F&PMT TRANSMITTAL

NO. 87-178-001

FUEL & PLANT MATERIALS TECHNOLOGY

FINAL REPORT

RHR PUMP WEAR RING
SURVEILLANCE EXAMINAT[illegible]ESULTS
PILGRIM NUCLEAR POWER STATION

WORK PERFORMED FOR
BOSTON EDISON COMPANY

January 23, 1987

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DED8701.11

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EXECUTIVE SUMMARY

Wear ring samples were removed from two Pilgrim RHR pump impellers and sent to General Electric's Vallecitos Nuclear Center for metallurgical evaluation. This is a report the results of the metallurgical evaluation performed on the wear ring samples.

On May 20, 1986, the Nuclear Regulatory Commission issued an Information Notice to alert licensees of RHR pump impeller wear ring failures. The notice was issued as a result of multiple RHR pump failures at Philadelphia Electric's Peach Bottom Unit 2 and 3, and at Tennessee Valley Authority's Browns Ferry Units 1, 2, and 3. The failures affect the RHR pump impeller wear rings on pumps manufactured by Bingham-Willamette with motors supplied by General Electric. The initial cause of the failure sequence was identified as defective impeller wear rings.

The wear rings are 410 stainless steel, A 182 grade F6 with a specified Rockwell C hardness of 33 to 39. The rings are press fit to the impeller, and attached with eight dowel pins. Metallurgical analysis of failed Peach Bottom wear rings revealed evidence that IGSCC was the cause. The failed rings may have had increased SCC susceptibility due to unusually high hardness levels of the ring material.

By visual examination, the wear ring samples which had been removed from the RHR pump impellers at Pilgrim Nuclear Power Station, showed no evidence of cracking. However, by optical metallographic, and scanning electron microscopic evaluation, one ring sample did show minor cracking thought to be stress corrosion of the type which had caused the degradation of similar RHR pumps at other domestic power plants.

The wear ring material had average hardness readings of 40 to 42.5 Rockwell C. (The manufacturer, Bingham-Willamette, specifies a range of hardness of C34 to C39.) The ring sample with minor cracking had average hardness readings of 42 to 43 Rockwell C. With hardness levels greater than C40, the material has increased susceptibility to crack initiation and growth by IGSCC.

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EXAMINATION RESULTS
PILGRIM NUCLEAR POWER STATION

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1.0 BACKGROUND

On May 20, 1986, the Nuclear Regulatory Commission (Office of Inspection and Enforcement) issued an Information Notice[1] (Attachment #1) to alert licensees of RHR pump impeller wear ring failures. The IE was issued as a result of multiple RHR pump failures at Philadelphia Electric's Peach Bottom Units 2 and 3, and at Tennessee Valley Authority's Browns Ferry Units 1, 2, and 3. The failures affect the RHR pump impeller wear rings on pumps manufactured by Bingham-Willamette with motors supplied by General Electric.

The most severe degraded pump impeller wear ring condition, and subsequent total pump failure, occurred at PECo's Peach Bottom Unit 3 during a refueling outage in a Bingham-Willamette single stage centrifugal pump (Figure 1), model 18X24X28 CVIC, powered by a 2000 HP GE vertical induction motor. The initial cause of the failure sequence was identified as defective impeller wear rings. Subsequent inspections of other pumps revealed multiple similar wear ring failures.

The wear rings are 410 Stainless steel, A 182 grade F6 with a specified Rockwell C hardness of 33 to 39. The rings are press fit to the impeller, and attached with eight dowel pins. Metallurgical analysis of failed wear rings revealed evidence that IGSCC contributed to the failure. The unusually high hardness levels of the ring material may have contributed to an increased SCC susceptibility.

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1. IE Information Notice No. 86-39: FAILURES OR RHR PUMP MOTORS AND PUMP INTERNALS, issued by United States Nuclear Regulatory Commission - Office of Inspection and Enforcement, Washington, DC., May 20, 1986.

RHR pumps of the type which had impeller wear rirg failures are in use at Boston Edison Company's PILGRIM Nuclear Power Station. In order to preclude a similar problem occurring at their facility, the RHR pump impeller wear rings at PILGRIM UNIT 1 were inspected for degradation, or susceptibility to damage.

2.0 INTRODUCTION

RHR pump impeller wear ring samples were removed from two Pilgrim pumps and sent to GENERAL ELECTRIC'S VALLECITOS NUCLEAR CENTER for metallurgical evaluation (Figure 2). This report presents the results of the metallurgical evaluation performed on the Pilgrim wear ring samples.

3.0 VISUAL EXAMINATION

A. PUMP "A" WEAR RING SEGMENTS

A single segment of the "A" RHR pump impeller wear ring measuring approximately 10 inches in circumferential length was received at Vallecitos Nuclear Center (VNC) for metallurgical analysis. A radiological survey was performed, and showed the maximum contact radiation level to be approximately 50 mrem/hr. Further decontamination at VNC was not performed. Figure 3 is a photo of the sample removed from RHR pump impeller "A", taken at the time of visual examination.

The pump "A" wear ring segment was penetrant examined for evidence of crack indications. All surfaces of the segment were examined and no relevant indications were found.

B. PUMP "B" WEAR RING SEGMENTS

The complete RHR pump "B" lower impeller wear ring was sent to VNC for metallurgical evaluation. During removal from the impeller, the ring was separated into two approximately equal segments. A radiological survey showed the surface activity readings to be approximately 50 to 60 mrem/hr. Further decontamination was not performed. Figure 4 is a composite photograph of the lower impeller wear ring removed from the RHR pump "B", upon receipt at VNC.

The "B" pump wear ring segments were penetrant examined for evidence of crack indications. All surfaces were examined and no relevant indications were found.

4.0 METALLOGRAPHIC ANALYSIS

A. PUMP "A" WEAR RING

Following visual examination, the segment of RHR Pump "A" wear ring was sectioned for metallographic examination. Figure 5 is a sketch of the sectioning plan. Since no relevant indications were found, a random "typical" area was selected for sampling. As indicated in Figure 5, seven samples were cut for metallurgical characterization. Five samples were used for optical microscopy, one for scanning electron microscopy, and one for chemical analysis.

The results of the optical microscopic metallurgical characterization are provided in Figures 6 through 10. Each sample was polished, etched and examined on a plane normal to the wear(convex) wear surface, on that plane marked with an "x" in Figure 5. Each metallographic section was then photographed on two edges; the edge adjacent to the wear surface, and the edge adjacent to the surface which had been in shrink fit contact with the impeller. The two surfaces were studied to possibly reveal evidence of surface degradation that could be due to the pump operational environment.

On Section 3 (Figure 8), a shallow (1/8 inch) intergranular crack was noted at the wear surface. Since the sections were randomly selected, it must be presumed that the presence of other shallow cracks is not uncommon and in time these cracks could propagate through the wear ring thickness and cause impeller failure (seizure). Due to the similarity of the metallurgical (hardness) design, and service condition of these rings with those of Peach Bottom, with confirmed stress corrosion cracking, it is assumed that cracking in the Pilgrim ring is also due to stress corrosion. It must be noted, however, that fabrication related quench cracking (intergranular) could be a possible, albeit improbable, cause as SCC and shallow quench cracks have similar appearances.

Other noteworthy microstructural features associated with the wear surface were not observed. The microstructure is typical of a correctly fabricated martensitic type 410 S/S. Surface tearing or corrosion attack was not observed.

Sample 6, removed from RHR Pump "A" wear ring segment, was selected for study by Scanning Electron Microscopy(SEM). Figure 11 provides the results of the SEM evaluation. Figure 11 has low (20X) and high (250X) magnification views of the wear surface. Minor surface imperfections/degradation can be observed in the 250X view. This view is rather typical of the condition of the wear surface. Such imperfections tend to promote crack initiation (of the type observed in Section 3) in a susceptible material, if the stress and environmental conditions are favorable for SCC.

B. PUMP "B" IMPELLER WEAR RING

Following visual examination, samples of RHR Pump "B" wear ring were removed for metallurgical evaluation. Figure 12 is a set of photos showing the RHR Pump "B" metallurgical sectioning plan. The arrows in the photos indicate the plane of polish. Since no relevant indications were found by penetrant examination on this wear ring, typical random areas were selected for sampling. As indicated in Figure 12, a total of 7 samples were selected for metallurgical characterization. (A portion of sample #3 was used for SEM evaluation). Five samples were used for optical microscopy, one for SEM and one for chemical analysis.

The results of the optical microscopic metallurgical characterization are provided in Figures 13 through 17. Each sample was polished, etched, and examined on a plane normal to the wear surface, on that plane indicated with an arrow in Figure 12. Each metallographic sample was then photographed on two edges; one edge was adjacent to the wear surface, and the other was adjacent to the surface which had been in shrink fit contact with the impeller. The two surfaces were studied to reveal small microstructural features that could be due to pump operation.

Noteworthy microstructural features associated with the wear surface were not found. The microstructure is typical of a correctly fabricated martensitic type 410 S/S. Surface tearing or corrosion attack was not observed.

The SEM sample(a portion of sample #3) was examined for wear surface degradation. Figure 18 provides the results of the evaluation. Figure 17 has low(20X) and high(250X) magnification views of the wear surface. Minor surface imperfections can be observed in the 250X view. While the imperfections found on the surface would not in any way impair operation of the pump, they would be the preferential sites for IGSCC crack initiation in a susceptible material, if the stress and environmental conditions are also favorable for SCC.

5.0 OTHER METALLURGICAL TESTS

A. HARDNESS MEASUREMENTS

Microhardness measurements were made on optical metallographic samples 1 through 4 removed from the A pump wear ring, and samples 1 through 5 removed from the B pump wear ring. The locations are identified in Figures 19, and 20. The numbers on the sketches represent the hardness readings at that location. All measurements were made on the Rockwell - C scale, using a 500 gram load. The measurements can be summarized as follows for the "A" Pump wear ring:

average hardness................ 42.4 Rc
average near wear surface....... 42.8 Rc
average near impeller surface... 42.8 Rc

and as follows for the "B" pump wear ring:

average hardness................ 40.0 Rc
average near wear surface....... 39.5 Rc
average near impeller surface... 39.9 Rc

Note that in the case of each ring, the average hardness level exceeds the specified maximum hardness level of 39 Rockwell C. At this level of hardness Type 410 Stainless Steel is known to have a susceptibility to stress corrosion crack initiation and growth under suitable conditions of stress and environment.

The average hardness in the region of the crack at the wear surface edge on sample 3) is 42 to 43 Rockwell C and represents the highest values found on the samples. Since increasing hardness levels increase the propensity for IGSCC, it is consistent to have observed cracking in the highest hardness region.

B. CHEMICAL ANALYSIS

The RHR Pump wear rings were fabricated of a Type 410 Stainless steel, A 182, Grade F6, with a specified hardness range of Rc 33 to 39. A sample of each wear ring was analyzed by an independent laboratory for a chemical check analysis. The purpose was to establish compliance with the material specification. The results are presented in Figure 21. It is noted that the chemistry of the PILGRIM samples is in compliance with the requirements of ASTM A 182, Grade F6. (See Attachment 2.)

6.0 DISCUSSION

By visual examination, the wear ring samples which had been removed from the RHR pump impellers at PILGRIM Nuclear Power Station, showed no evidence of cracking. However, by optical metallographic and scanning electron microscopic evaluation, one ring sample did show the stress corrosion cracking of the type which had caused the degradation of similar RHR pumps at other domestic power plants.

The wear ring material had average hardness readings of 360 to 44 Rockwell C. (The manufacturer, Bingham-Willamette, specifies a range of hardness of C34 to C39.) The ring sample with minor cracking had average hardness readings of 42 to 43 Rockwell C. The material has increased susceptibility to crack initiation and growth by IGSCC at hardness levels greater than C40. It is, therefore, consistent to have observed minor cracking in the highest hardness regions of wear ring sample "A".

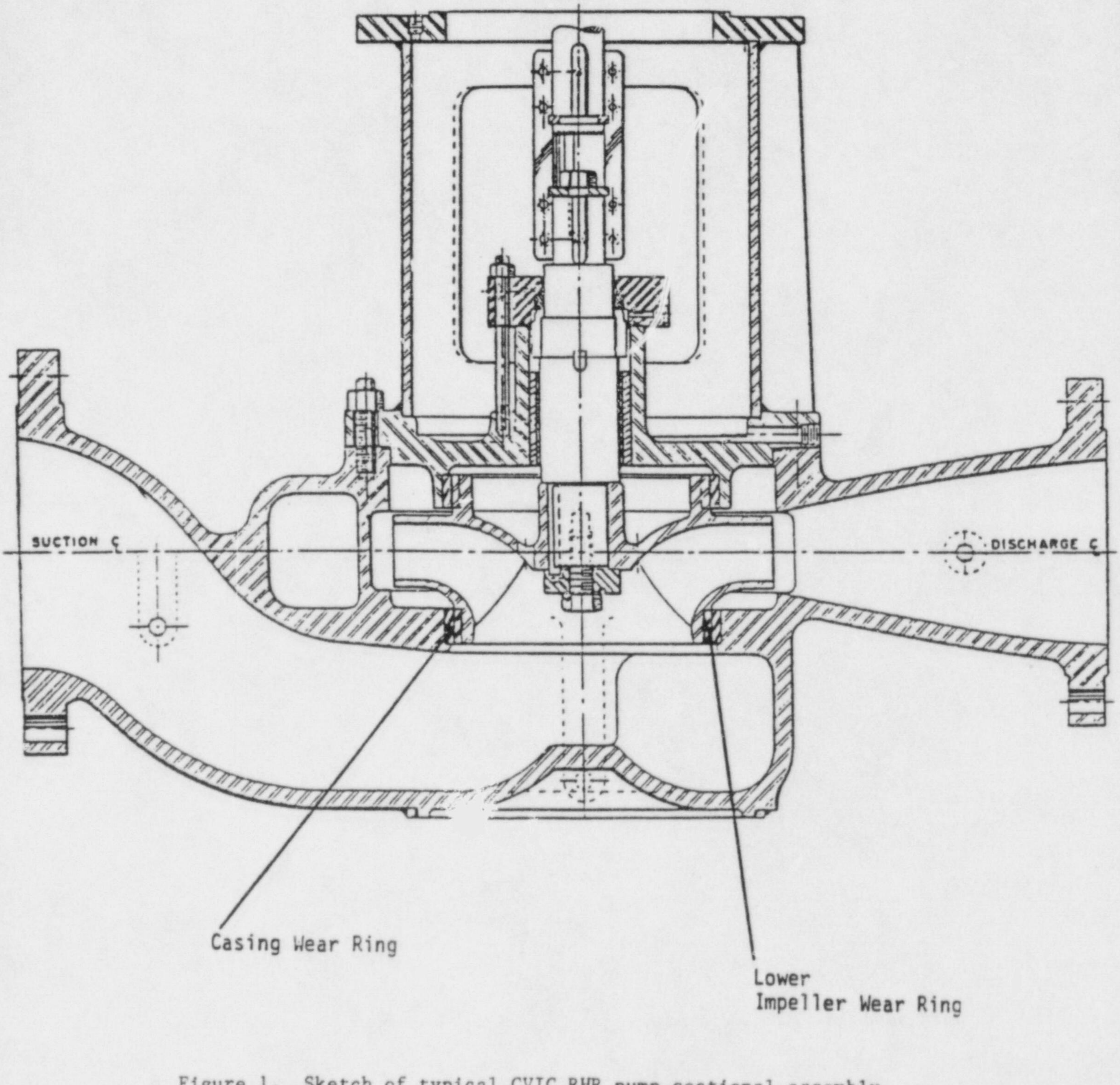


Figure 1. Sketch of typical CVIC RHR pump sectional assembly, showing locations of impeller and casing wear rings.

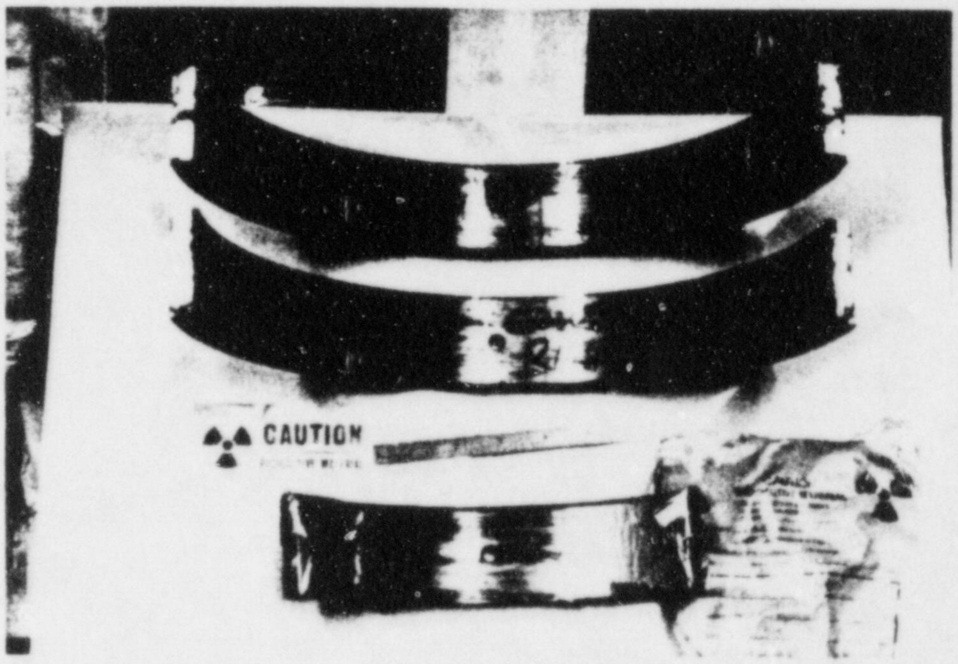


Figure 2. Photo of Pilgrim RHR pump wear ring sent to VNC for metallurgical evaluation.

Figure 3. Closeup photo of wear ring segment removed from RHR pump "A" impeller.

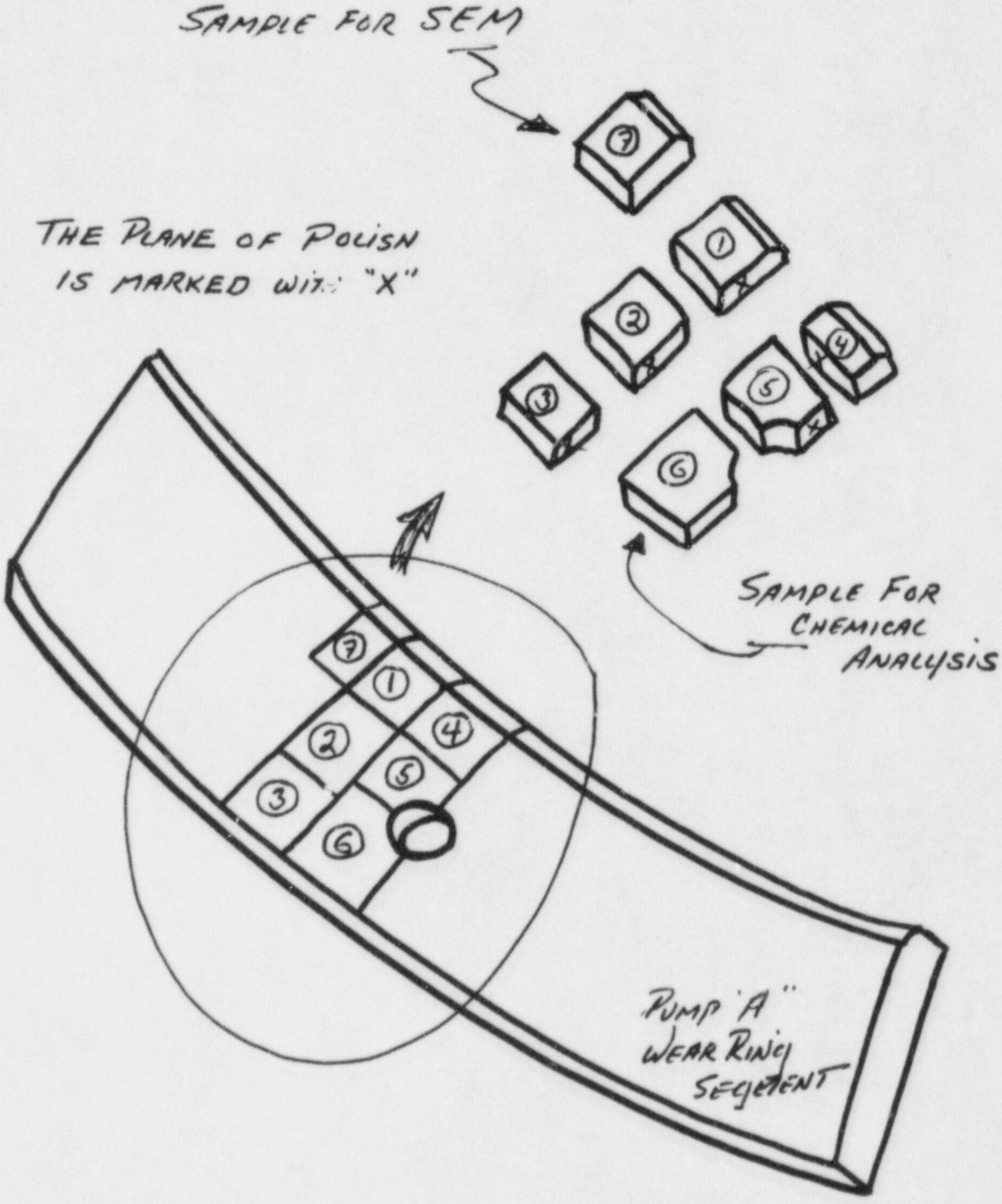


Figure 5. Sketch of sectioning plan for RHR pump "A" wear ring segment metallographic examination.

Figure 6. Typical edge views of section 1 removed from RHR pump "A" wear ring segment. The edge in the upper photo was adjacent to the wear surface, and the edge in the lower photo was adjacent to the impeller.

Wear Surface

125X

Impeller Edge

Figure 7. Typical edge view of section 2 removed from RHR pump "A" wear ring segment. The edge in the upper photo was adjacent to the wear surface and the edge in the lower photo was adjacent to the impeller.

Wear Surface

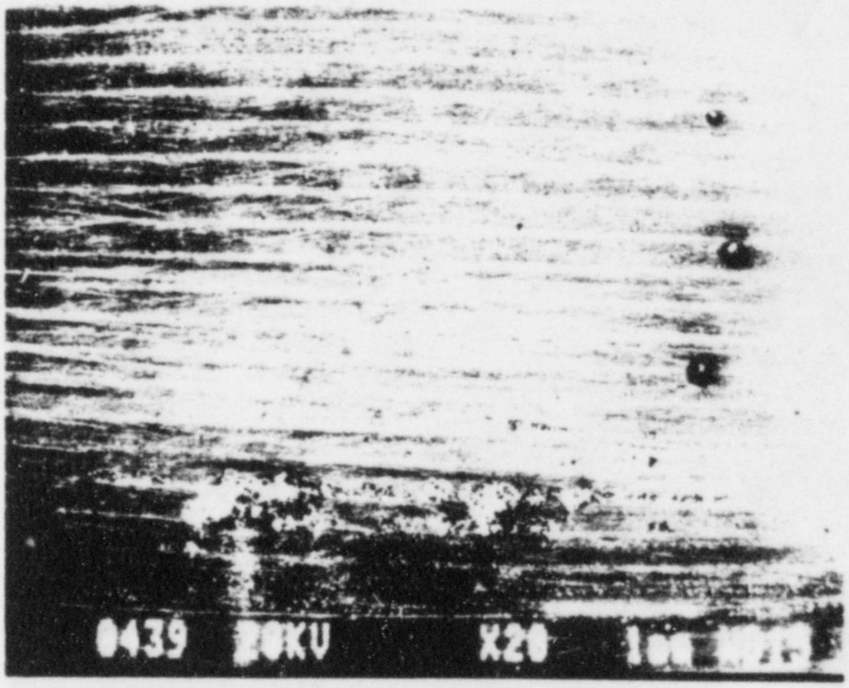
Impeller Edge

Figure 8. Typical edge views of section 3 removed from RHR pump "A" wear ring segment. The edge in the upper photo was adjacent to the wear surface and the edge in the lower photo was adjacent to the impeller. Note shallow intergranular crack in upper photo. Hardness at this location is approximately 43 Rockwell C.

Figure 9. Typical edge views of section 4 removed from RHR Pump "A" wear ring segment. The edge in the upper photo was adjacent to the wear surface and the edge in the lower photo was adjacent to the impeller.

Figure 10. Typical edge views of section 5 removed from RHR pump "A" wear ring segment. The edge in the upper photo was adjacent to the wear surface and the edge in the lower photo was adjacent to the impeller.

250X



20X

Figure 11. Low (20X) and high (250X) magnification views of wear surface of wear ring of RHR pump "A". Note the minor surface degradation in the 250X view. Such imperfections tend to promote crack initiation in a susceptible material if stress and environment conditions are favorable for SCC.

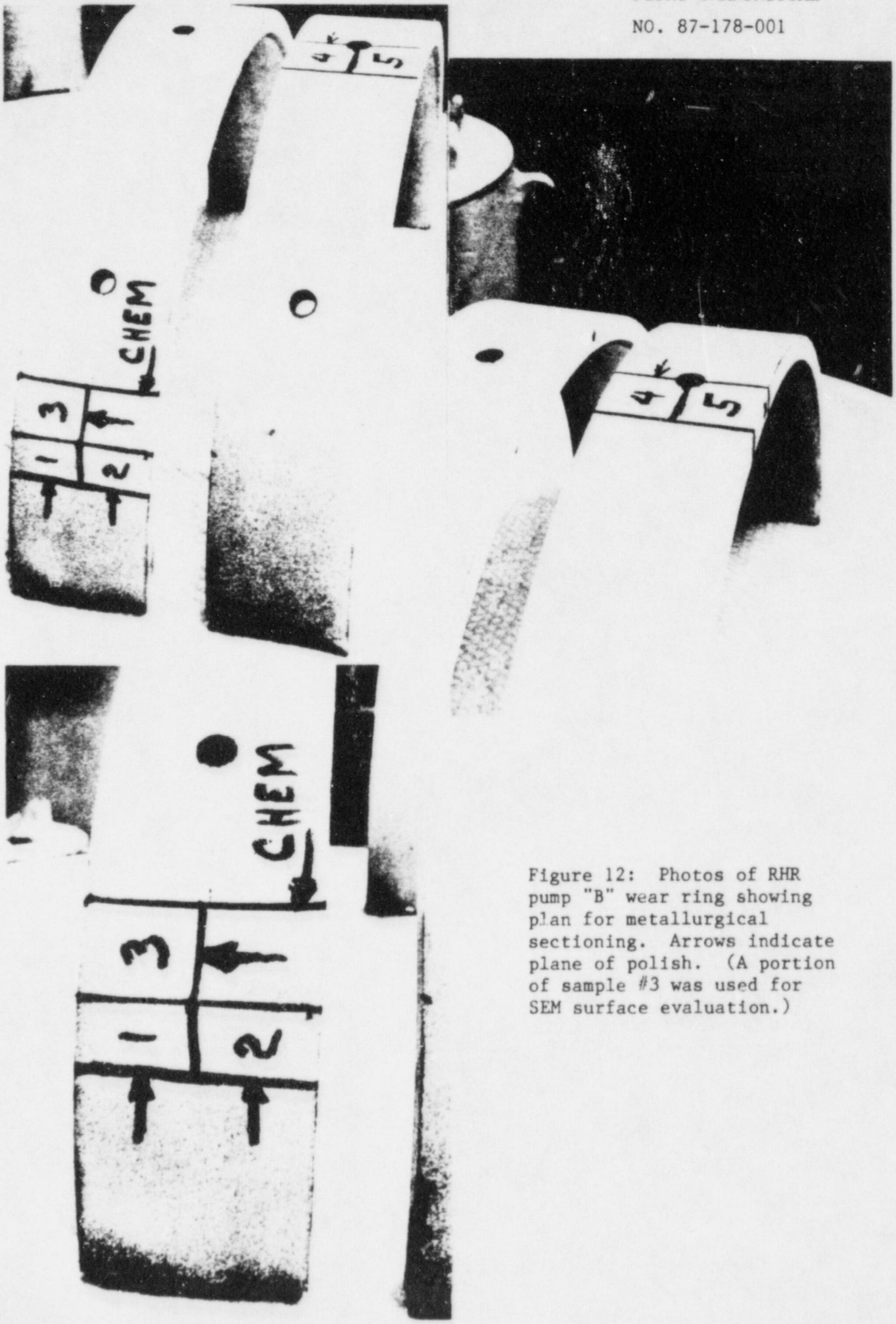


Figure 12: Photos of RHR pump "B" wear ring showing plan for metallurgical sectioning. Arrows indicate plane of polish. (A portion of sample #3 was used for SEM surface evaluation.)

Figure 13. Typical edge view of section 1 removed from RHR pump "B" wear ring. The edge in the upper photo was adjacent to the wear surface and the edge in the lower photo was adjacent to the impeller.

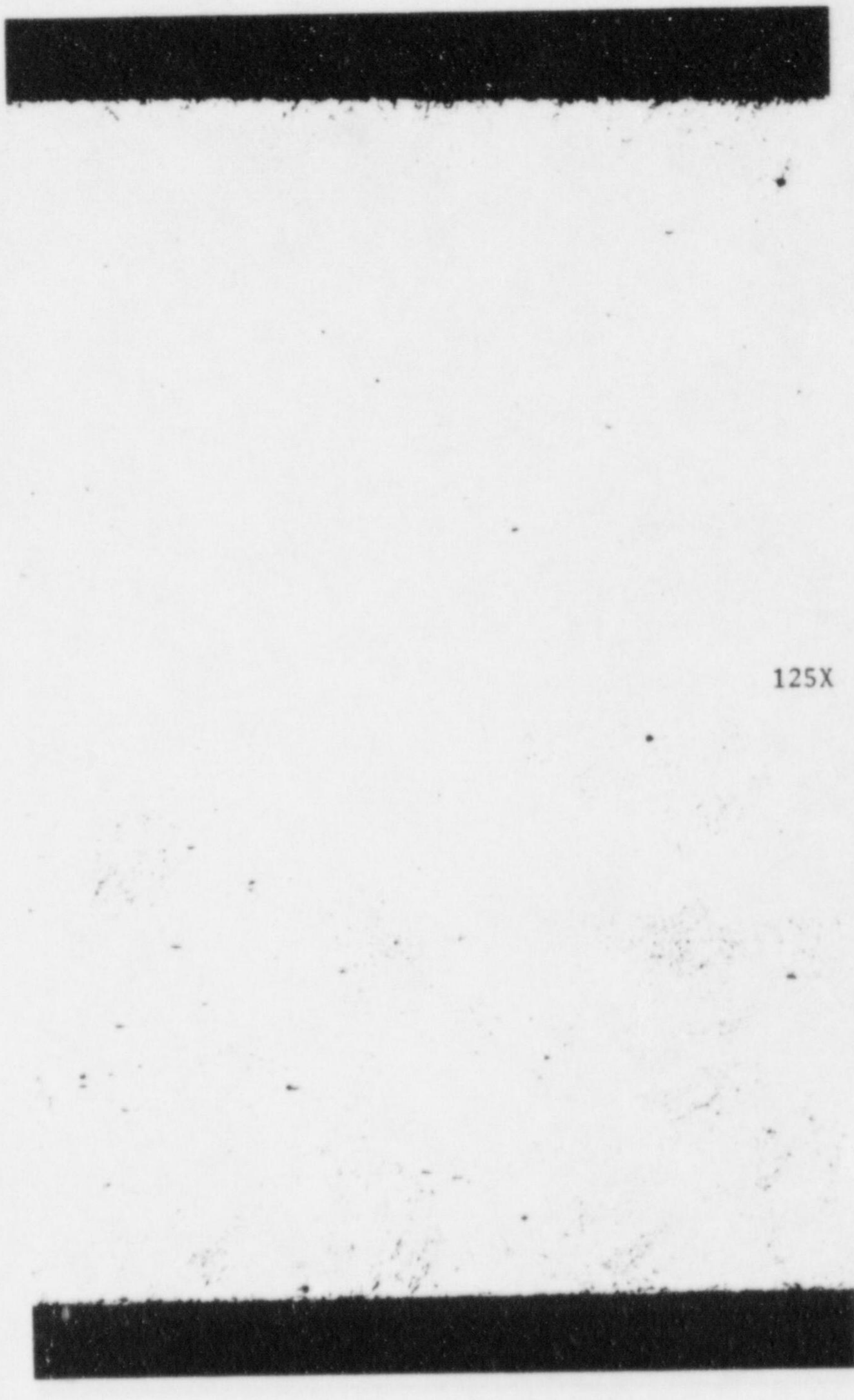
Wear Surface

125X

Impeller Edge

Figure 14. Typical edge view of section 2 removed from RHR pump "B" wear ring. The edge in the upper photo was adjacent to the wear surface and the edge in lower photo was adjacent to the impeller.

Wear Surface



Impeller Edge

Figure 15. Typical edge view of section 3 removed from RHR pump "B" wear ring. The edge in the upper photo was adjacent to the wear surface and the edge in the lower photo was adjacent to the impeller.

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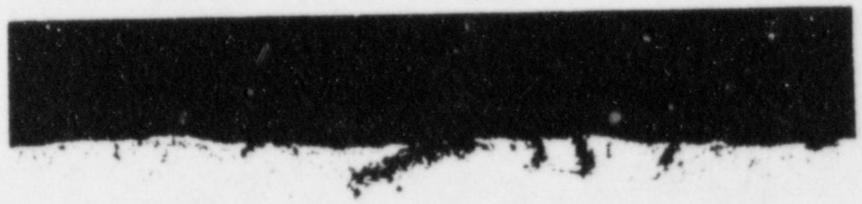
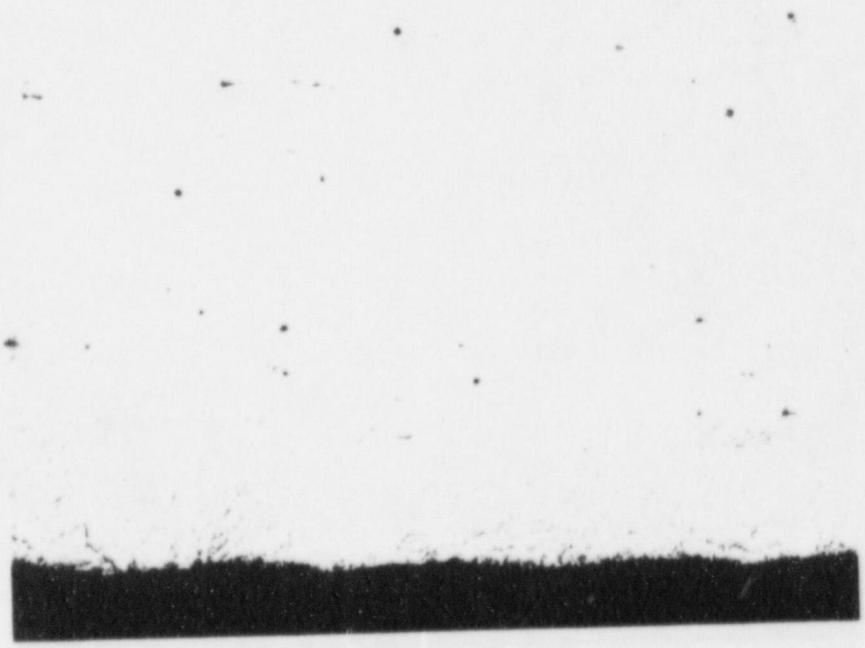
Wear Surface

125X



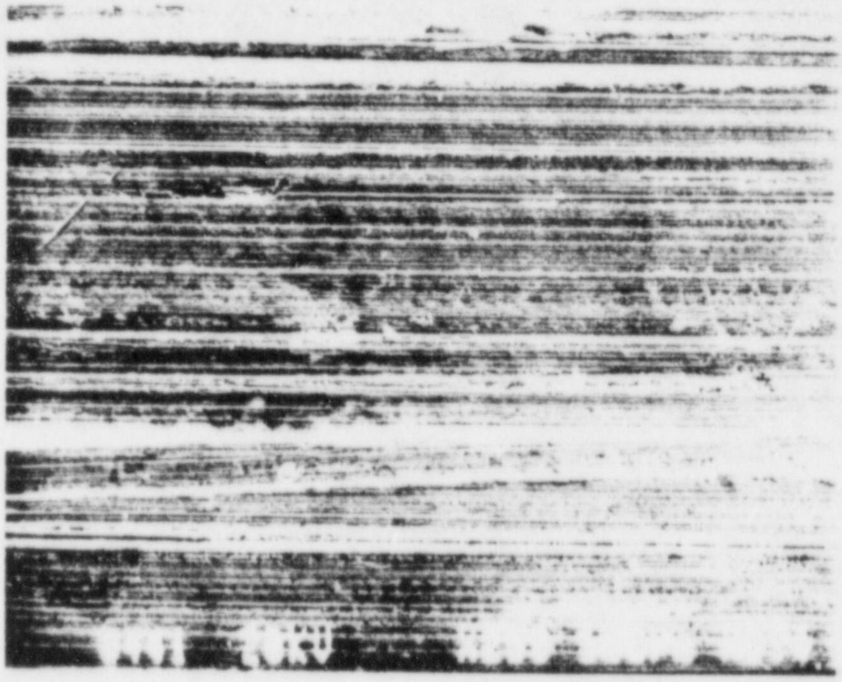
250X



Impeller Edge

Figure 16. Typical edge view of section 4 removed from RHR pump "B" wear ring. The edge in the upper photos was adjacent to the wear surface and the edge in the lower photo was adjacent to the impeller.

Figure 17. Typical edge views of section 5 removed from RHR pump "B" wear ring. The edge in the upper photo was adjacent to the wear surface and the edge in lower photo was adjacent to the impeller.



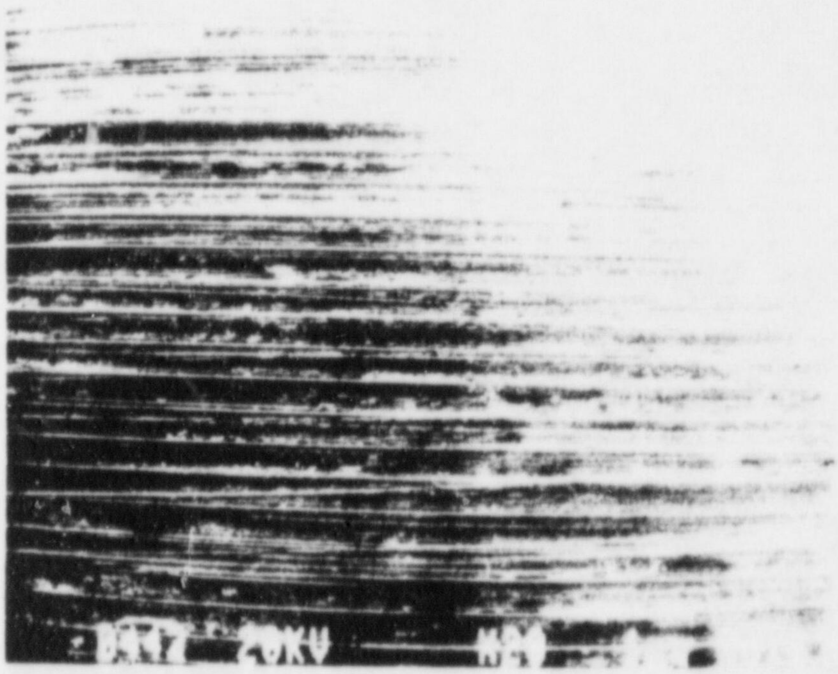
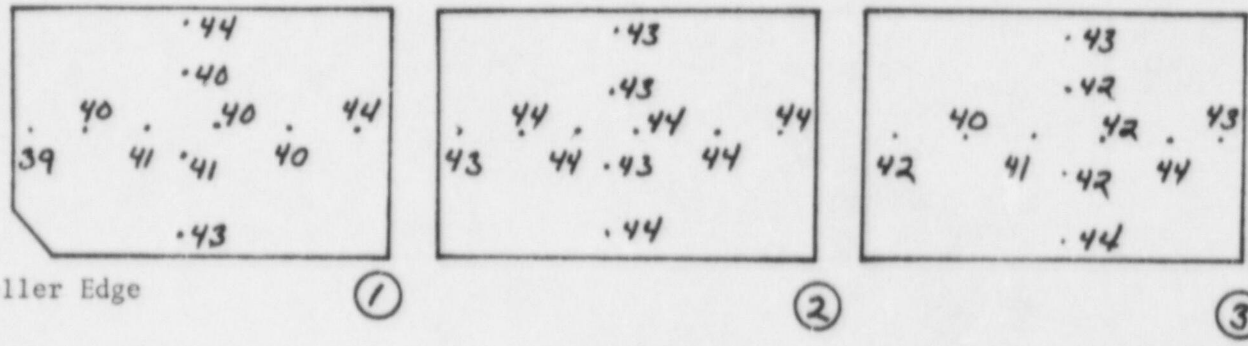


Figure 18. Low (20X) and high (250X) magnification views of wear surface of lower wear ring of RHR pump "B". Note the minor surface imperfection in the 250X view. Such imperfections tend to promote crack initiation in a susceptible material if stress and environmental conditions are favorable.

Wear Surface

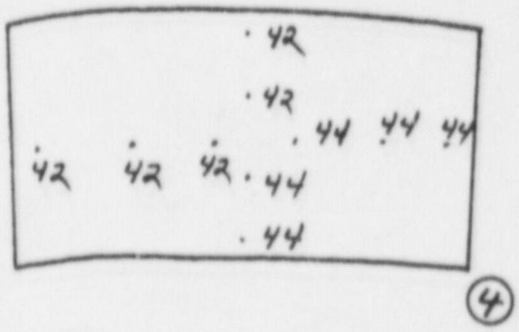


Impeller Edge

Avg. overall hardness........42.4

Avg. near wear surface.......42.8

Avg. near impeller surface...42.8



Wear surface

Impeller Edge

Figure 19: Hardness measurement for RHR pump "A" wear ring.

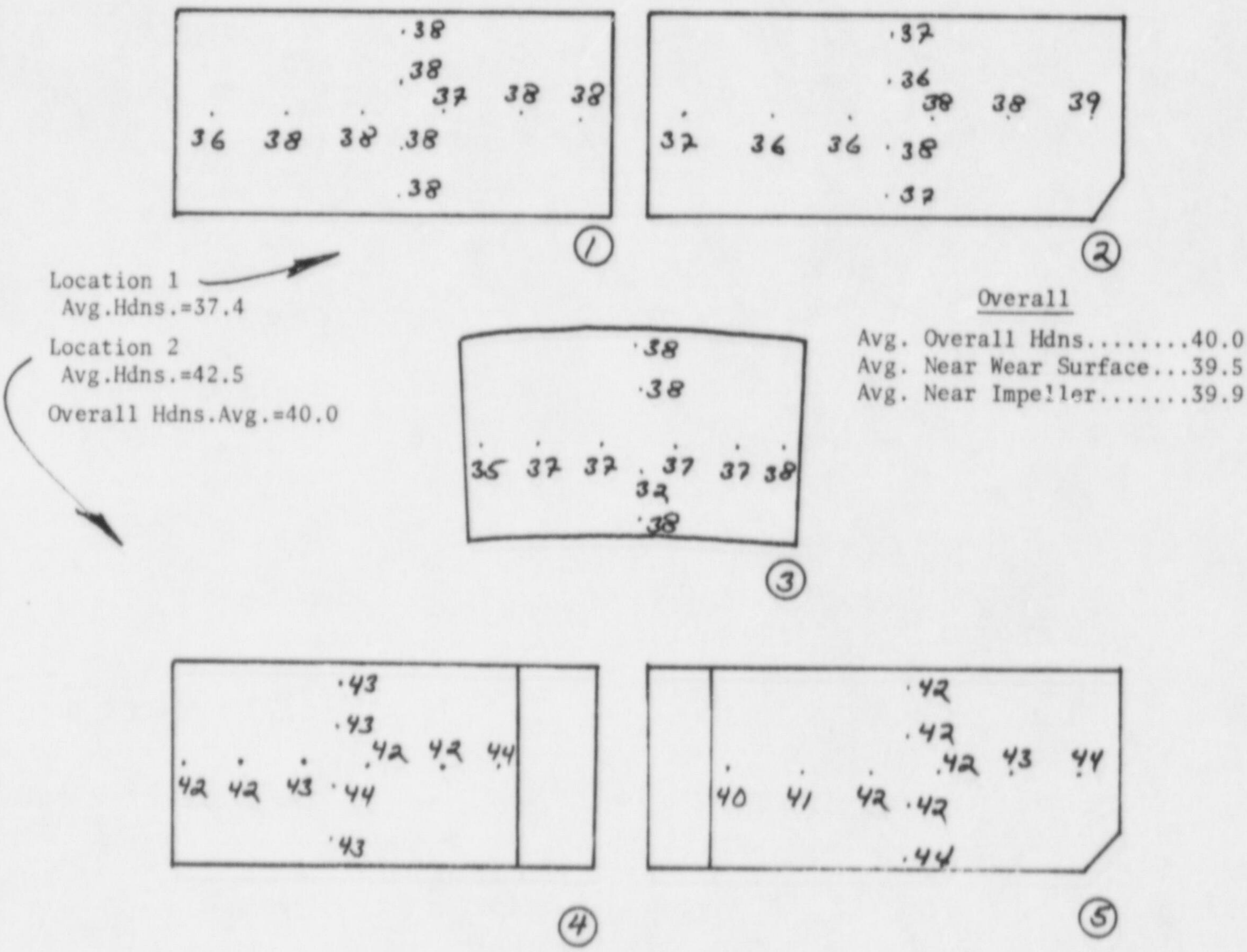


Figure 20. Hardness measurements for RHR pump "B" wear ring.

CHEMICAL ANALYSIS COMPARISON

	A 182 Gr. F6	"A" Pump Sample	"B" Pump Sample
C	0.12 max	0.12	0.10
Cr	11.5 - 13.5	12.33	11.79
Mo	1.0 max	0.36	0.44
P	0.040 max	0.013	0.013
Si	1.00 max	0.28	0.36
S	0.030 max	0.015	0.007

Figure 21. Comparison of chemical analysis with the requirements of ASM specifications.

ATTACHMENT 1

SSINS No.: 6835
IN 86-39

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF INSPECTION AND ENFORCEMENT
Washington, DC 20555

May 20, 1986

IE INFORMATION NOTICE NO. 86-39: FAILURES OF RHR PUMP MOTORS AND PUMP INTERNALS

Addressees:

All nuclear power reactor facilities holding an operating license (OL) or a construction permit (CP).

Purpose:

This notice is provided to alert licensees to serious damage which has occurred at a licensed nuclear power plant to residual heat removal (RHR) pumps manufactured by Bingham-Willamette with motors supplied by General Electric. The damage identified at the Philadelphia Electric Co. (PECO), Peach Bottom facility involved failure of motor bearings and/or failure of pump impeller wear rings.

It is expected that recipients will review this notice for applicability to their facilities and consider actions, if appropriate, to preclude a similar problem occurring at their facilities. However, suggestions contained in this notice do not constitute requirements; therefore, no specific action or written response is required.

Description of Circumstances:

On November 2, 1985, during core reload of PECO's Peach Bottom Unit 3, a fire occurred in the 3C RHR pump motor which totally engulfed the motor and rendered the pump inoperable. A lower guide bearing high temperature alarm had been received for 3 days prior to the pump failure, but this warning of potential pump failure went unnoticed by personnel because of the large number of other alarms that were received during the shutdown. The motor, a 2000 HP GE vertical induction model 5K6348XC29, and pump, a Bingham-Willamette single stage centrifugal model 18x24x28 CVIC (Figure 1), were uncoupled, disassembled and inspected for damage. Results of the inspection identified that the motor lower guide bearing was destroyed, the rotor bars were gouged and scorched, and the stator windings were burned and gouged. The pump internals were found to have sustained internal damage. Specifically, the lower impeller wear ring (Figure 1) was separated from the impeller and fused to the casing wear ring. No other wear surfaces indicated wear or damage. On November 16, 1985, while replacing the lower pump casing gasket on the 3A RHR pump, PECO personnel discovered that the lower pump impeller wear ring was separated from the impeller and cracked in three places. Subsequent inspections of the remaining two unit 3 RHR pumps and two unit 2 pumps (2A and 2C) revealed similar wear ring failures in three of the pumps inspected.

~~8605150473~~ (5pp)

On December 22, 1985, after several overcurrent alarms with pump 2D from Unit PECO inspected this pump and discovered the lower pump impeller wear ring separated and cracked, a 6-inch piece of wear ring missing, and the impeller vanes damaged. Not all failures noted above were as severe as the ones identified on pumps 3C and 2D. However, the similarity was evident.

The RHR pump impeller wear rings are press fit to the impeller and attached with eight dowel pins. The wear rings provide a wearing surface on the pump impeller. The wear rings are 410 stainless steel, A 182 grade F6 with a Rockwell C hardness of 33 to 39. Metallurgical examinations of the wear ring fracture surfaces indicate the presence of intergranular stress corrosion cracking (IGSCC). PECO has classified the wear ring failures as IGSCC. On November 26, 1985, PECO made an INPO Network notification regarding these RHR pump failures. PECO has repaired all affected pumps by replacement of damaged motors and pump internals. Tennessee Valley Authority's Browns Ferry Units 1, 2, and 3 utilize the identical pumps for RHR service. Similar motor and pump impeller wear ring failures have occurred at these facilities, but not to the extent identified at Peach Bottom. Pumps of similar design, but different size, are utilized for core spray service both at Peach Bottom and Browns Ferry. However, these pumps use the "integral" impeller wear ring design, i.e., extended impeller part replaces separate wear ring and forms a single unit, and therefore are not susceptible to the type of wear ring failure previously described.

Discussion:

These multiple events are of concern because of the potential for common-mode failures of all pumps in the same system. At Peach Bottom, six of eight pumps inspected exhibited degraded pump impeller wear rings and internals. These flaws could lead to pump hydraulic degradation and, under the worst conditions, complete pump failure. The motor guide bearing failures are significant because they could cause failure of the pump motors and pump internal damage.

The full extent to which this type of pump may be used in safety-related services at other facilities is not known with complete certainty. According to information ascertained from Bingham-Williamette records and confirmed by contact with affected sites, other plants utilizing this type of pump in the RHR system include the following: Cooper, Pilgrim 1, and Vermont Yankee.

The exact cause of the pump internal failures has not been fully determined, except that there is evidence that IGSCC has contributed to the impeller wear ring failures. Operating pumps with inadequate flow and lubrication, whereby high internal temperatures develop, is also a likely contributor, e.g., pump cavitation. PECO is continuing to pursue root causes and wear ring redesigns to prevent such occurrences in the future.

No specific action or written response is required by this information notice. If you have any questions regarding this matter, please contact the Regional Administrator of the appropriate NRC regional office or the technical contact listed below.

Edward L. Jordan, Director
Division of Emergency Preparedness
and Engineering Response
Office of Inspection and Enforcement

Technical Contact: Ronald M. Young
(301) 492-8985

Attachments:
1. Figure 1 - Typical CVIC RHR Pump
Sectional Assembly
2. List of Recently Issued IE Information Notices

Attachment 1
IN 86-39
May 20, 1986

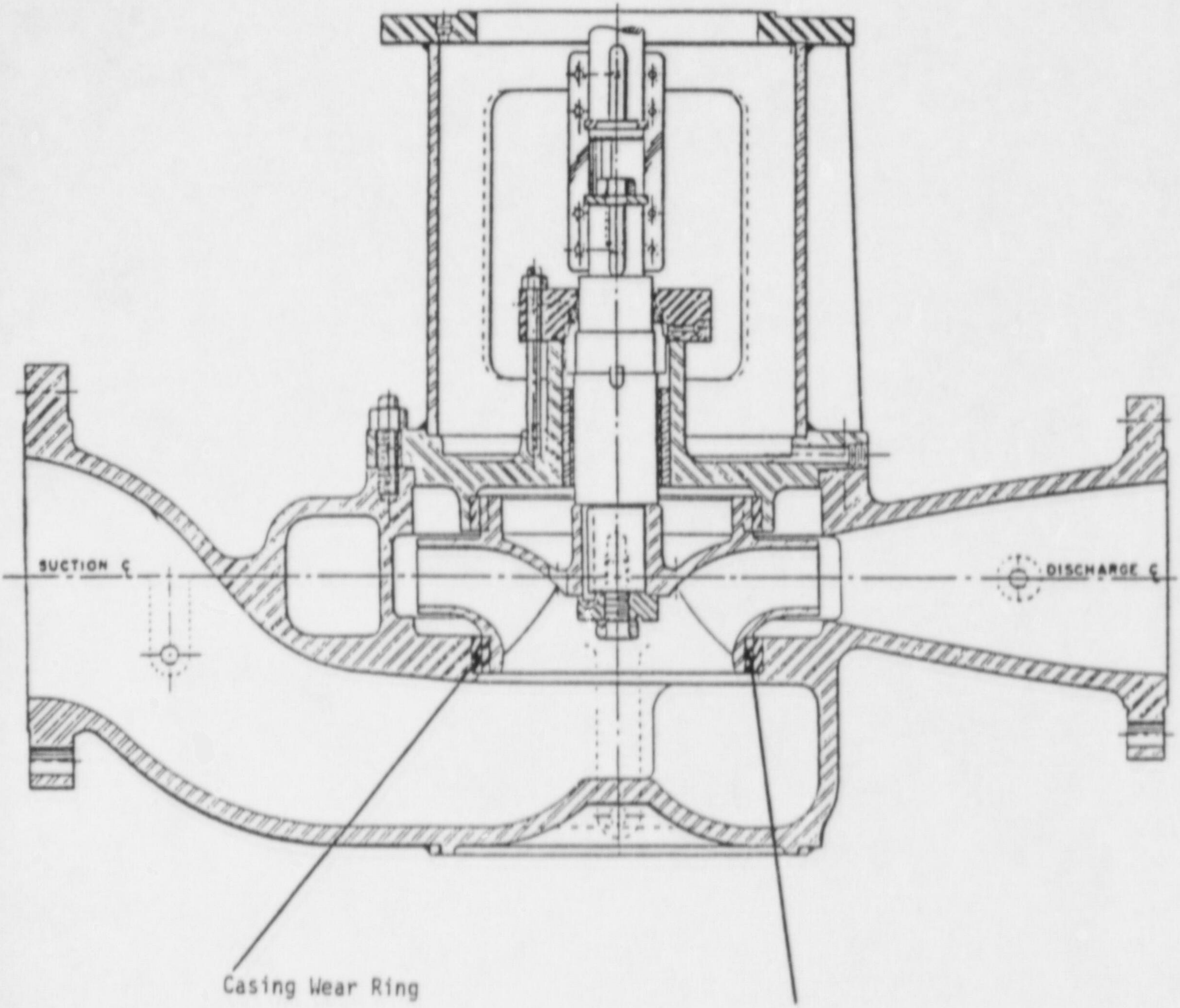


FIGURE 1 - Typical CVIC RHR Pump
Sectional Assembly

LABORATORY CERTIFICATE ATTACHMENT 2

Anamet Laboratories, Inc.

3400 INVESTMENT BOULEVARD • HAYWARD, CALIFORNIA 94545-3811 • (415) 887-8811

Laboratory Number: 187.17
Purchase Order: 205-XI 143
Date Submitted: January 6, 1987
Date Reported: January 12, 1987

General Electric
Nuclear Energy Business Operations
Attn: D. E. Delwiche
175 Curtner Avenue, M/C 785
San Jose, CA 95125

SUBJECT:

Two metal coupons were submitted for chemical analysis. The samples were identified as follows: RHR-A and RHR-B, 410 martensitic stainless steel.

SPECTROCHEMICAL ANALYSIS
(reported in wt. %)

Mark:		RHR-A	RHR-B
Carbon	(C)	0.12	0.10
Chromium	(Cr)	12.33	11.79
Manganese	(Mn)	0.36	0.44
Phosphorus	(P)	0.013	0.013
Silicon	(Si)	0.28	0.36
Sulfur	(S)	0.015	0.007

This testing was performed in accordance with the purchase order.

Respectfully Submitted,
ANAMET LABORATORIES, INCORPORATED

By E. A. Foreman
E. A. Foreman
Manager, Quality Control

3c/bh123186