U.S. NUCLEAR REGULATORY COMMISSION
REGION I

Report Nos. 50-387/89-37
50-388/89-36

Docket Nos. 50-387
50-388

License Nos. NPF-14
NPF-22

Licensee: Pennsylvania Power & Light Company
2 North Street
Allentown, Pennsylvania 18101

Facility Name: Susquehanna Units 1 & 2

Meeting At: USNRC Region I, 475 Allendale Road, King of Prussia, PA

Meeting Date: December 19, 1989

Meeting Topic: Susquehanna Emergency Diesel Generator Crankcase Explosions of Cooper EDGs

Prepared by: Carl S. Woodard — 1/19/90
Carl Woodard, Reactor Engineer, PSS, EB, DRS — date

Approved by: C. J. Anderson — 1/19/90
C. J. Anderson, Chief, Plant Systems Section, EB, DRS — date

Meeting Summary: Pennsylvania Power and Light Company (PP&L) personnel made a presentation of their preliminary root cause findings for recent EDG crankcase explosions at Susquehanna along with possible corrective actions to prevent recurrence. They confirmed their commitment to submit a formal report to the NRC by January 8, 1990.

1.0 Meeting Attendees

Pennsylvania Power and Light Company (PP&L)

C. Boschetti, Project Engineer, Risk Assessment
J. Kenny, Licensing Supervisor
S. Kuhn, Technical Electrical Supervisor
D. Roth, Senior Compliance Engineer
B. Swoger, Project Engineer
L. Willertz, Senior Consulting Engineer

United States Nuclear Regulatory Commission (NRC)

C. Anderson, Chief, Plant Systems Section, RI
C. Berlinger, Chief, Generic Branch, NRR
J. Strosnider, Chief, Materials and Processes Section, RI
P. Swetland, Chief, Reactor Projects Section, RI
E. Tomilson, Project Engineer, NRR/PDIV
M. Thadani, Project Manager, NRR
R. Winters, Senior Engineer, RI
C. Woodard, Reactor Engineer, RI

2.0 Background and Purpose

This meeting was called at the request of Region I in response to Emergency Diesel Generator (EDG) crankcase explosions that have occurred at the Susquehanna Power Plant (the most recent explosions occurred on September 16 and October 7, 1989). Since the cause of the recent explosions could not be identified during Region I inspections of the explosions, the licensee committed to submitting a root cause analysis report to the NRC by January 8, 1990. The licensee had essentially completed their evaluations and root cause analysis of the failures. This meeting included a presentation of their findings prior to the submission of the formal report.

3.0 Meeting Summary

The licensee presentations are detailed in the enclosures: Diesel Generator Failure Team Objective, Operability, and Photographs. The licensee identified several potential causes of the explosions and corrective actions under consideration to prevent recurrence. Corrective actions being considered include equipment design changes to remove the piston pin end cap covers to eliminate a source of cylinder liner gouging, the removal of the bottom piston skirt oil scraper ring to provide for better piston/cylinder liner lubrication, procedural changes to eliminate the surveillance test fast start immediate overloading of the EDG to reduce engine stresses, maintenance changes to provide for proper engine break-in following major maintenance for parts "seating," and change to a non-foaming engine lubricating oil.

4.0 Conclusions

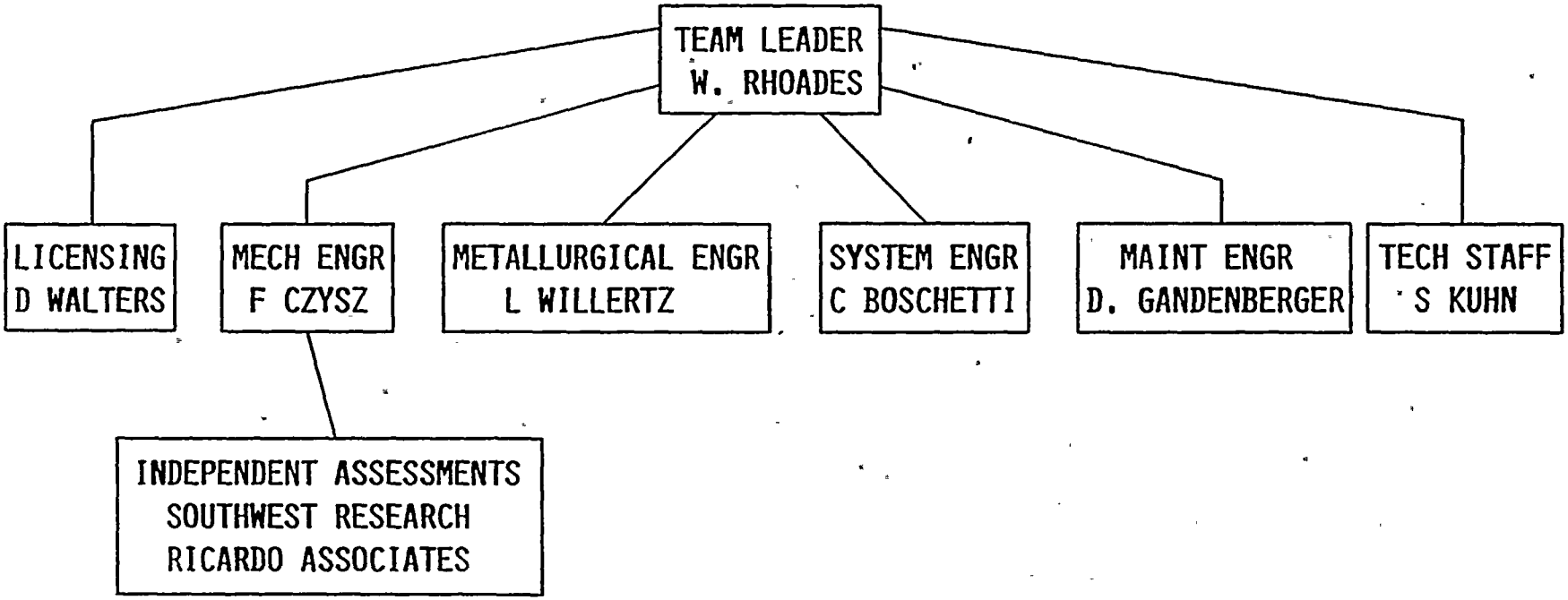
The licensee identified several issues that could have contributed to the engine failures. They also identified corrective actions under consideration. A formal report will be issued in the near term addressing these issues.

DIESEL GENERATOR FAILURE

TEAM OBJECTIVE

TO DEVELOP AND IMPLEMENT A PLAN THAT ASSURES ALL DIESEL GENERATORS CONTINUE TO MAINTAIN AN OPERABLE STATUS. THE PLAN MUST ADDRESS BOTH THE OPTIONS OF FINDING THE ROOT CAUSE AND NOT FINDING THE ROOT CAUSE. THE PLAN MUST ALSO ADDRESS THE LONG AND SHORT TERM IMPLEMENTATION ITEMS.

DIESEL GENERATOR TASK FORCE



SUSQUEHANNA DIESEL GENERATOR PLAN/TASKS

- DEVELOP DG RUN HISTORIES FOR ANY TRENDS
- DEVELOP INSPECTION CRITERIA/INSPECTION PLAN
- DETERMINE DESIGN LOADING ON EACH ENGINE
- DETERMINE LOAD LIMITATIONS OF DG's
- ASSESS INDUSTRY INFORMATION ON COOPER CRANKCASE EXPLOSIONS
- ASSESS INDUSTRY INFORMATION ON LOADING AND LENGTH OF RUNS
- COOPER FAILURE REPORTS
- PP&L ROOT CAUSE ANALYSIS/FAILURE REPORT/B&C ENGINES
- INDEPENDENT ANALYSIS - SOUTHWEST RESEARCH INSTITUTE
- INDEPENDENT ANALYSIS - RICARDO CONSULTING ENGINEERS
- ASSESS PP&L MAINTENANCE PRACTICES
- COMPARE FOAMING OF OIL
- REVIEW PP&L DG START AND LOAD RECORDS/MAINTENANCE RECORDS/ENGINE ANALYSIS RECORDS

OUTLINE OF THE ROOT CAUSE DIESEL FAILURE REPORT
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Chapter Subject
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I. ABSTRACT

II. EXECUTIVE SUMMARY
- A. PROBLEM
- B. FINDINGS
- C. CONCLUSIONS
- D. RECOMMENDATIONS

III. FAILURE HISTORY
- A. TABULATION OF ALL D/G PISTON FAILURES
- B. TABULATION OF ALL INSPECTION RESULTS RELATED TO FAILURES
- C. DISCUSSION OF FAILURES IN GENERAL
- D. CONSULTANTS ANALYSIS
- E. MAINTENANCE PROCEDURES
- F. FAILURE SCENARIOS

IV. OPERABILITY ASSESSMENTS

V. METALLURGICAL ANALYSIS OF "B" DIESEL 7L FAILURE
- A. BRIEF DISCUSSION OF FAILURE AND OBSERVATIONS
- B. SPECIFIC OBSERVATION OF METALLURGICAL CONDITION OF EACH PART
- C. DISCUSSION OF RESULTS
- D. CONCLUSIONS

VI. METALLURGICAL ANALYSIS OF "C" DIESEL 5R FAILURE
- + SAME AS SECTION V. ABOVE

VII. MISCELLANEOUS FINDINGS
- A. PISTON RING FINDINGS
- B. PISTON PIN FINDINGS
- C. OIL FOAMING DISCUSSION
- D. OBSERVATIONS OF "C" DIESEL INSPECTIONS 12/15/89
- E. OBSERVATIONS OF "B" DIESEL INSPECTIONS 10/20/89
- F. OBSERVATIONS OF "A" DIESEL INSPECTIONS 11/15/89

VIII. APPENDIXES
- A. INCOMPLETE WORK
- B. FUTURE DIRECTION
- C. FORMATION OF OWNERS GROUP
- D. CONSULTANTS FINDINGS
- E. QUALITY ASSURRANCE REVIEW OF COOPERS PROGRAM

D/G ROOT CAUSE ANALYSIS

CRANCKASE EXPLOSIONS

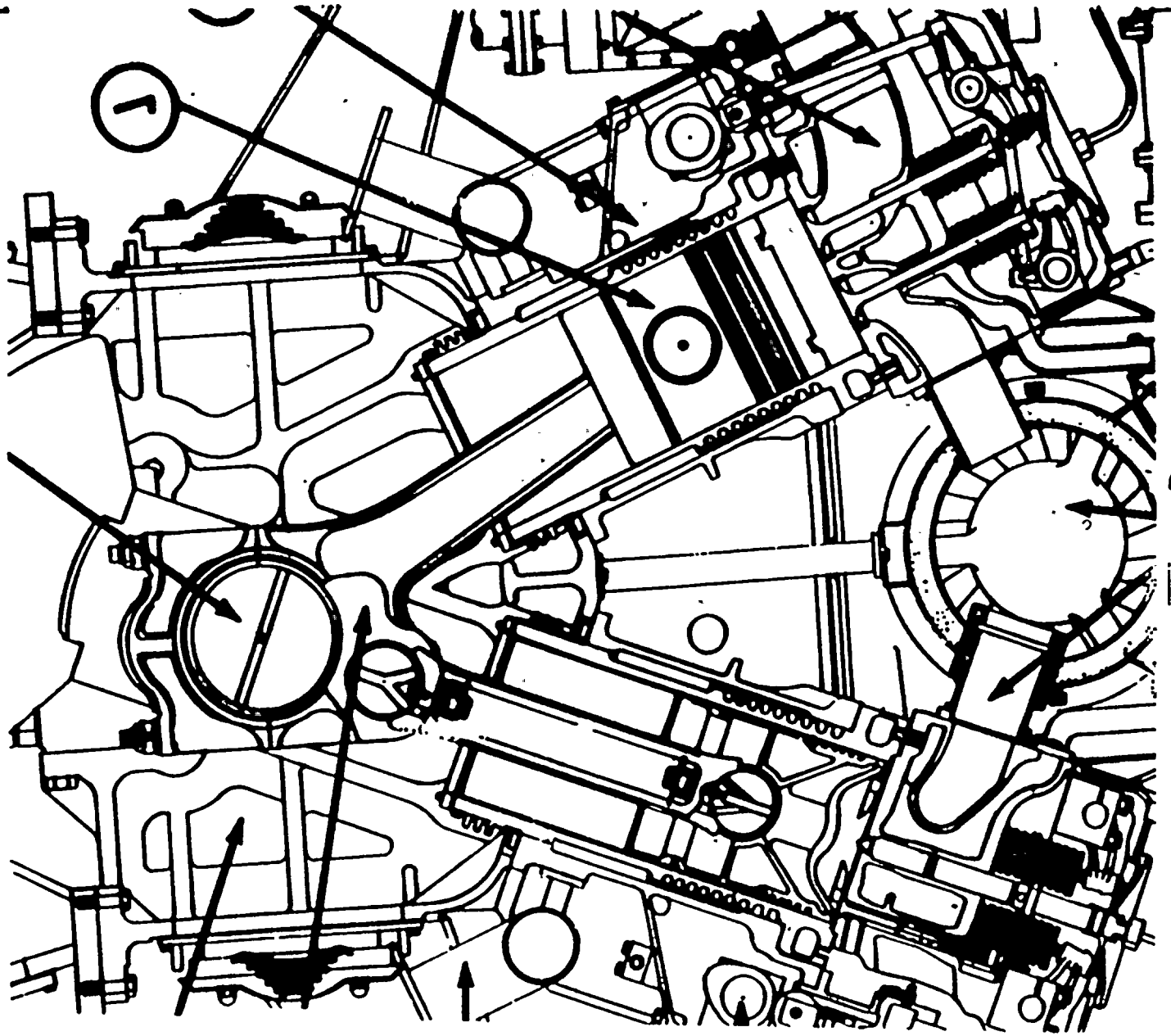
A. BACKGROUND
- ENGINE DESIGN
- CRANKCASE EXPLOSIONS AT SSES
- CRANKCASE EXPLOSIONS AT OTHER UTILITIES (C-B DIESELS)

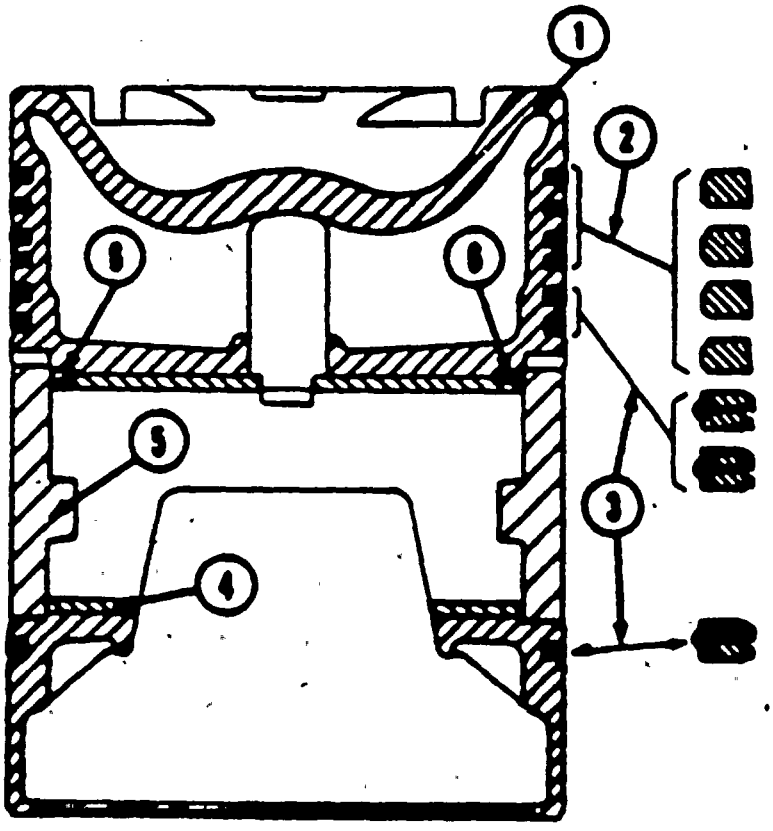
B. INVESTIGATION SUMMARY
- INCORRECT COMPRESSION RINGS
- WORN RINGS (FLAT)
- PISTON TIN LOSE
- END CAPS NOT SEATED
- BLUED PISTON PINS
- OIL FOAM TEST

C. CURRENT THEORY OF THE CAUSE OE SSES FAILURES

D. OTHER UTILITY DIESEL PROBLEMS

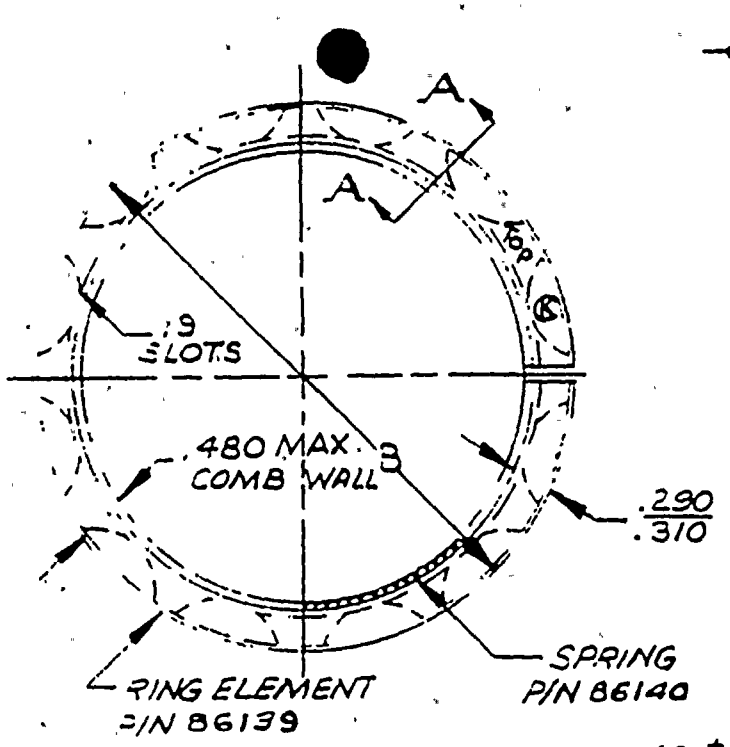
E. OUR OPINIONS ON THE RELATIONSHIP WITH SSES

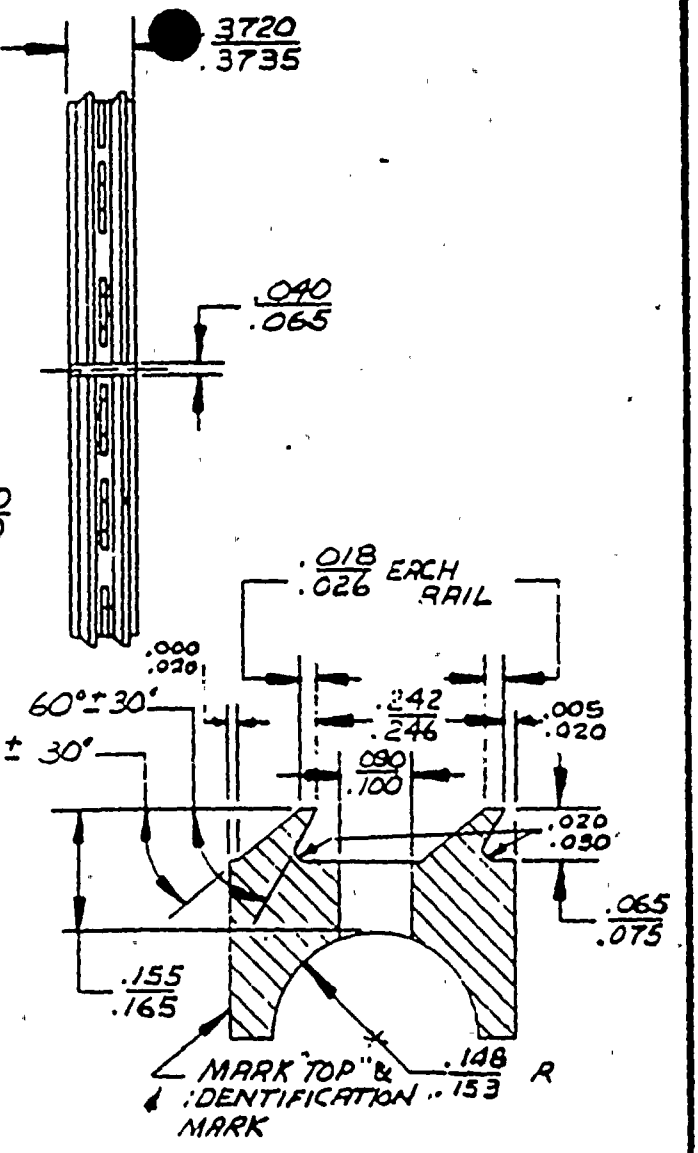




1. Piston
2. Compression Rings
3. Oil Rings
4. Pin Bushing
5. Pin Cap
6. Screw Dowel

Piston and Rings.





SEC. A-A

1. INSTALL WITH SIDE MARKED "TOP" TOWARD HEAD OF PISTON.
2. RING MUST BE LIGHT TIGHT ON O.D. AS PER SD-93
3. FOR SPECIFIC APPLICATIONS REFER TO SD-94 LISTINGS
4. ASSY TO YIELD A NOM. CALCULATED UNIT PRESSURE OF 188 PSI
5. MAT'L - RING: KOPPERS K-6E, PARCO LUBRIZED
   SPRING: TEMPERED STEEL

C-B PT. NO.	NOM DIA	NOM WIDTH	'B' DIA IN PLACE	HEAD PT. NO.	COIL SPRING LGTH.	DIA.	LB/IN/LB
-001	3 1/2	3/8	13.500	88188	41.23-41.36	.279-.285	.0003445

MFR. BY KOPPERS CO. INC

RING-OIL

PROCUREMENT DWG.

REV. NO.	REVISION	DATE
	SPECIFIC RING TO VENDOR DIMS & PT. NO'S. JES	12-20-72
1	REVSD. TBL. TO INCLUDE EXPANDER SEE NOTICE JES	5-4-72
ISSUE	SUPERSEDES SF 396-37	12-28-70

DRAWN RJF | CHECKED JOB | APPROVED L.P.H.

SHEET 1 OF 1 SHEETS | MK 8C | 2-20R-652

Event No.	Unit	Event	Date
1	B	Loose piston pin bolt 5L. Due to looseness of pin on rod oil "spilled" through pin to rod clearance thereby precluding adequate piston cooling.	Jan. 18, 1986
2	B	Piston skirt distress 7L. Unknown source of material "rolled" between piston and liner.	Sept. 16, 1989
3	C	Piston skirt distress 5R. Defect in piston skirt - unique.	Oct. 7, 1989
4	D	Lube oil pump bearing failure on initial start-up.	Nov. 29, 1981
5	D	Fuel oil dilution of lube oil in cylinder 2L caused high friction between piston and liner.	Jan. 14, 1984

OTHER CRANCKCASE EXPLOSIONS

A. PALO VERDE
   - DUE TO IMPROPER BLUING OF PISTON PIN BUSHING

B. BRAIDWOOD
   - DUE TO METAL CUTTINGS IN PISTON PIN OIL GROOVES

C. BYRON
   - CAUSE WAS NOT CONCLUSIVELY DETERMINED

D. ZION
   - DUE TO PISTON BUSHING FAILURE

E. COOPER
   - THREE OVERPRESSURIZATIONS DUE TO WATER LEAKS

ATTACHMENT A

PISTON RING DIMENSIONAL DATA

D/G	PISTON	RING #	RADIAL WIDTHS (INCHES)	COMMENT
B	7L	1	-	Missing
		2	.450	Wrong Ring
		3	.454-.460	OK
		4	-	Missing
C	5R	1	-	Missing
		2	.437	OK
		3	.448	OK
		4	.449-.450	OK
D	8R	1	.429	OK
		2	.429	OK
		3	.445	OK
		4	.454	OK
?	A	1	.455-.460	Wrong Ring
	Exact Piston	2	.453-.455	Wrong Ring
	Location Unknown	3	.450-.456	OK
		4	.458-.463	OK
?	8	1	.428-.432	OK
	Exact Piston	2	.455-.460	Wrong Ring
	Location Unknown	3	(.435?)-.458	OK
		4	.451-.459	OK
A	1R	1	.425-.428	OK
		2	.428-.432	OK
		3	.448-.454	OK
		4	.450-.450	OK
A	2R	1	.424-.430	OK
		2	.422-.430	OK
		3	.442-.450	OK
		4	.450-.455	OK
A	7R	1	.440-.446	May Be Wrong Ring
		2	.443-.452	Wrong Ring
		3	.458-.460	OK
		4	.458-.461	OK
B	1R	1	.449-.456	Wrong Ring
		2	.462-.464	Wrong Ring
		3	.451-.456	OK
		4	.455-.458	OK

ATTACHMENT A

PISTON RING DIMENSIONAL DATA

D/G	PISTON	RING #	RADIAL WIDTHS (INCHES)	COMMENT
B	5L	1	.436-.437	OK
		2	.437-.438	OK
		3	.456-.459	OK
		4	.459-.460	OK
A	3R	1	.429-.434	OK
		2	.432-.433	OK
		3	.464-.466	OK
		4	.457-.460	OK
New (from stock)		1	.436-.437	OK
		2	.437-.438	OK
		3	.457-.462	OK
		4	.459-.460	OK

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REVIEW OF RING SET SD-94-KSV-9

	COOPER	KAYDON
TOP COMPRESSION RING 2ND COMPRESSION RING	Cooper Spec. ↓	Handbook data. ↓
TYPE: TAPER FACE/TWISTED		
PART NO:	2-20R-005-001	A5701
WIDTH:	.2465/.2480	.2475/.2490
RADIAL THICKNESS:	0.430/0.450	0.455/0.470
END GAP:	0.080/0.105	0.054 MIN.
DIA. TENSION:	50-60 LBS (To close gap)	50-60 LBS
MATERIAL:	K-28, PARCO	K-28, PARCO
BACK CL. IN GROOVE:	0.020/0.050	0.054 MIN.
MIN. GROOVE DEPTH:	0.470	0.524
MIN. SIDE CLEARANCE:	0.007	0.008
3RD COMPRESSION RING 4TH COMPRESSION RING		
TYPE: TAPER FACE/TWISTED		
PART NO:	2-20R-354-001	80731
WIDTH:	.2465/.2480	.2475/.2490
RADIAL THICKNESS:	0.445/0.465	0.455/0.470
END GAP:	0.080/0.105	0.054 MIN.
DIA. TENSION:	34-44 LBS.	34-44 LBS.
MATERIAL:	K-IRON, PARCO	K-IRON, PARCO
BACK CL. IN GROOVE:	0.005/0.035	0.054 MIN.
MIN. GROOVE DEPTH:	0.470	0.524
MIN. SIDE CLEARANCE:	0.004	0.008
5TH OIL RING 6TH OIL RING 7TH OIL RING		
CONFORMABLE DOUBLE HOOK SCRAPER, VENTILATED		
PART NO:	2-20R-652-001	86188 RING 86139 SPRING
WIDTH:	0.372/0.3735	0.3715/0.373
RADIAL THICKNESS:	0.290/0.310	NO INFO
END GAP:	0.040/0.065	0.03375 MIN.
UNIT PRESSURE:	188 PSI	188 PSI
MATERIAL:	K6E PARCO	K6E PARCO
BACK CL. IN GROOVE:	NA	NA
MIN. GROOVE DEPTH:	0.544	NA
MIN. SIDE CLEARANCE	0.0035/0.0065	0.0025 MIN.

OBSERVATIONS ON REMOVED PISTONS

D/G	Cylinder	Tin Smear on Non-Thrust Side of Liner	Blued Pin	End Caps	COMMENTS
C	5R	Piston involved in crankcase explosion. Non-thrust side tin smearing noted in previous inspection.	Yes.	Not seated.	
B	7L	Piston involved in crankcase explosion.	Slight bluing.	Not seated.	
D	8R	Yes.	Not blued, but pin is 5 mils out of round.		
A	1R	Yes.	Yes. Pin needed to be hammered out.	Not seated.	
A	2R	Yes.	Yes.	Not seated.	
A	7R	Yes.	Yes.	Not seated.	
B	1R	Yes.	No bluing, but pin is worn.*		
C	6L	Yes.	Scratched parallel to pin axis.	Not seated.	
B	7R	No tin smear. Burnishing due to end-cap rubbing.	Showed signs of wear. Pin was replaced.	Not seated.	Liner replaced. Piston replaced (non-thrust tin removed).
C	8R	Yes.	?	?	
A	3R	Good piston pulled for inspection. Some burnishing of tin on non-thrust side.	No, bushing needed to be scraped to obtain proper bluing.	?	

* Per Mike Schleigh of C-B.

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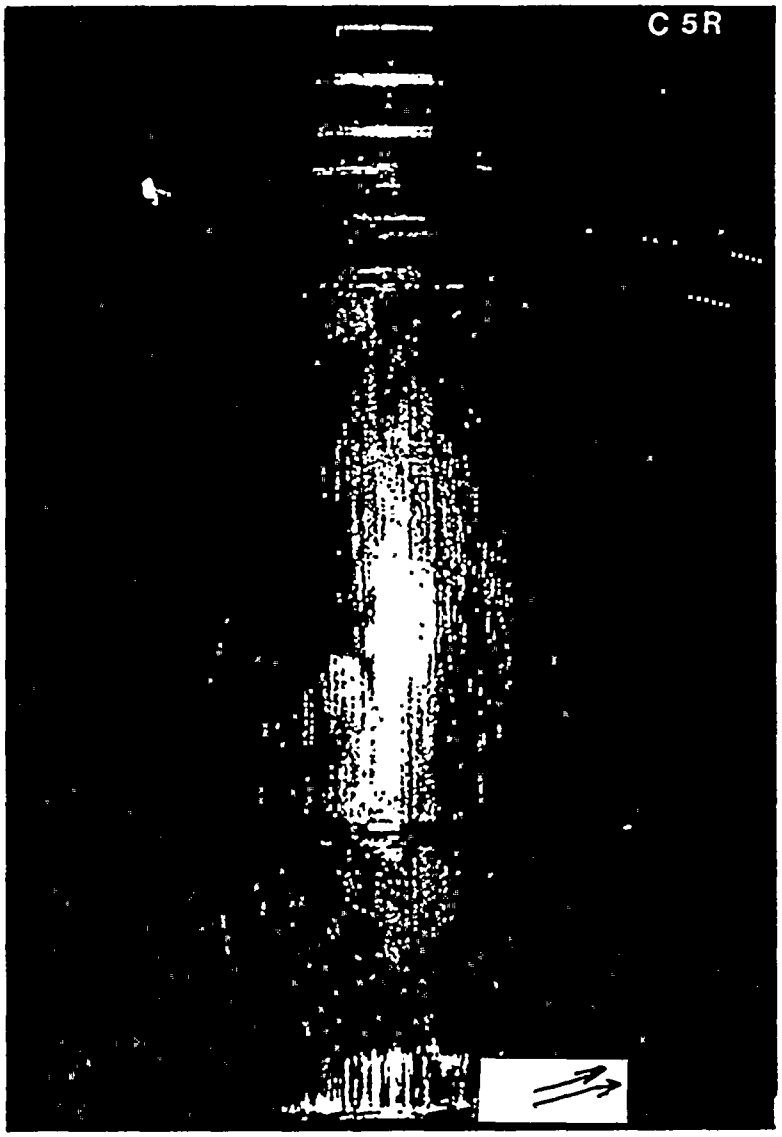
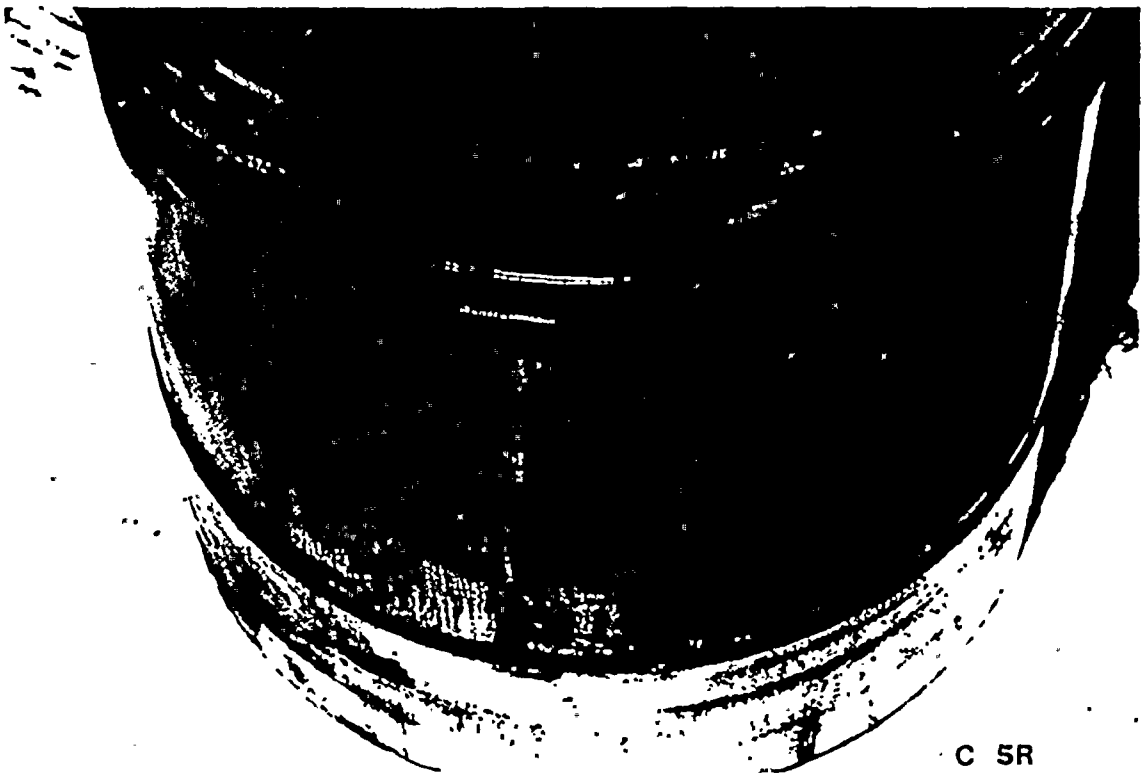
PISTON AFTER CRANKCASE EXPLOSION.



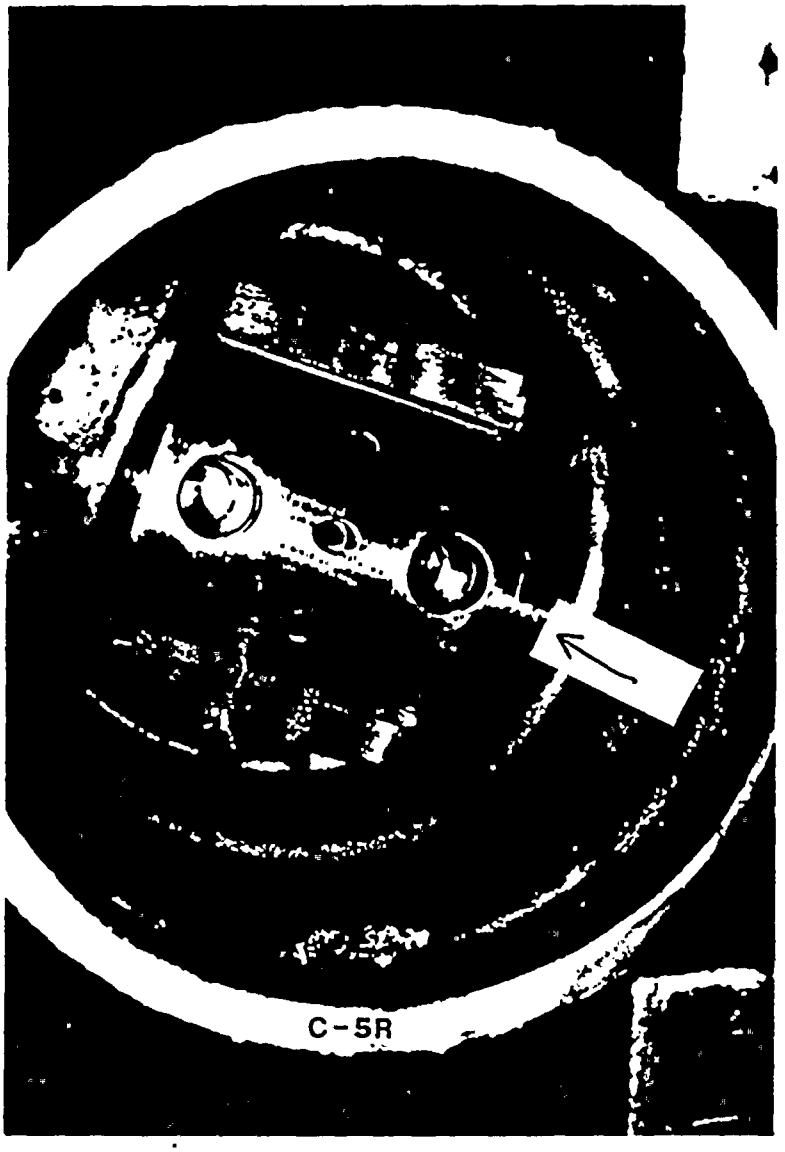
PISTON AFTER CRANKCASE EXPLOSION.

NOTE: CASTING DEFECTS LOWER RIGHT.

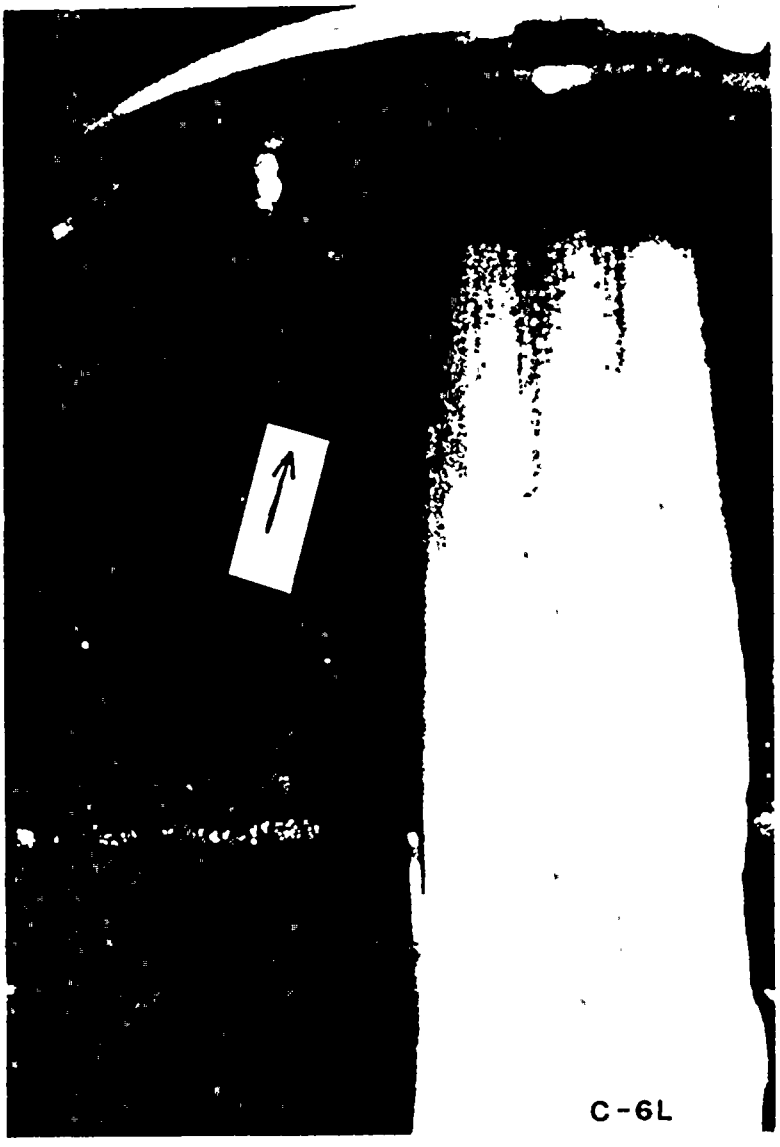
LINER AFTER CRANKCASE EXPLOSION.



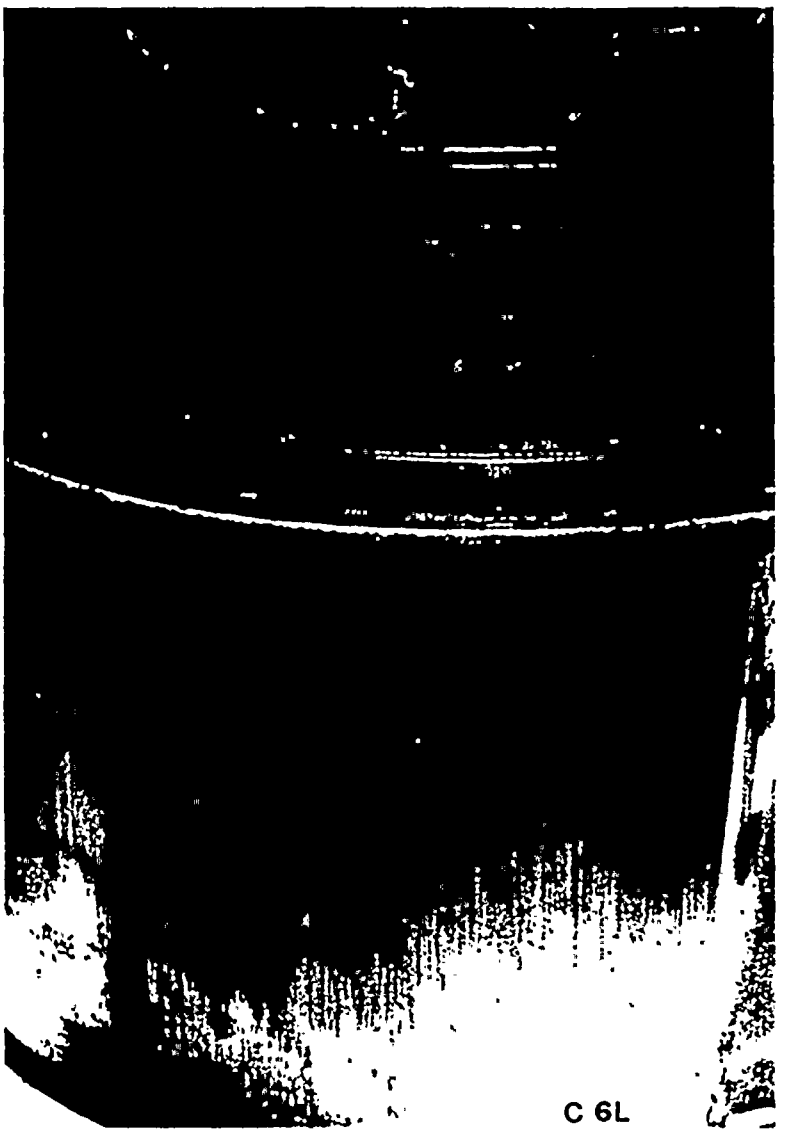
PISTON END CAP UNSEATED.



BLUED PIN.



TIN SMEAR ON LINER.



WORN PISTON RINGS - FLAT

LOSS OF TIN ON NON THRUST SIDE.

OPERABILITY

- **ROOT CAUSE INVESTIGATION**
- **RISK ASSESSMENT**
- **OPERABILITY TESTS**
- **RELIABILITY ASSURANCE**

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ROOT CAUSE INVESTIGATION

- NO SINGLE POSITIVE CAUSE
- SEVERAL POTENTIAL CAUSES

-LUBRICATION

-RING WEAR

-PIN BLUING

-PISTON END CAP SCUFFING

-TESTING

RISK ASSESSMENT

- LIMITING DBA IS LOOP
  - LOCA not Probable NUREG/CR-4792
  - Age Related
  - A or B DG Required
- DG PERFORMANCE
  - Weibull Distribution
  - Increasing Failure Rate
  - Wearout

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FREQUENCY

* LOCA - FRACTURE MECHANICS/ PROBABILISTIC MODEL
  - <10 yrs - Negligible
  - 1 x .001/yr at 10 yr
  - 2 x .001/yr at End
  - Conservative
* LOOP - NUREG-1032
  - 0.052 Dec, Jan, Feb
  - Plant / Grid Centered
  - Severe / Extremely Severe Weather
  - 24 hr Max Duration
  - A or B DG

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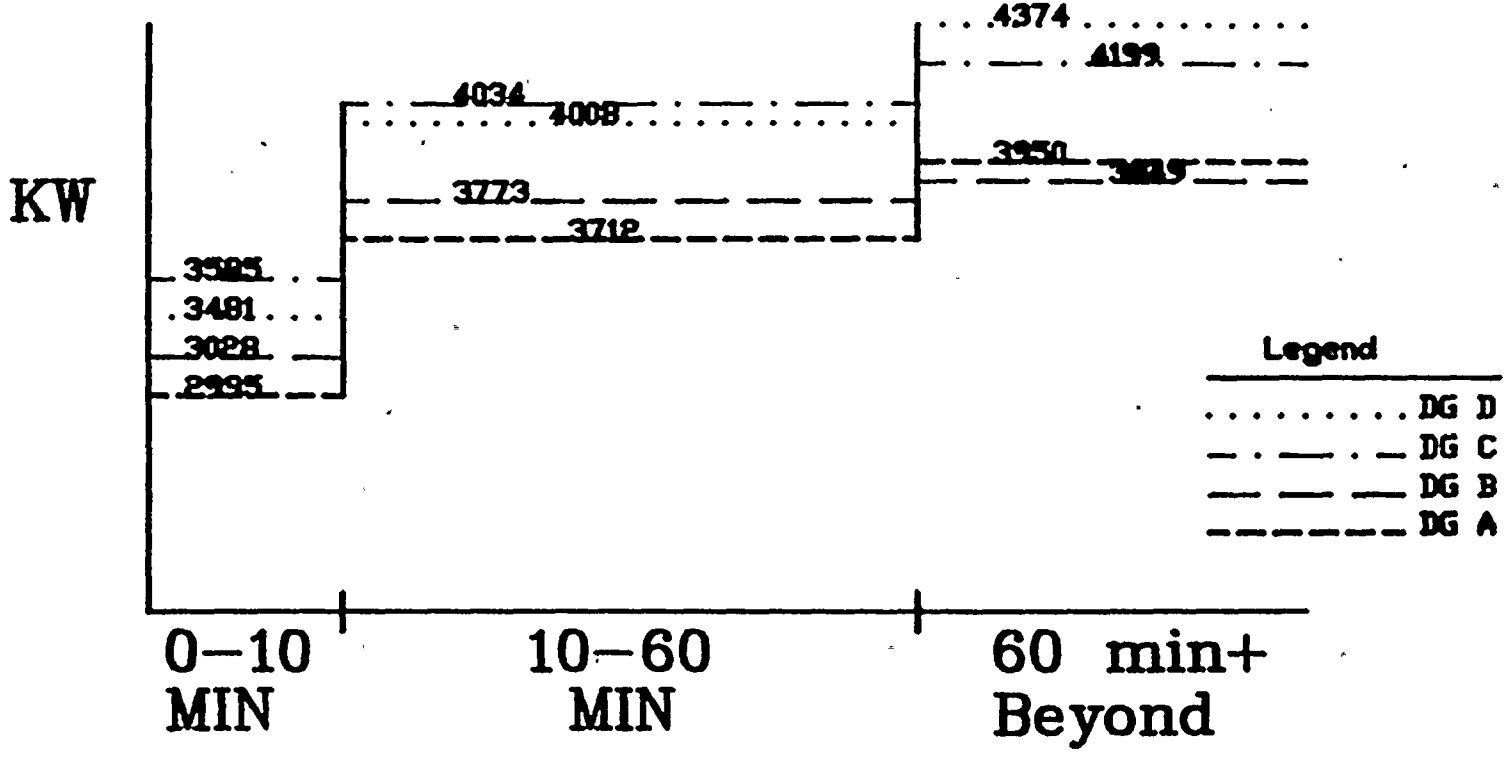
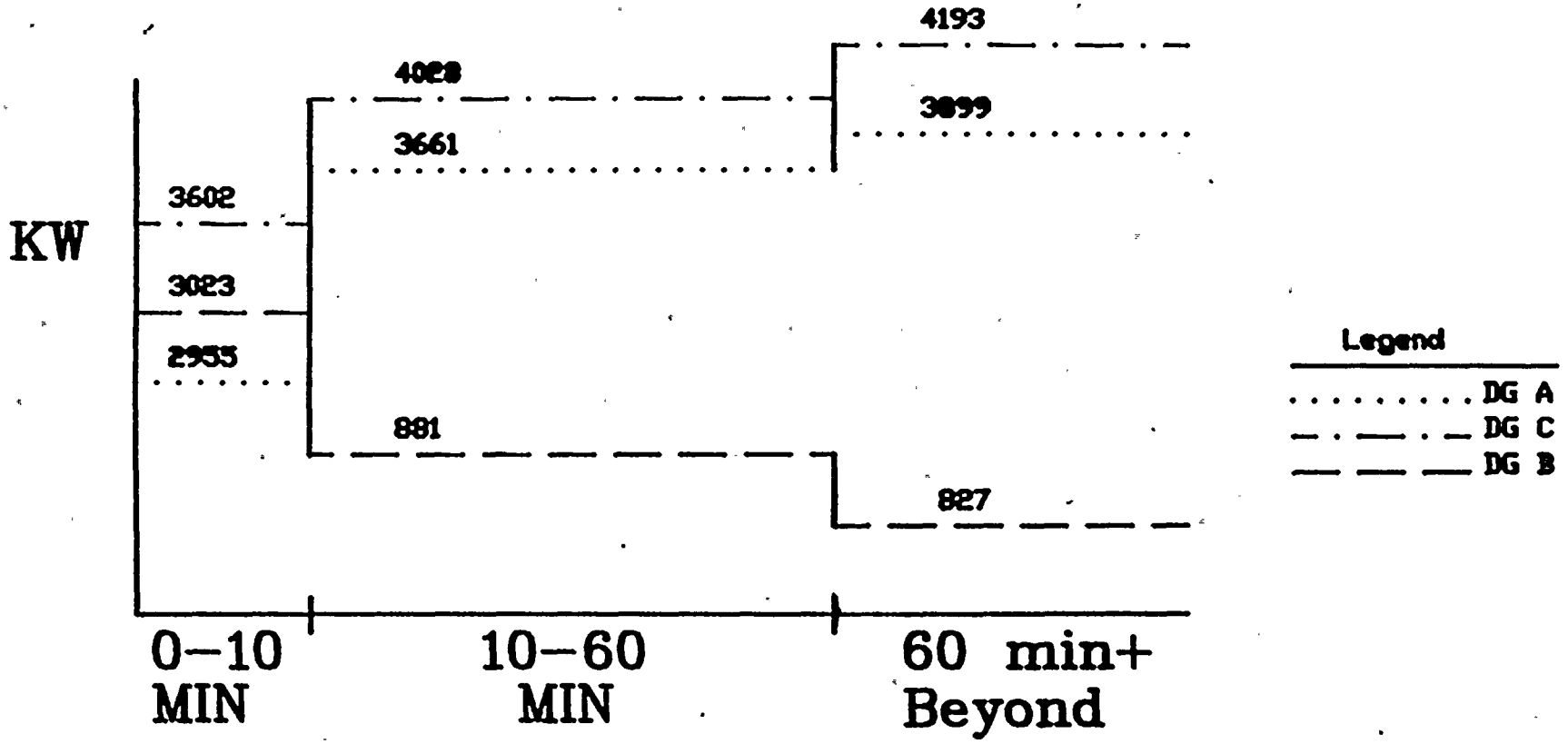


DG LOADING – U1 LOCA / U2 FORCED SHUTDOWN

ALL LOADS ASSUMED ON.
APPROX. 8000kw LOAD AVAILABLE FOR SHUTDOWN



DG LOADING – D DG FAILURE

	0–10 min	10–60 min	>60 min	DG UNAVAILABLE
A DG	2955	3669	3907	B
	3066	2384	2547	C
	2955	3661	3899	D
B DG	3027	3761	3836	A
	2940	2236	2311	C
	3023	881	927	D
C DG	3668	3208	3378	A
	3602	4028	4178	B
	3602	4028	4193	D
D DG	2727	1250	1569	A
	2733	437	495	B
	3531	3955	4072	C

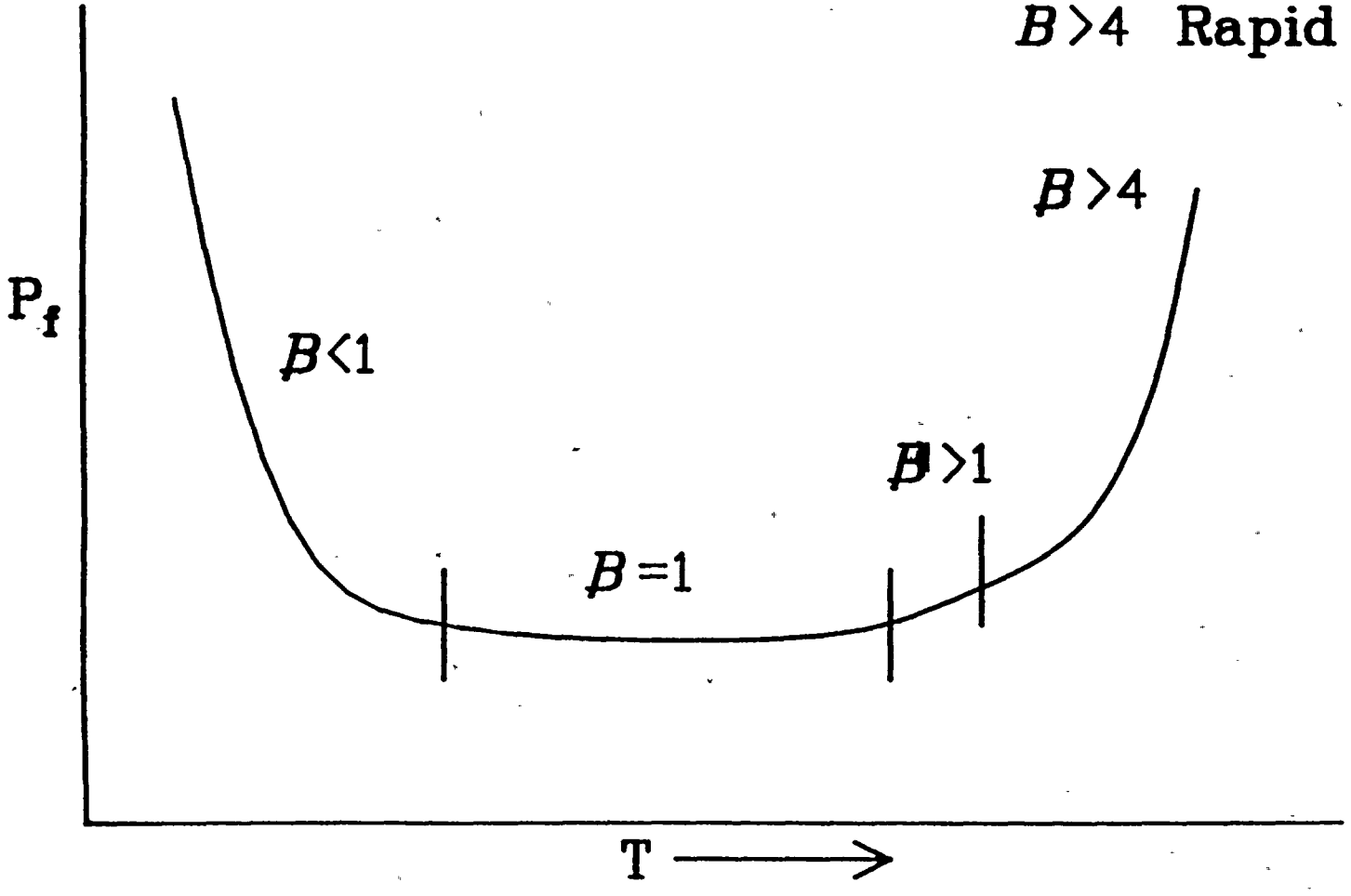
DG LOADING — 1 DG FAILURE

β<1 Infant Mortality

β=1 Random Failure Rate

1<β<4 Wearout

β>4 Rapid Wearout



WEIBULL DISTRIBUTION FUNCTION

OPERABILITY TESTS

- 24 hr CAPABILITY
- LOCA / LOOP
- LOOP
- MONTHLY SURVEILLANCE

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RELIABILITY ASSURANCE

* *INSPECTIONS*

DG	DATE	REPLACEMENTS
B	9/23	7L/R PISTON/LINER
	10/26	1R PISTON/LINER
C	10/22	5R PISTON/LINER
		6L PISTON
D	11/4	8R PISTON
A	12/1	1R, 7R PISTON

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RELIABILITY ASSURANCE

* **POST REPLACEMENT TESTING**
  - 2 hr Idle
  - 4 hr 25%
  - 2 hr 50,75,100%

  ---

  12 hr Total

* **PER MFGR RECOMMENDATION**
  - Seats rings
  - Proves Capability
* **TOTAL RUN TIMES**
  - A 42.5 hrs
  - B 59.1 hrs
  - C 65.9 hrs
  - D 47.1 hrs
  - E 17.8 hrs

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RELIABILITY ASSURANCE

- 2 – 4 hr SURVEILLANCE
- TECH SPEC CHANGES
- FUTURE INSPECTIONS
- MODIFICATIONS

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SUMMARY

OPERABILITY BASED ON:

* **OPERABILITY TESTING**
  - **Meets All Tech Specs**
  - **Proves Capability To Perform Design Functions**
* **INSPECTED and REPLACED WORN COMPONENTS**

ASSURE FUTURE OPERABILITY BY:

* **INSPECTION PROGRAM**
* **LESS SEVERE TESTING**
* **DESIGN CHANGES**

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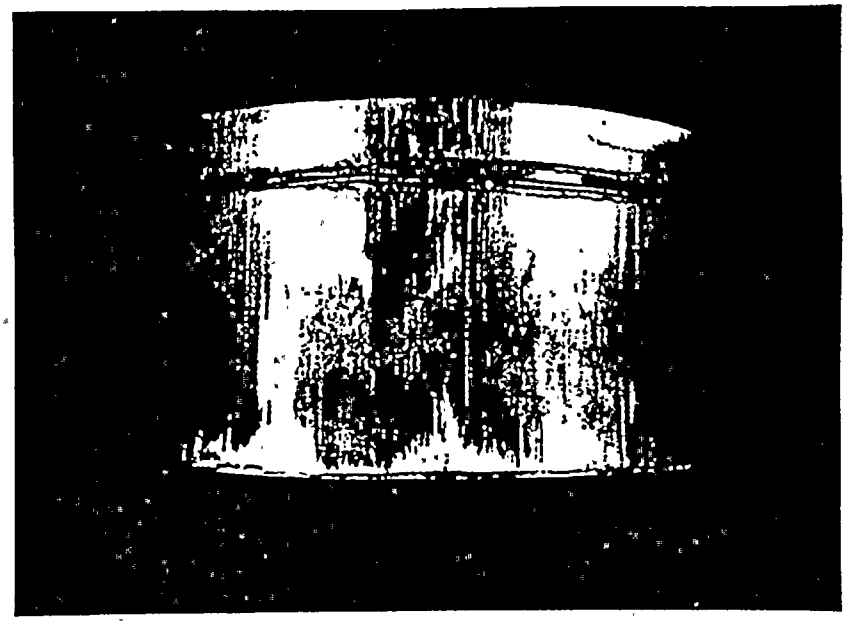


Figure B-1 Picture of the skirt of the B diesel 7L piston showing heavy wear and metal distortion in the lower ring area.

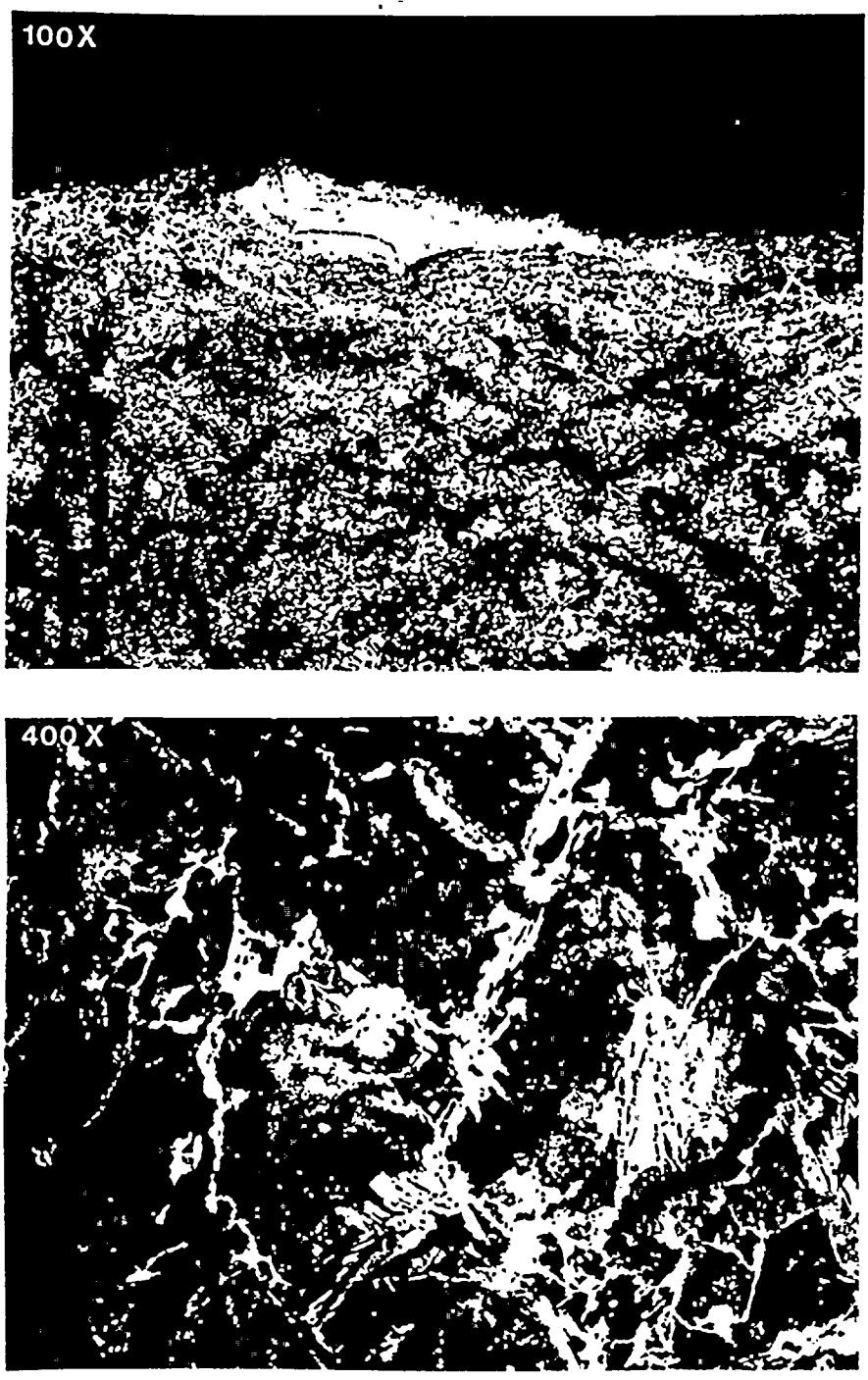
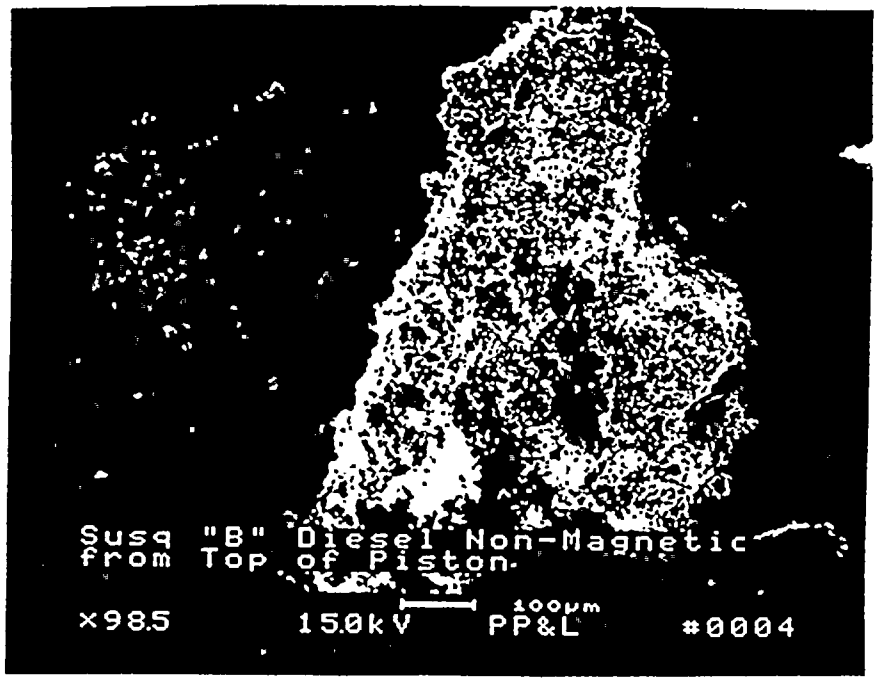


Figure B-2. Cross-section of the B diesel 7L piston skirt area showing deposited metal in the upper micrograph and martensite formation in the microstructure in the lower micrograph. The latter indicates temperatures in excess of 1350 deg F were experienced by the material locally.

Figure B-3. Enlarged section of the deposits on the skirt of the D diesel 7L cylinder showing the layering evident there.



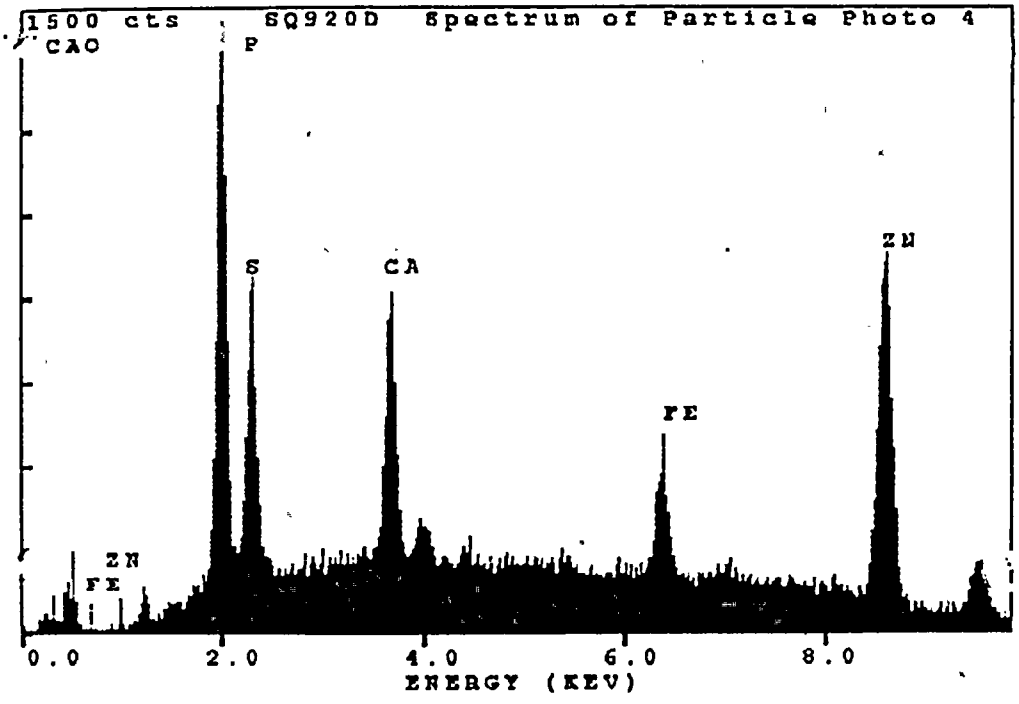
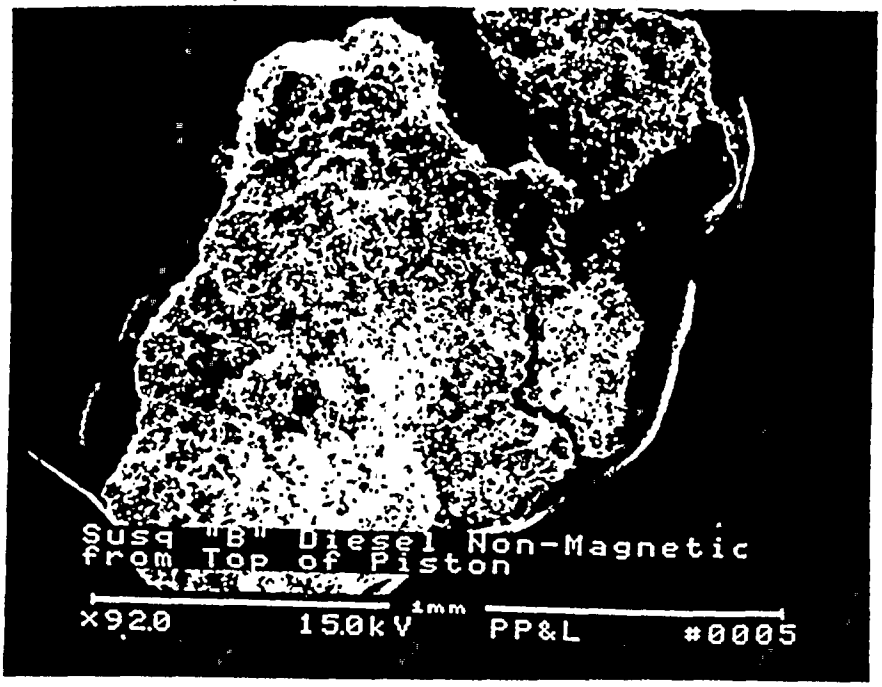


Figure B-4. Micrograph and EDS analysis results of non-magnetic debris taken from the head of the B diesel 7L piston.



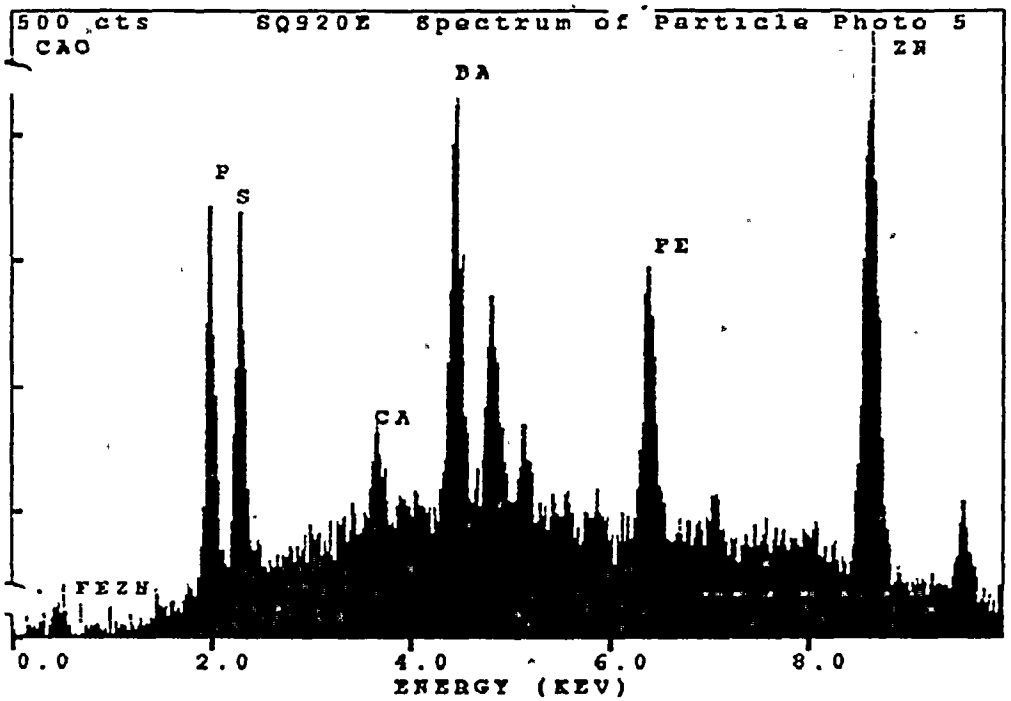
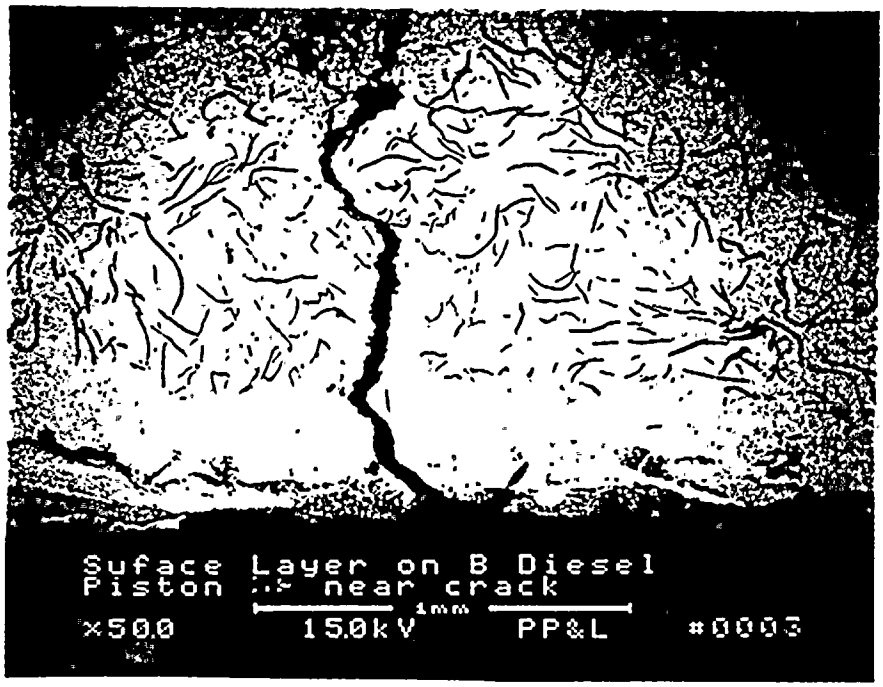
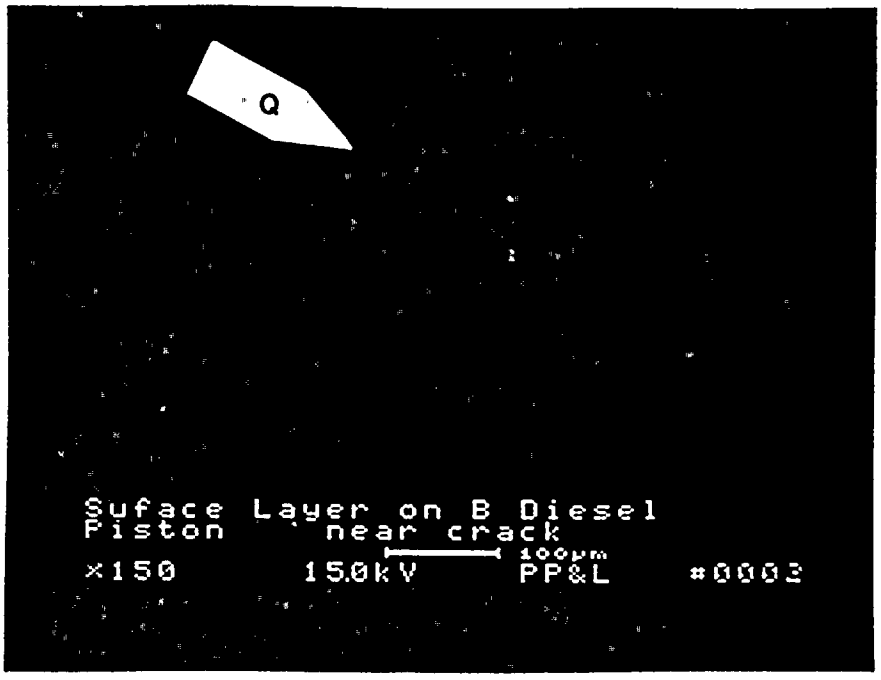


Figure B-5. Micrograph and EDS analysis results of non-magnetic debris taken from the head of the B diesel 7L piston on another particle from that analyzed in the figure B-4.



A



B

Figure B-6. Cross-section of a cracked area of the B diesel 7L piston skirt showing metal deposits on the surface.

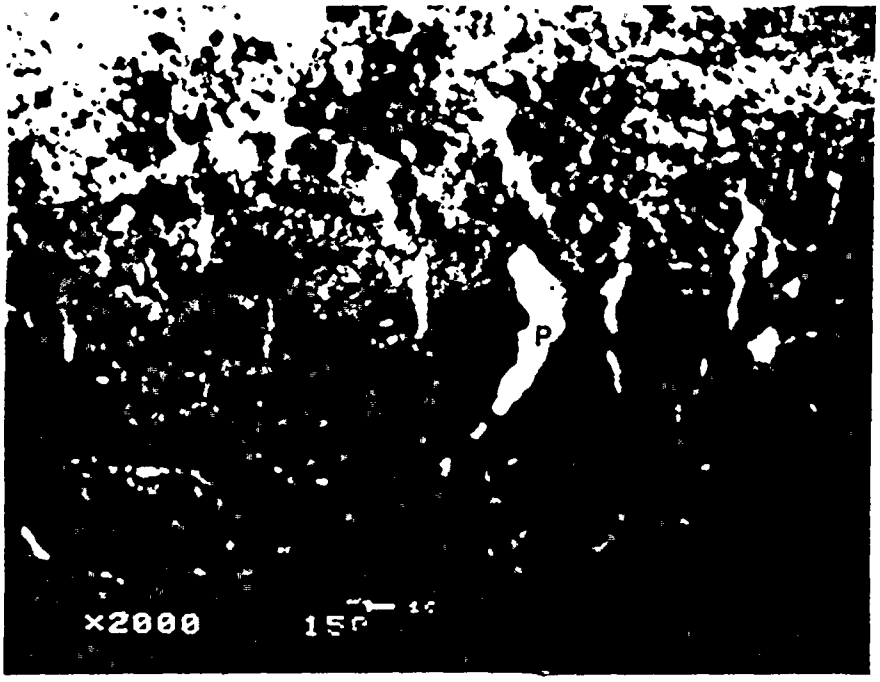
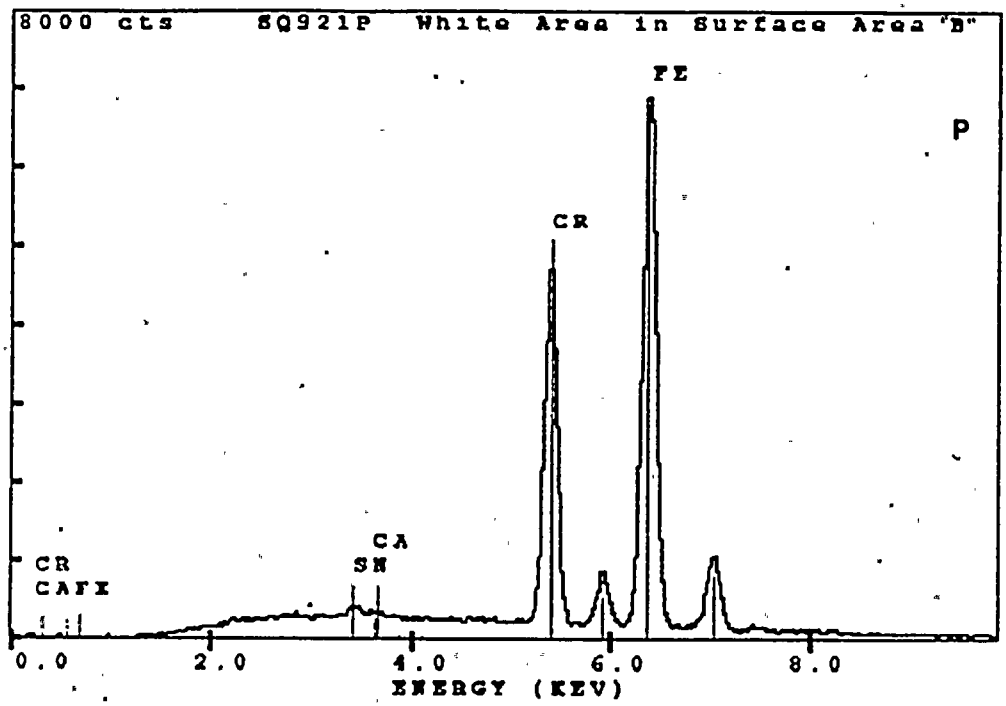


Figure B-7. Enlarged area of the bottom right portion of figure B-6 showing where analysis 'P' was taken.



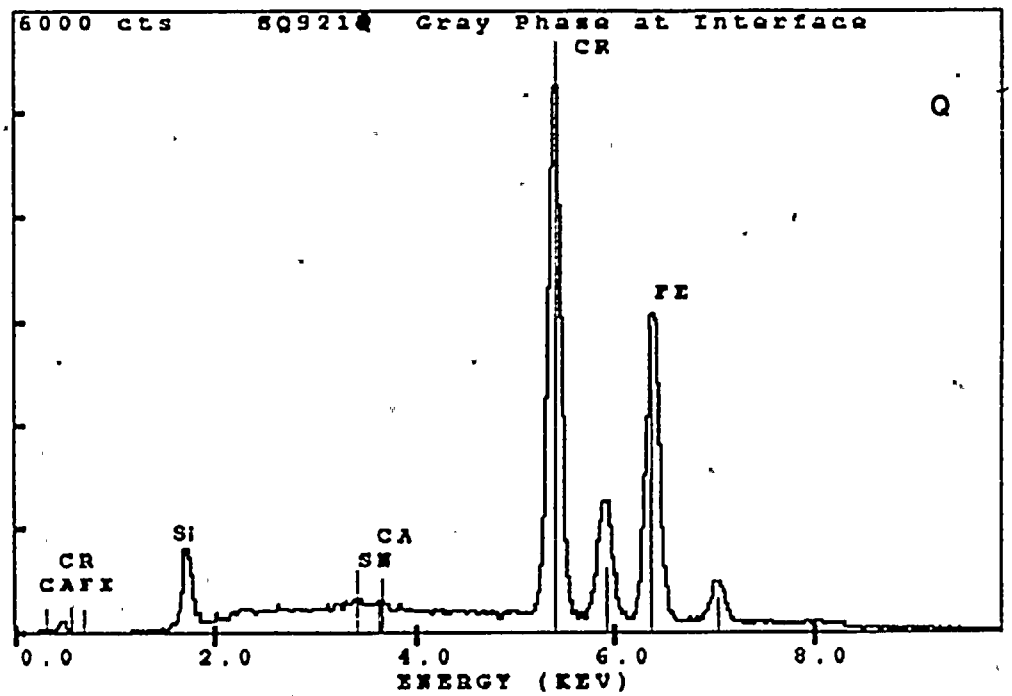


Figure B-8. EDS analysis of areas 'P' and 'Q' in figures B-7 and B-6.

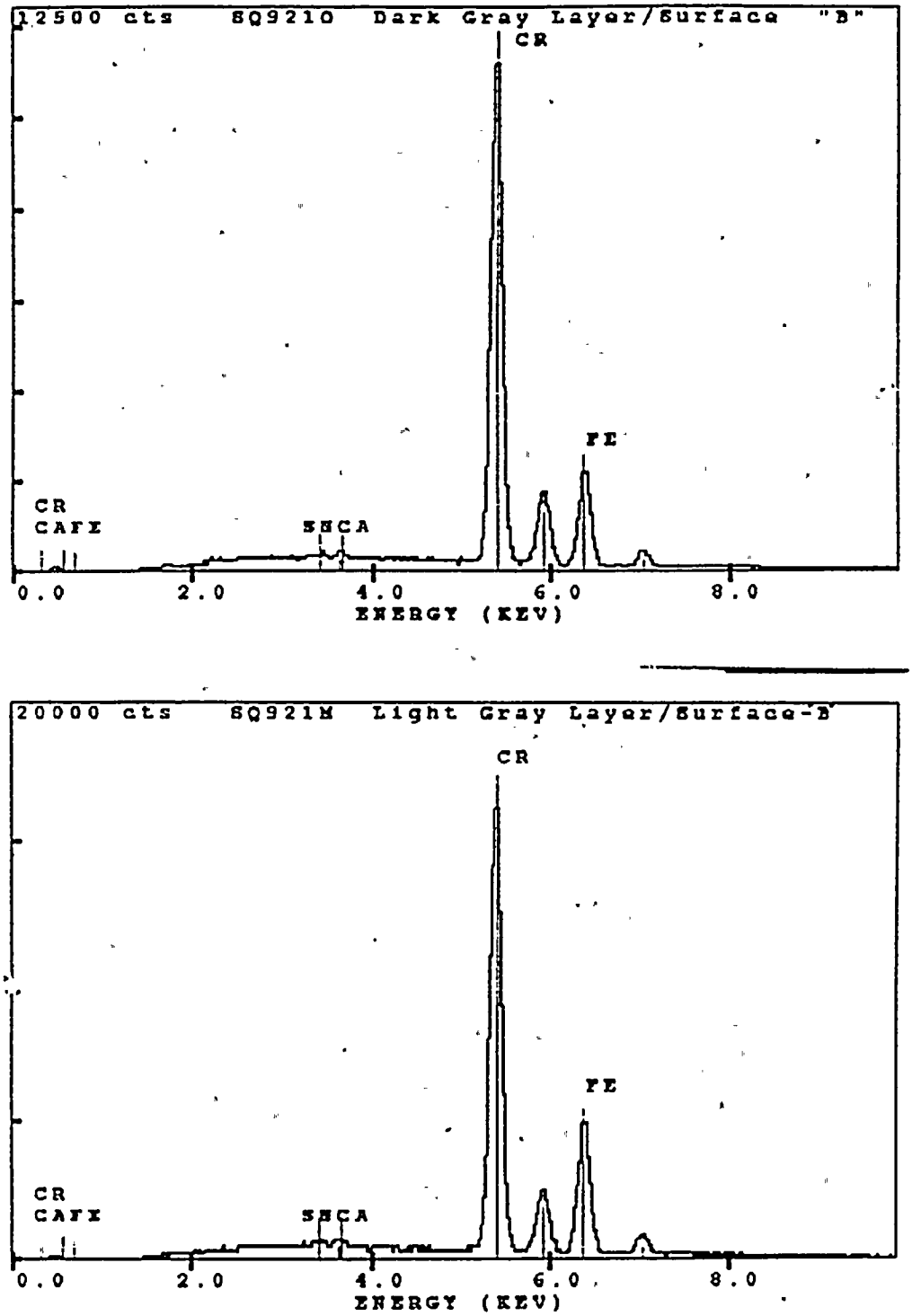


Figure B-9. Spectra of the light and dark phases in figure B-7.

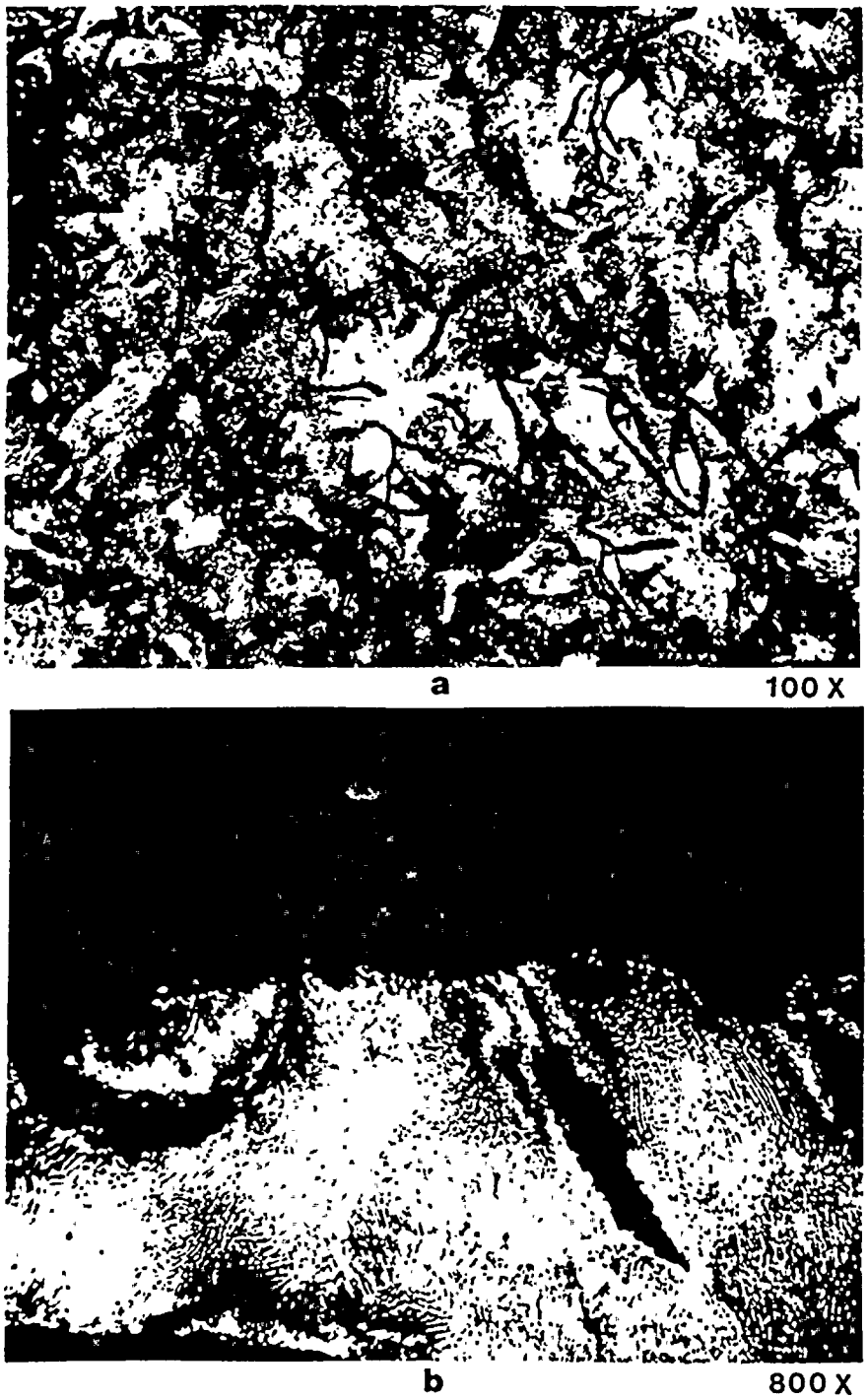


Figure B-10. Microstructure of the head of the B diesel 7L piston showing a normal pearlitic, graphite flake condition
a. Thick section b. Thinnest section

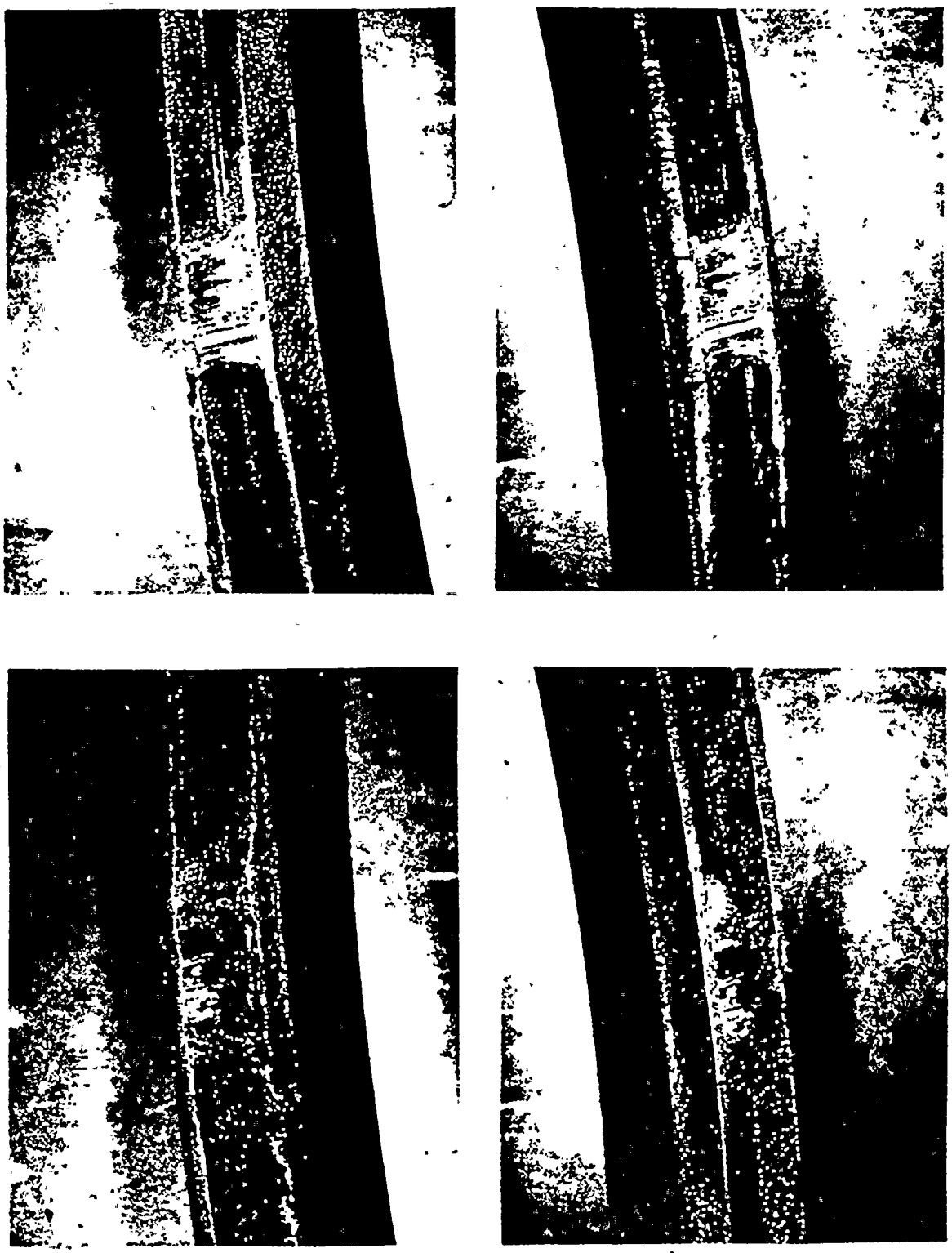


Figure B-11. Portions of the top wiper ring of the B diesel, 7L piston showing the pickup of metal and debris on the surfaces touching the liner.

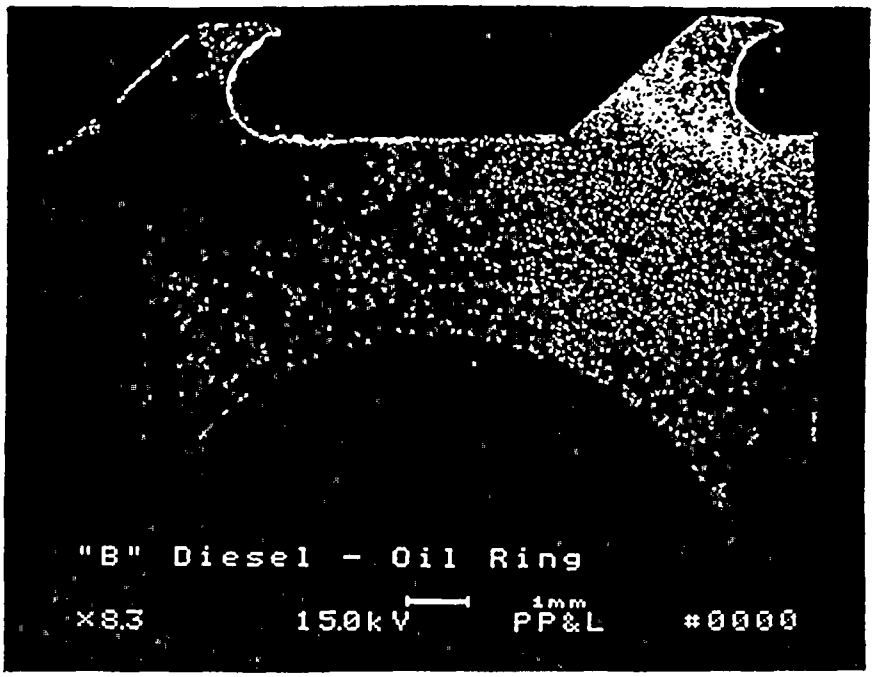


Figure B-12. Cross section of the lower oil ring from the B diesel 7L piston showing the wear and deformation on the two wiper surfaces.

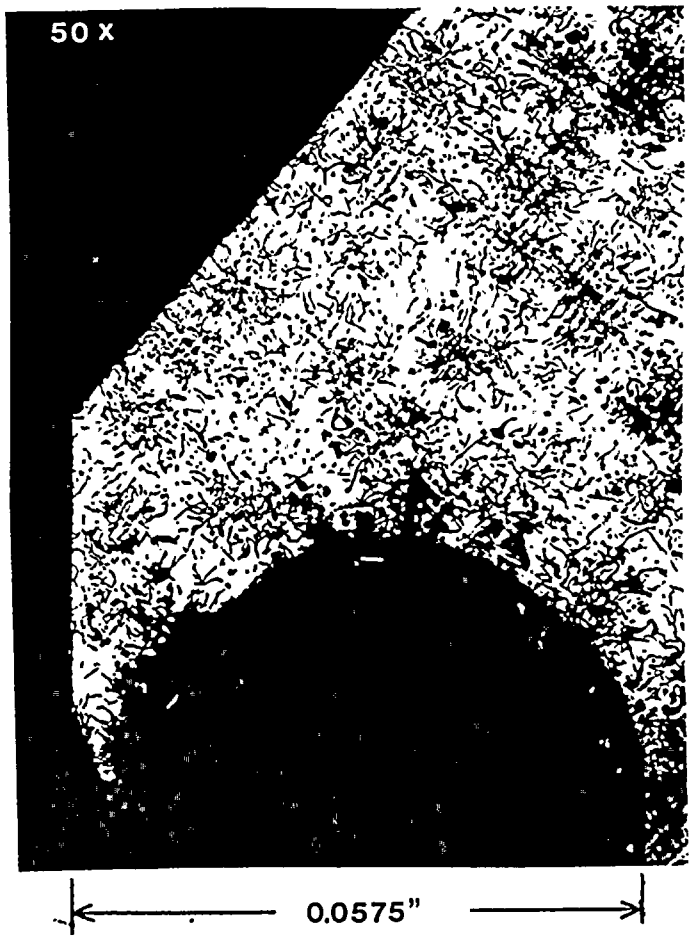


Figure B-13. Picture of oil ring profile at high magnification. To be taken later. Magnified image of oil ring finger from B diesel, 7L piston lower oil ring showing structure deformation and size of the finger.

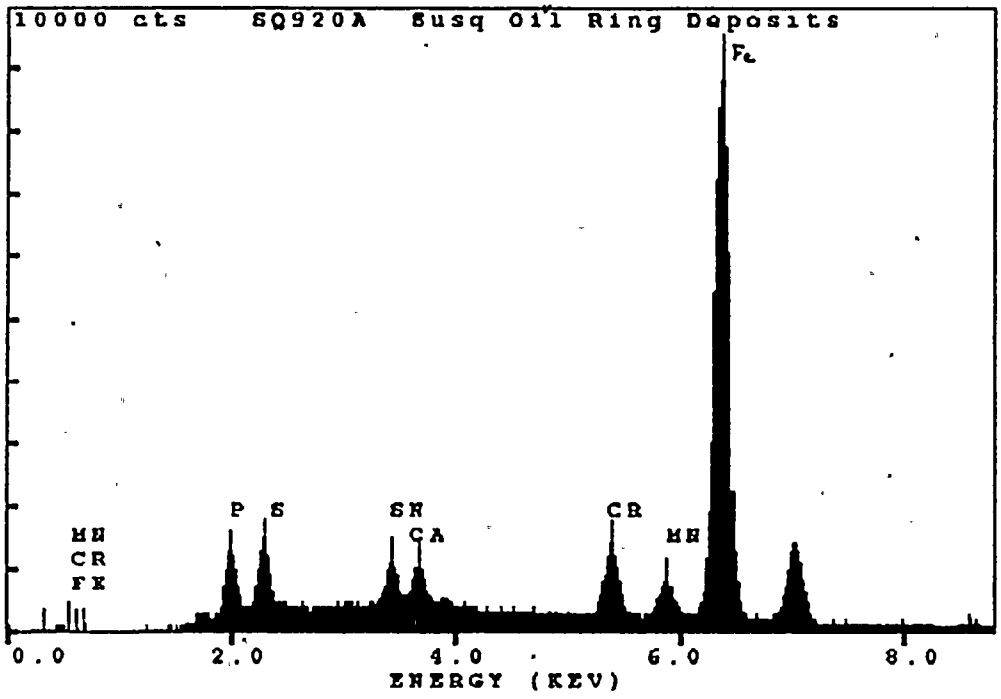


Figure B-14. Debris EDS analysis from the spring behind the lower oil ring from the B diesel 7L piston.

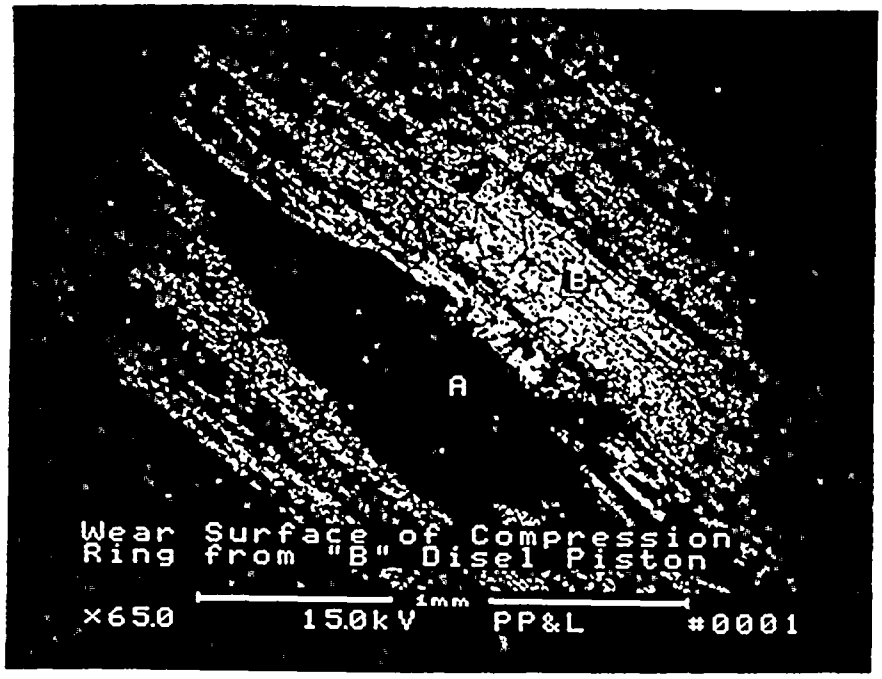


Figure B-15. Smeared metallic deposits found on the #4 compression ring of the B diesel, 7L piston are shown here as the dark gray area labeled 'A'. EDS analysis of area 'A' shows it to contain Cr, Fe, Si(trace) and Sn(trace). Area 'B' shows only Fe with a trace of Cr.

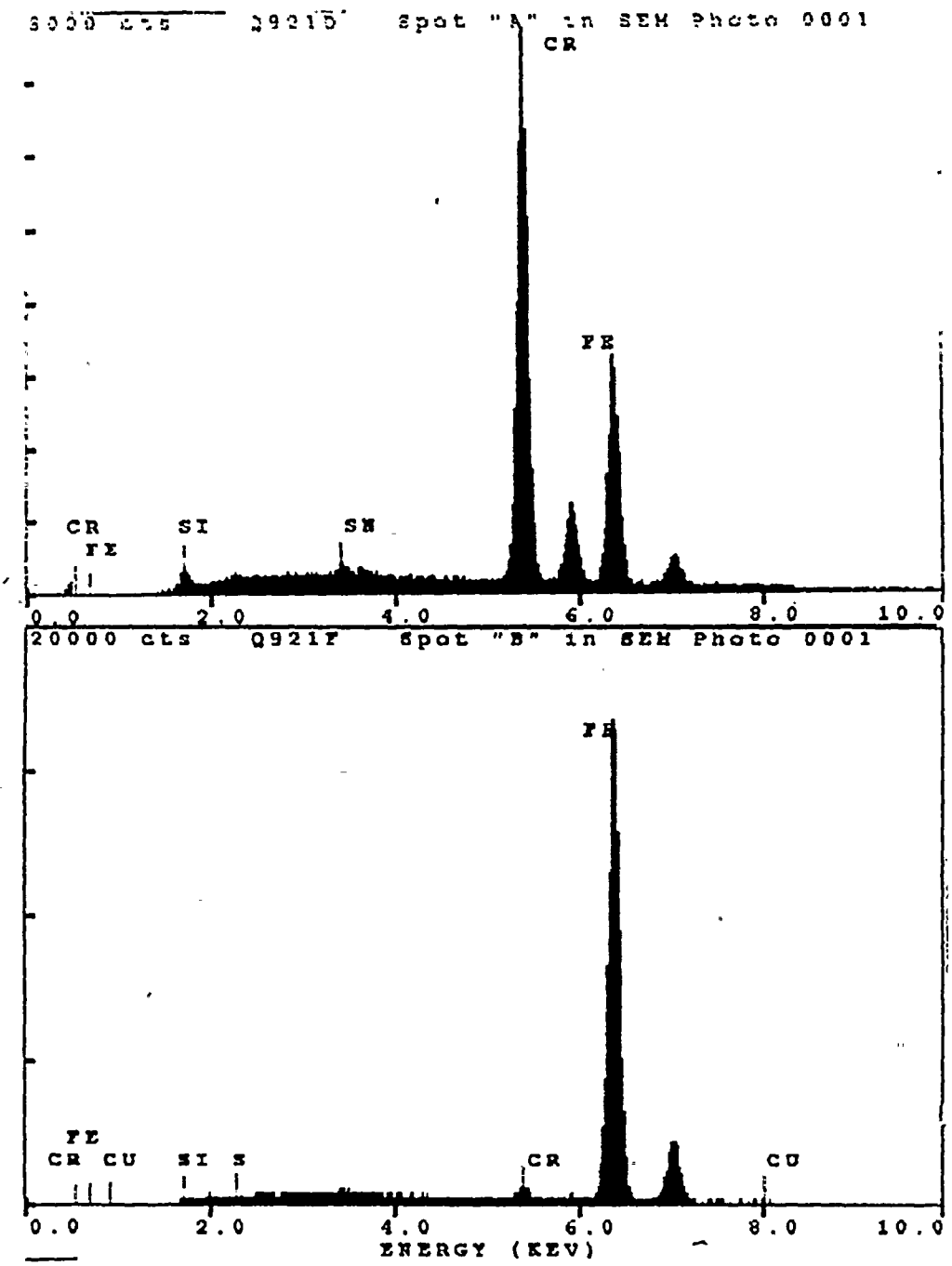
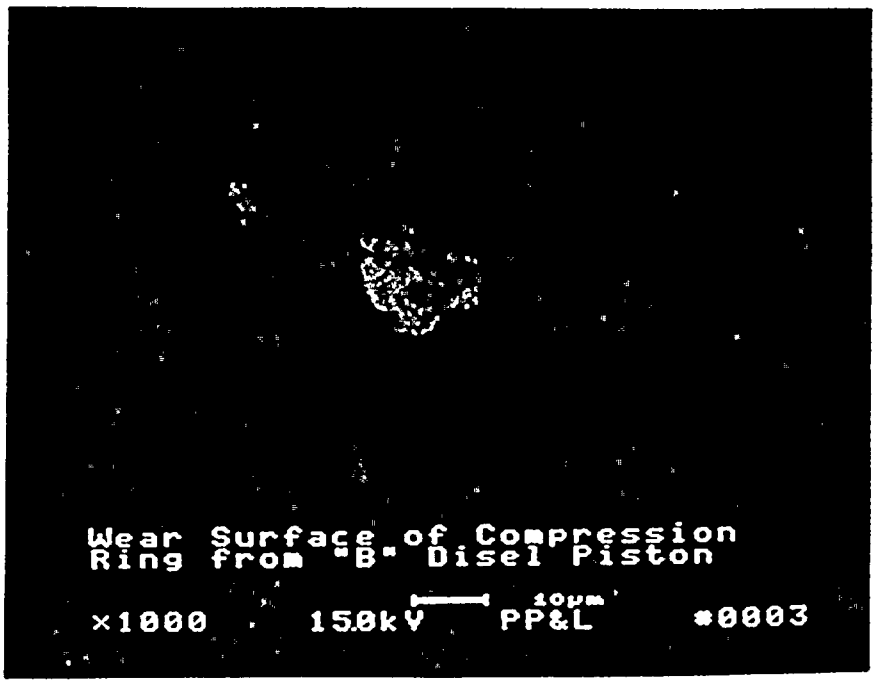


Figure B-16. EDS analysis of the #4 compression ring from the B diesel 7L piston in areas 'A' and 'B' of Figure B-15.



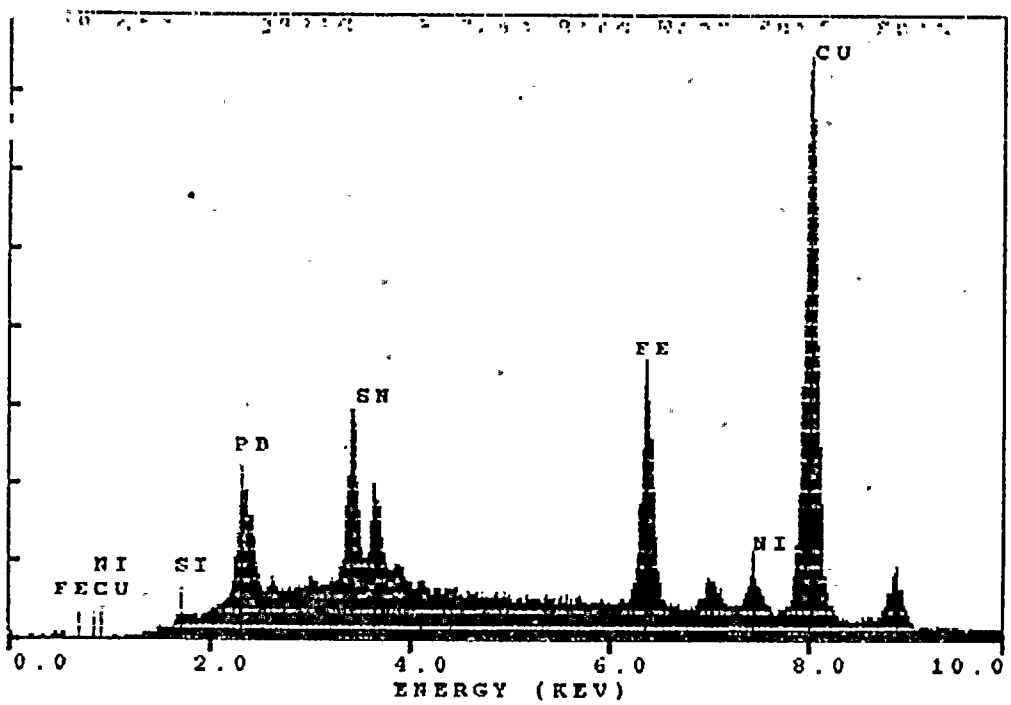


Figure B-17. An unusual spot of foreign material found embedded in the #4 compression ring from the B diesel 7L piston. EDS analysis shows it to contain Cu, Fe, Sn, Pb, and Ni.

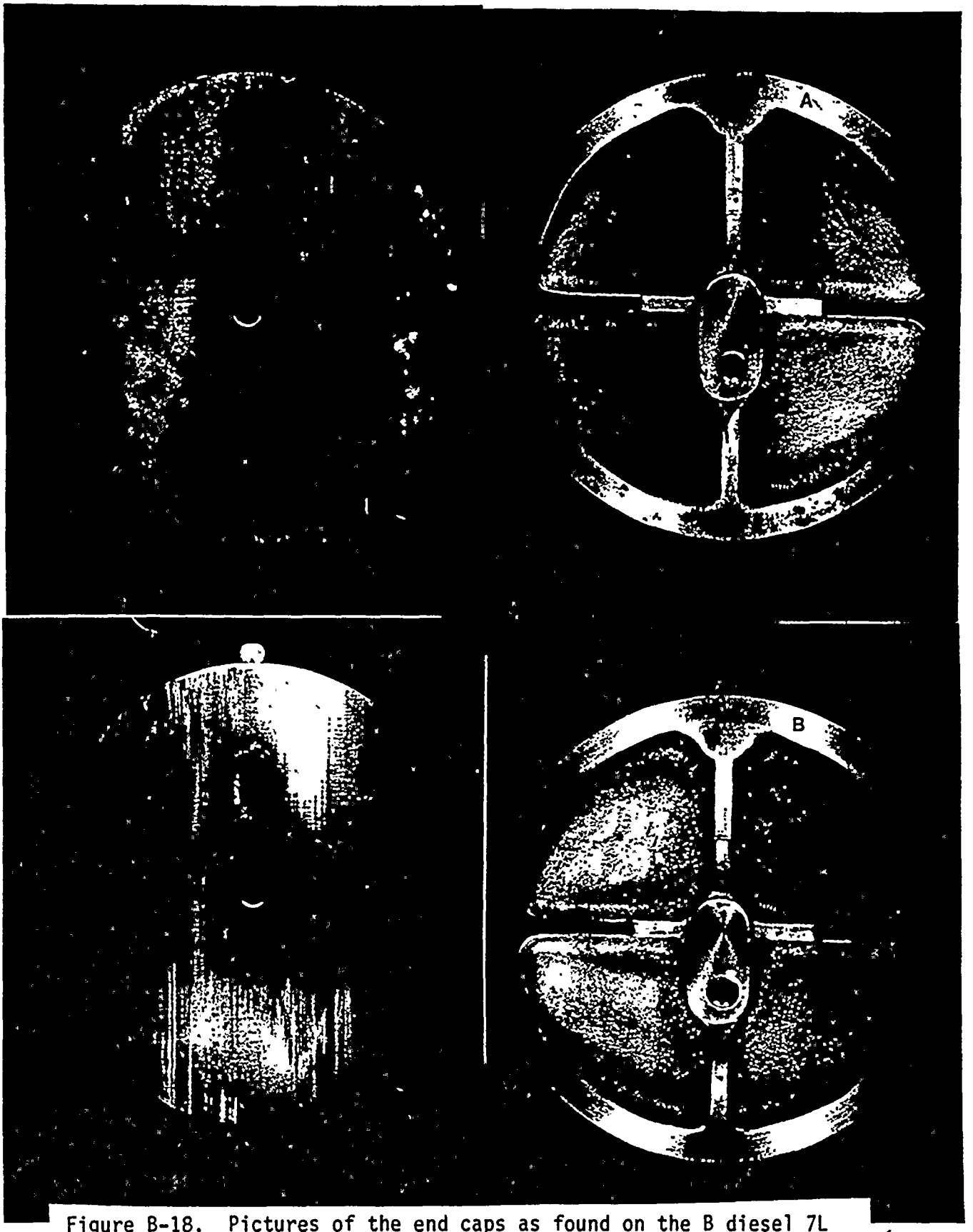


Figure B-18. Pictures of the end caps as found on the B diesel 7L piston showing the scraping and local heating experienced by these parts during the failure sequence.

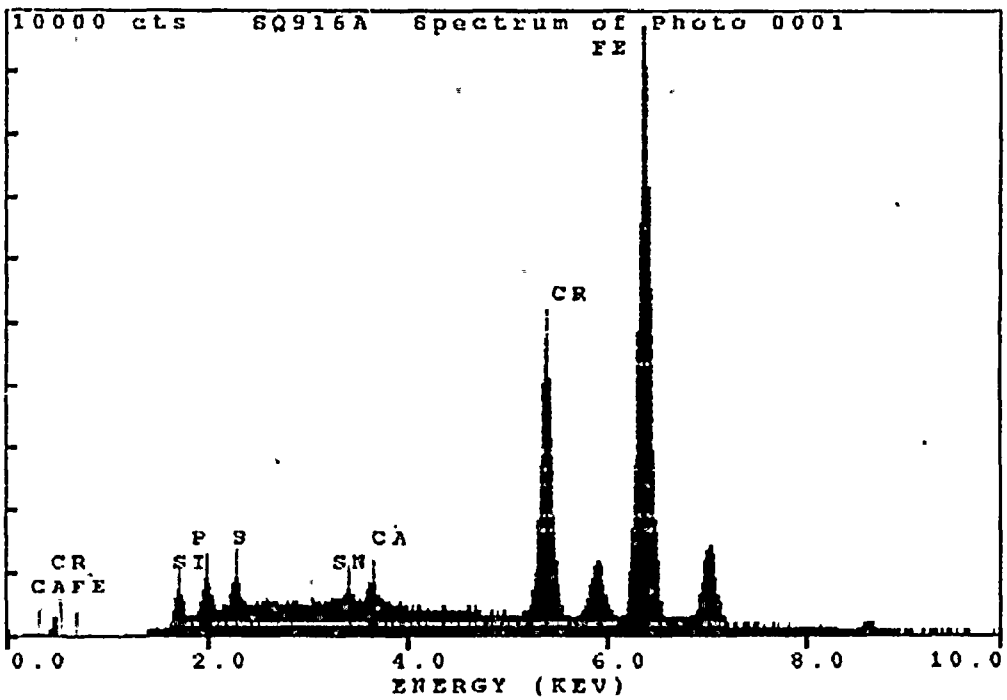
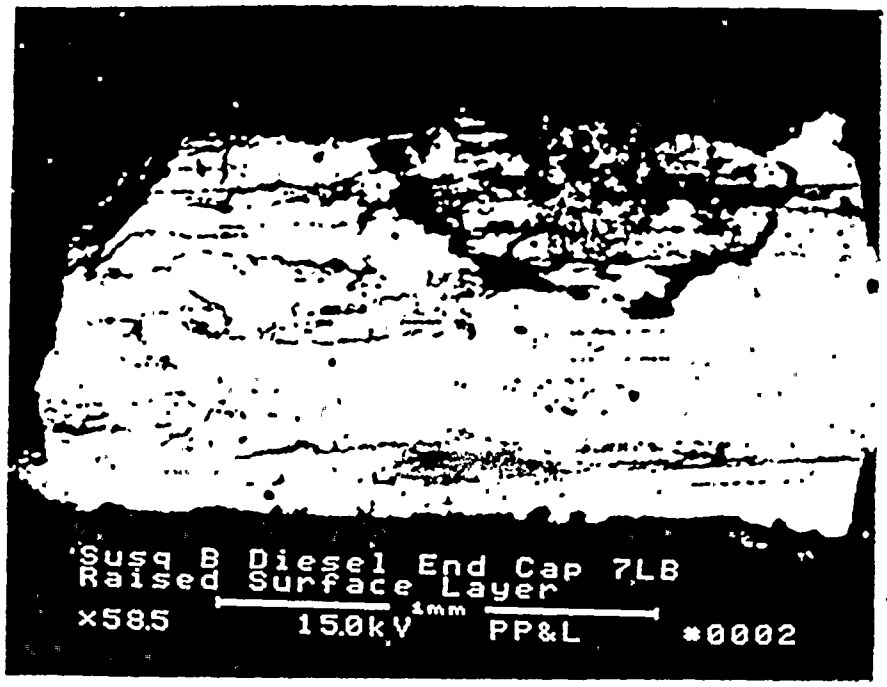


Figure B-19. Picture and EDS analysis of a piece of smeared metal removed from end cap 'A' from the B diesel 7L piston.



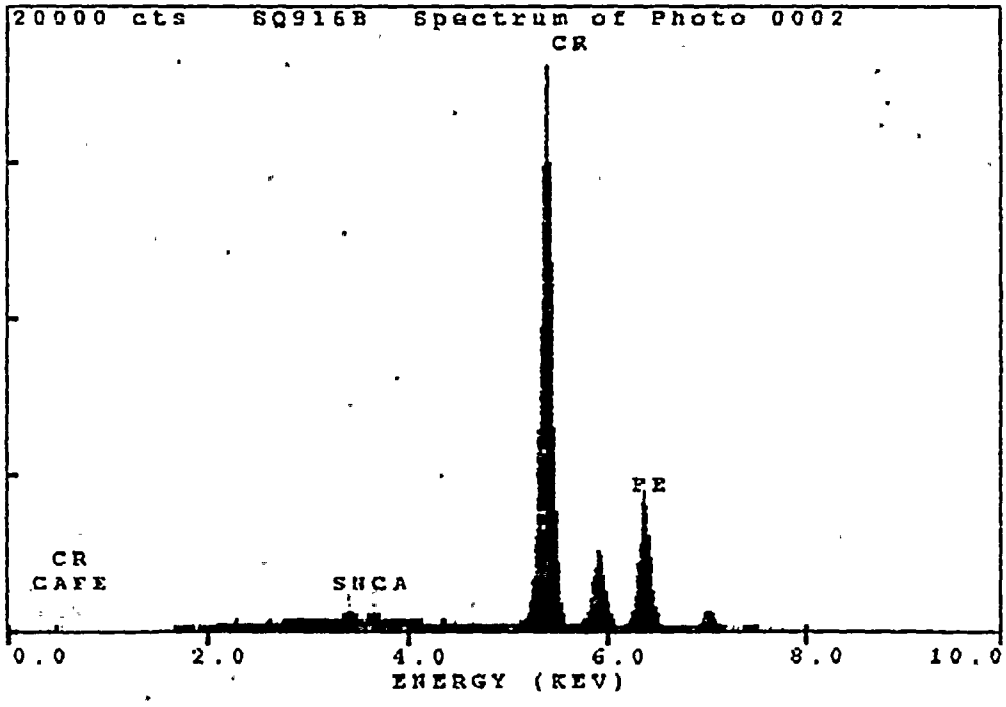


Figure B-20. Particle of smeared metal removed from pin end cap 'B' from the B diesel 7L piston. The EDS analysis shows that it consists primarily of Cr with some Fe and a trace of Ca and Sn.

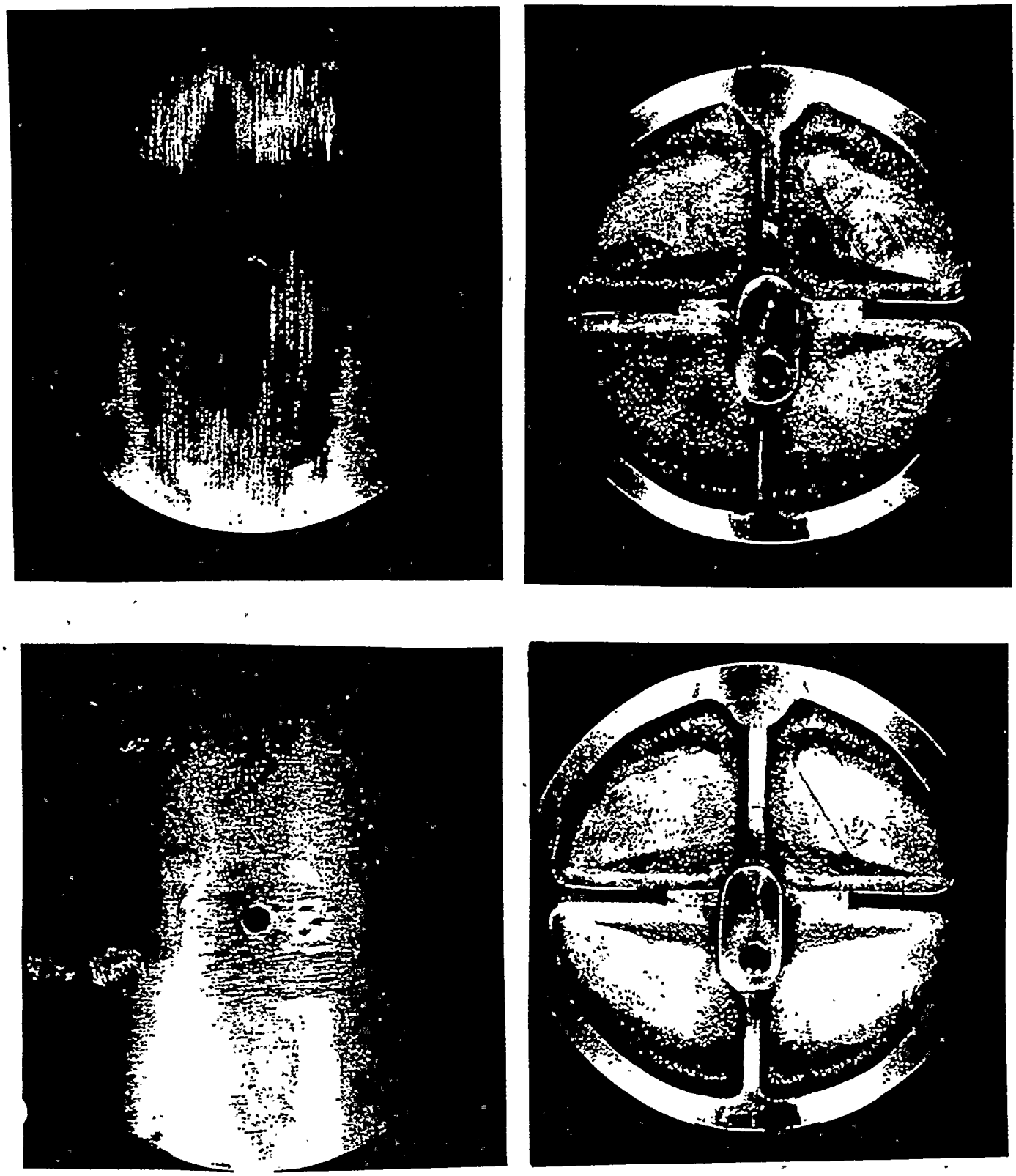


Figure B-21. Abrasion and wear found on the B diesel 7R piston pin end caps.

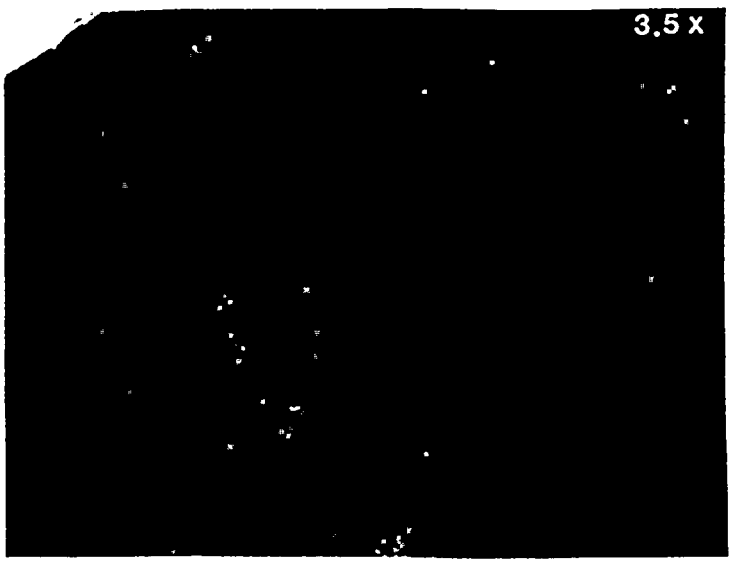
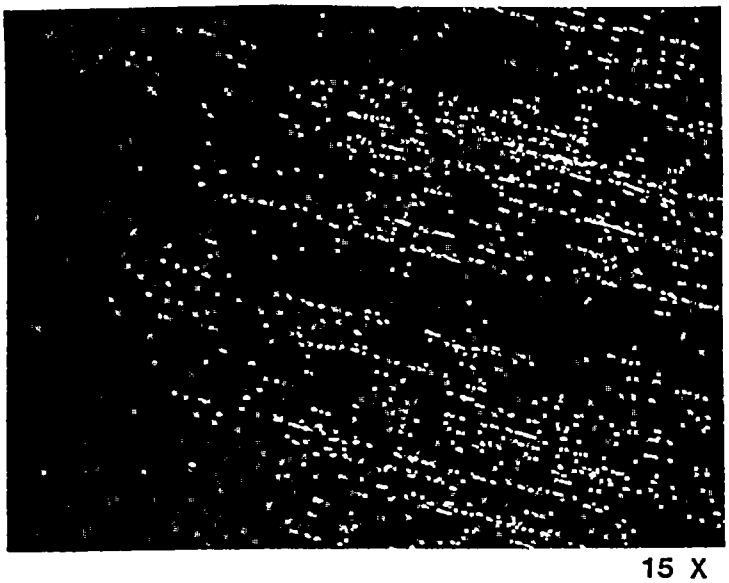


Figure B-22. Photograph of the B diesel 7R piston end cap which showed the worst amount of wear, heating and metal transfer.

3.5X



15 X

Figure B-23. B diesel 7R end cap showing the least amount of wear, but does show that the cap was touching the surface of the liner as evidenced from the light scratch marks on the surface perpendicular to the machining marks.

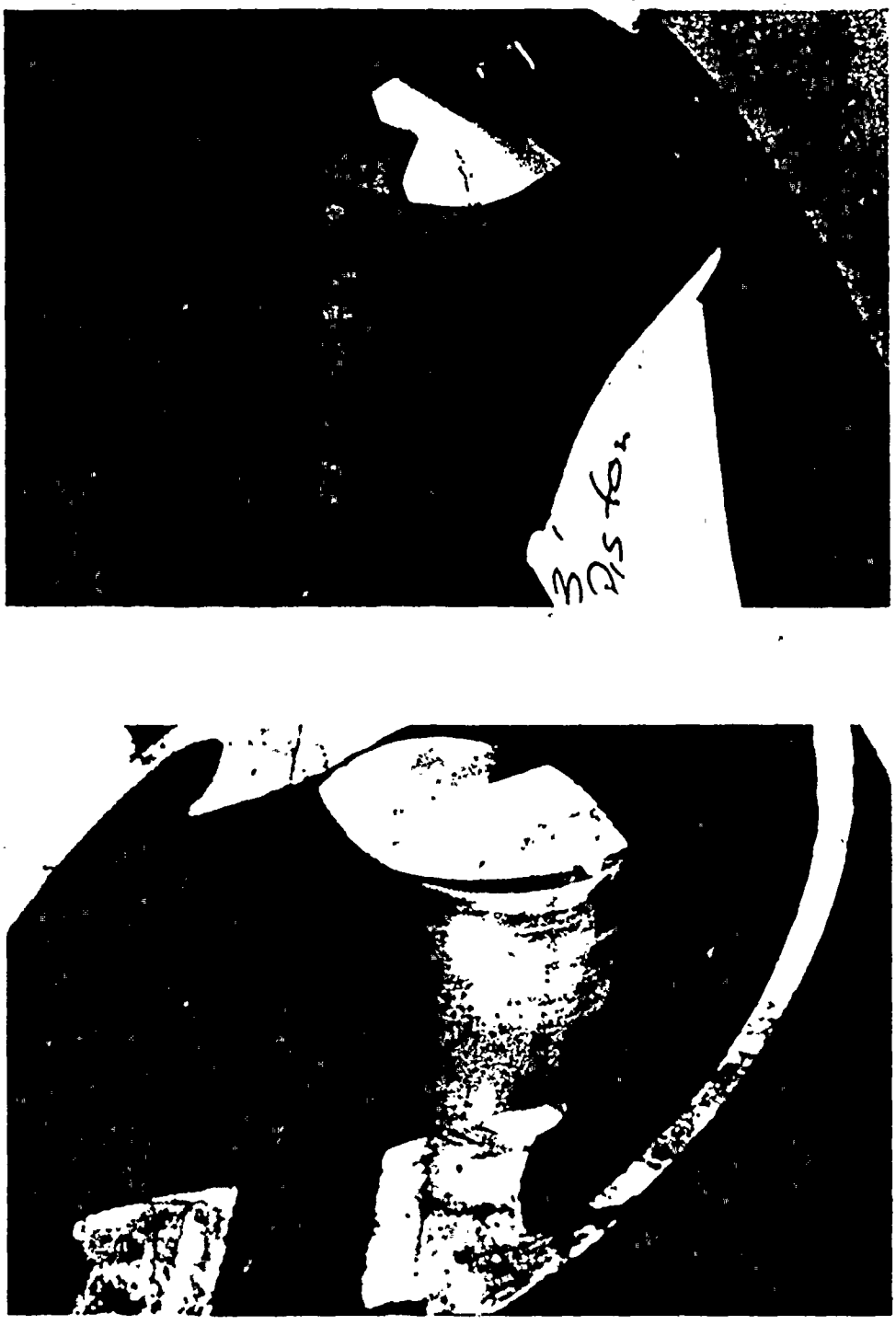


Figure B-24. Photographs of both ends of the B diesel 7L piston bronze bushing showing the heat tinting and decomposed oil products near the ends 90 degrees to the top of the bushing.

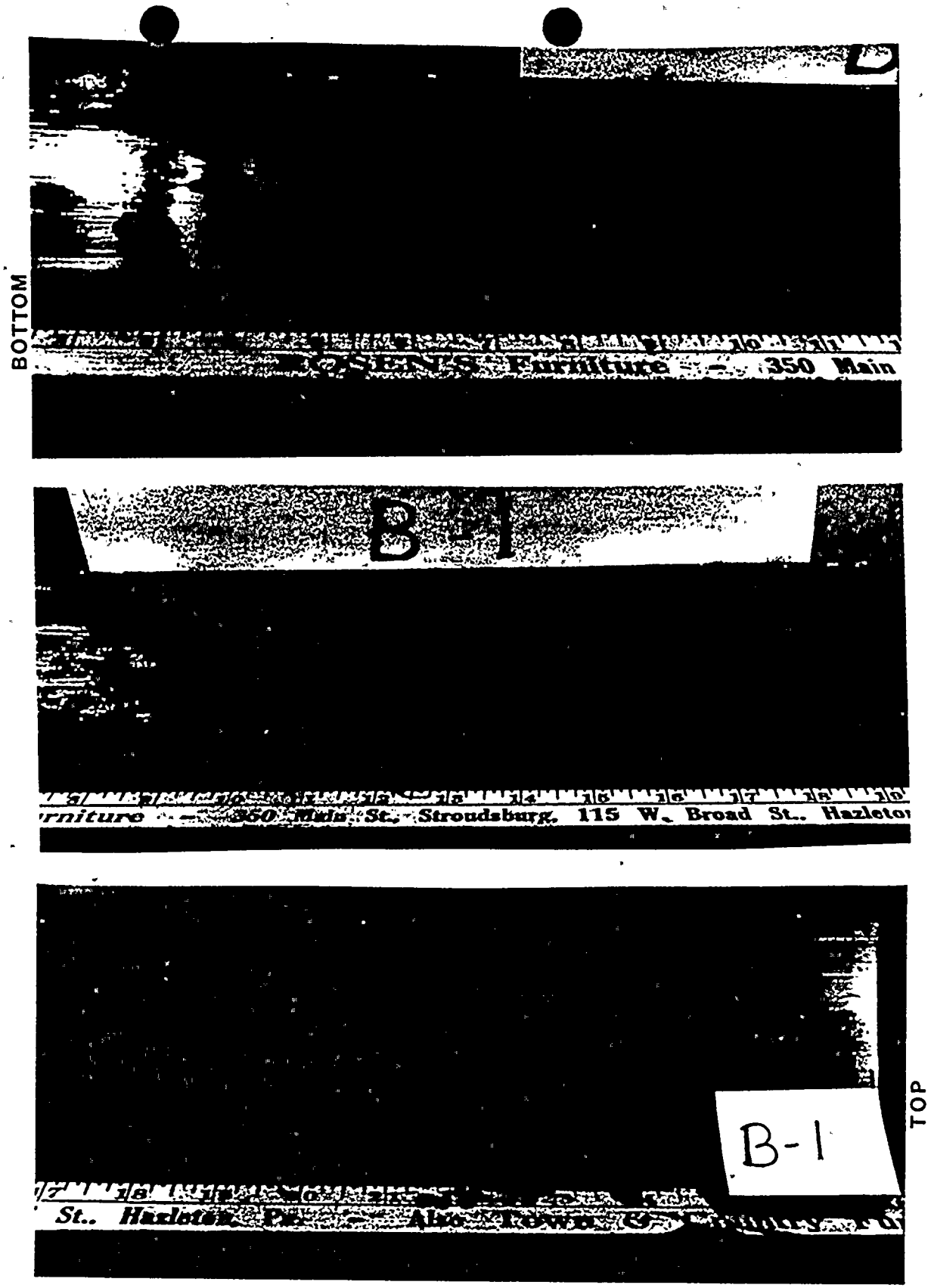


Figure B-25. Full length view of the B diesel 7L liner surface on the thrust side of the liner(identified as piece B-1)

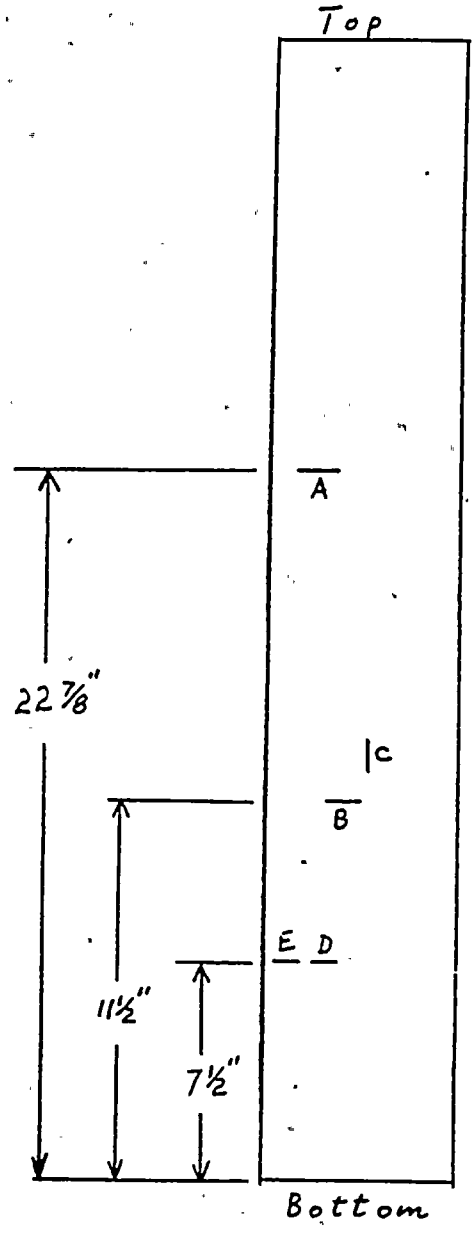


Figure B-26. Sketch of the thrust side of the B diesel 7L liner showing the location and orientation of the sections removed for metallurgical cross-sectioning(part labeled B-1).

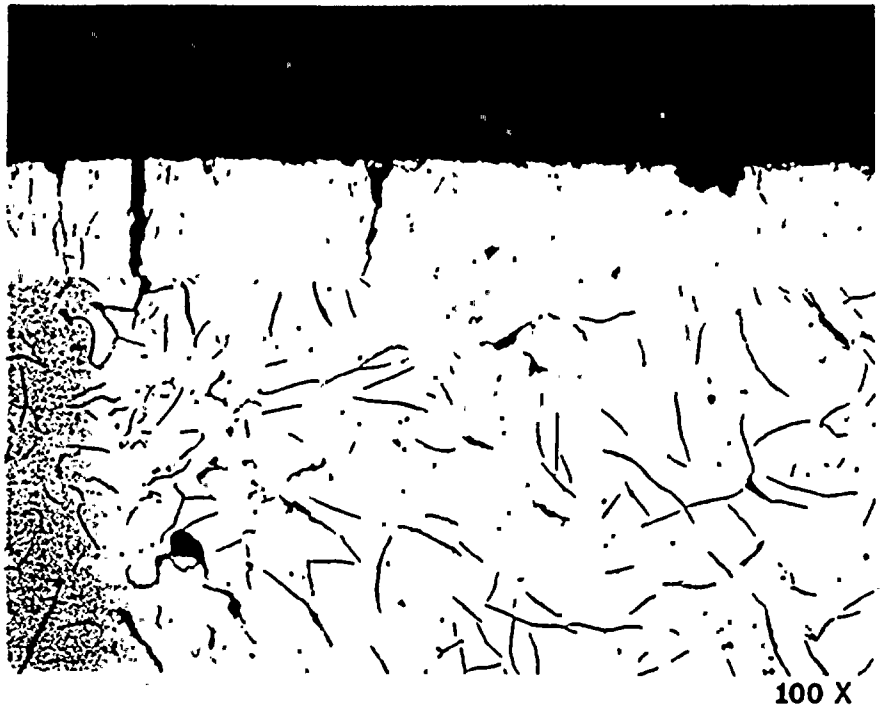


Figure B-27. Transverse cross-sectional views of the thrust side of the B diesel 7L liner 22 7/8 inches from the bottom(piece 'A'). The chromium plating is cracked and some of the pores are filled with metallic particles.

100X

100X

Figure B-28. Longitudinal view of the B diesel 7L liner on the thrust side 11 1/2 inches from the bottom showing metallic deposits, filled pores and cracking in the Cr plating(piece labeled 'B').

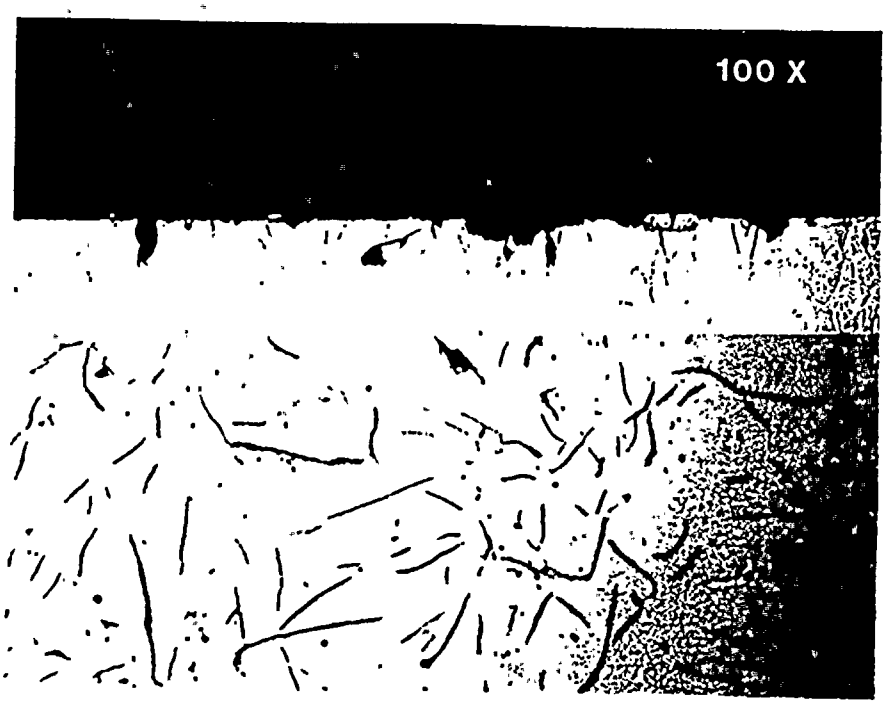


Figure B-29. Longitudinal cross-section (labeled 'C') taken 12 inches from the bottom of the B diesel 7L cylinder liner showing a rough fractured surface with pieces missing and some debris in the pores of the chromium plating layer.

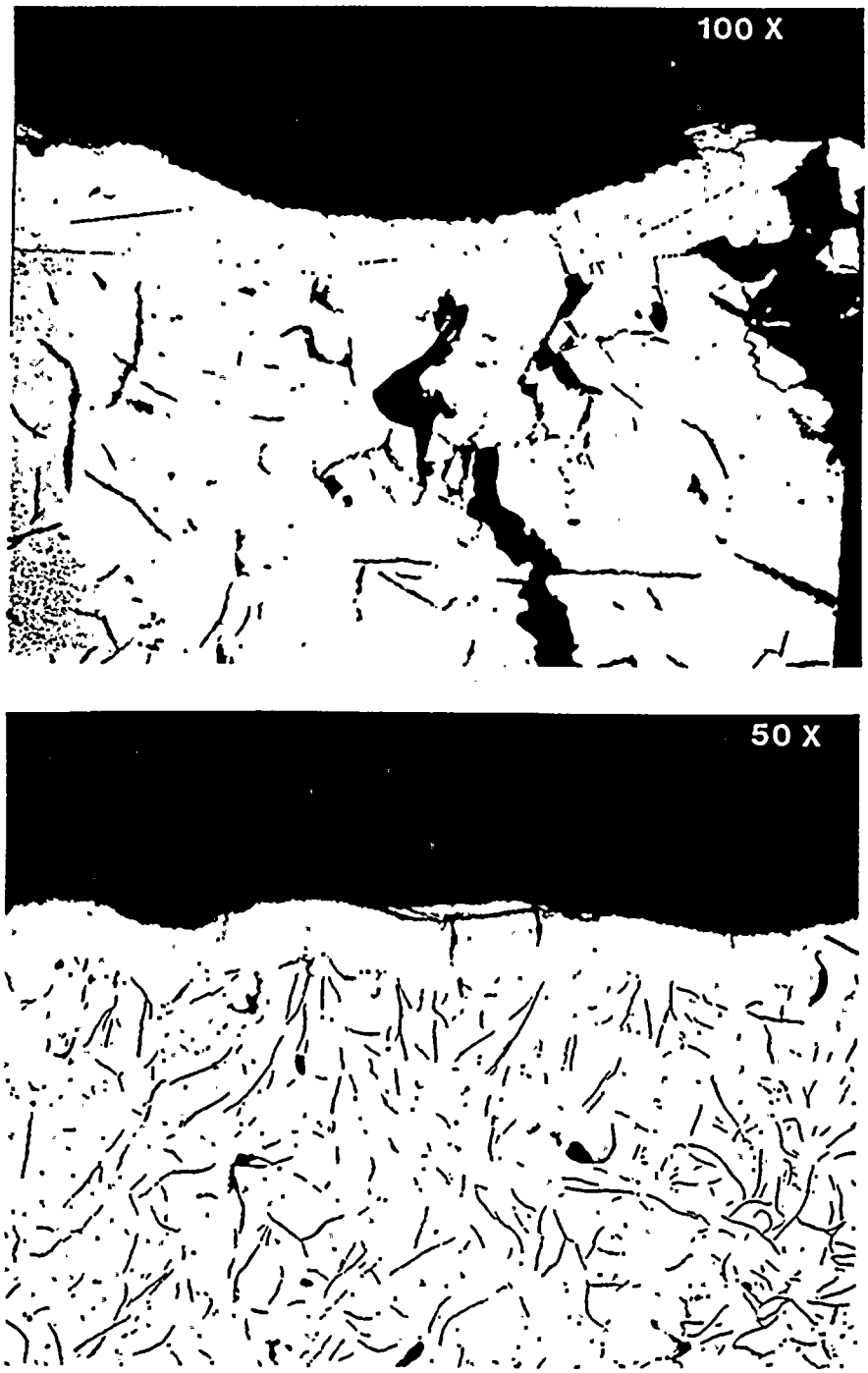


Figure B-30. Transverse cross-section(labled area 'D') taken 7 1/2 inches from the bottom of the B diesel 7L liner showing depressions in the Cr plating surface, cracking of the base metal casting and deposited metal.

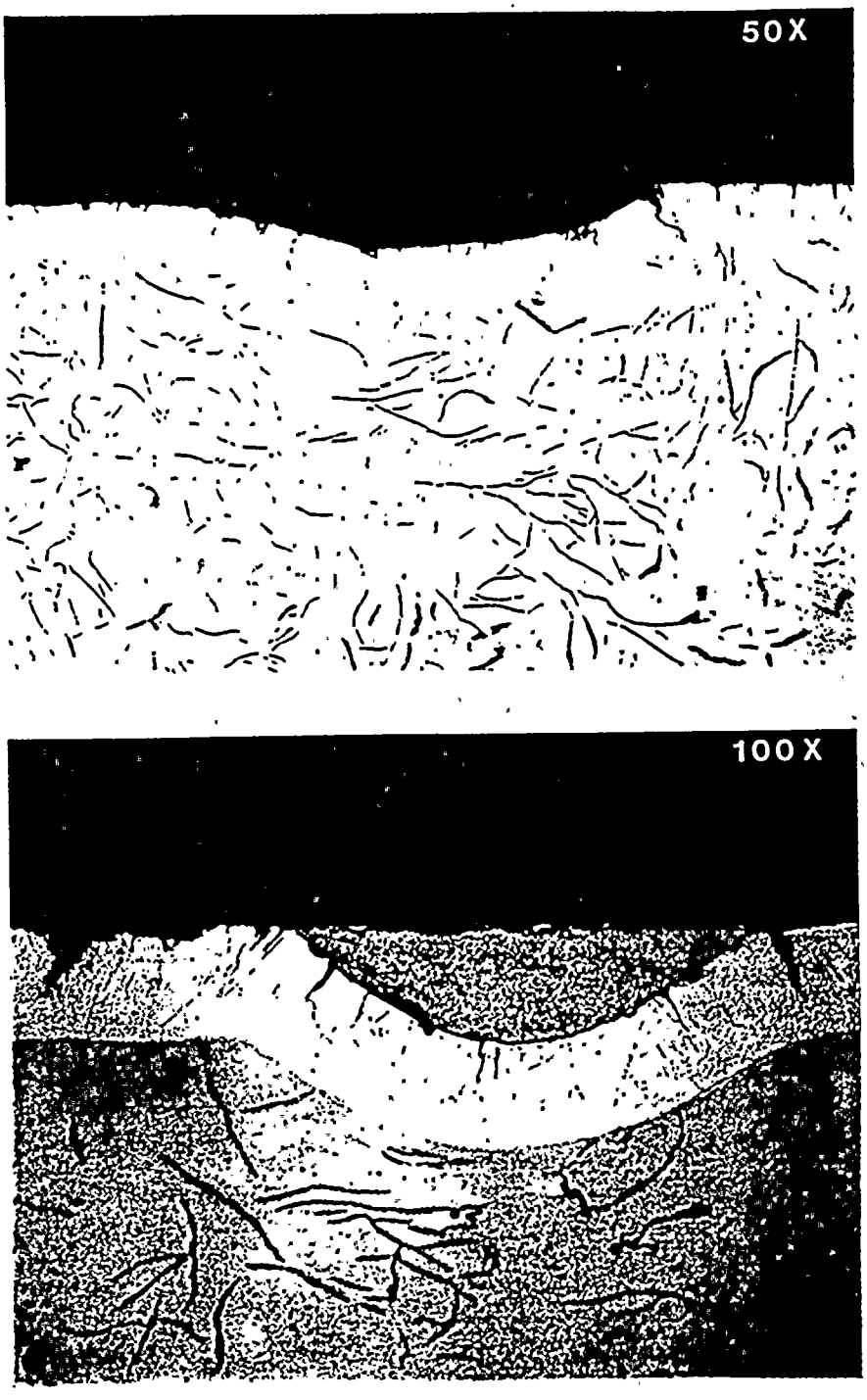
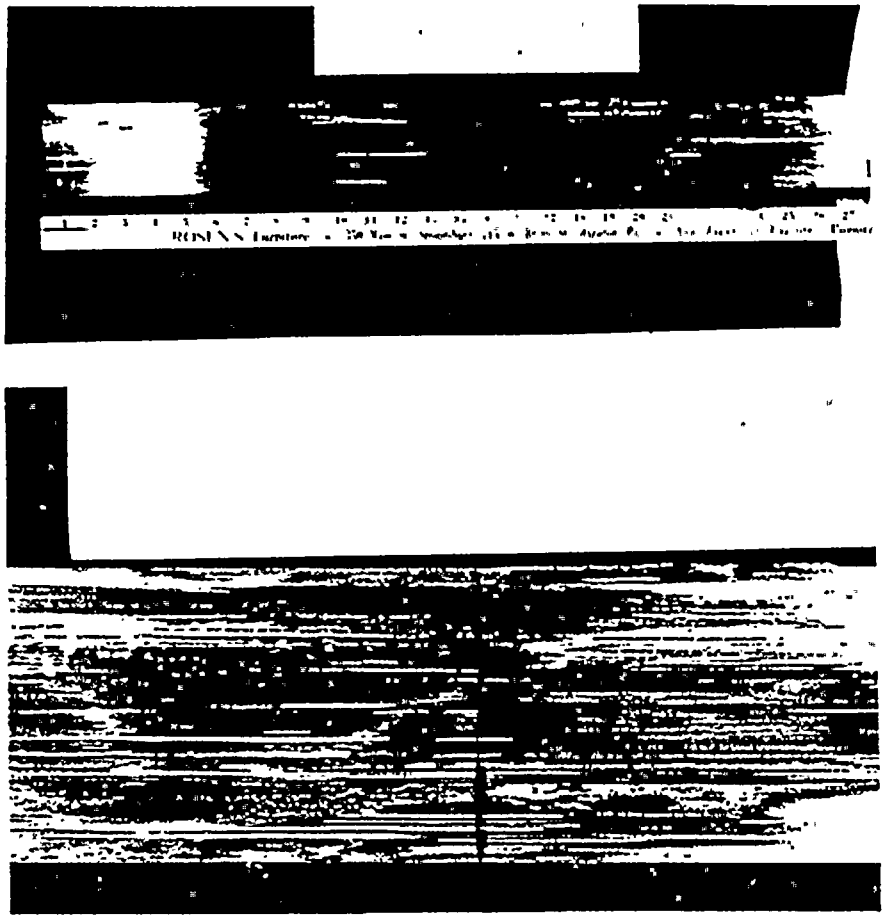


Figure B-31. Transverse cross-section (Labeled area 'E') of the thrust side of the B diesel 7L liner taken 7 1/2 inches from the bottom showing depressions in the Cr plating and deposited metal.



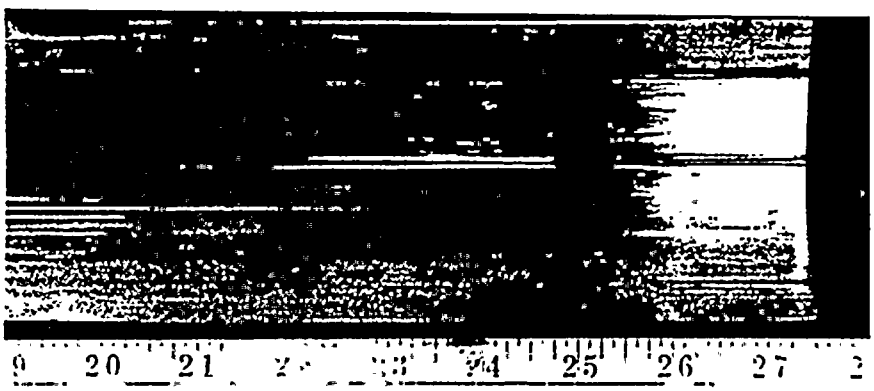


Figure B-32. Views of the length of the B diesel 7L cylinder liner in the area of pin end cap scraping (part B-2) showing heavy longitudinal marks and overheating over 20.5 inches of the center section.

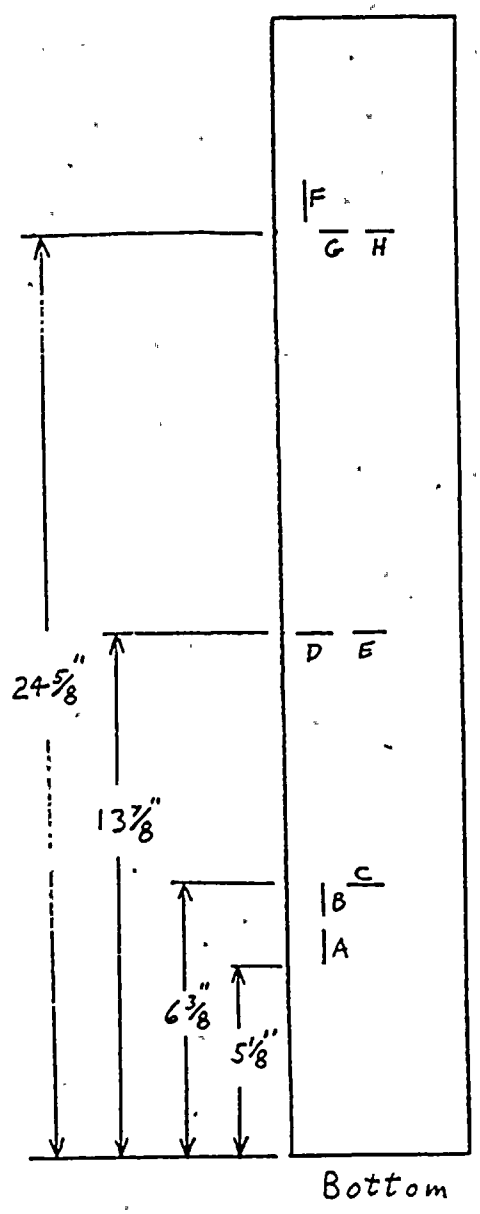
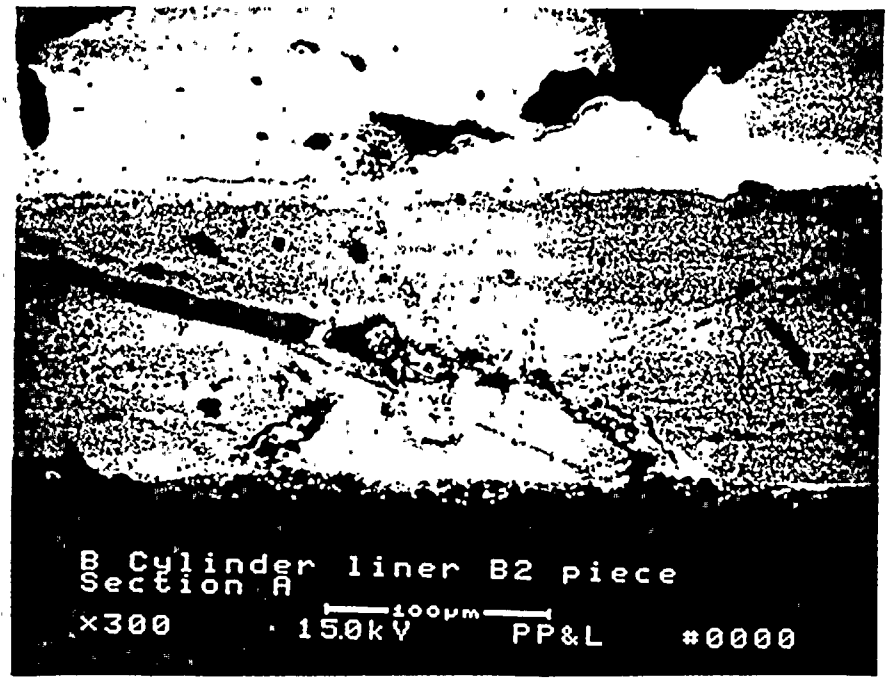


Figure B-33. Sketch of the end cap side of the 'B' diesel 7L liner showing the locations of the metallurgical samples taken for cross-sectional examinations(part labeled B-2).



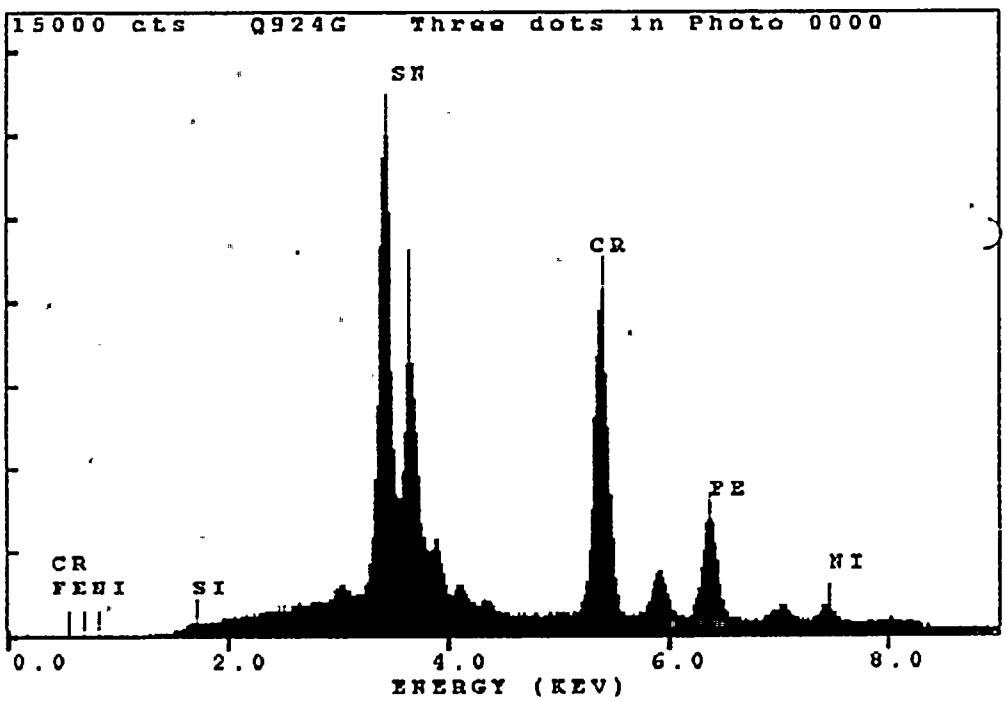
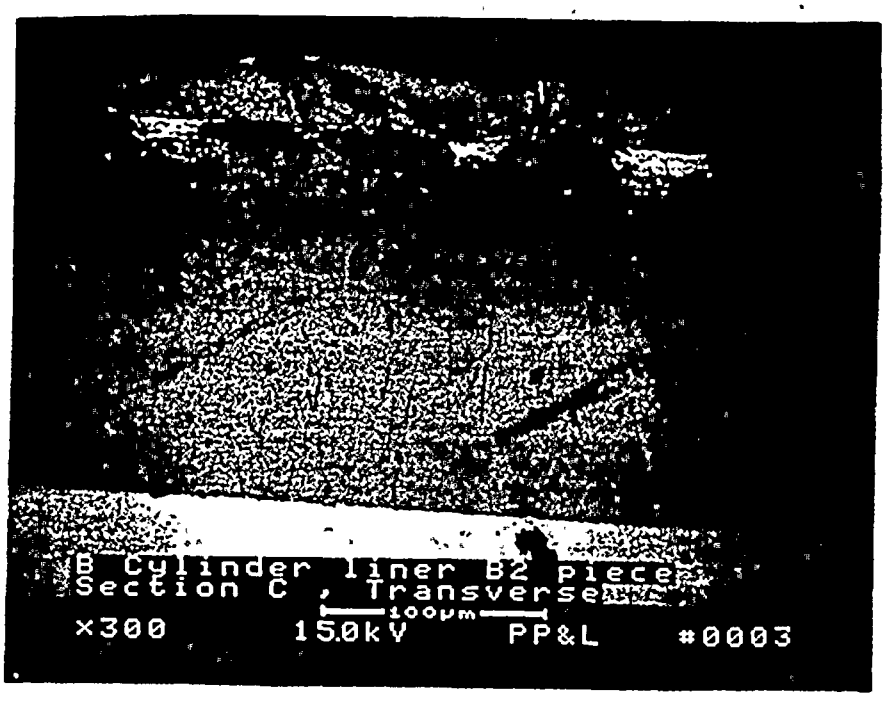
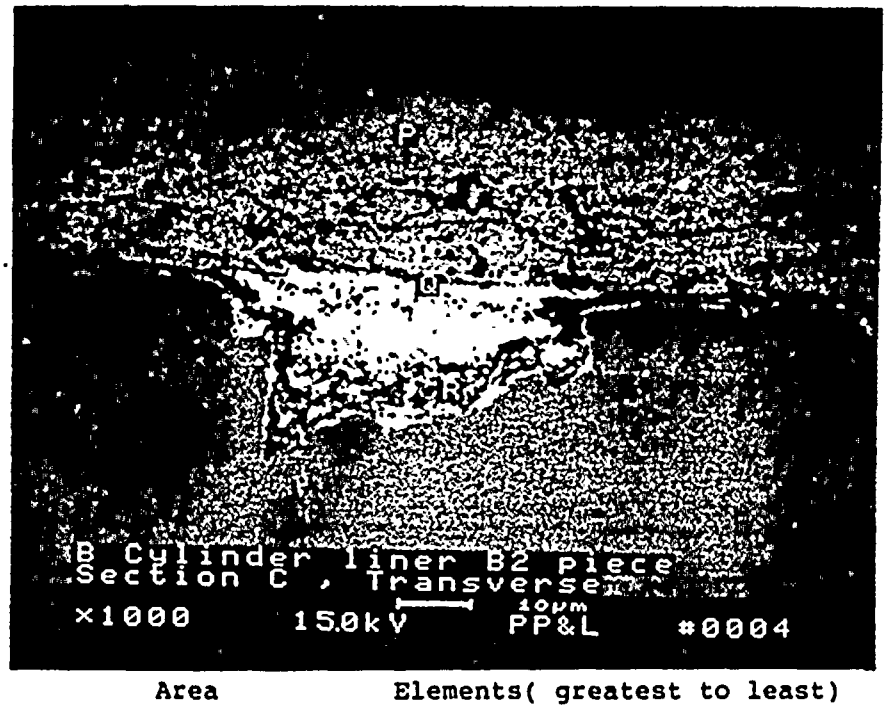


Figure B-34. Longitudinal section of B diesel 7L liner (labeled 'A' of part B-2) showing cracking in the Cr plating surface and the presence of Sn at the Cr-Fe base metal interface.





Area	Elements(greatest to least)
'R' Base of pit	Cr, Fe, and Sn
'Q' Top of pit	Fe, Sn, and Cr
'P' Center layer	Fe, Cr, and (Sn)
'P' Topmost layer	Fe, cr, and Si

Figure B-35. Transverse cross-section of the B diesel 7L liner (labeled 'C' of part B-2) showing areas of metal buildup and filling of pores with Cr,Sn and Fe.

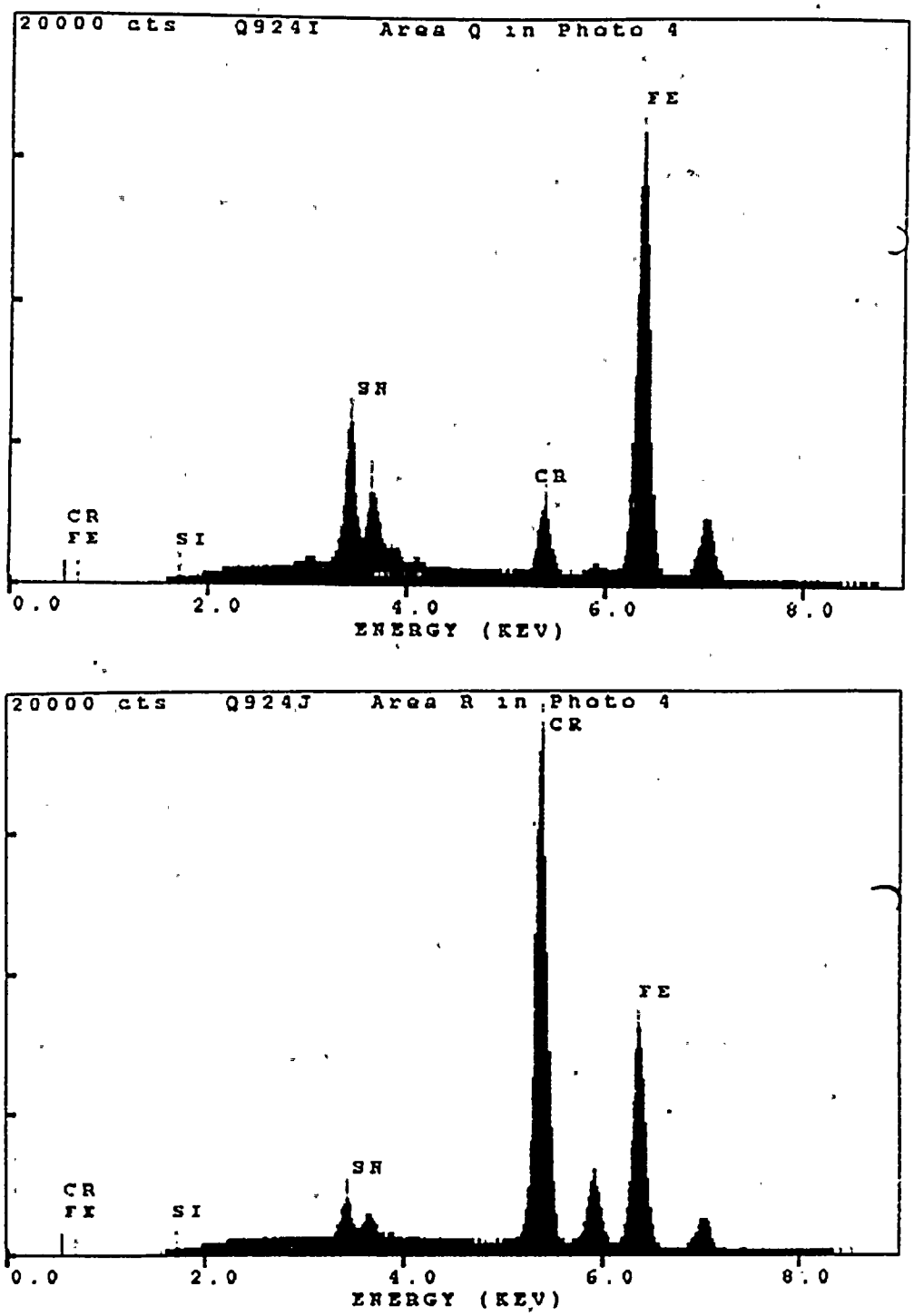


Figure B-36. EDS analysis of areas Q and R shown in figure B-35.

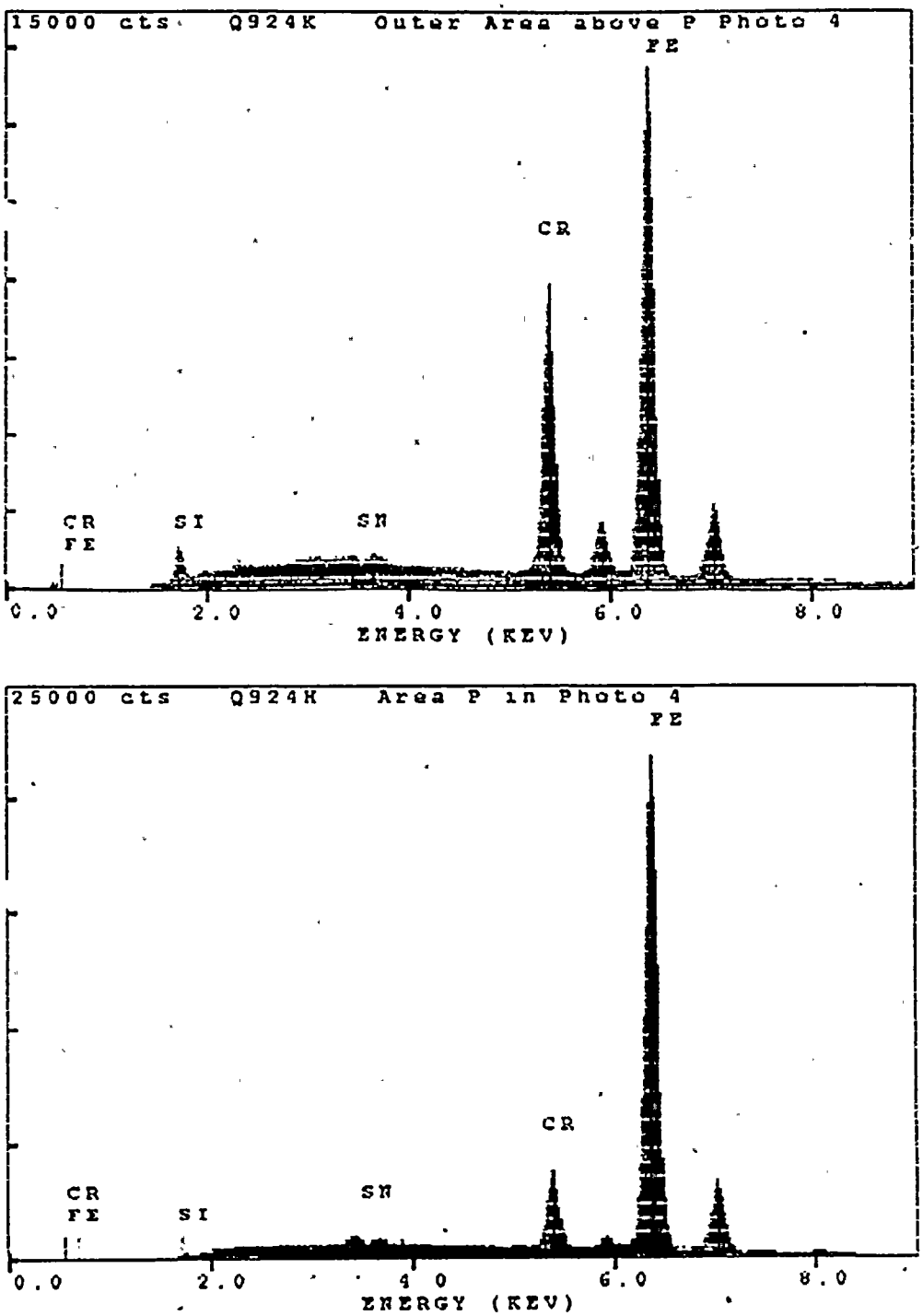


Figure B-37. EDS analysis of area P and the Dark layer above P in figure B-35.

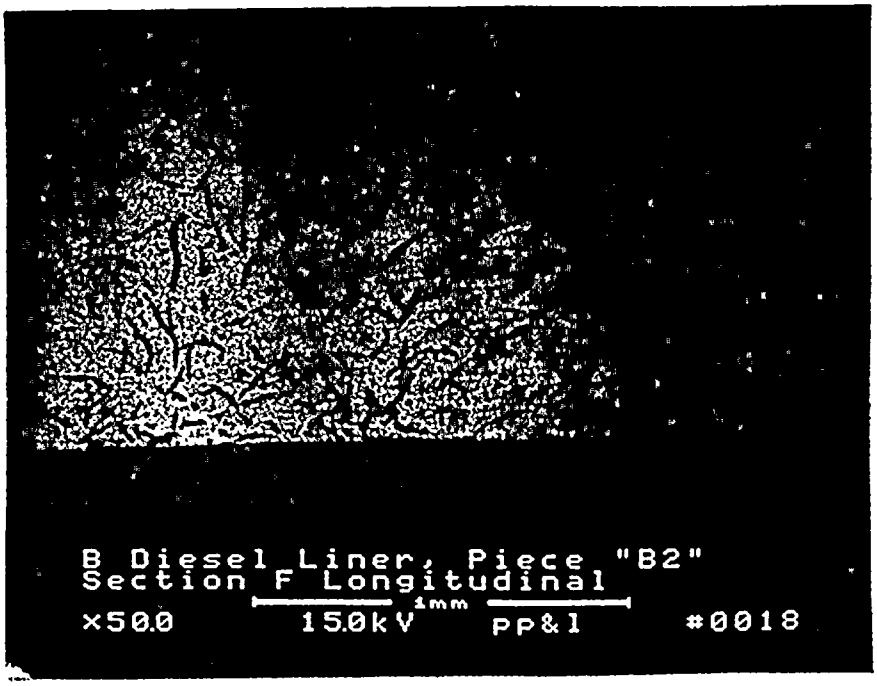
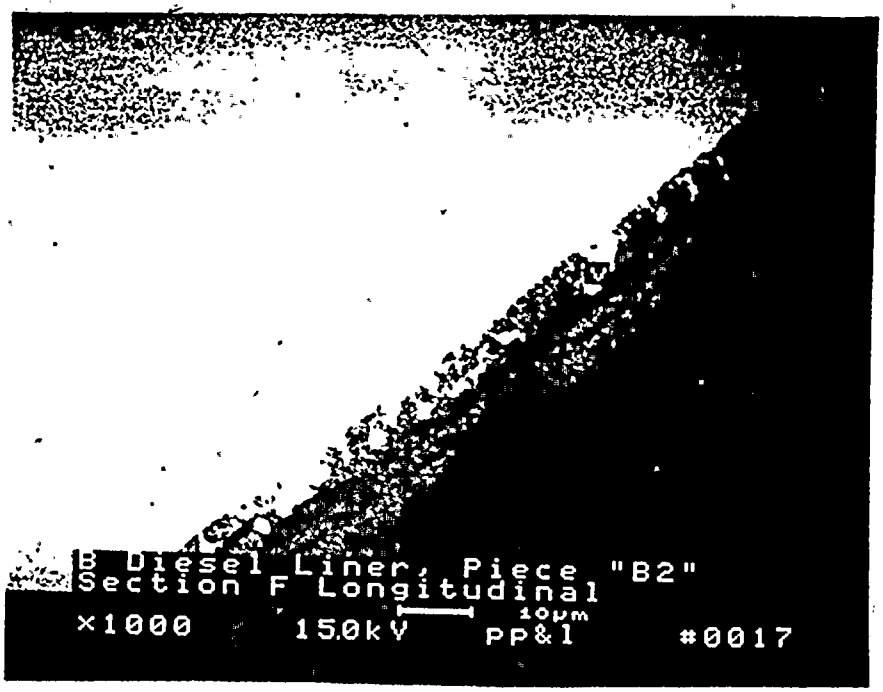


Figure B-38. Longitudinal section 'F' from B diesel liner 7L piece B-2 taken 24 5/8 inches above the bottom. This section does not show any pores filled or otherwise, but does show several cracks through the thickness of the Cr plate.



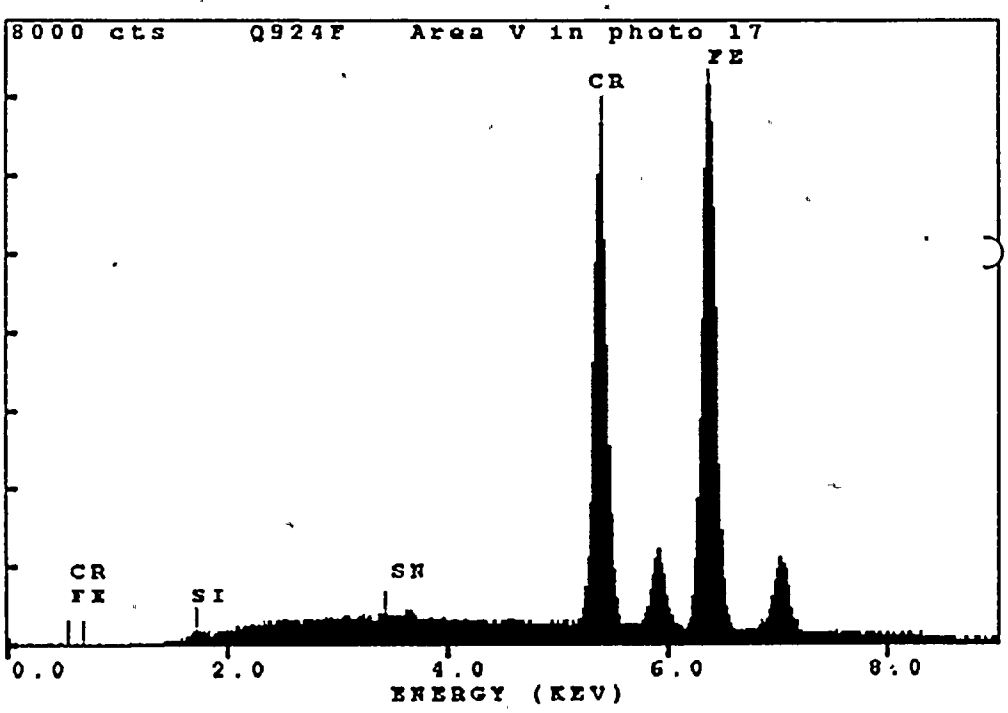
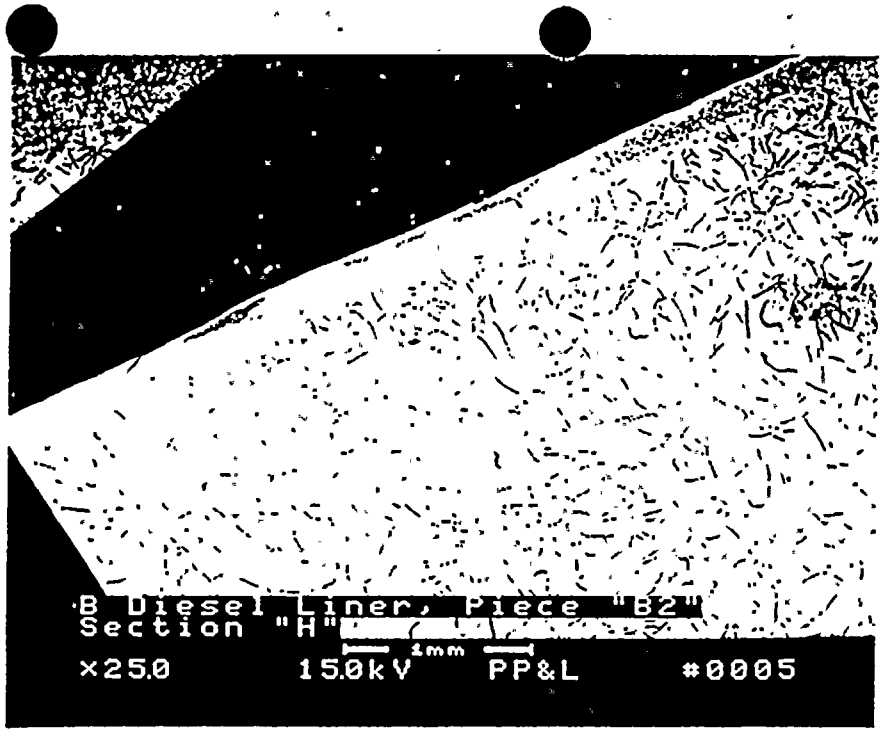
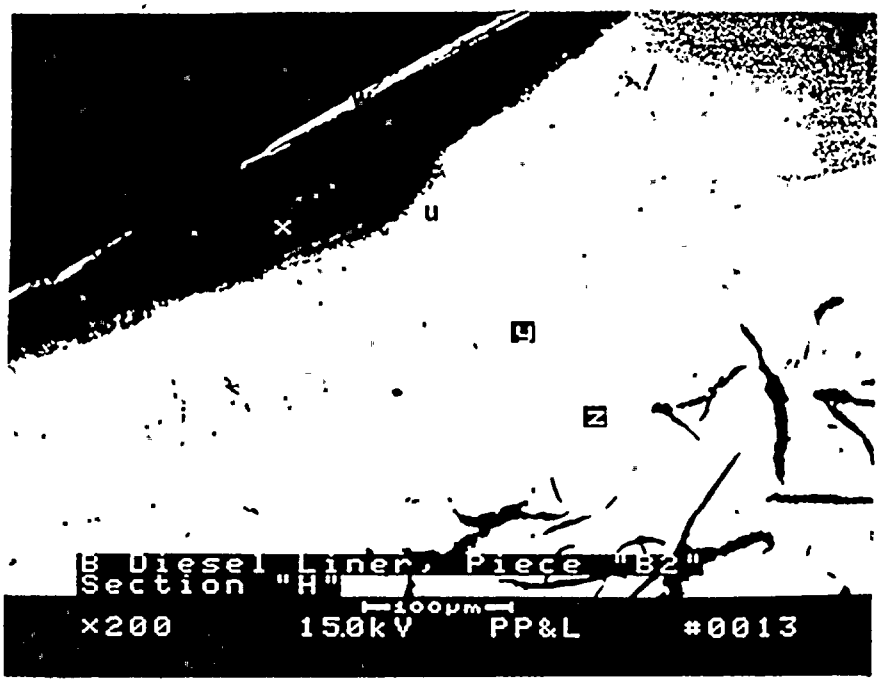


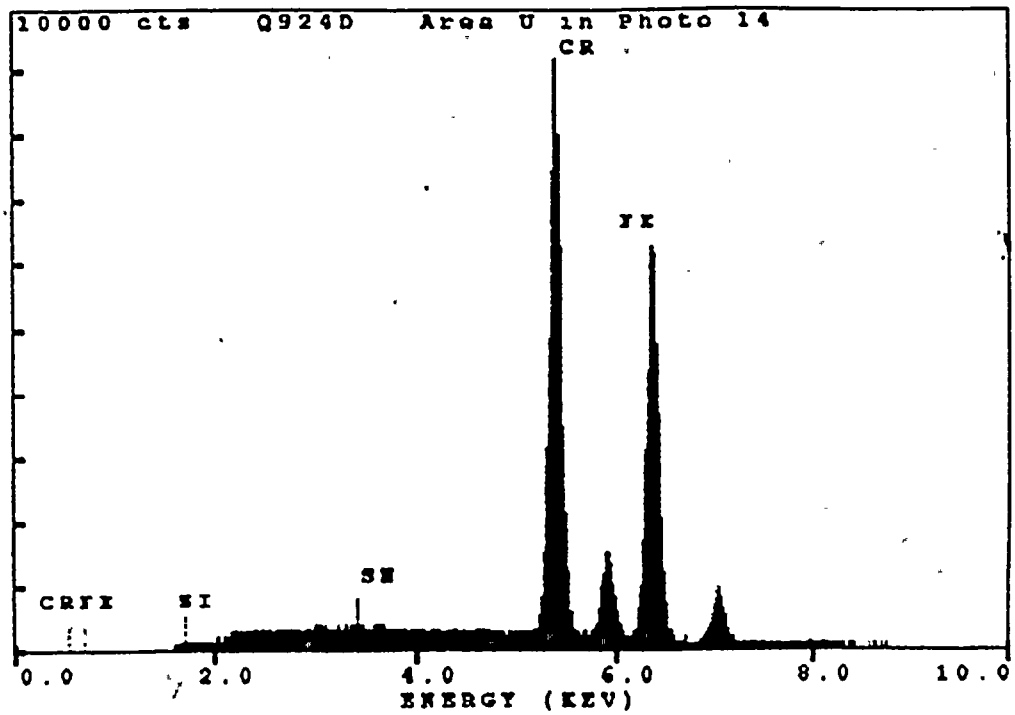
Figure B-39. Longitudinal section of B diesel 7L liner taken from the end cap side 24.625 inches from the bottom showing the layer of deposited metal and the EDS analysis of the lighter grey area.





Layer		Elements in decending order.
Z	Base metal casting	Fe
Y	Plating layer	Cr
U	Content of pore	Cr, Fe, Sn(Trace)
X	Thick dark layer	Cr, Fe, Si
W	Top layer	Fe, Cr, Sn(Trace)

Figure B-40. End cap side of the B diesel 7L liner taken from transverse section H showing damage to the chromium liner and deposited metal. EDS analysis of the various layers are shown in figures B-41 and B-42.



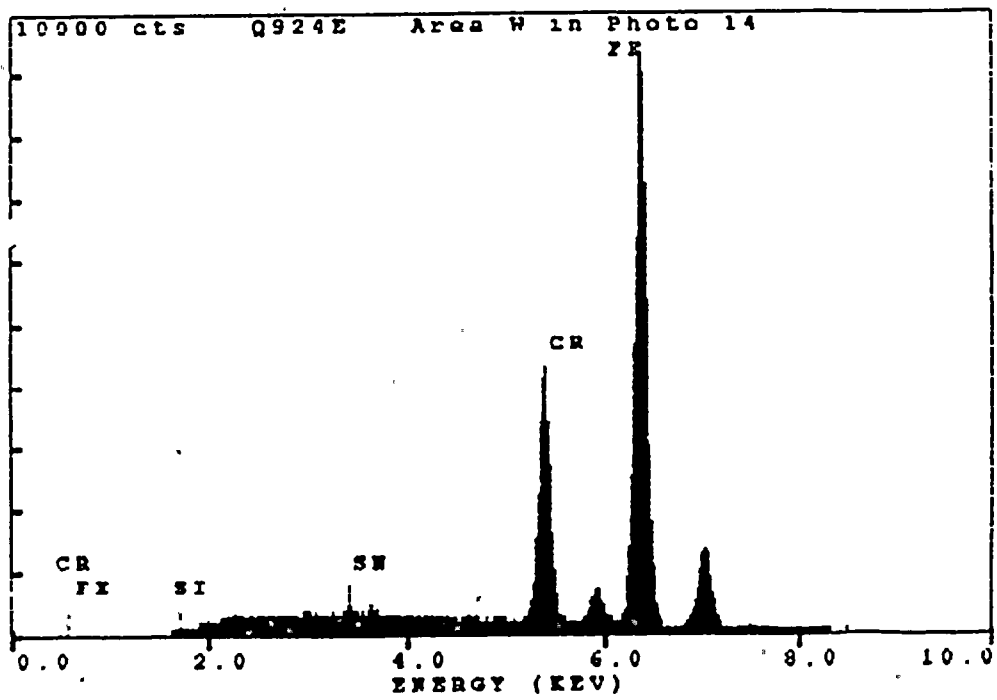
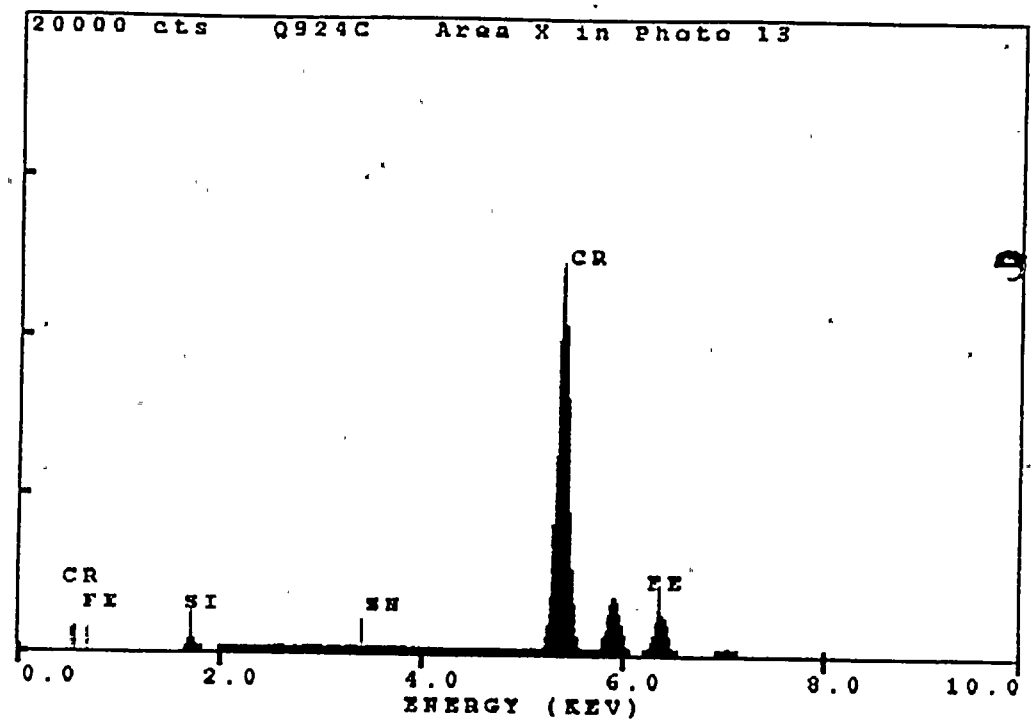


Figure B-41. EDS analysis of areas U and W shown in figure B-40.



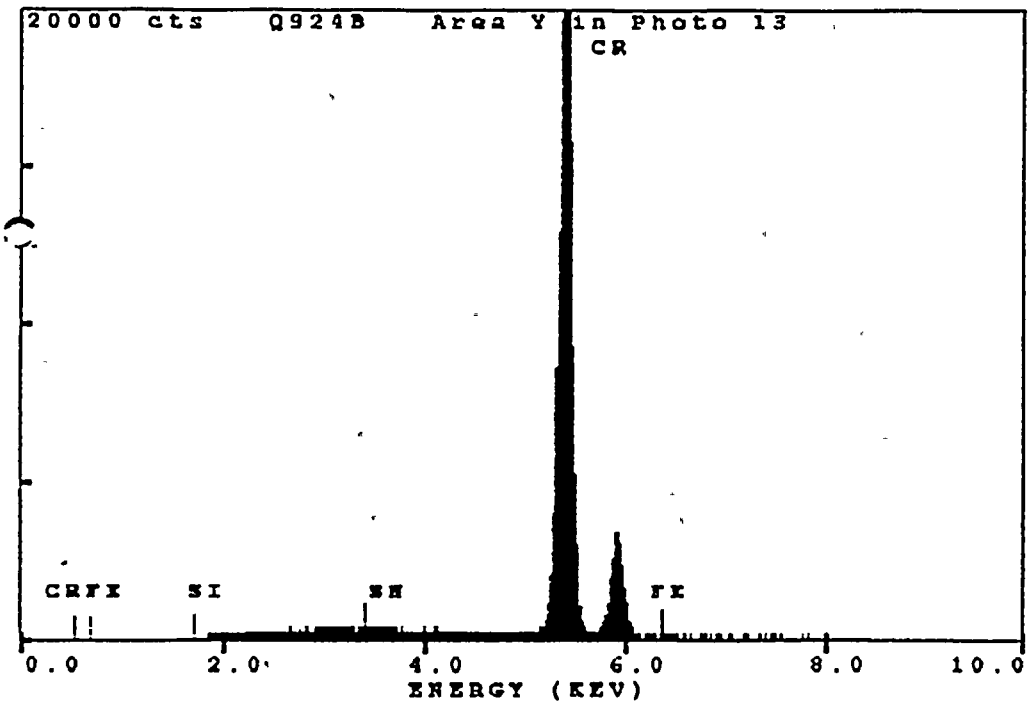


Figure B-42. EDS analysis of areas x and y shown in figure B-41.

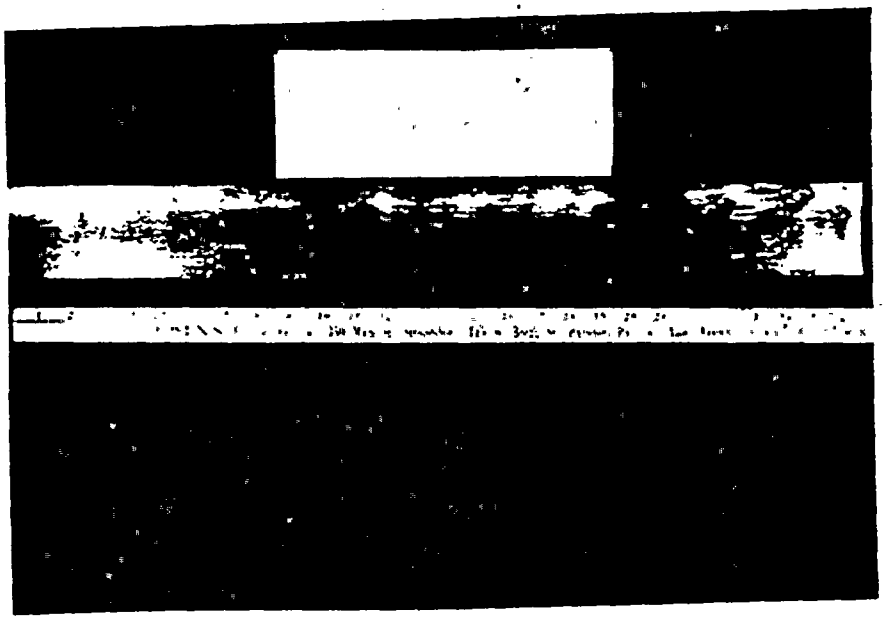


Figure B-43. General surface condition of the non-thrust side of the B diesel, 7L liner.

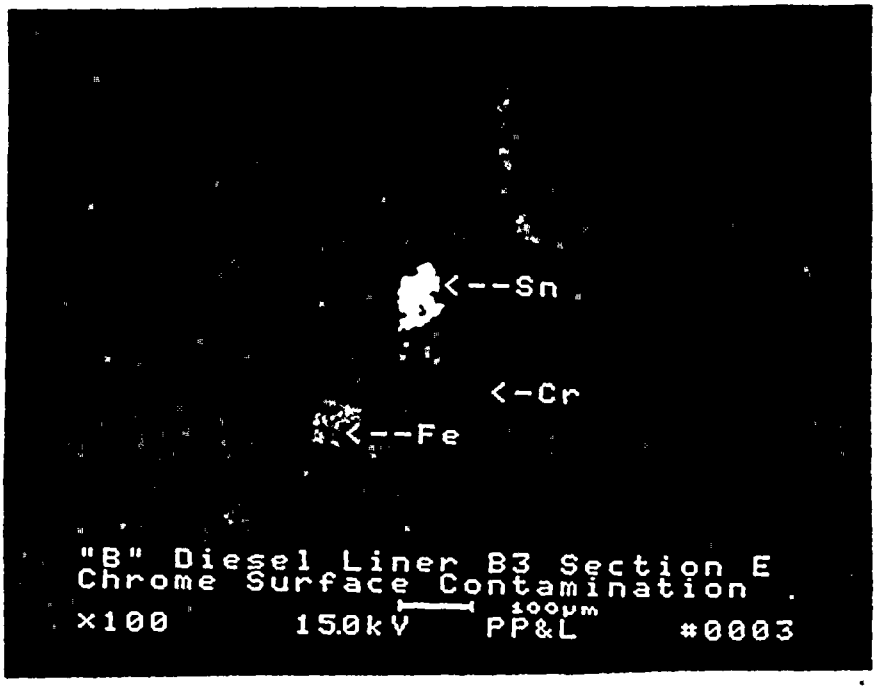


Figure B-44. Magnified image of the surface condition of the non-thrust side of the B diesel 7L liner near the upper position of the top compression ring. Both iron and tin are seen embedded in the chromium liner pores.

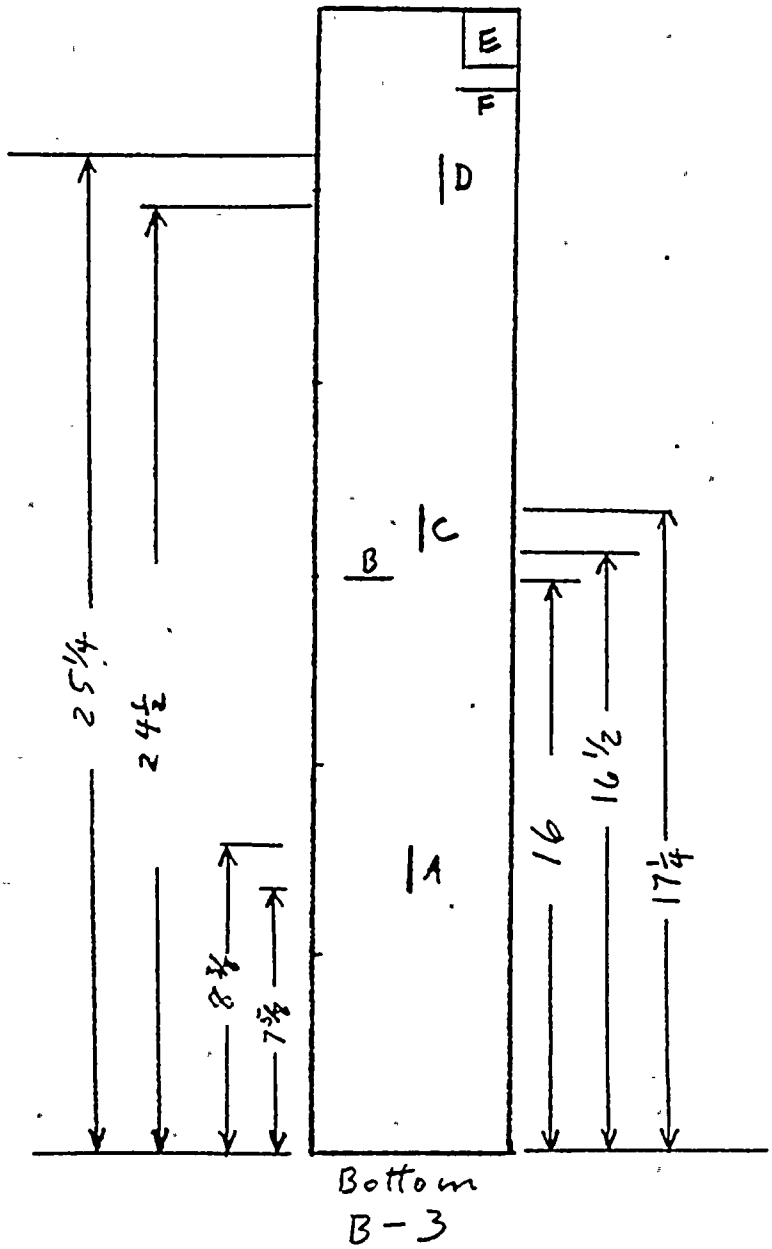


Figure B-45. Sketch of the non-thrust side of the B diesel 7L liner(designated B-3), showing the location and orientation of the metallurgical sections A, B, C, D, E, and F. Section E was for surface examinations, while the others were for cross-sections.

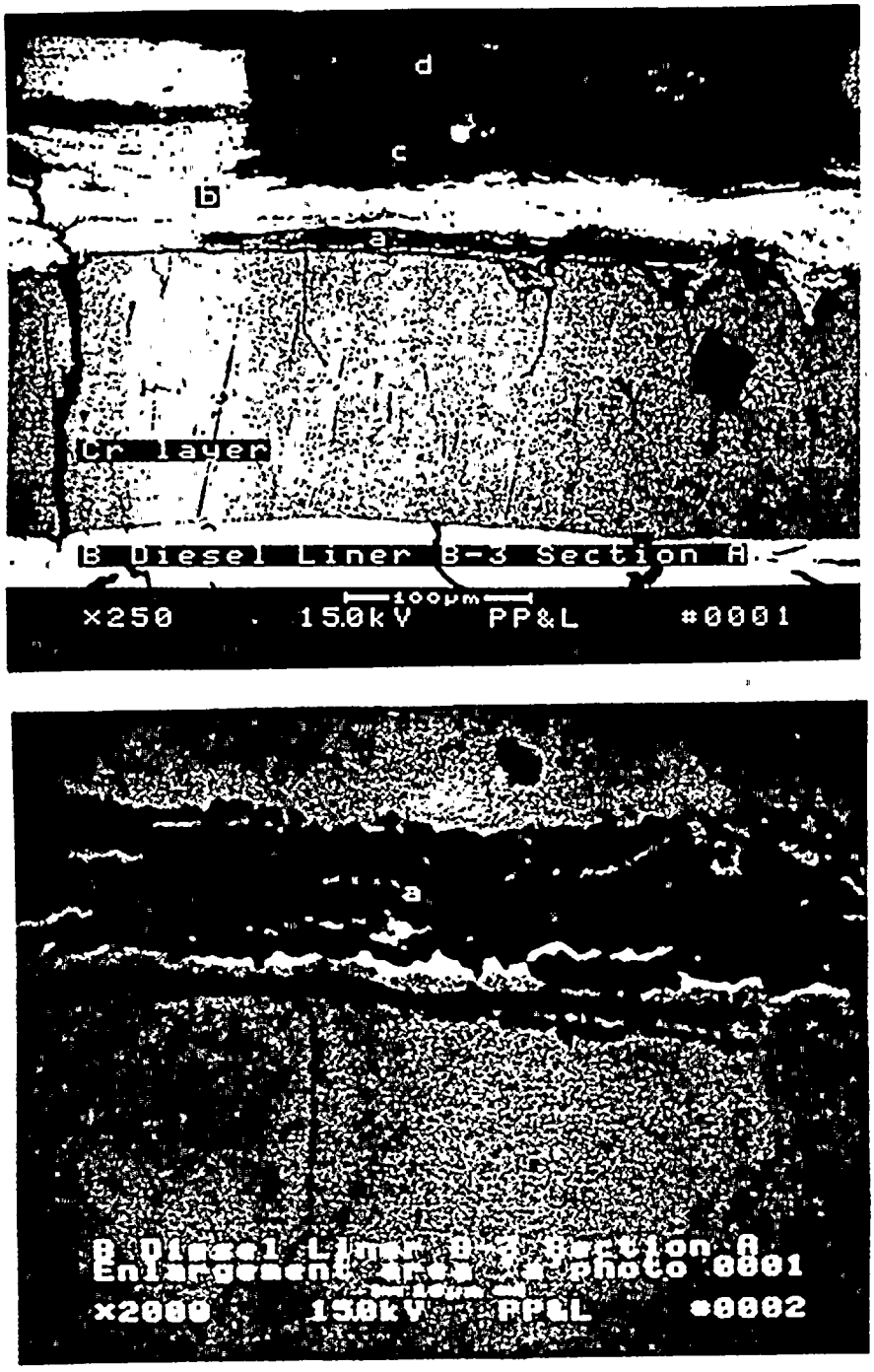


Figure B-46. Longitudinal section of the B diesel 7 L liner taken from an area 7 5/8 to 8 3/8 inches from the bottom. EDS analysis results are shown in figures B-47 and B-48.

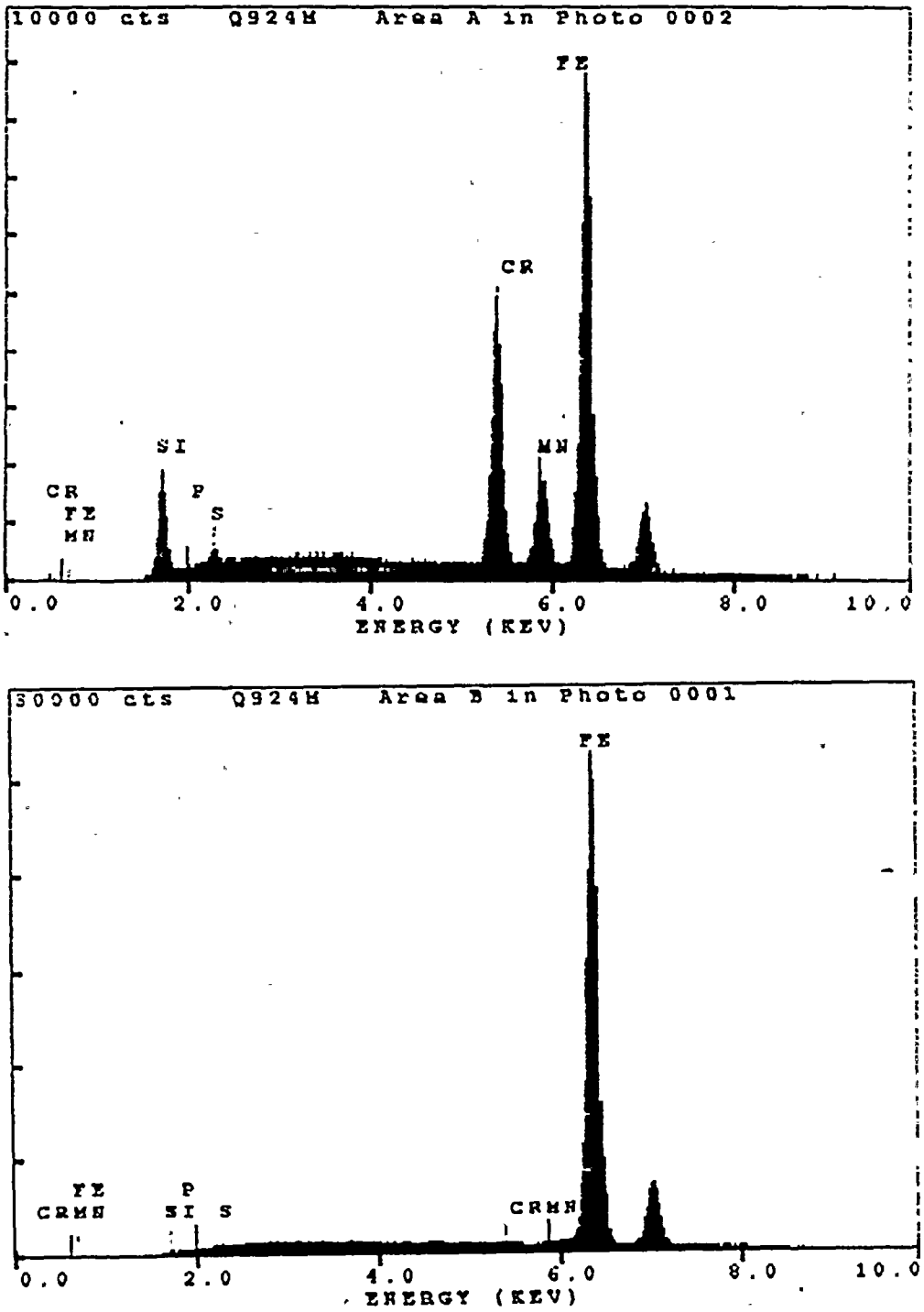
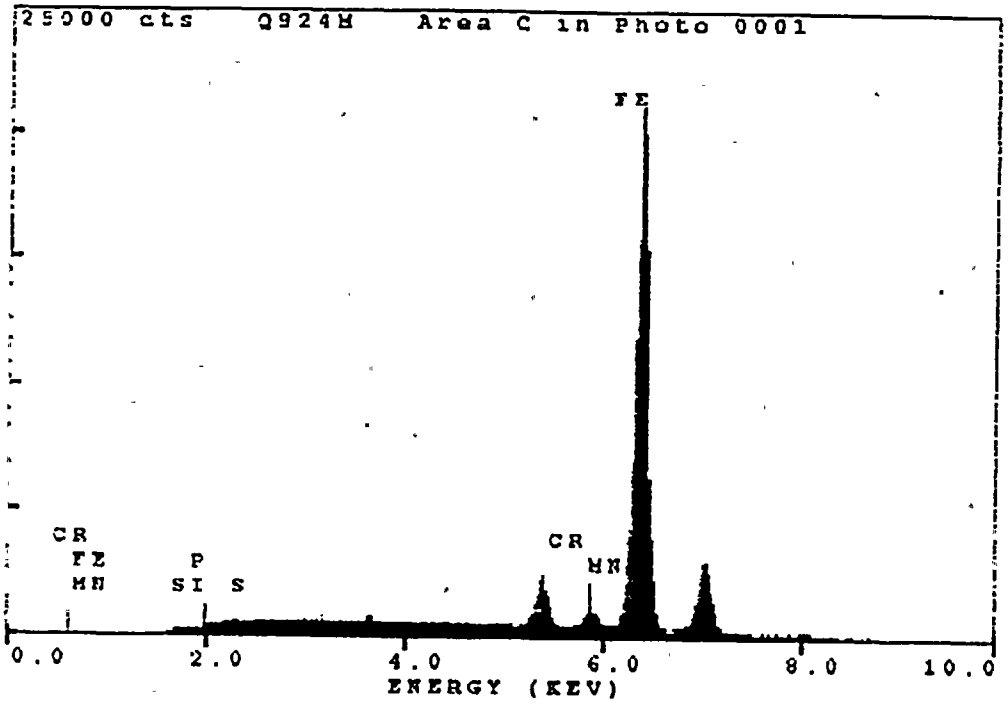


Figure B-47. EDS analysis of areas a and b in figure B-46.



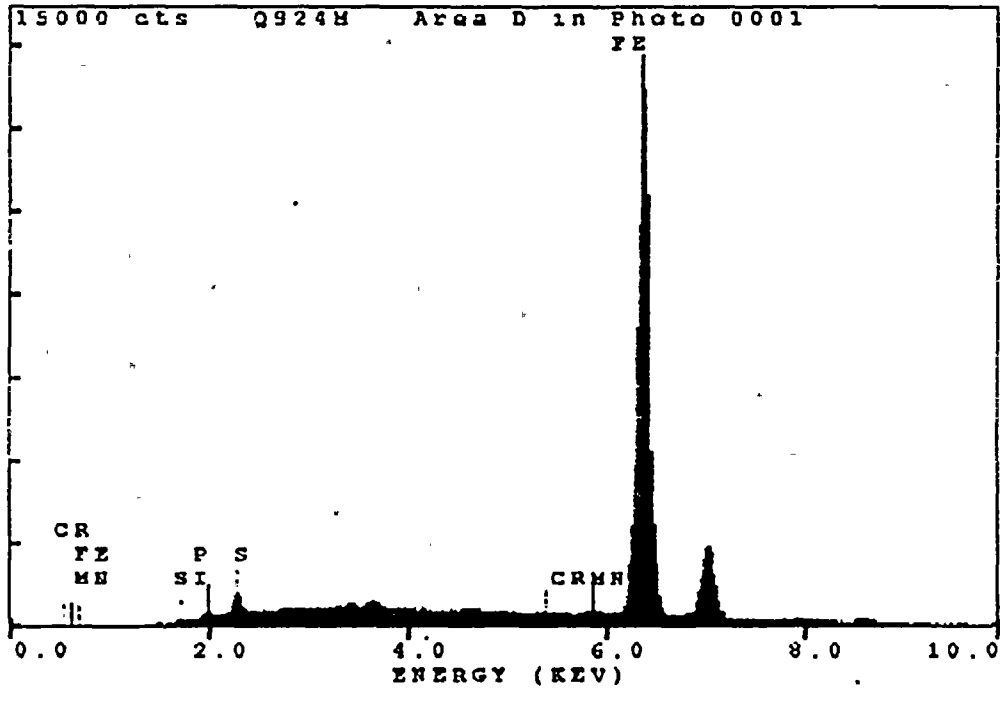


Figure B-48. EDS analysis of areas c and d in figure B-46.

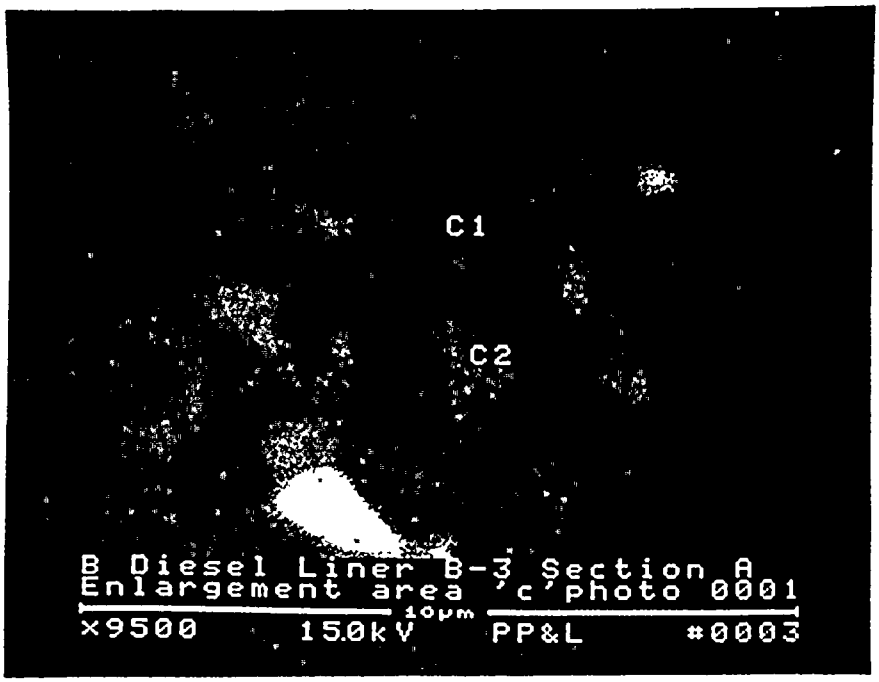


Figure B-49. Enlargement of area c in figure B-46 showing light and dark phases present. EDS analysis of these areas are shown in figure B-50.

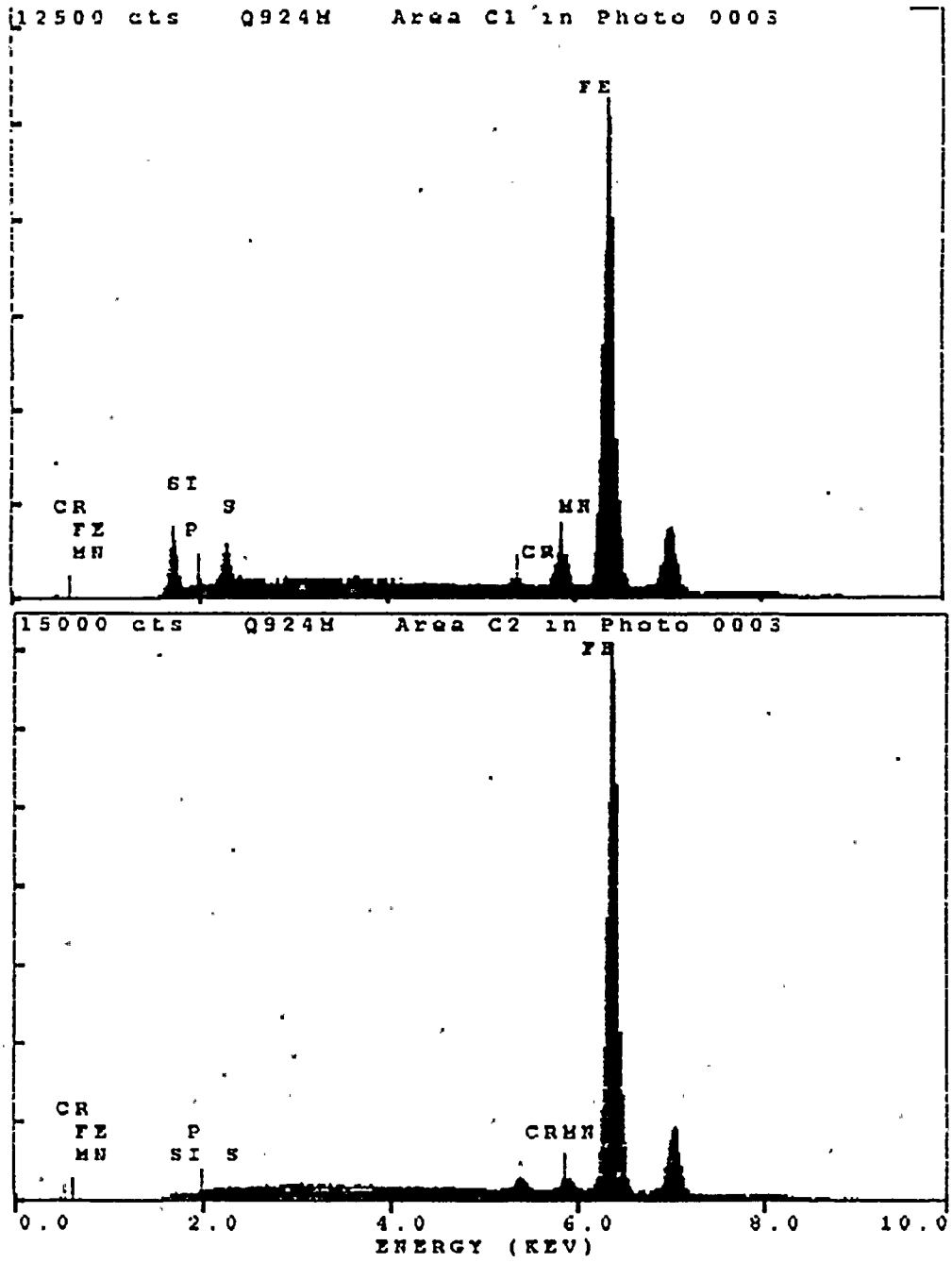


Figure B-50. Analysis of the pore from figure B-46 center right, showing that it contains mainly iron with only a trace of the elements Cr, S and Mn.

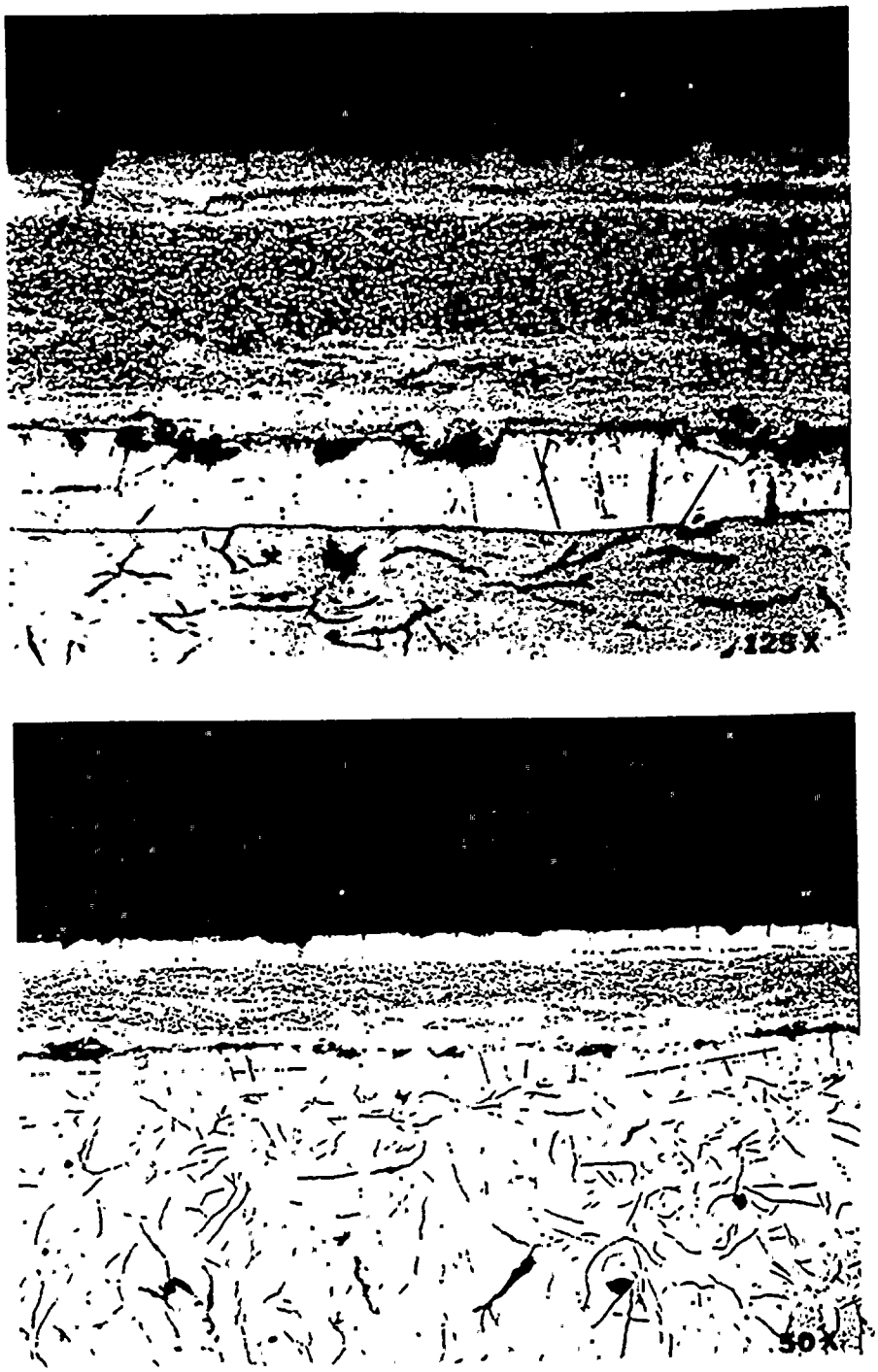


Figure B-51. Longitudinal cross-section of the B diesel 7L liner taken 7 5/8 inches from the bottom showing a very thick layer of metallic deposits covering the chromium plating.

Figure B-52. Transverse cross-section of a typical area of the non-thrust side of B diesel 7L liner 16 inches from the bottom (B-3 area B) showing the filled pores and the deposited metal from this location.

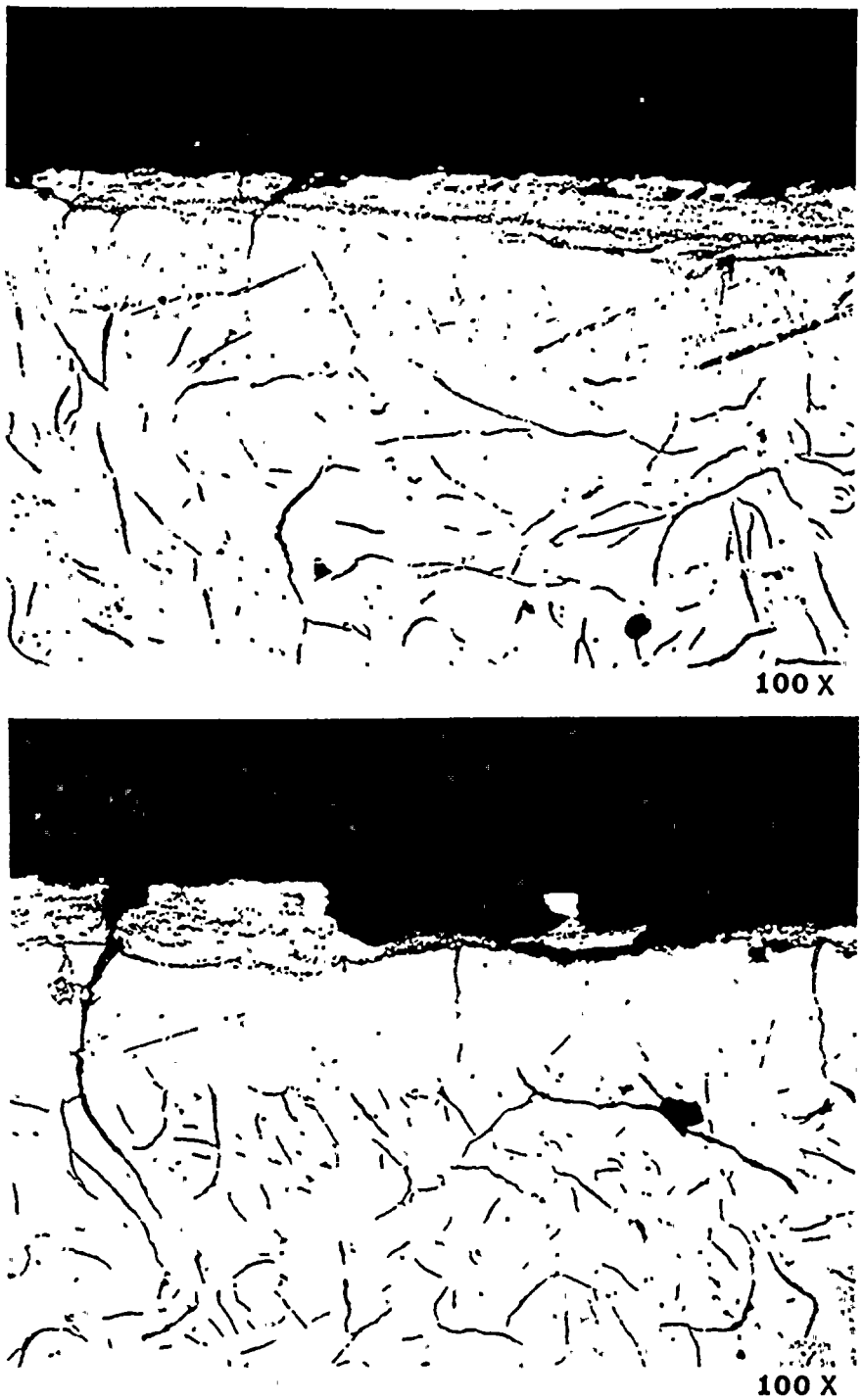


Figure B-53. Longitudinal cross-section of the non-thrust side of the B diesel 7L liner taken 16.5 inches from the bottom of the liner. Typical examples of the metal deposited from the piston and rings on the Cr plating.

Figure B-54. SEM micrographs of longitudinal cross-section 'C' part B-3 of the B diesel liner at a level 16.5 inches from the bottom. Elements shown were identified as being present in the pores indicated.

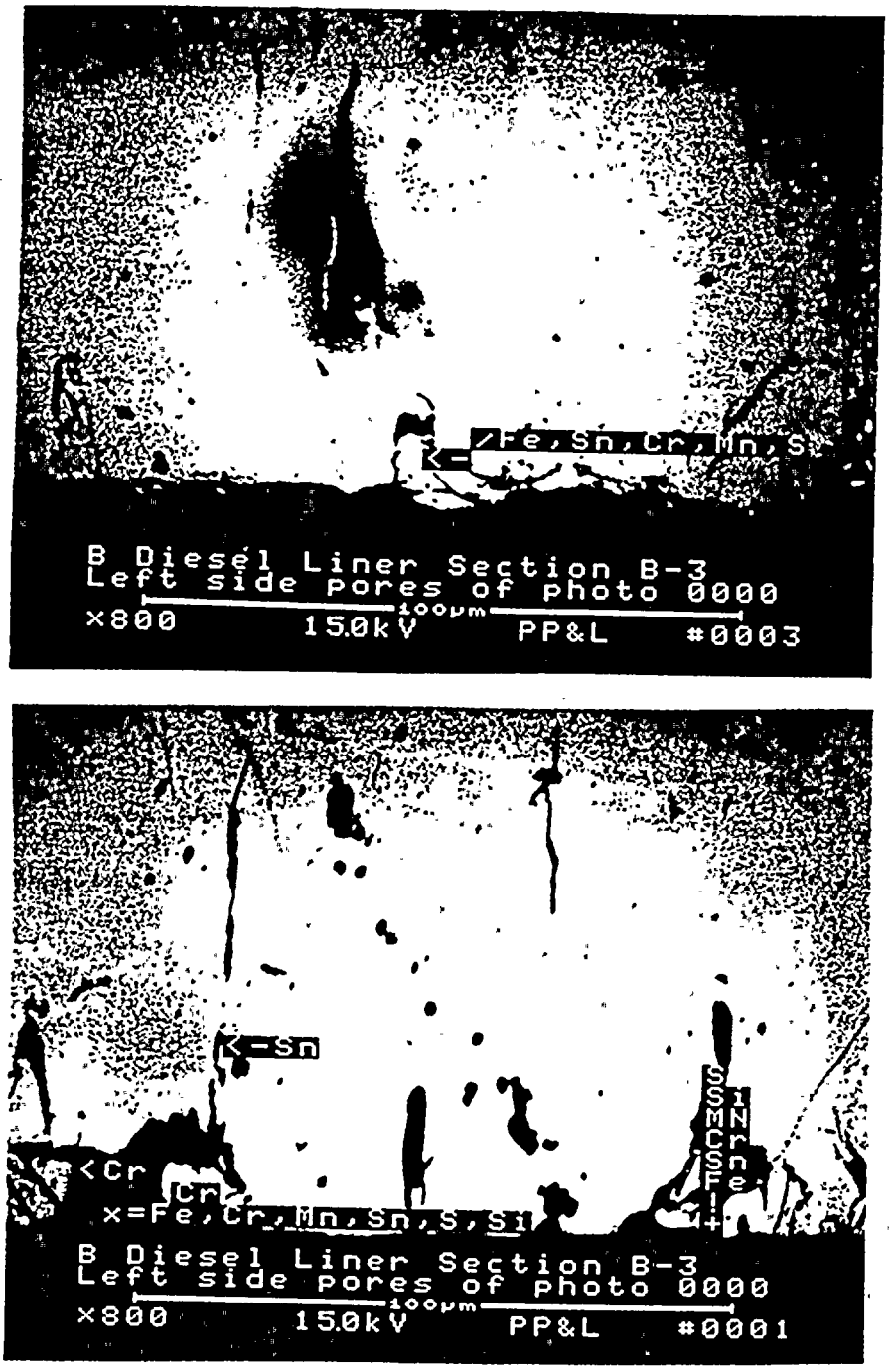


Figure B-55. Another area of pore deposits and elements found present in longitudinal cross-section 'C' part B-3 of the B diesel liner 16.5 inches from the bottom.

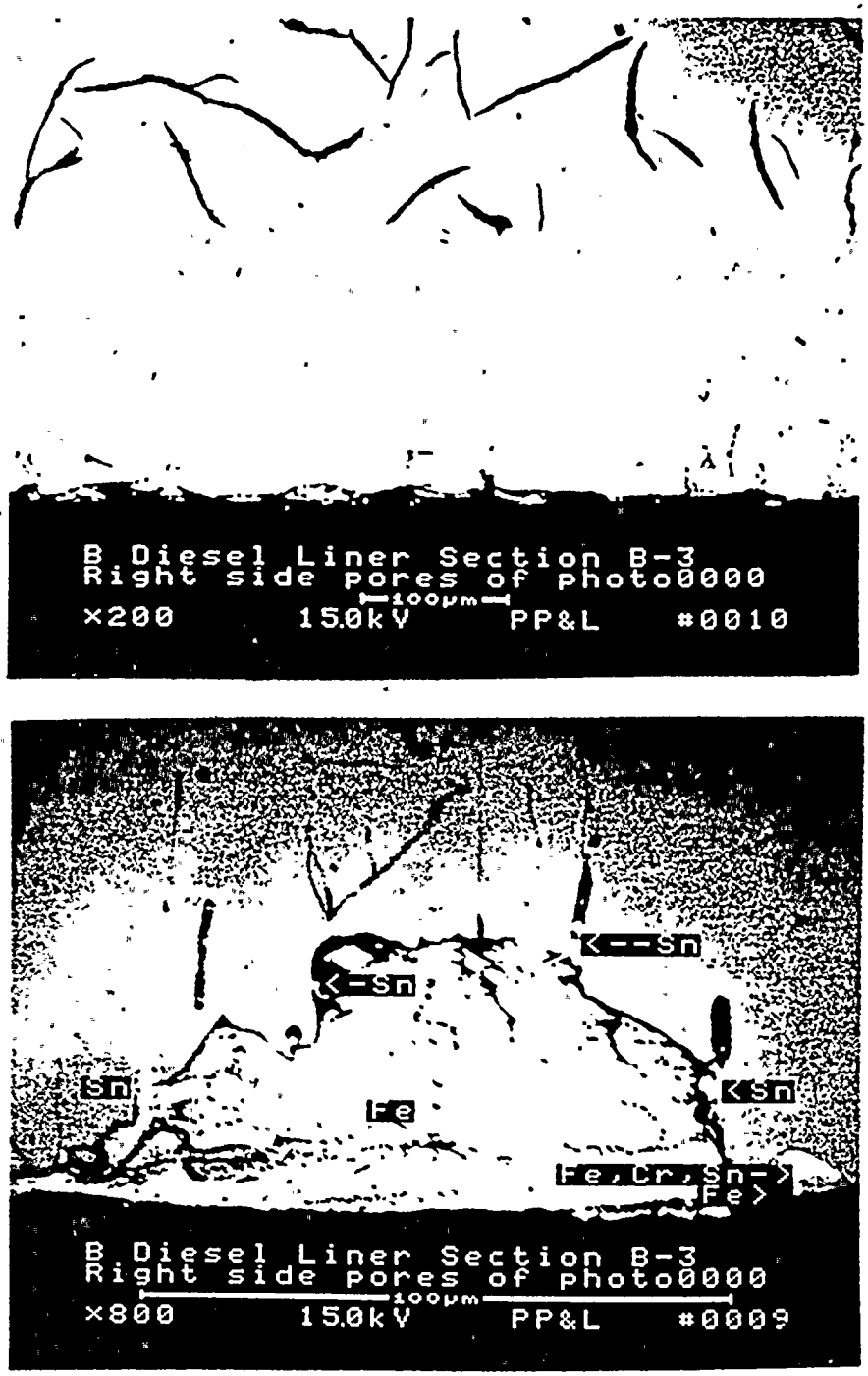


Figure B-56. Various elements and their location found in a pore from the B diesel liner 7L, part B-3, area 'C'.

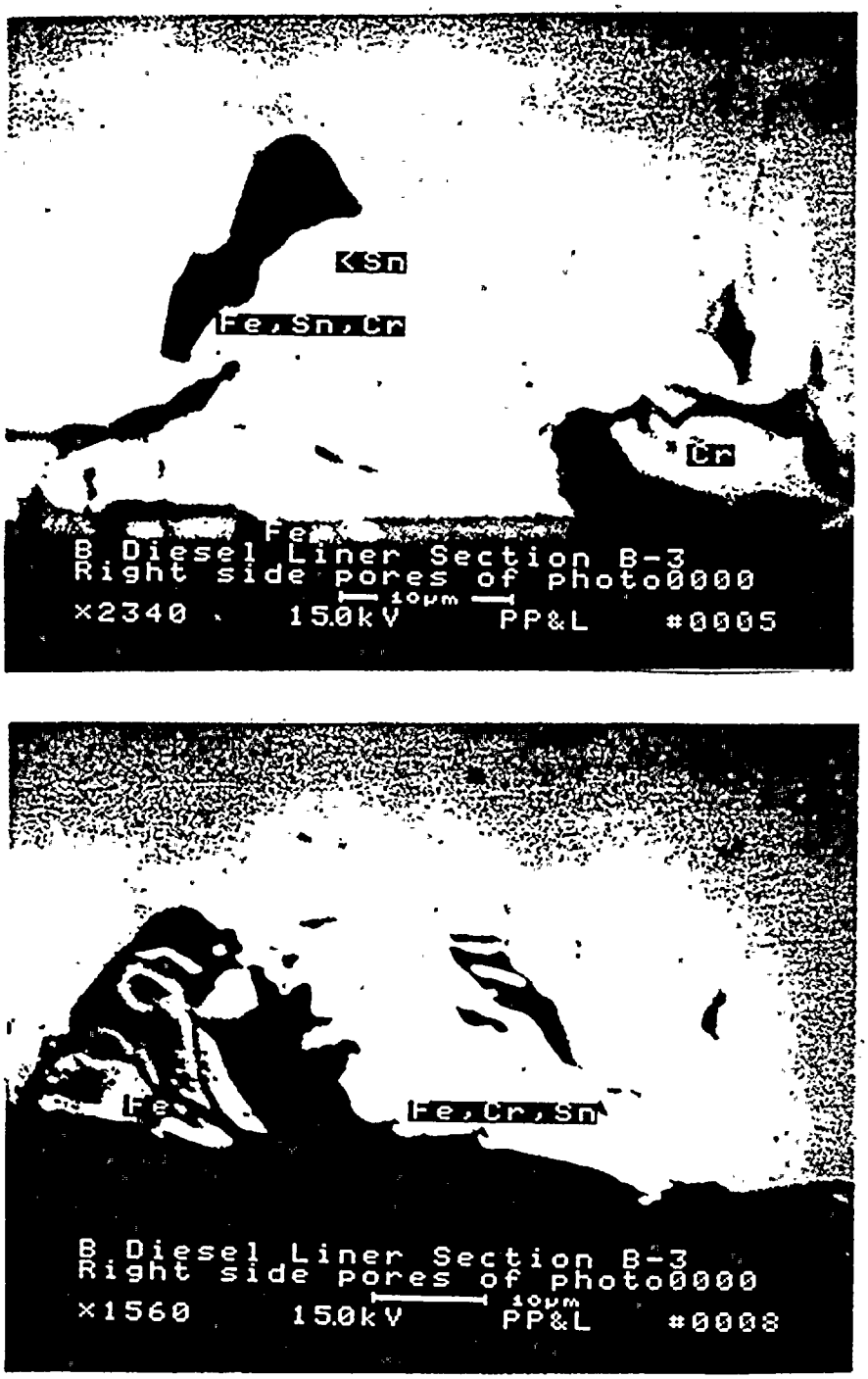


Figure B-57. Elemental contents of two pores filled with metal in the B diesel 7L liner 16.5 inches from the bottom of part B-3, area 'C'.

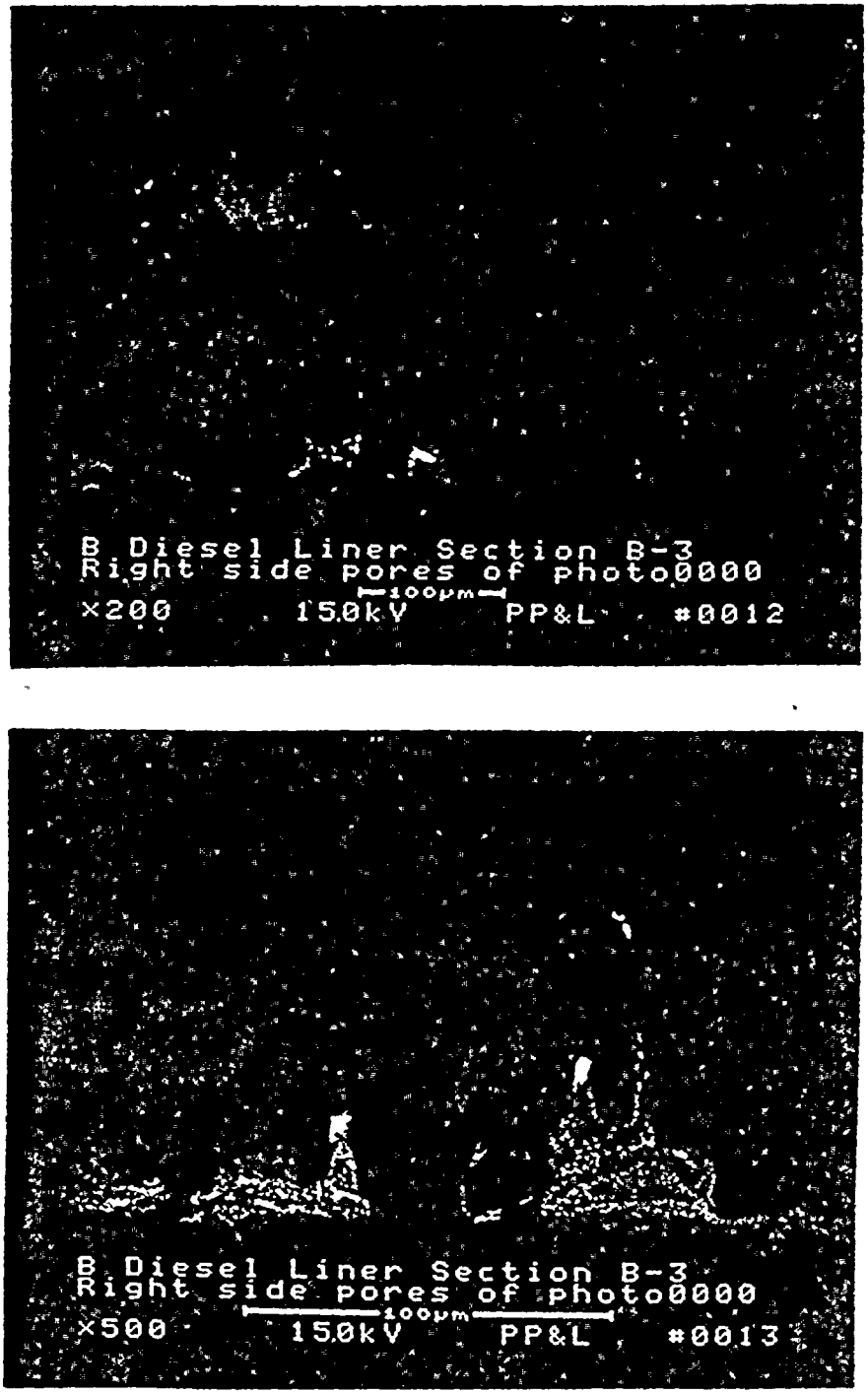


Figure B-58. Additional areas of filled pores found in area 'C' of part B-3 of the B diesel 7L cylinder.