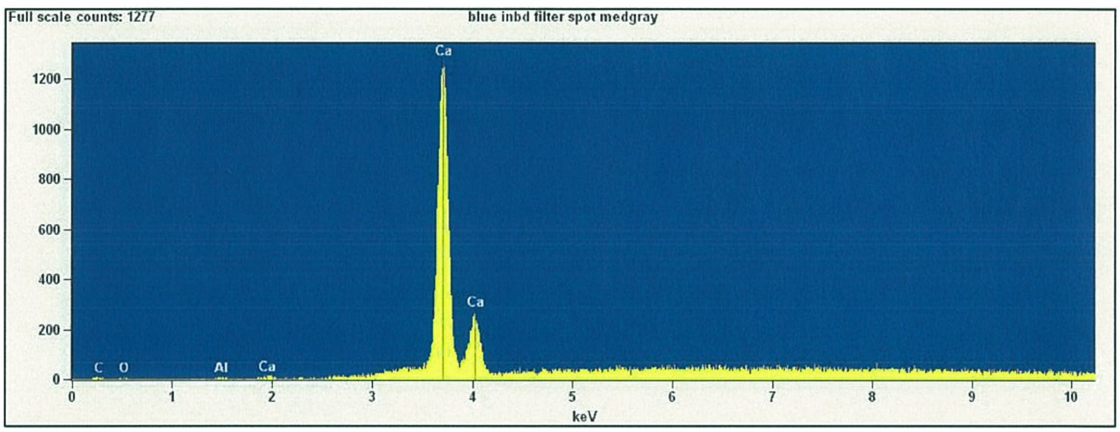


Figure 41. EDS spectrum of the green deposit shown in figure 38 obtained from an area between particles that appeared bright in the SEM using backscattered electrons.

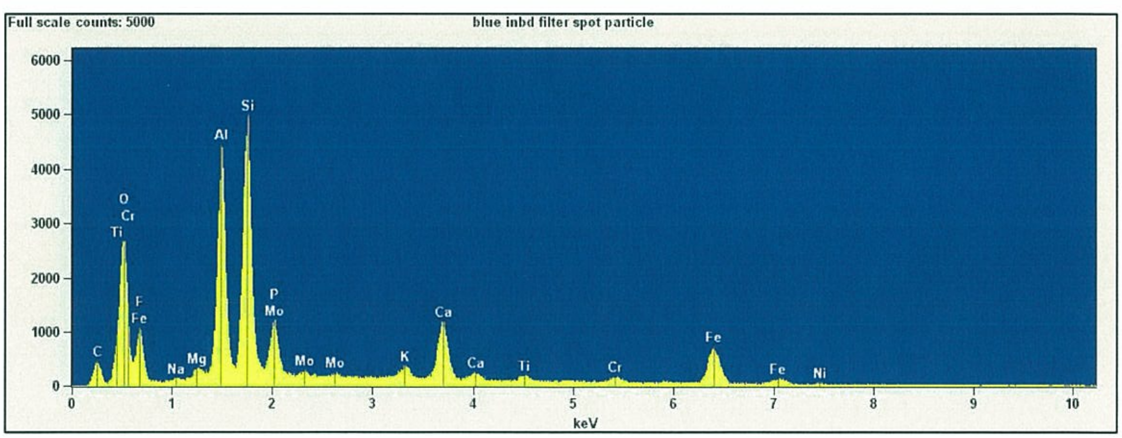


Figure 42. Typical EDS spectrum of the green deposit shown in figure 38 from an area that appeared bright in the SEM using backscattered electrons.

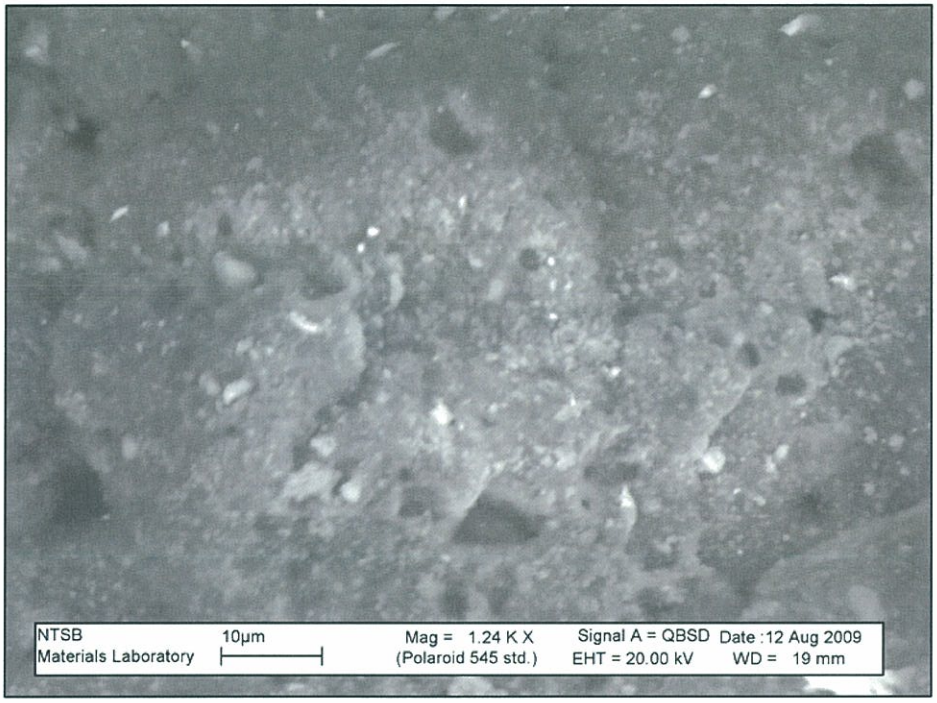


Figure 43. High magnification view of the green deposit from figure 38 as viewed in the SEM using backscattered electrons.

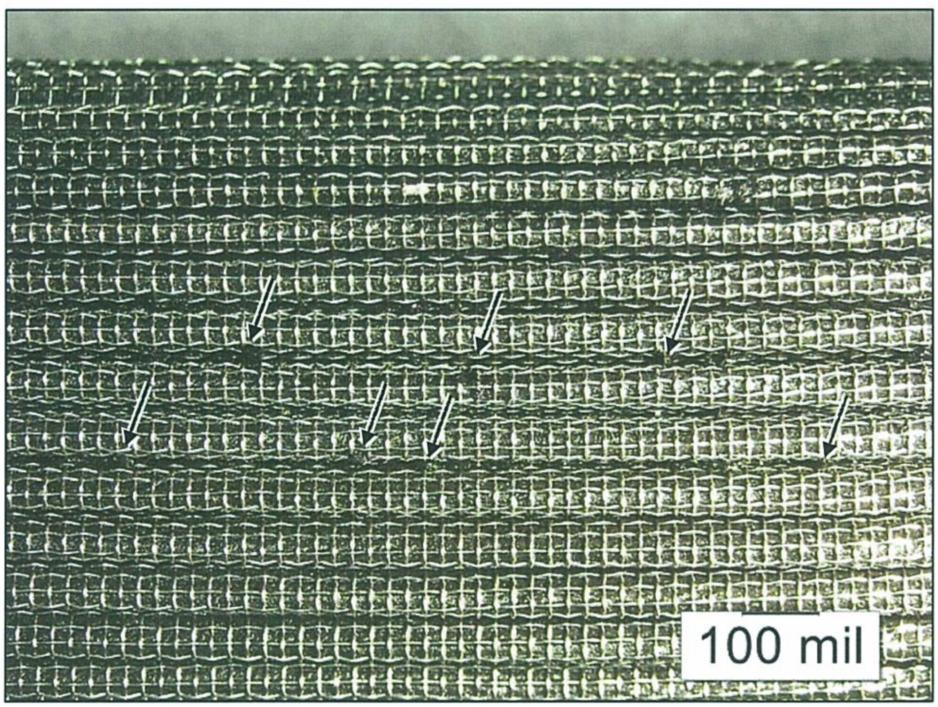


Figure 44. Close view of the outboard filter element from the blue hydraulic system. Arrows indicate black deposits in the filter.

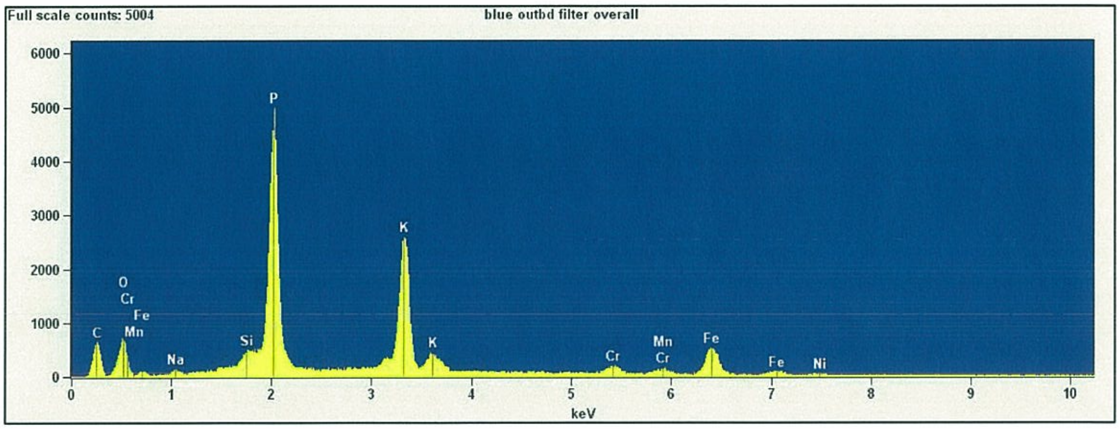


Figure 45. Typical EDS spectrum of a black globular deposit removed from the outboard filter of the blue hydraulic line.

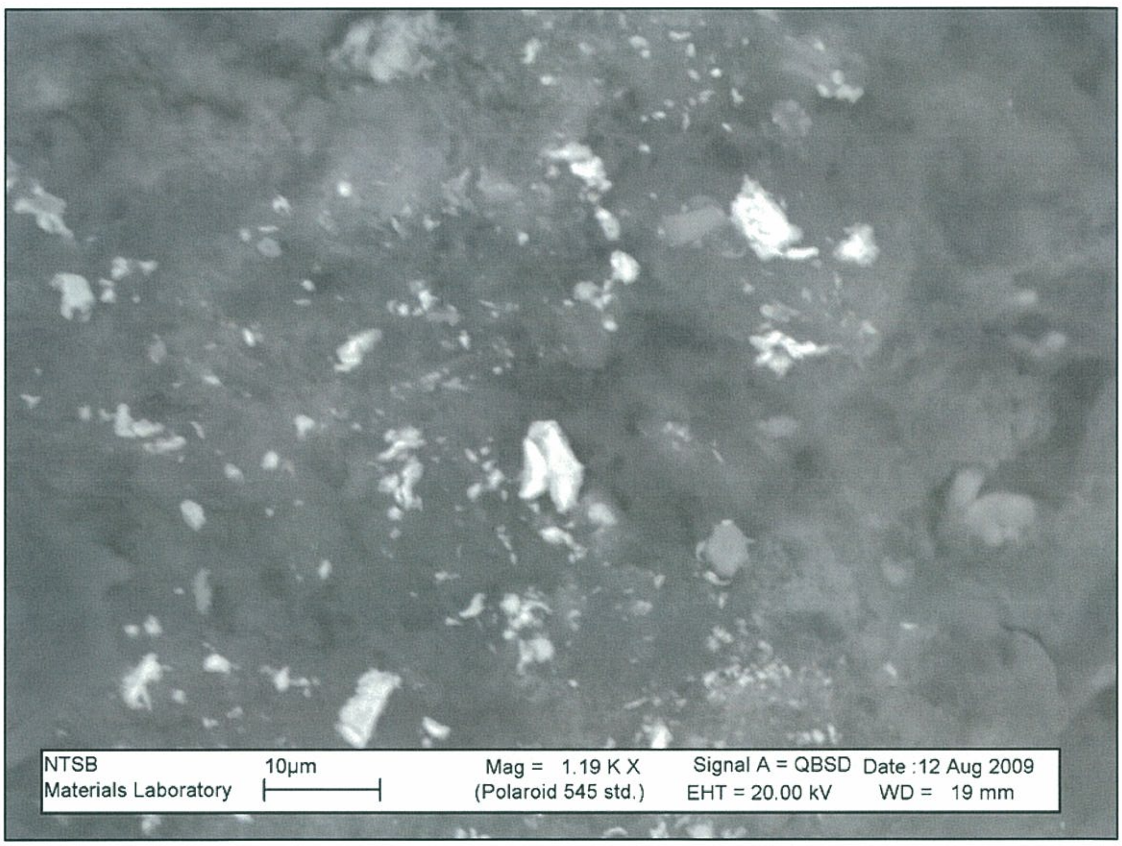


Figure 46. SEM view using backscattered electrons of the black particle removed from the outboard filter of the blue hydraulic line.

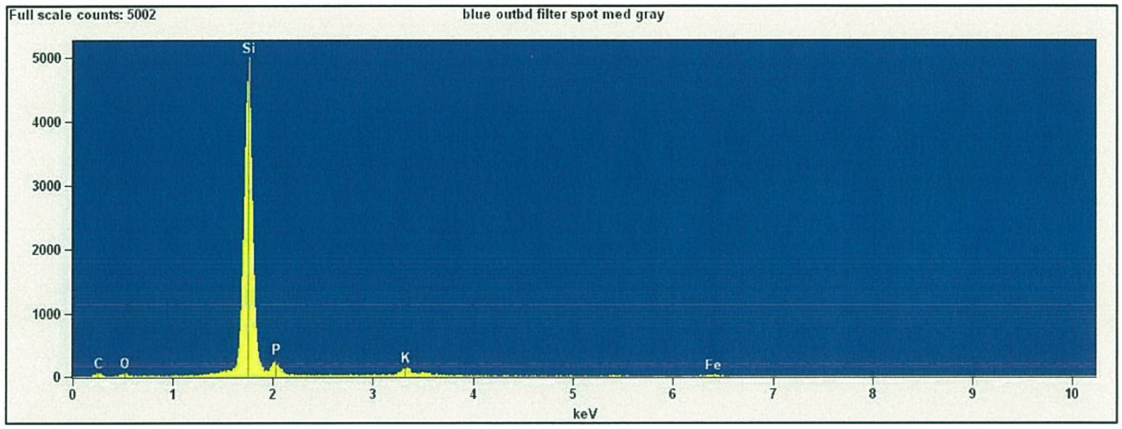


Figure 47. EDS spectrum of a particle in the black globular deposit removed from the outboard filter of the blue hydraulic line that appeared slightly darker gray than the background as viewed in the SEM using backscattered electrons.

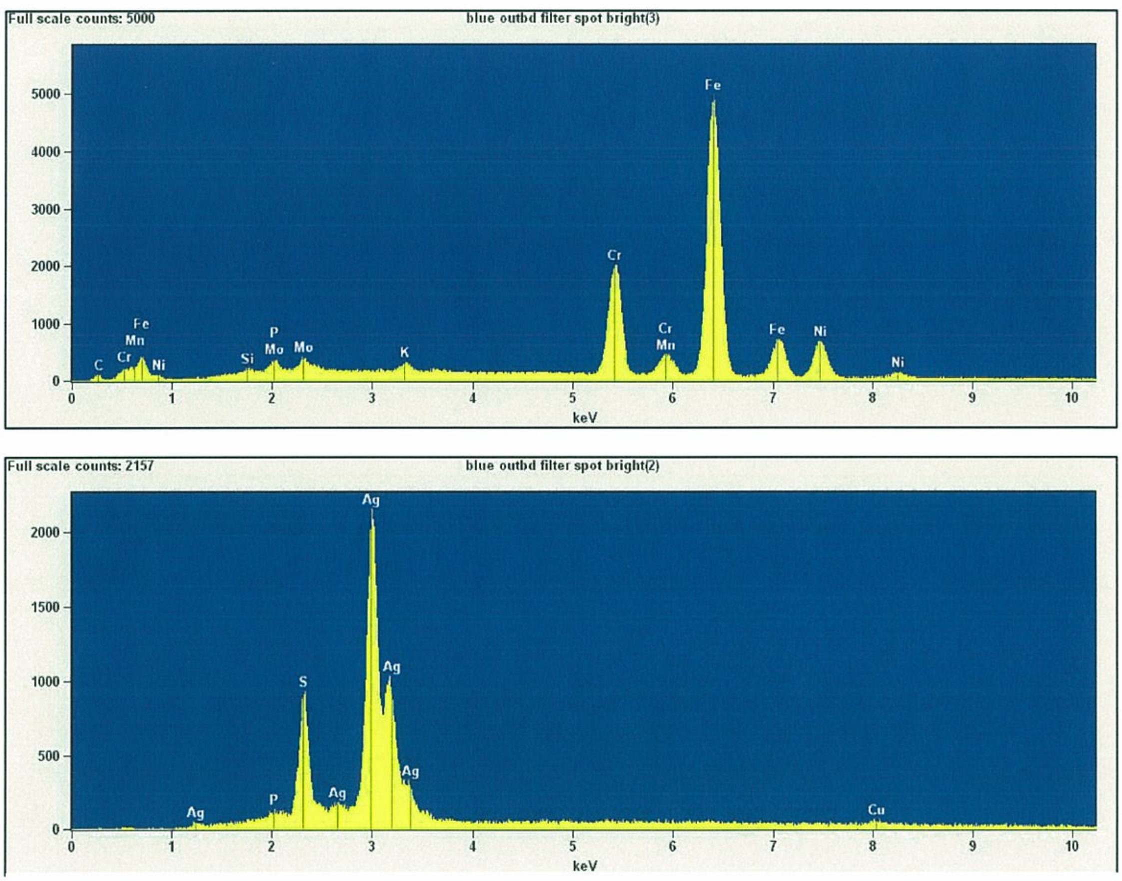


Figure 48. EDS spectra of two particles in the black globular deposit removed from the outboard filter of the blue hydraulic line that appeared relatively bright when viewed in the SEM using backscattered electrons.