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INDIAN POINT 2 REACTOR COOLANT PUMP SEAL EVALUATIONS

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ABSTRACT

This report summarizes the findings on Westinghouse Reactor Coolant Pump Seal Performance at the Indian Point 2 Nuclear Power Station. The study was conducted under the joint sponsorship of Consolidated Edison of New York and the U.S. Nuclear Regulatory Commission, Office of Research. The conclusions and recommendations herein are based on the review of the plant operational and maintenance data on seals, consultation with Westinghouse and Utilities, review of prior studies, and visual as well as in-depth examination of service exposed seals received from the plant.

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EXECUTIVE SUMMARY

At Indian Point Unit 2 Nuclear Station (IP2) there have been a significant number of reactor coolant pump (RCP) seal failures. Consolidated Edison Company of New York (Con Ed) initiated a research effort to determine the causes of these failures, and to develop appropriate ameliorative action to enhance seal reliability. The BNL effort is an outgrowth of the first phase effort performed by Failure Analysis Associates (FaAA). The objectives of the BNL program are to determine the root causes of seal failure, and to provide recommendations to improve seal reliability.

This program made significant advances in understanding the root causes of RCP seal failure. Prior to this effort, RCP seal failure studies were of the "desk top" variety, which formulated hypothetical explanations. For the first time, actual failed seals were examined in detail in BNL's hot cell, and laboratory tests were conducted to determine failure cause. Additionally, the results should be more beneficial to Con Edison, as specific Indian Point 2 seals and plant data were considered in the study.

This report summarizes findings from the following studies: review of plant operating and maintenance data, consultation with Westinghouse and utilities, review of prior RCP seal studies (including previous BNL work) and then visual and indepth examinations of the first batch of service exposed seals received from IP2.

In past years the No. 1 seal was the dominant contributor to the IP2 seal failures. However, as a result of improvements made in design, materials, startup and operating practices, improved maintenance techniques, and instrumentation changes, the No. 1 seal problems have been diminished. There are fewer failures occurring with the No. 1 seal, but the No. 2 and 3 seal failure rates remain relatively unchanged at an average of two failures per year.

Recent material changes by Westinghouse have contributed to the improvements in the No. 1 seal performance. These changes are as follows: changes of seal face material from aluminum oxide to silicon nitride, installing chrome carbide cladding on all seal rubbing surfaces, and a change to tetralon 720 for the double delta (or channel) seals.

The maintenance and operational data from IP2 indicate that most seal failures are attributed to improper seal injection, crud in the system, and fretting of rubbing faces in the inserts and seal housings. Some of these problems are now circumvented by improved maintenance and operating practices, which are enhanced by training, and the use of a seal assembly mockup.

Six canisters of service exposed seals received from Con Ed were visually examined for gross degradation and wear of the seal components. Two selected seals were further examined to determine the crud content and the condition of channel and O-ring seals.

Visual examination of a number of seals and in-depth examination of one seal revealed minor metallic wear, and seal face wear (with one major exception), but considerable degradation of channel seals (DDS) and O-rings. Major crud buildup was localized in the area of the DDS and O-rings and consisted of material from O-rings.

Based on this study, it is recognized that additional instrumentation is necessary to adequately monitor seal conditions. It also appears unnecessary to replace complete seal assemblies at each refueling outage, only the O-rings and channel seals should be replaced routinely.

Future work should focus on the following:

1) Examination of the remaining cannisters of used seals, with emphasis on the crud content, non-metallic component wear, fretting of steel surfaces, cocking of stationary rings, and thermo-hydraulic behavior of the seal assembly.

2) Observation of the channel seals and O-rings for further degradation and the evaluation of the causal mechanism.

3) Establishment of a condition monitoring program to identify incipient seal degradation.

4) Evaluation of plant operating and maintenance procedures in relation to seal performance.

Completion of the above tasks will result in the identification of IP2 seal failure modes and the mechanisms causing these failures. Remedial action can then be developed to monitor degradation as well as mitigate these failures.

1. INTRODUCTION

This report presents the initial phase findings on Westinghouse Reactor Coolant Pump (RCP) seal performance at the Indian Point 2 Nuclear Power Station. The study was conducted as an outgrowth of Consolidated Edison's effort to determine the causes of their seal failures, by examining certain service exposed seal conditions. The work was also co-sponsored by the U.S. Nuclear Regulatory Commission under the Nuclear Plant Aging Research program. This section provides background information on the RCP seal performance, objectives and the BNL scope of work.

1.1 Background

At Indian Point Unit 2 Nuclear Station (IP2) there have been a number of primary reactor coolant pump (RCP) shaft seal failures which have led to loss of reactor primary coolant. Most of the earlier failures were caused as a result of abnormal leakage through the No. 1 seal. After the implementation of improved startup techniques, maintenance practices and monitoring procedures, and the installation of newly designed seals, the plant has experienced fewer No. 1 seal failures. In recent years, fretting of the inserts and/or housing surfaces against which the double delta (also known as channel seal) and O-ring seals are rubbing and excessive No. 3 seal leakage have been the predominant failure modes. Similar occurrences were also reported at other nuclear facilities with Westinghouse reactor coolant pumps.

Each of the four PWR loops at IP2 contains one Westinghouse Reactor Coolant Pump as shown in Figure 1. These pumps are designated as #21, #22, #23, and #24. Each pump has one set of the first generation of Westinghouse 8" RCP seals consisting of three seal stages in series (Figure 2). The first stage (#1) seal is the primary component separating the reactor coolant at 2250 psig from the seal leakage water at 30 psig. This seal is a "hydrostatic filmriding face seal" in which the mating surfaces of the stationary seal (upper half) and rotating seal (lower half) do not touch, but are separated by a thin film of water upon which the stationary seal floats. Therefore, a design leak rate of 3 gpm translates to one-half mil gap with a taper angle of less than 1/1000 radians between the two seal halves. Figure 3 shows both the runner (which rotates with the shaft) and the stator (which floats up and down). These have an aluminum-oxide faceplate clamped to a stainless steel holder. Recent designs use silicon nitride faceplates instead of aluminum oxide.

The second stage (#2) seal, as shown in Figure 4, is a rubbing-face seal in which a carbon graphite insert on the stationary ring rubs on a chrome-carbide-coated insert on the stainless steel runner. When the No. 1 seal fails, this seal is designed to convert from a rubbing face to a film-riding seal. The third stage (#3) seal is also a rubbing-face seal similar to that of the No. 2 seal and is shown in Figure 5.

Consolidated Edison, the plant owner/operator, initiated a research effort to determine the causes of their RCP seal failures, and to develop appropriate ameliorative actions to enhance seal reliability in the plant. The first phase of the work[1] was completed by Failure Analysis Associates (FaAA). The FaAA report includes a general description of the IP2 RCP seals, an assessment of both the Con Ed experience, and the industry-wide experience with Westinghouse seals, and recommendations on specific tasks that should be performed. This BNL study is an outgrowth of the first phase effort.

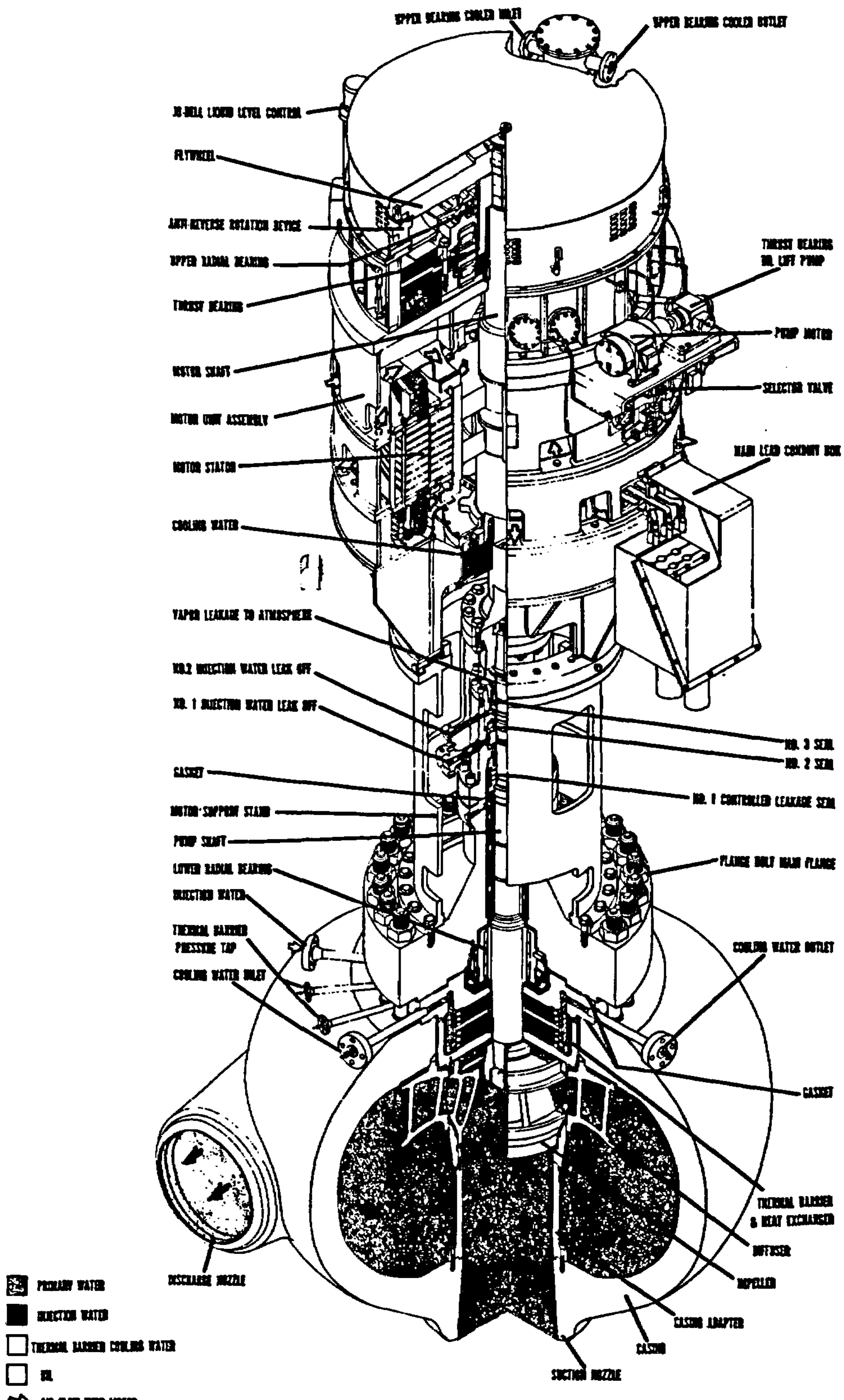


Figure 1: Westinghouse RCP at IP2

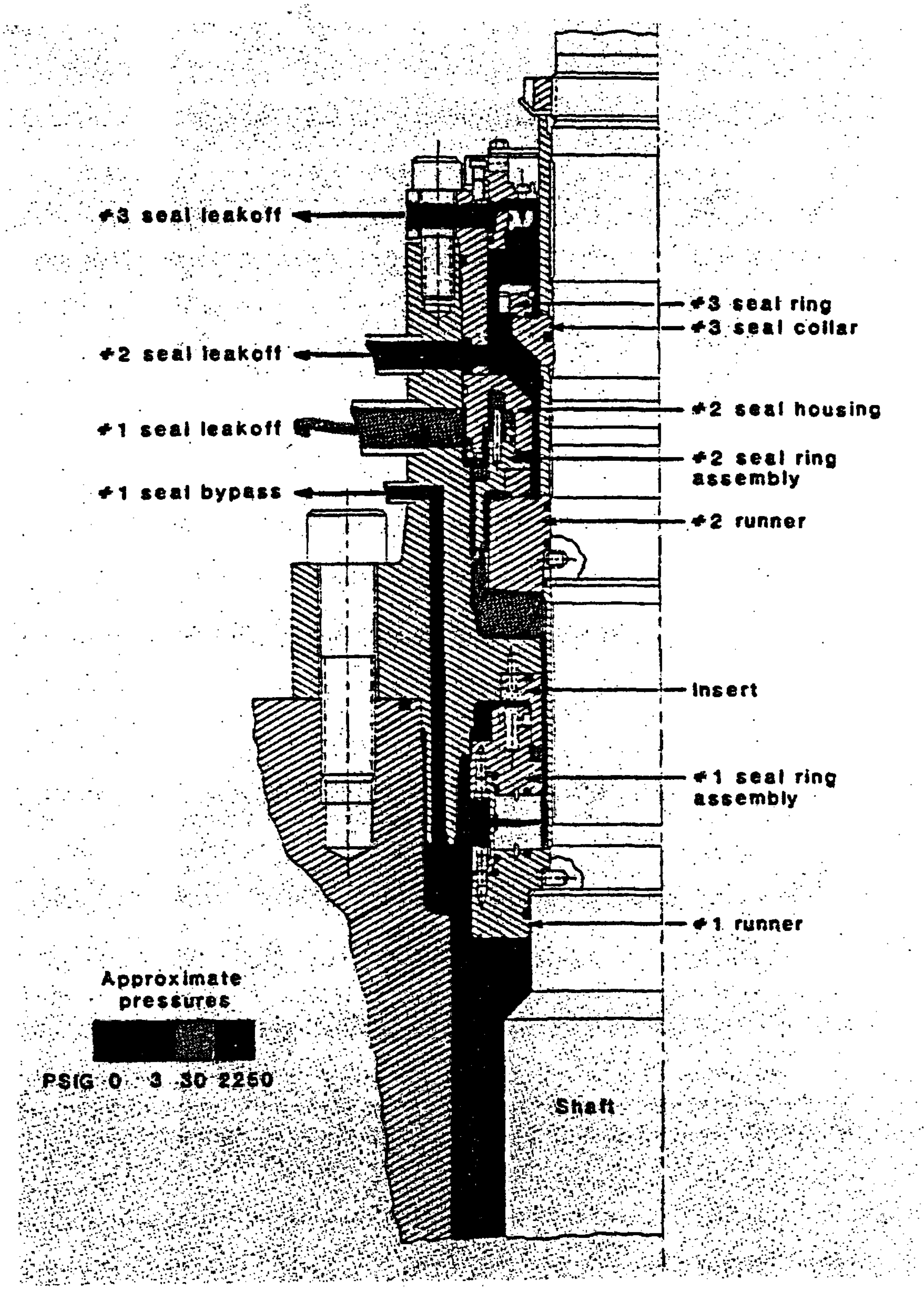
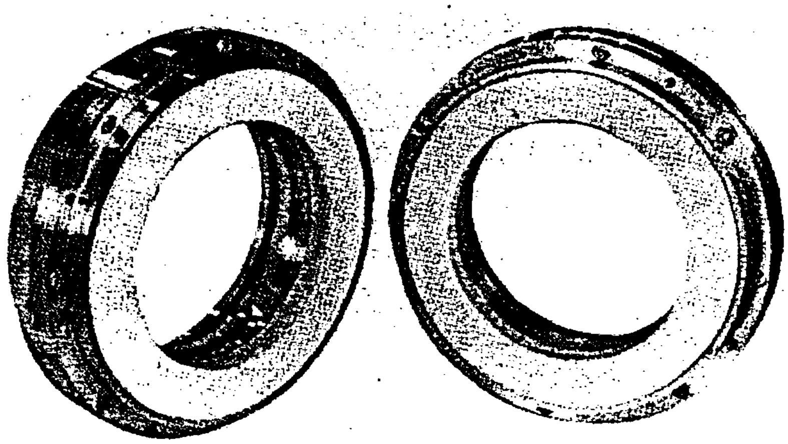


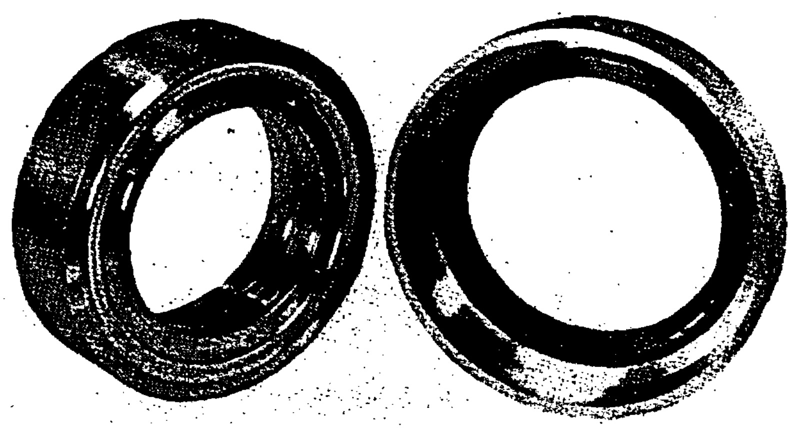
Figure 2: Westinghouse hybrid-hydrostatic RCP seal configuration.



#1 Stationary Ring Assembly

#1 Runner

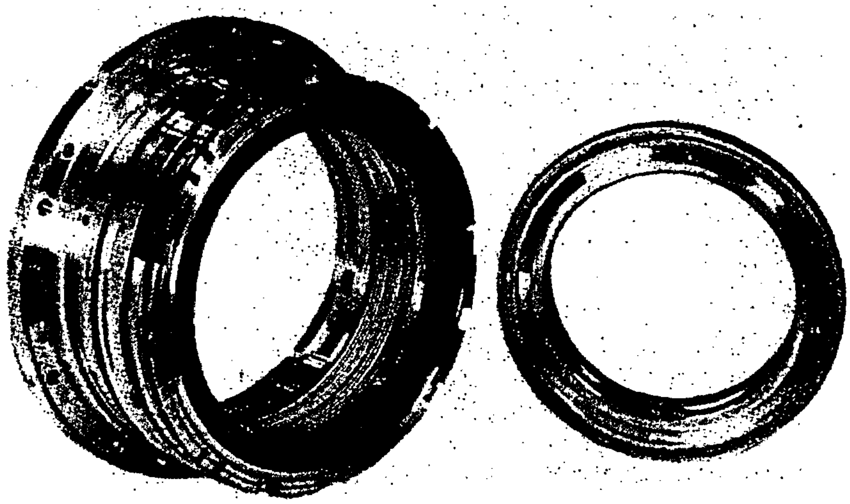
Figure 3: First Stage RCP Seals for Westinghouse Pumps



#2 Runner

#2 Seal Ring Assembly

Figure 4: Second Stage RCP Seals for Westinghouse Pumps



#3 Seal Ring Assembly

#3 Seal Collar

Figure 5: Third Stage RCP Seals for Westinghouse Pumps

1.2 Objectives

The objectives of the BNL effort are:

- to identify the time-dependent failure mechanisms that are responsible for premature RCP seal failures,
- to recommend remedial actions to aid in extending RCP seal reliability and life.

1.3 Scope

The complete scope of the BNL study includes:

- a review of the relevant literature relating to RCP seal failures
- discussions with Westinghouse concerning the design and manufacturer of their RCP seals

- interviews with IP2 maintenance personnel
- a review of plant startup and operating practices at IP2
- a review of the adequacy of instrumentation and monitoring methods for detecting seal operation
- visual inspection of service exposed seal components received from IP2
- in-depth examination of selected seals which include:

  a. chemical analysis of crud build-up on seal faces

  b. dimensional changes on seal surfaces

  c. scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) on failed or damaged surfaces

  d. material analysis of non-metallic components

  e. assessment of mechanical damages

Figure 6 depicts the general BNL scope to determine the root causes of failure and to develop recommendations for mitigating them.

To aid in the examination, a potential failure mode and effect study will be conducted as illustrated in Figure 7. This would help determine the root causes and the mechanisms responsible for IP2 seal failure. The three primary failure mechanisms leading to excessive seal leakages at various stages are: catastrophic seal failures, cocking of stationary seal ring, and excessive wear of seal faces. Various elements contributing to these familiar mechanisms will be evaluated before establishing the necessary remedial actions to prevent them from occurring prematurely.

If necessary, a thermo-hydraulic analysis of the seal assembly will be performed for establishing the flow, temperature and pressure distribution inside the seal for the normal operating condition.

The actual scope of this study as presented in this report is as follows:

- a preliminary evaluation of the progress made in the seal design and manufacturing process,
- a preliminary assessment of seal performance and maintenance at IP2,
- visual examination of six cannisters of service exposed seals for any physical evidence of degradation,

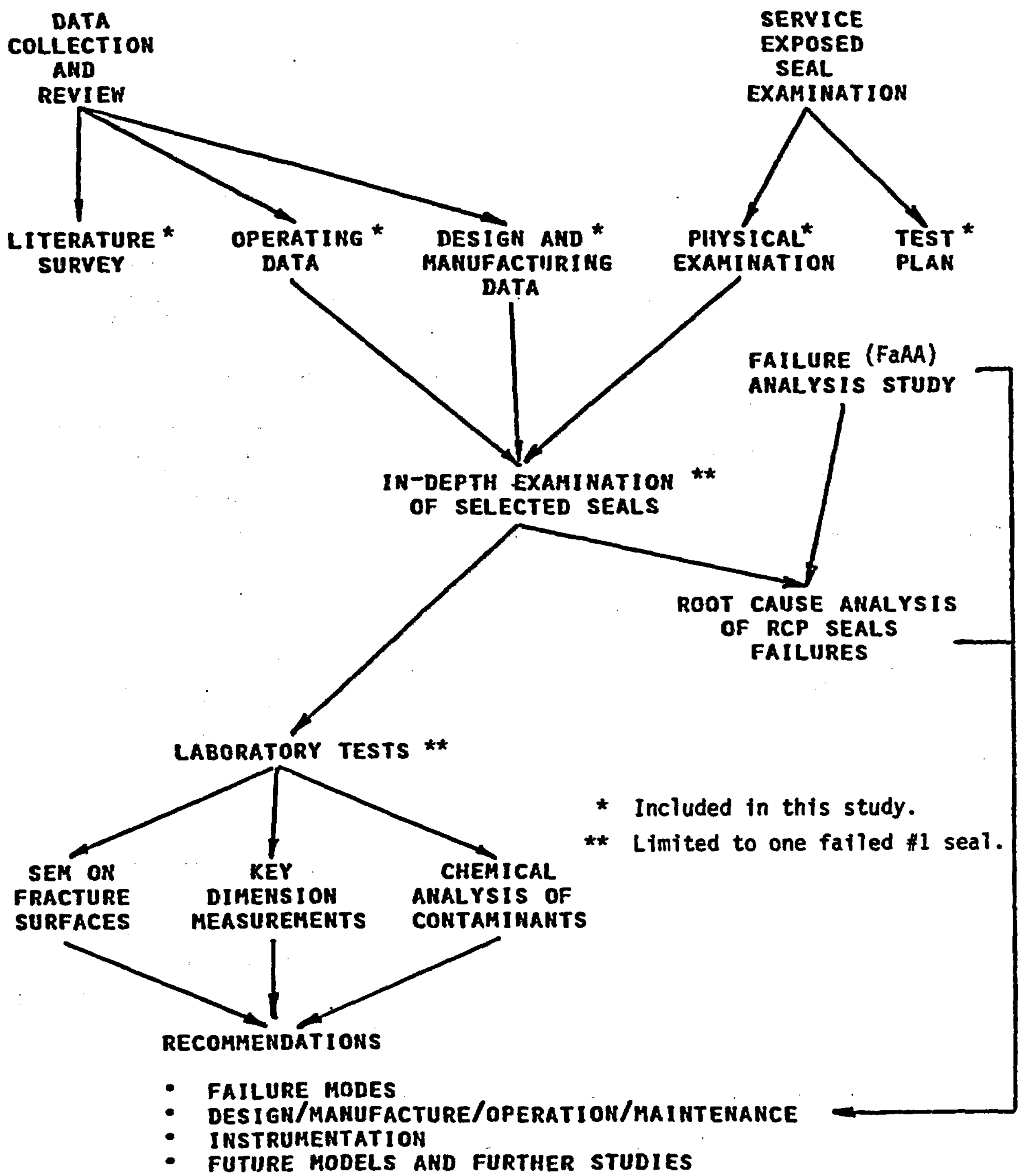


Figure 6: BNL RCP Seals Study Scope

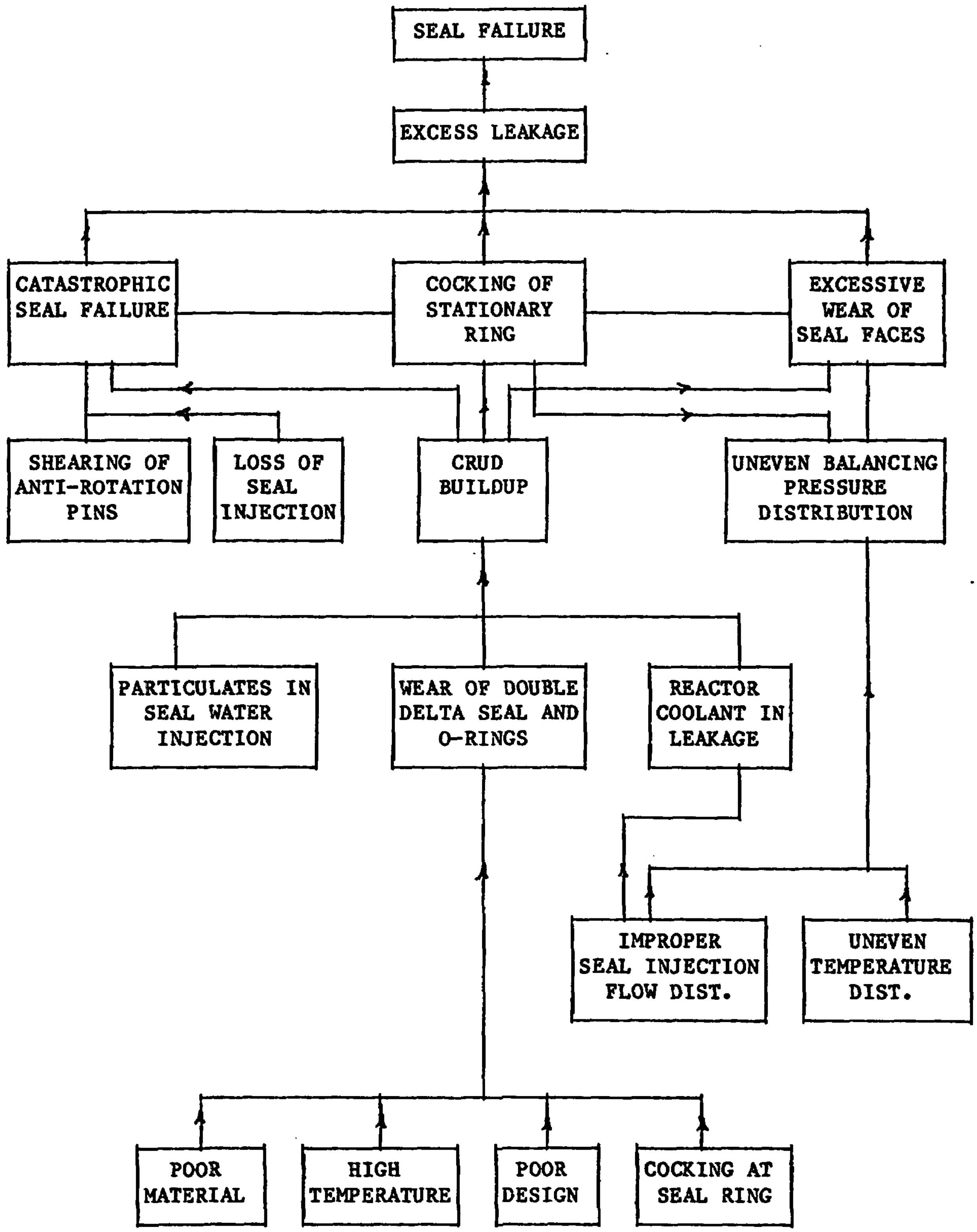


Figure 7: Failure Mechanisms

- in-depth examination (SEM and EDS) of the obviously damaged seals, specifically the channel and O-ring seals on a No. 1 seal, for potential failure modes, and

- radiochemical analysis of crud taken from seal surfaces near the channel seals.

This report is organized in six sections followed by a list of references, and an appendix which contains photographs of all service exposed seals received from the Indian Point 2 nuclear station. Section 2 discusses the previously published RCP seal related literature, historical evolution of the Westinghouse seal design gathered from a field visit to the Westinghouse seal manufacturing facilities, and seal performances at the GINNA nuclear station. Section 3 provides the assessment of IP2 plant operating procedures and maintenance data, and identifies the typical failure modes experienced at the plant during the last decade of operation. Section 4 is devoted to visual examination of seals in the BNL hot cell and a limited in-depth examination of two obviously failed seals for assessing the root cause of failure.

Conclusions from the above investigations are summarized in Section 5. The section also includes a preliminary list of recommendations based on these conclusions. Section 6 presents the scope of the work which should be performed in order to achieve the goals presented in Section 1.

2. RCP SEAL PERFORMANCE REVIEW

Research activites relating to Westinghouse RCP seals were searched and reviewed to evaluate the seal behavior under both normal and station blackout conditions. This included a comprehensive literature survey which yielded a great deal of information on the subjct by both the NRC and industry, but the major focus of this work was on the seal behavior under station blackout conditions. A trip to the Westinghouse seal manufacturing plant site was made, and the design evolutions during the last decade was assessed. Finally, the seal performances at the GINNA Nuclear Station was reviewed to compare the different philosophies that exist between two utilites in operating and maintenance programs.

2.1 Previous Studies

Efforts by the United States Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI) to identify and mitigate the causes of RCP seal failures are ongoing at various research institutions. The Westinghouse Owners Group (WOG) has also sponsored a separate study to answer questions and resolve NRC concerns as detailed in "Generic Issue 23: Reactor Coolant Pump Seal Failures," and "Unresolved Safety Issue A-44: Station Blackout."

NRC sponsored research activities are focussed on the possible primary coolant pump seal failures from overheating during a postulated station blackout condition. During station blackout, all onsite and offsite ac electric power is unavailable to the plant, thereby tripping and stopping the RCPs.Seal injection and cooling water is lost, permitting RCP shaft seal exposure to hot primary coolant. This may result in a catastrophic seal failure due to high temperature abrasive action, which would allow significant primary coolant release (small break LOCA).

Postulated leakage rates through the three seals during a station blackout resulting from loss of ac electrical power as calculated by Westinghouse, were independently verified[2] by NRC. The leakage rates for cases with all seals functioning, No. 1 seal failed, and all seals failed, were found to agree with the manufacturer's predicted values.

The laboratory testing effort[3] performed at Atomic Energy of Canada Limited (AECL) included blowdown tests on two separate hydrostatic seals, which have lapped conical faces to simulate the hydrostatic lubrication conditions of a typical Westinghouse No. 1 seal. The objective of these tests was to qualitatively estimate the leak rate and seal stability when primary coolant leakage flashes to steam across the seal face during blackout. The study has concluded that the potential for unstable seal behavior exists when this two phase flow condition prevails. The AECL report also analyzes the O-rings and polymeric channel seal material behavior under the "worst-case" conditions. Based on this study, the original O-ring material is recommended to be replaced with E740-75 which has a better resistance to high temperature conditions. However, the new channel seal material, tetralon 720 would be adversely affected by exposure to relatively low levels of radiation (less than 10^5 R).

Two other studies sponsored by NRC were conducted at Brookhaven National Laboratory (BNL). One study[4] has identified 173 seal failures industry wide, and that for PWR plants, 49% of the seal failures were attributable to seal wearout, 27% were judged to be maintenance induced, and the remaining 26% were considered to be the result of plant transients, seal surface contamination, etc. The second study[5] developed the concept of "seal failure criteria", and included a diagnostic approach to the detection of any incipient failure conditions. Recommendations were provided for additional instrumentation, operator response procedures and potential automatic actions.

In parallel with the NRC efforts, EPRI has ongoing programs[6,7] to study various aspects of reactor coolant pump seal failures. However, all of these studies have focussed on the "worst-case" scenario in evaluating the performance and material characteristics of RCP seal components.

The second BNL study[5] may help in upgrading the IP2 RCP Seal instrumentation and operator response procedures to detect seal degradation and failure. To achieve this, it is recommended that the Westinghouse RCP seal system should include; (a) pressure measurement in No. 1 seal leakoff, (b) pressure measurement in the thermal barrier heat exchanger Component Cooling Water (CCW) return line, and (c) radial pump bearing temperature displayed on the main control board. These recommendations would involve automatic closure of No. 1 seal leakoff on high flow except during station blackout. The report includes a detailed description of seven recommendations for the plant operating procedures, most of which IP3 complies with according to the study.

Several other ongoing studies relating to RCP seals have concentrated their efforts on the station blackout condition rather than normal operation of these pumps. The seal problems germinating from a station blackout condition is somewhat different from that arising from normal operation of RCP seals. In the case of the former condition, where hot primary coolant enters the seal area the fluid flow is two phase and the temperatures inside the pump at various locations are high enough to cause deleterious effects on the non-metallic components such as O-rings, channel seals and seal surfaces. Under normal condition of seal injection and thermal barrier cooling by CCW, however, the seals inside the RCP experience lower temperature, pressure and flow conditions, and can be considered as normal aging and service wear.

2.2 Historical Design Evolutions

The first generation of Westinghouse RCP seals (which includes the IP2 seals) have a similar design to the second generation except for some geometric differences, and in the method that the No. 1 seal seats on the shaft. It is claimed by Westinghouse that the estimated design life of these seals is well beyond plant design life.

An evolutionary process on the design of RCP seals continues as the data base expands on pump seal performances in nuclear facilities.

Material development in the seal design during the last decade includes:

(1) changes in face plate material from aluminum oxide to silicon nitride in the No. 1 seal ring and stationary assemblies of No. 2 and 3 seals.

(2) the rubbing faces on the No. 2 seal runner and No.3 seal collar were changed from aluminum oxide to chrome carbide coated stainless steel.

(3) the No. 2 seal housing design has been modified into a two piece unit, to enable removal of the insert from the housing for the purpose of re-coating chrome carbide surface on the insert outside face.

(4) the rubbing surfaces by the channel seal on the No. 1 insert and No. 2 seal housing have now been coated with chrome carbide;

(5) the material for the channel seals has been changed from graphite impregnated teflon (black appearance) to tetralon 720 (grey look) for better performance.

(6) the O-ring material has been changed from Parker Seal ethylene propylene compound E515-80 to E740-75.

In addition to the above material changes in the manufacturing of RCP seals, Westinghouse has developed a new cartridge seal design for 8" RCP seals for easier removal and replacement on to the pump shaft for preventive maintenance purposes. Westinghouse claims that with some design modifications or by using adaptors, the IP2 RCP seals can make use of these new cartridge seals.

Every seal, leaving the Westinghouse manufacturing facility undergoes a full performance test, including No. 2 seal testing for full reactor pressure in case of failure of the No. 1 seal. Both stationary and running halves of the No. 1 seal are marked as one set (i.e., not interchangeable with other No. 1 seal sets) since the wedge angle on the seal surface is critical to seal operation and the flow through the No. 1 seal is approximately a cubic function of this angle.

All thermo-hydraulic and dynamic analyses of seal geometries are performed using an axisymmetric assumption of the complete pump model. Cocking of the No. 1 seal stationary half (which translates vertically around the shaft) cannot be analyzed with the axisymmetric model. However, Westinghouse has made design modifications to minimize the friction forces around the shaft seal O-ring or channel seal areas and has recommended administrative procedure and control to avoid any cocking prior to starting the pump.

2.3 GINNA RCP Seals

Rochester Gas and Electric (RG&E) was contacted in reference to RCP seal performance at their Ginna station. GINNA is a two loop unit with two Westinghouse reactor coolant pumps that are similar to those at IP2. RG&E does their own maintenance work and has a Westinghouse technical representative available for guidance.

The No. 2 seal has caused GINNA the most problems. The most common failure mode is "hanging up" of the stationary seal face, allowing excessive leakage. The cause of this failure mode does not appear to be related to O-ring degradation, but rather related to uneven temperature expansion (seal housing-seal insert have very tight clearances) caused by external air conditioning cooling.

The No. 1 seal has not caused GINNA the same problem that Con Ed has experienced. In fact, in one pump the same set of aluminium oxide face seals has been in service for 16 years. GINNA attributes this success to good filling and venting operations, and proper seal injection. Most No. 1 seal problems have been due to "fretting" (degradation) of the channel seal (DDS).

The No. 3 seal has performed very well and has not caused any operating difficulties.

The GINNA RCP seal maintenance is based on a two year frequency. At each inspection, the pump seals are disassembled and examined for physical degradation, the "nose" heights are measured, and parts are replaced where necessary. O-rings and channel seals are always replaced at the time of inspection. RG&E is presently in the process of extending this cycle to three years for GINNA. Both pumps presently have over two years of operation without seal failure. The instrumentation and modifications at GINNA include the following:

Existing:	Leak-off Flow,	#1 seal with hi/lo alarm
		#2 seal standpipe level with hi/lo alarm
	Temperature:	#1 seal inlet/outlet
Proposed:	#2 seal leak-off flow measurement	
	#1 seal leak-off line check valves	

2.4 Interim Conclusions

- seal wear and "roll up" (vertical seal movement) problems should be mitigated by the use of improved non-metallic seal materials, such as O-rings and channel seals, and the coating of rubbing surfaces with chrome carbides.

- No. 1 seal face plate wear should be reduced with the change in seal face material from aluminium oxide to silicon nitride.

- improved startup procedures should help mitigate many of the contaminant problems which have caused seal failures.

- a good inspection program of examining seal conditions, measuring nose heights of seal faces, and replacement of all gaskets and polymer seal components should enhance the seal performance significantly.

- improved monitoring and instrumentation should be implemented to identify incipient seal degradation.

3. DATA REVIEW AND ANALYSIS

To characterize seal performance at Indian Point 2, an interview with maintenance personnel at the plant site was conducted, as well as a review of plant maintenance seconds. The seal failure symptons and corrective maintenance measures taken by the plant maintenance department were discussed. This section presents the seal failure trends observed at IP2 during the last decade of operation. Typical failure causes and remedial actions taken are discussed.

3.1 Operating and Maintenance Data

All the reported RCP seal failures and resulting maintenance performed on the four pumps between October 1974 and January 1985 have been reviewed, using the maintenance records supplied by Westinghouse[8], and the Con Edison plant maintenance and operating records. A major portion of the RCP failures have been attributed to the pump seals, followed by pump motors and mechanical components such as bearings and flanges. Table 1 summarizes all failure for the period October 1974 to January 1985. Prior to 1980, failures primarily involved the No. 1 seal. The primary root causes were attributed to fretting of the No. 1 seal inserts and intrusion of contaminants into the seal assembly by improper filling techniques. The total number of seal failures/replacements was reduced by approximately 50% during the post-1980 period. However, there has been no appreciable change in the No. 2 seal failure data. There is still considerable room for improvement in seal performance. Due to the large number of seal failures, Con Ed has been replacing all of the seals regardless of their condition each time the seals were disassembled for inspection. In the meantime, Westinghouse is continually improving the seal designs, pump startup procedures, and instrumentation for monitoring seal leak-off. Untimely seal failures at IP2 have been decreasing and most of the recent failures have been attributed to the No. 2 and 3 seals.

The other root causes of these seal failures, although not definitely known or yet investigated, is believed to be: 1) crud buildup in the seal ring assembly preventing normal vertical movement, 2) the lodging of some contaminant between the seal faces, 3) worn channel seals, or 4) movement of O-Rings. Tables 2 provides some seal failure modes and causes described in the maintenance records. Table 3 summarizes some of the remedial actions taken by Con Ed in the last decade to improve the pump seal reliability.

Instrumentation presently available on the RCP seals include No. 1 seal high and low flow alarms (rotary type flow meter), No. I seal leakoff temperature detector, and pump inlet pressure and temperature indicators. A high flow alarm may be caused by loss of injection water followed by high seal temperature, high temperature of the injection water supply, and No. 1 seal damage. A low flow alarm may be caused by a differential pressure of less than 275 psi across the No. 1 seal, excessive leakage of a No. 2 seal and damage to the No. 1 seal. The leakoff in the No. 2 seal is indicated by the water level in the stand pipe. Low stand pipe level is an indication of higher leak rate in the No. 3 seal. If this condition exists, the coolant leak on the floor from the No. 3 leakoff is checked for possible No. 3 seal failure.

Table 1 - Summary of IP2 Seal Performance for the Period 10/74-1/85

Description	Number of Occurrences: Pre-1980 Period	Number of Occurrences: Post-1980 Period
Fretted ** No. 1 Seal	16	5
Fretted No. 2 Seal	11	9
Fretted No. 3 Seal	10	5
Pump Failed While Operating	7	2
Pump Failed During Start-up	12	7
Preventive Maintenance (PM) Performed	10	9 *

* During PM on any pump, Con ED chose to replace all seals regardless of their conditions.

** Fretted of seal components includes seal adaptor surface distortion caused by the rubbing action of the channel seals.

Table 2 - Typical Failures of IP2 RCP Seals

- #1 Seal Assembly
  - Worn channel
  - Fretted insert
  - Runner O-ring rolled, extruded
  - Loose face plate
  - Seal face damaged
  - Shaft sleeve loose
  - Cracked ring
  - Anti-rotation pin broken in runner
- #2 Seal Assembly
  - Fretted housing
  - Worn seals
  - Runner grooved
  - Damaged during handling
  - Seal ring "hanging up" in housing
  - leak-off high
- #3 Seal Assembly
  - Worn seals
  - Runner grooved
  - Damaged during handling
  - Shipping brace left inside assembly
- Motor Bearings
  - Lower motor bearing clearance too large
  - High vibration in pump
- Probable Causes
  - Improper assembly
  - Old channel seals were vulnerable to degradation
  - Seal fretting - due to dirt in seal injection water
  - Main flange leaks due to relaxed bolt stretch.

Table 3 - Remedial Actions Taken by IP2

- Changed motor thrust bearing oil tubing from copper to stainless steel
- Modified shaft sleeve in seal area from pin fastening to shrink fit
- Flush seals prior to startup
- All #2 seals replaced with new seal housing with 2-piece design and insert. Chrome carbide surface on channel seal rubbing faces.
- A seal assembly mockup was used for training.
- The fill check list was reorganized and a check valve was added to prevent filter back flush into seals.

Out of the four RCP is at IP2, pump 23 has experienced more failures than the other three. Although most of the recent failures did not occur while the plant was in operation, the diagnosis of No. 2 and No. 3 seal failures has indicated some inherent vibration related problem existing with this particular pump installation.

Indian Point 2 RCP seal failures have been attributed to all of the following four areas:

- Design and Manufacturing
- Instrumentation
- Start-up and Operational Procedures
- Maintenance (PM and CM)

3.2 Interim Conclusions

Based on the data analysis, the following interim conclusions are drawn:

- Many of the early failures were caused by the No. 1 seals because of improper seal injection and pump start-up procedures.
- Recent failures have been attributed to fretted or worn nonmetallic seal materials, i.e., O-rings and channel seals.

- Pump 23 at IP2 has some inherent problems and has exhibited more failures than other pumps.
- Proper flushing of seals prior to startup and prevention of contaminant intrusion are important contributors to extended seal life at the pump start-up.
- Pressure indicators and flowmeters in No. 1 and No. 2 leakoffs may help monitor the seal behavior under abnormal conditions.
- Replacement of all seals at each inspection cycle as has been the practice by Con Ed, is not justified by this study.

4. EXAMINATION OF SERVICE EXPOSED SEALS

This section presents the results of the laboratory examinations of service exposed seals received from the IP2 nuclear station. Each seal was examined inside a hot cell facility at BNL to determine any obvious damage or wear. The photographs of all seals, as well as a summary of findings associated with each seal is included in Appendix A. However, typical degradation observed for each seal stage are discussed here. In addition to the physical examination, two additional obviously failed seals were selected for further study to identify the root causes of their failure. Both scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were utilized to assess the failed seal surfaces for deterioration and contamination.

4.1 Visual Examination

In February 1986, six drums containing components from several sets of reactor coolant pump seals were shipped to BNL from Con Ed's IP2 Nuclear Power Station. No documentation was provided to indicate either the contents of the individual drums nor the service history of the seal components received. The drums were opened, the contents were photographed and identified, and an attempt was made to obtain the serial number for each piece. Each piece was visually examined for gross wear or damage. The following table summarizes the list of parts received:

Items Received From Indian Point 2

Seal Stage	Component	Number
First (No. 1)	Runner	4
	Stationary Ring	4
	Faceplate	2
	Housing Insert	1
Second (No. 2)	Runner	1
	Stationary Ring	1
	Housing	1
	Graphitar Insert (broken)	1
Third (No. 3)	Runner	2
	Stationary Ring	3
Miscellaneous	Lock Washers	2
	Loose O-Rings & Channel Seals	10-12
	Impellers	3

Each part received was assigned a BNL identification number - e.g., BNL #2A indicates that the part is "Item A" from "drum 2." The photographs of the seal parts are identified with this number plus the BNL negative number for the photograph - e.g., BNL #2A-CN3-481-86. The following section should be read while examining the relevant photographs.

First-Stage Seals

The first-stage seal, as discussed earlier, is a hydrostatically-balanced, film-riding, face seal in which a non-rotating stationary ring assembly rides axially on a thin film of water that passes between its faceplate and the faceplate of the runner assembly that rotates with the pump shaft. As the ring moves, a rubbing contact occurs between the channel seal on the stationary ring and the outside surfaces of the first-stage housing insert. Seal failure has often been associated with degradation of the channel seal, and fretting of the rubbing surface in the insert.

First-Stage Seal Runners

ID #	Photograph #
BNL #3A	CN3-555-86
	CN3-552-86
BNL #5A	CN3-825-86
	CN3-831-86
BNL #5D	CN3-823-86
	CN3-834-86
BNL #6A	CN3-817-86
	CN3-819-86

Only one of the four first-stage runners was severely damaged. Item BNL #5A was missing its faceplate, the support-surface that had been beneath the faceplate was deeply scratched, the antirotation pin that had been located on the support-surface was sheared off flush with the surface, and the O-ring that had been in the channel on the support-surface was torn and only a portion of it remained in the channel. These observations suggest that the faceplate had been forceably rotated against the support-surface; probably as a result of the faceplate of the rotating runner making contact with the the stationary ring faceplate . Both faceplates would probably be badly damaged or destroyed by such an occurrence. It should be noted, however, that no first-stage stationary ring with a damaged or missing faceplate was received. Since the surfaces of the runner were only lightly stained with oxides, it is likely that the event that caused the damage occurred at or shortly after the pumps were started. White-colored, borate deposits were present on the inner circumference of the runner.

The other runners appeared to be essentially undamaged. Their faceplates and the metal surfaces exposed to water in the seal chamber were stained with oxides and crud. The depth of color in the faceplates ranged from nearly white, which is the color of new faceplate, to a deep amber, and the metallic surfaces ranged in color from light tan to deep reddish-brown. Presumably the depth of color is correlated with the length of time the runners had been in service. In most cases, the faceplates exhibited smudges or smears of dirt or grease that were probably produced when the runners were being removed from the pumps, although they might have resulted from handling during the time the seals had been stored at the plant, or during preparations for shipment to BNL.

First-Stage Stationary Rings

ID #	Photograph #
BNL #1A	CN3-445-86
	CN3-447-86
BNL #4A	CN3-828-86
	CN3-829-86
BNL #4B	CN3-830-86
	CN3-836-86
BNL #5C	CN3-822-86
	CN3-832-86

Only BNL #4A showed clear signs of damage. BNL #4B and #5C appeared to be undamaged. The faceplate of BNL #1A was hidden by a protective cover and was not examined for damage.

BNL #4A is the seal component that we selected to examine in detail. This selection was based primarily upon the fact that the channel seal, which has been implicated in many of the seal failures that have occurred at Indian Point, was still attached to the stationary ring. The channel seal is located, along with an O-ring that is placed behind it, in a channel on the surface of the inner circumference of the ring close to the upper (nonfaceplate) surface. The channel seal and the O-ring in BNL #4A were both severely degraded, and a black-colored material was found adhering to the inner circumference of the ring in a position where, if it were to come loose, it could interfere with the motion of the ring. The condition of the channel seal, the O-ring and the black-colored deposits will be discussed in more detail in the section describing the examinations that were made on BNL #4. Two pairs of dents, which are located approximately 180° apart, are located on the rim of the outer circumference of the upper ring surface.

As in the case of the first-stage runners the metallic surfaces that were exposed to water in the seal chamber were discolored. However, the color of these surfaces depended not only upon how long the seals had been in service, but also upon whether a surface was inside or outside of the seal. Surfaces located outside the housing were stained some shade of brown, while those enclosed by the housing ranged from silvery to purplish-black in color. These components, like the first-stage runners, were smudged with dirt or grease.

First-Stage Seal Housing Insert

ID #	Photograph #
BNL #5B	CN3-824-86
	CN3-833-86

The channel seal in the first-stage stationary ring rubs against one surface of the seal housing insert and, over time, causes this surface to wear. In the past, the rubbing surface was stainless steel, but in newer versions of the part the rubbing surface has been coated with chrome carbide for greater wear resistance. This insert is one of the older versions. Black marks on the rubbing surface of the insert show where contact with the channel seal had occurred.

Second-Stage Seals

The second-stage seal is a rubbing face seal in which the nose piece of a graphitar insert in the stationary ring assembly rubs against an insert in the runner assembly that rotates with the pump shaft. In older runner assemblies, such as the type that was sent to BNL, the runner insert is aluminum oxide, however, in newer runners the aluminum oxide has been replaced by chrome carbide.

Second-Stage Seal Runner

ID #	Photograph #
BNL #2D	CN3-478-86 CN3-479-86

Black deposits on the aluminum oxide show where the graphitar nosepiece had rubbed. Unless the aluminum oxide insert is worn, this runner appears to be undamaged.

Second-Stage Stationary Rings

ID #	Photograph #
BNL #2A	CN3-481-86 CN3-483-86

The inner surface of the ring assembly cowl that encloses the graphitar insert is stained a deep reddish-brown by oxides and crud, but the outer surface is relatively free of such staining. The channel seal is intact in this piece. A shattered graphitar insert (BNL #2), of unknown source and cause, is shown in photographs BNL #2B-CN3-482-86 and BNL #2E-CN3-484-86.

Second-Stage Seal Housing

ID#	Photograph #
BNL #1B	CN3-442-86 CN3-446-86

Except for discolorations around the O-ring channels on the outside circumference of the housing and on the outside circumference of the inner housing skirt, this piece looks almost new. The discoloration on the outside surface of the inner housing skirt is in the area where the channel seal of the second-stage ring assembly slides against the housing. In older versions of the housing, such as the piece sent to BNL, the contact surface for the channel seal was stainless steel, but in more recent versions this surface is coated with chrome carbide for greater wear resistance. Also, in the newer versions, the one-piece, housing construction has been replaced by a two-piece construction in which the housing section that contacts the channel seal can be replaced independently of the rest of the housing.

Third-Stage Seals

The third-stage seal, like the second-stage seal, is a rubbing face seal in which the nosepiece of a graphitar insert on the stationary ring rubs against the insert on a runner that rotates with the shaft. In older versions of the seal, such as those that were sent to BNL, the insert on the runner was aluminum oxide, but in newer versions the insert is chrome carbide.

Third-Stage Seal Runners

ID #	Photograph #
BNL #3B	CN3-554-86
	CN3-556-86
BNL #3E	CN3-553-86
	CN3-557-86

The components appear to be essentially undamaged. However, the photographic enlargement was insufficient to allow a close examination of the aluminum oxide inserts. The metallic surfaces of these parts is stained dark reddish-brown by oxide and crud. Runner BNL #3B was photographed with two lock washers (BNL #3C and #3D).

Third-Stage Stationary Rings

ID #	Photograph #
BNL #1C	CN3-443-86
	CN3-444-86
BNL #5E	CN3-821-86
	CN3-835-86
BNL #6B	CN3-815-86
	CN3-816-86

Examinations of BNL #1C and #6B with a hand lens revealed that both had damaged graphitar inserts. The graphitar nosepiece of BNL #1C was chipped in at least three locations, and also appeared to be much worn in some places. The nosepiece of BNL #6B was also chipped. In addition, a groove could be seen along one sector of the nosepiece, while another sector appeared to be worn down to expose a metallic surface which was more highly polished than were other parts of the nosepiece. Heavy deposits of borate were visible on the inside circumference of BNL #1C, and #5E was secured for shipping and was not opened for examination.

4.2 In-depth Examinations

4.2.1 Examination of First-Stage Seal Runner, Item #5A

Item #5A is the only one of the seals received that showed severe damage. The faceplate was missing, and visual examination suggested that it had been destroyed shortly after the pumps were started.

A question was raised as to whether the antirotation pin had really been sheared due to a forced rotation of the faceplate or whether the faceplate had rotated because the antirotation pin had broken from fatigue. It was thought that a scanning electron microscopic examination of the fractured end of the antirotation pin might be able to resolve this question. However, when item #5A was retrieved from its drum, the support surface and the end of the anti-rotation pin were found to be so badly scoured that it did not seem likely that a microscopic examination would be useful. Hence, further examination of this seal was not pursued. However, after review of all failure modes and root causes, it is most likely that the seal insert cocked, causing improper hydraulic pressure distribution, which resulted in rubbing of the seal faces, and eventual destruction of these faces and shearing of the anti-rotation pin.

4.2.2 Investigations of Samples Removed from Item #4A; First Stage Stationary Ring Assembly

A number of the reactor coolant pump seal failures that have occurred at the IP2 nuclear power station have involved problems associated with the channel seal in the stationary ring of the first-stage seal. Since one of the seal components that was received from Indian Point was a first-stage, stationary ring with the channel seal still attached, interest was focused on that part. This was the component that has been designated as Item #4A. Photographs of the part (BNL #4A-CN3-828-86 and BNL #4A-CN3-829-86) showed that there was black-colored material adhering to the inner surface of the ring immediately below the channel seal channel in a location where it could have interfered with the axial mobility of the ring. It was decided that the following steps would be taken: (1) recover of some of the adherent material and (2) removal of the channel seal and its associated O-ring. These items would then be examined (1) visually to observe gross structural features, (2) by scanning electron microscopy (SEM)/energy dispersive spectroscopy (EDS) to observe ultrastructural details that might have a bearing on the mode of failure and to identify elemental contaminants present on the surfaces of the materials, and (3) by radiochemical means to identify gamma-emmitting radionuclides associated with the materials.

In-Depth Visual Examination

For purposes of orienting the ring and identifying the locations from which samples were removed, a circular, plastic insert marked in 10 degree increments was placed into the shaft opening of the stationary ring. The 0-degree mark was set at the position of the antirotation pin hole. This insert can be seen in the photographs (BNL #4A-CN3-794-86, #4A-CN3-793-86, #4A-CN3-795-86, #4A-CN3-796-86, and #4A-CN3-797-86) in Figure 8 - 12 in the order of the BNL ID numbers. The orientation of the ring in the photographs, with the faceplate down, is the same as the ring had when installed in the coolant pump.

It can be seen from the photographs that, although it was still attached to the part, the channel seal was partially displaced from its normal position in the seal channel. Consequently, the O-ring that underlies the channel seal was visible in the channel. The channel seal can be seen to be severely worn; especially along its lower edge where the flange that should have been present was either worn or broken away around almost the whole circumference of the seal. Only in the 240° to 280° sector was any portion of this flange visible (Figure 10). The lower edge of the seal was worn thin, eroded, and portions of the seal were broken out in at least two areas-at approximately 0° (Figure 8), and approximately 160° (Figure 9). In the 270° to 330° sector (Figures 8 and 10), the channel seal was rolled into the channel and behind the O-ring. This in-rolling by the channel seal undoubtedly became possible when abrasion reduced the thickness of the ring and resulted in the loss of the lower seal flange. Most exposed portions of the O-ring had a very roughened texture, and a tuft of peeled O-ring material was attached to the ring at approximately the 90° position (Figures 9 and 11).Additional pieces of peeled material were attached to the O-ring in the 80° to 120° sector. Black material, which appeared to have been peeled O-ring material, was found adhering to a number of sites on the inner surface of the stationary ring beneath the channel seal channel (see especially the 80° to 120° sector in Figure 10). Pieces of this material, to be used in SEM, DES, and radiochemical studies, were scraped from three locations on the ring (approximately 130°, 240°, and 270°) and placed into glassine bags (Figure 12). A line of demarkation between roughened and apparently undamaged O-ring surface was visible at approximately the 160° position. It seems most likely that the roughened texture over most of the O-ring surface resulted from peeling away of material from the surface of the O-ring.

The stainless steel surfaces on the inside of the stationary ring were colored black by a polished enamel-like coating that could not be scratched off with the tools available. The nature of this coating is not known.

There was no visual evidence of metal wear on the ring assembly or of the presence of metallic particulates associated with either the channel seal or its underlying O-ring.

<u>Preparation of Channel & O-Ring Pieces for SEM/EDS Examinations</u>

As the channel seal and its associated O-ring were removed from the stationary ring they were marked so that they could be properly oriented when sections were cut for the SEM and EDS examinations. A razor blade was used to cut five approximately 20° wide sectors from the channel seal and six sectors from the O-ring.

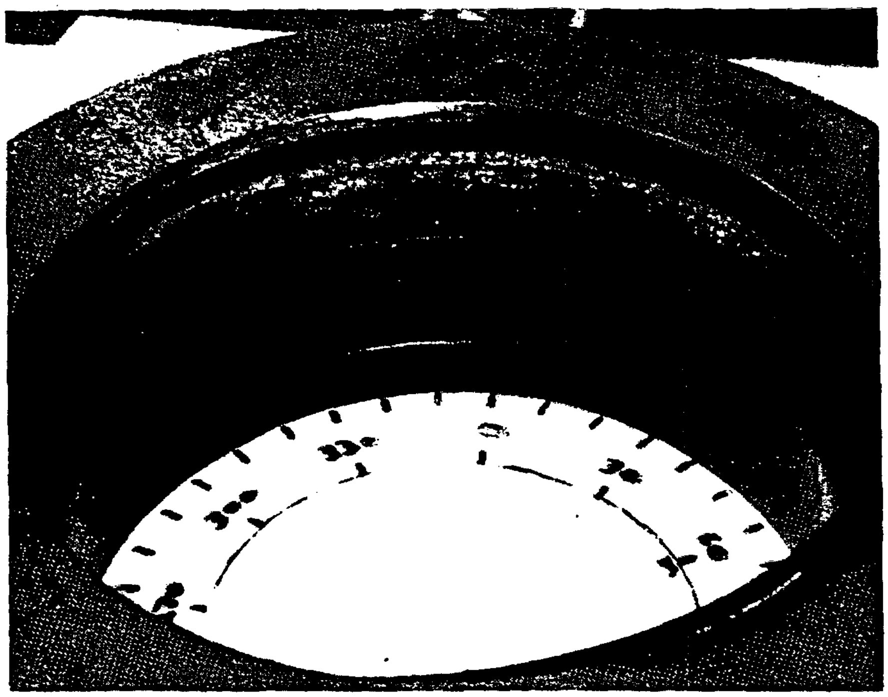


Figure 8: BNL ID #4A-CN5-794-86: Inner Surface of the #1 Ring (270°-60°)

Figure 9: BNL ID #4A-CN5-793-86: Inner Surface of the #1 Ring (90°-250°)

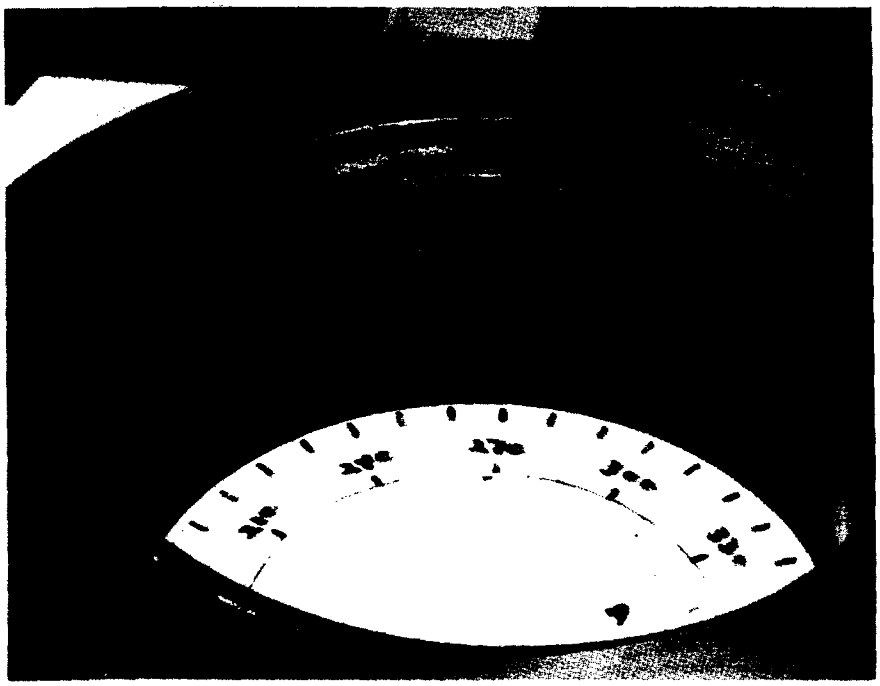


Figure 10: BNL ID #4A-CN5-795-86: Inner Surface of the #1 Ring (200°-330°)

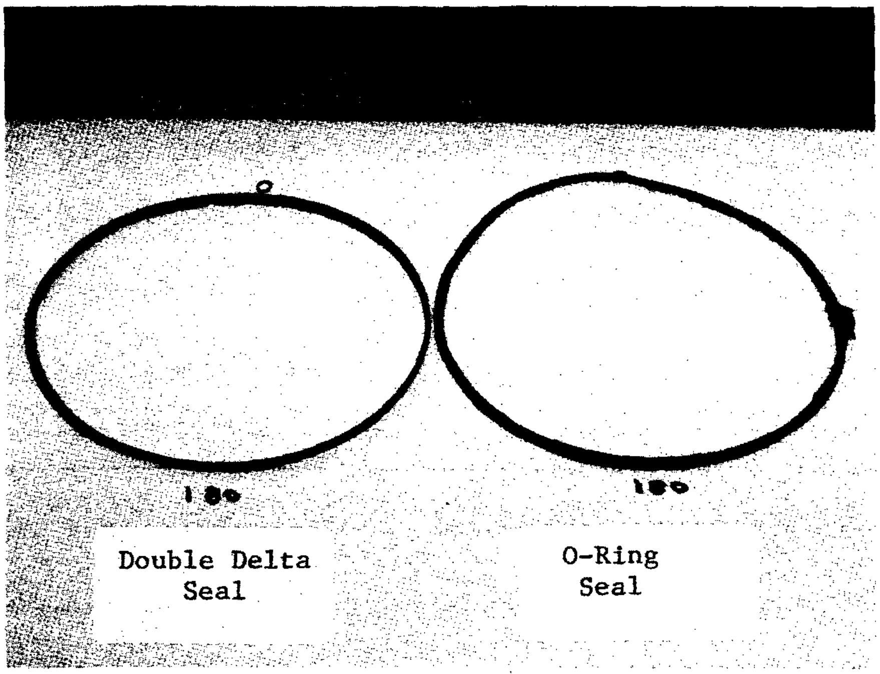


Figure 11: BNL ID #4A-CN5-796-86: Double Delta Chanel & O-Ring Seals

Figure 12: BNL ID #4A-CN5-797-86: Scraping of Crud From Seal Surfaces

Locations of the Sampled Sectors of the Double Delta Seal & its Associated O-ring

O-Ring	Double Delta Seal
340° - 360°	350° - 10°
80° - 100°	90° - 110°
130° - 150°	
150° - 170°	150° - 170°
170° - 190°	
	200° - 220°
270° - 290°	280° - 300°

Sectors not taken as samples were placed in marked plastic bags and stored for future use.

The selected sectors were soaked for approximately 5 hours in absolute methanol to reduce the level of surface radionuclide contamination, then wiped lightly with tissue paper and stored in individual plastic bags until they were used in the SEM and EDS examinations.

A. Scanning Electron Microscopic (SEM) Examination

Insulating materials or nonconducting particles build up a space charge region by accumulation of absorbed electrons which deflect the incident beam of the scanning electron microscope. This deflection produces intense image distortion. These charging effects can be minimized by applying conductive coatings to the specimens. This coating ideally should be thick enough to provide a conductive path, yet, thin enough in order not to mask any fine details of the specimen. Various materials can be applied, e.g., carbon, gold, palladium, platinum, silver, aluminum, or copper by either high vacuum evaporation or cathode sputtering. For purposes of this investigation, a gold/palladium alloy was used to cathode sputter the samples to a thickness of approximately 100 A.

A new neoprene O-ring (not a sealing ring) was coated by sputtering (Figures 13 and 13a) in order to have a record of the type of surface anew ring would exhibit after sputter coating. It is evident from the two SEM photographs that the pressing marks on the new ring are clearly visible and that the coating is fairly uniform, although some particulate is noted on the surface due to not cleaning it prior to coating.

Figure 14 is a low magnification SEM photograph of a section of the channel seal from 150-170°. The photograph shows a continuous wear line and that the channel seal was virtually abraded in half with evidence of wear clearly marked on the feathered edge. This wearing away of the channel seal is more readily apparent in the seals cross section (A-A) as seen in Figure 15. The effective cross section of the seal has been significantly reduced by a wearing mechanism.

Figure 16 is a higher magnification SEM photograph of Area 1 of Figure 14. The area appears to have been degraded by an abrasion mechanism probably accompanied by a subsequent heating mechanism (associated with material removal). This observation is partially substantiated by the next fractograph (Figure 16a) which shows that a ductile type material removal mechanism was at work on the seal.

An area of apparent cracking was observed adjacent to the wear edge the channel seal (Figure 17). This observation would indicate the final tearing of the seal material after a quantity of cross sectional area has been previously removed.

There was no evidence of foreign particulates or of mechanisms other than wear on the areas examined.

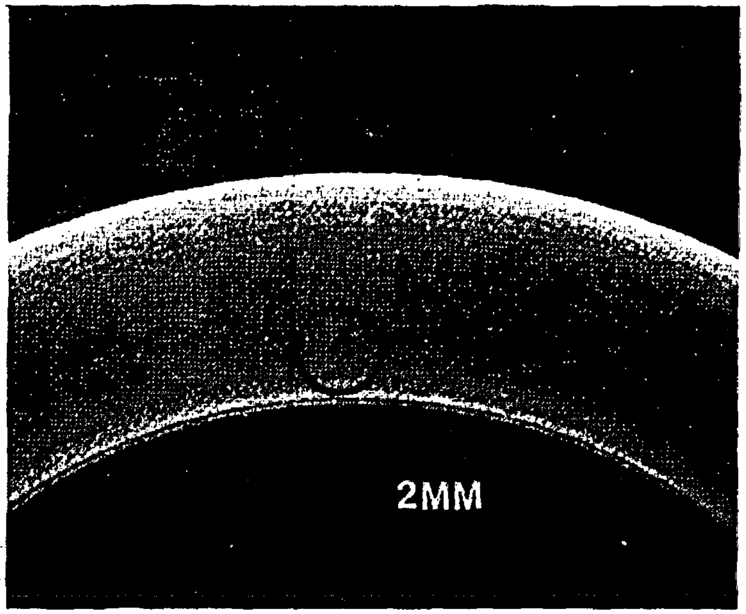


Figure 13: Low Magnification SEM Photo of New Neoprene "O" Ring After Sputter Coating.

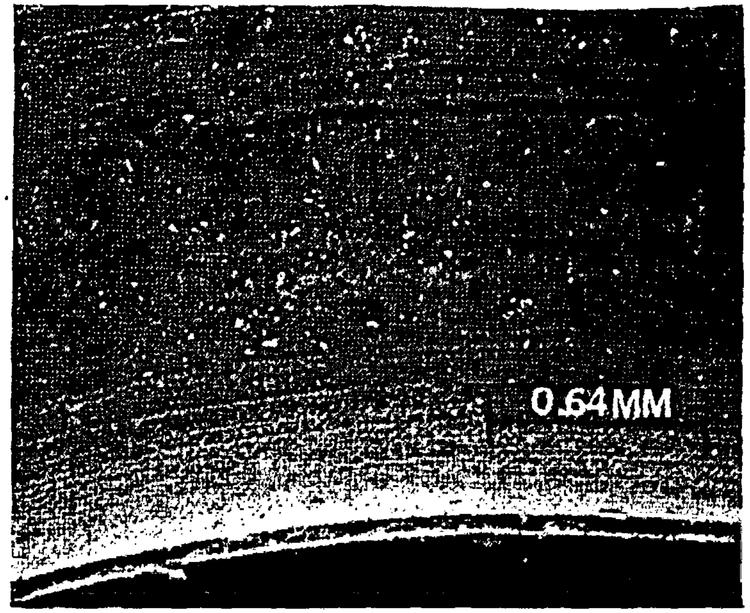


Figure 13a: Higher Magnification SEM Photo Showing Pressing Marks on "O" Ring.

Figure 14: SEM Photo of Double Delta Seal (Area 150°-170°) Showing a Definite Wear Line on the Seal. The Cross Section Was Taken From A-A.

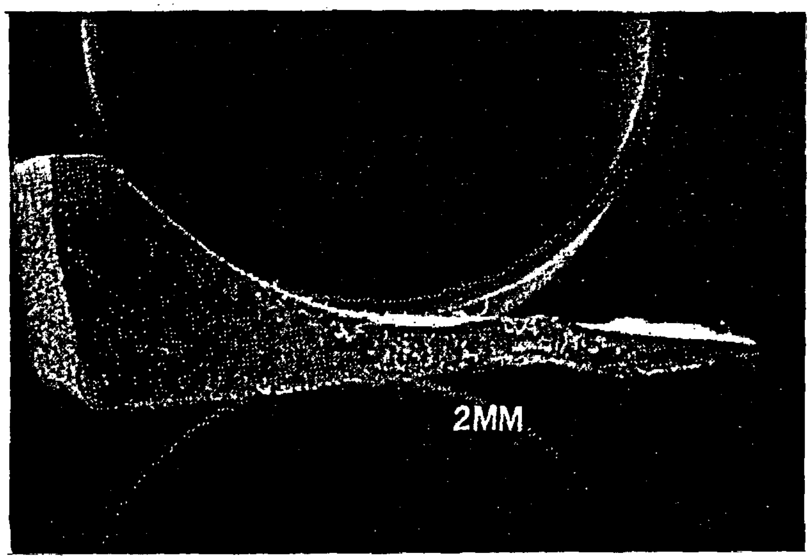


Figure 15: Cross Section of Double Delta Seal in Cut A-A of Figure 14.

Figure 18 is a low magnification SEM photo of the O-ring located in the approximate area of the channel seal specimen (150°-170°). The outside surface of the O-ring is abraded with a large area of the surface being torn away with an "orange peel" type material removal. Figure 19 is a higher magnification SEM photo taken in area 3 which shows an area of obvious cracking of the O-ring. This abrasion mechanism was the only mechanism apparent during the O-ring examination.

Figure 20 is a fractograph of the channel seal from area 200°-220°. Although not nearly as damaged as the 150°-170° segment, this specimen had the same worn, abraded edge and reduced cross section (Figure 21) associated with it.

Figure 22 is a higher magnification fractograph of an area of the worn edge of the specimen. It is seen on the fractograph that the only mechanism at work was abrasion which thinned the cross section of the channel seal.

The fractograph in Figure 23 displays the corresponding O-ring from the 170°-190° area of the seal. This segment of the O-ring showed the previously described "orange peel" damage though to a lesser extent than the 150°-170° segment of the O-ring. This segment of the O-ring also had some initiation of cracking associated with it (Figure 24). Again, the only mode of damage visible was an abrasion mechanism possibly combined with subsequent heating of the O-ring material.

B. Energy Dispersive Spectroscopic (EDS) Examination

EDS is an analytical technique, capable of performing elemental analysis of microvolumes, typically on the order of a few cubic microns in bulk samples and considerably less in thinner sections. Analysis of x-rays emitted from a sample is accomplished by crystal spectrometers which use energy dispersive spectrometers and permit analysis by discriminating among x-ray energies.

The feature of electron beam microanalysis that best describes this technique is its mass sensitivity. For example, it is often possible to detect less than 10^{-16} grams of an element present in a specific microvolume of a sample. The minimum detectable quantity of a given element or its detectability limit varies with many factors, and in most cases, is less than 10^{-16} grams/microvolume.

For purposes of this report, EDS was considered to be a satisfactory method of chemical analysis. (Note: EDS will only discern elements with atomic numbers greater than Na so certain light elements will not be detected).

Two samples of debris from the inside surface of the seal (see Figure 12) were subjected to EDS examination. Figure 25 is an SEM photograph of the first sample taken.The corresponding EDS scan (Figure 25a) showed that the sample had iron (Fe), manganese (Mn) and aluminum (Al) associated with trace gold (Au) and palladium (Pd) from the sputter coating process.

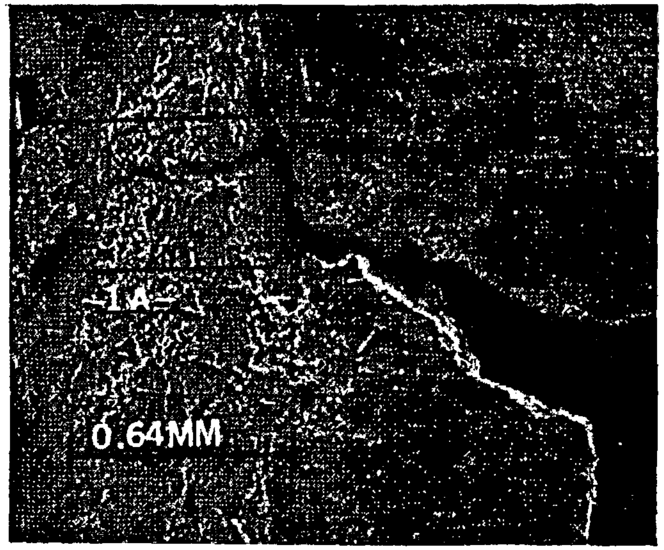


Figure 16: Higher Magnification SEM Photo of Area 1 (Figure 14)

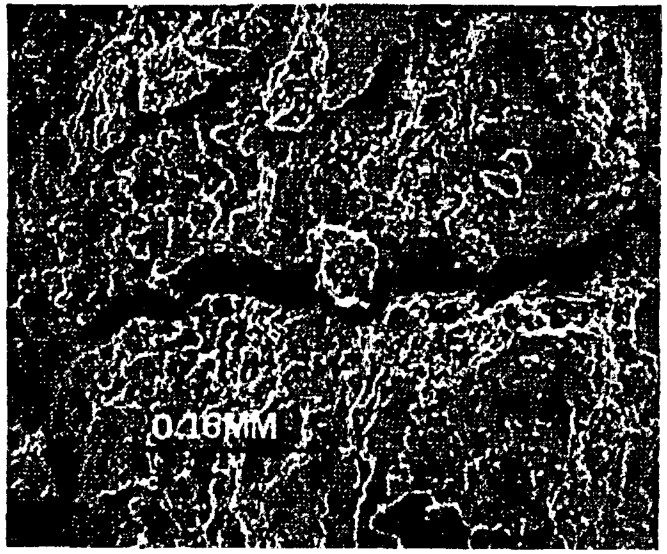


Figure 16a: Ductile Material Removal is Evident in this SEM Photo of Area 1A

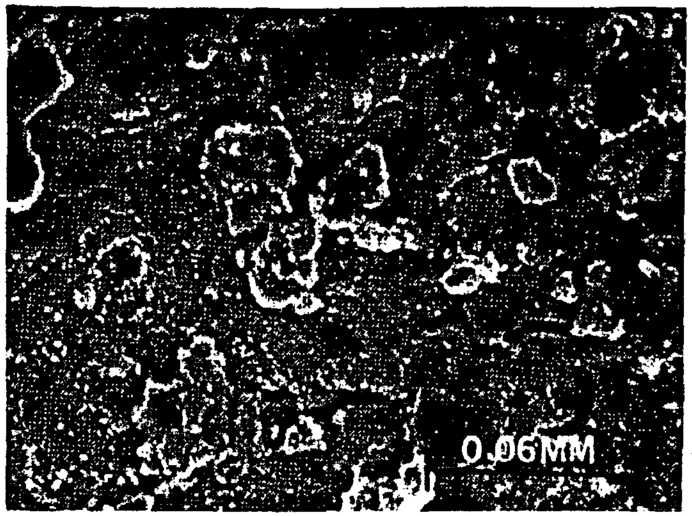


Figure 18: SEM Photograph of "O" Ring Area Corresponding Approximately to Area 150°-170° of Double Delta Seal

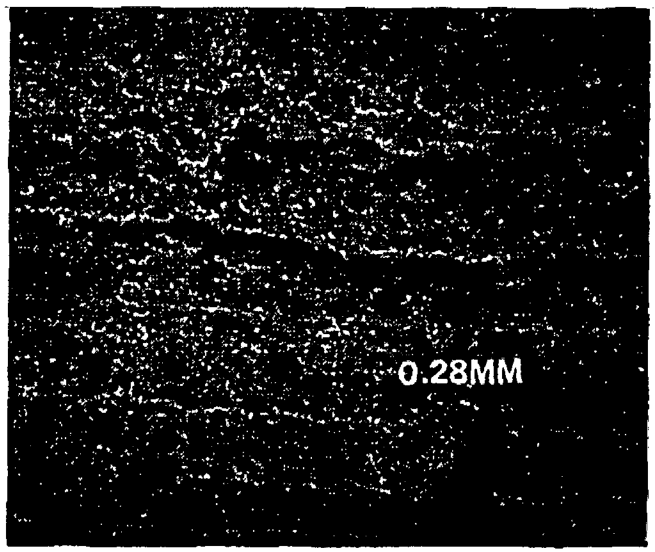


Figure 19: Cracking of the "O" Ring is Evident in Area 3 of Figure 18

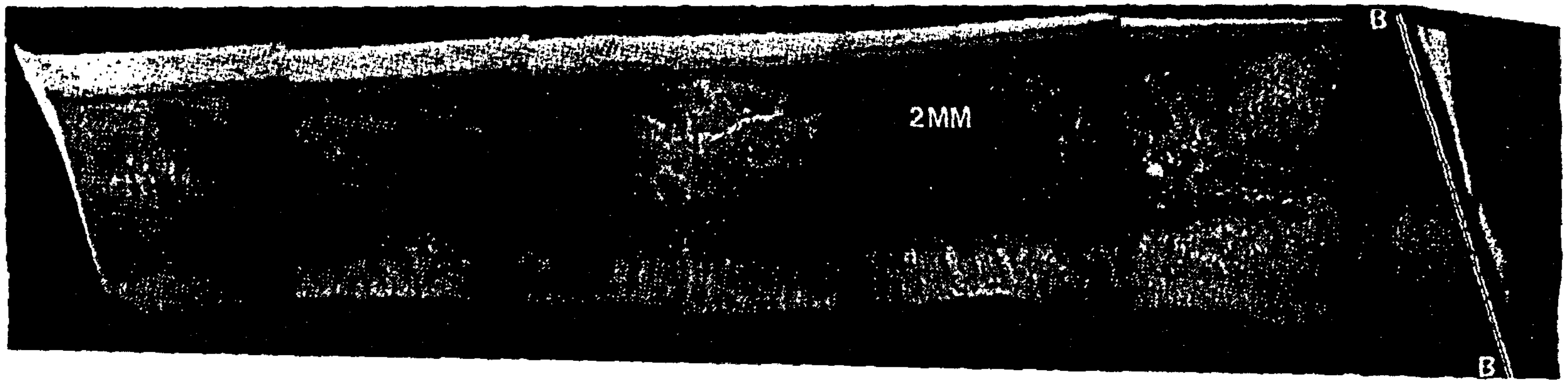


Figure 20: Fractograph of Double Delta Seal From Area 190°-220°. Note the Reduced Cross Section and Wear Line Running the Length of the Segment (B_B).

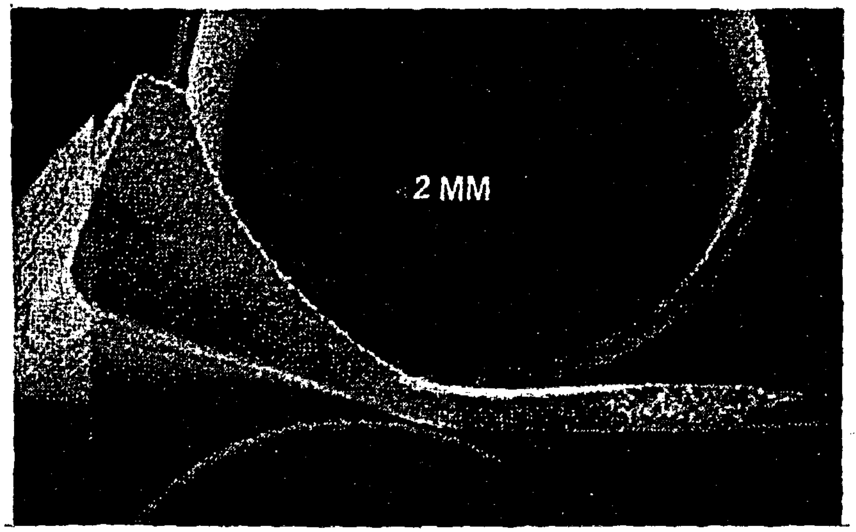


Figure 22: Higher Magnification Fractograph of the Worn Edge of Figure 20.

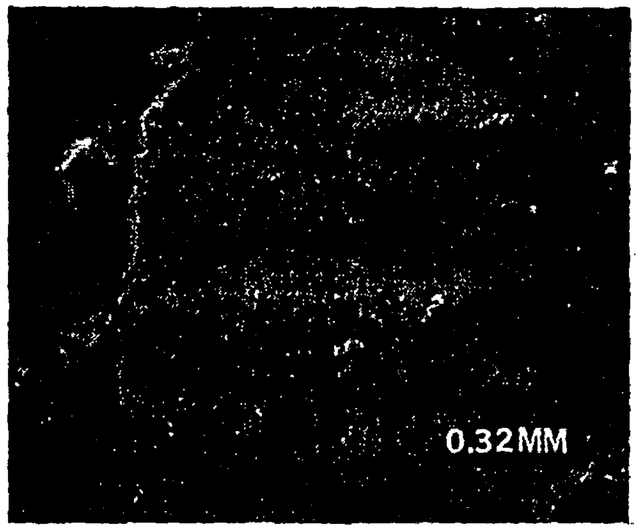


Figure 21: Cross Section of Double Delta Seal in Cut B-B of Figure 19.

Figure 23: SEM Photograph of the "O" Ring Segment Associated With Section 190°-220° of the Seal. Circled Area is Zone of Cracking.

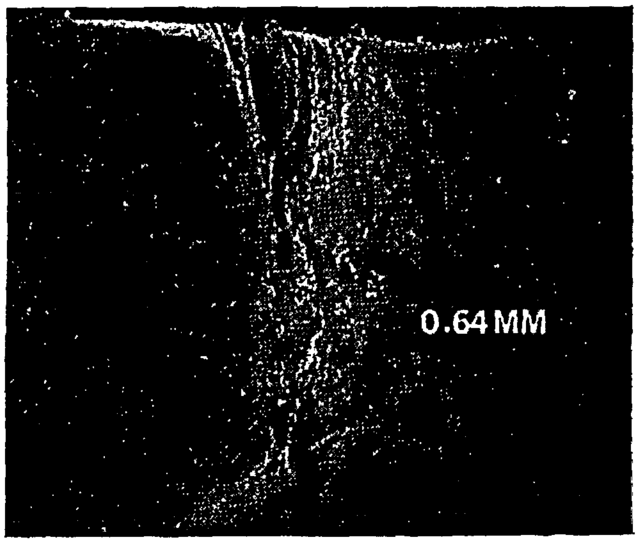


Figure 24: Higher Magnification Fractograph of Cracking in the Circled Area of the "O" Ring.

Figure 26 is a fractograph of the second sample of debris taken from the seals inside surface. The three scans associated with the specimen (Figures 26a-26c) has Mn and Fe associated with them with one scan also exhibiting a Pd and nickel (Ni) peak.

Figures 27 and 28 are EDS scans of the channel seal and O-ring seal respectively. Both scans had Mn and Fe associated with them with traces of other elements associated with them. In no instance could any of these elements be considered as potentially detrimental contaminants to the rubber seals.

C. Radiochemical Examination

The piece of black material scraped from approximately the 240° position on the ring was examined for gamma-emitting radionuclides. Initially, a 7.6 mg portion of the sample was placed in a plastic petri dish and countered for 3600 seconds in a Ge(Li) detector (95 cc crystal, 19% relative efficiency, FWHM approximately 2.1 keV at the 1332 keV Co-60 peak). Peaks for the following nuclides could be identified in the spectrum: Mn-54, Co-60, Ag-110m, Sb-125, Cs-134, and Cs-137. Since no equivalent standards were available for a sample of this nature, it was not possible to quantify the nuclides, but Co-60 and Cs-137 appeared to be the principal isotopes present. A 5.1 mg portion of this material was transferred to a small Ehrlenmeyer flask and leached for 5 hours with hot concentrated HNO_3. The leachate was collected and diluted to 12.2145 ml with deionized water. A 10 ml aliquot of this solution and the leached piece of material were then counted separately for 20,000 seconds each. Peaks for Co-60, Ag-110M, Cs-134, and Cs-137 were identified in the leachate solution spectrum, while the leached sample spectrum showed peaks for Mn-54, Co-60, Sb-125, Cs-134, and Cs-137. The activity of each nuclide in the 10 ml leachate solution was calculated by comparison with a 10ml mixed gamma standard and these activities were expressed in microcuries per milligram of material.

Gamma-Emitting Radionuclides Leached From Material Scraped from the Inner Surface of First-Stage Stationary Ring BNL #4A

Nuclide	Activity (uCi/mg)
Co-60	1.7 E-02
Ag-110M	3.8 E-04
Cs-134	1.1 E-04
Cs-137	8.4 E-04

All of the nuclides identified are activation products or fission products that one might expect to find in reactor coolant water samples.

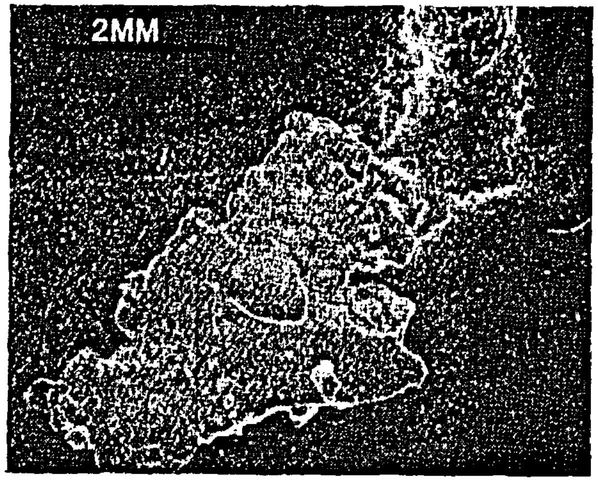


Figure 25: SEM Photo of the First Sample of the Debris Examined.

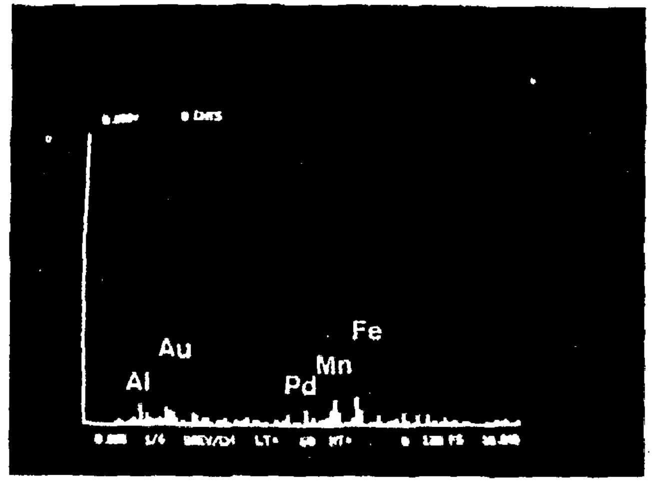


Figure 25a: EDS Scan of the Sample For Contaminants.

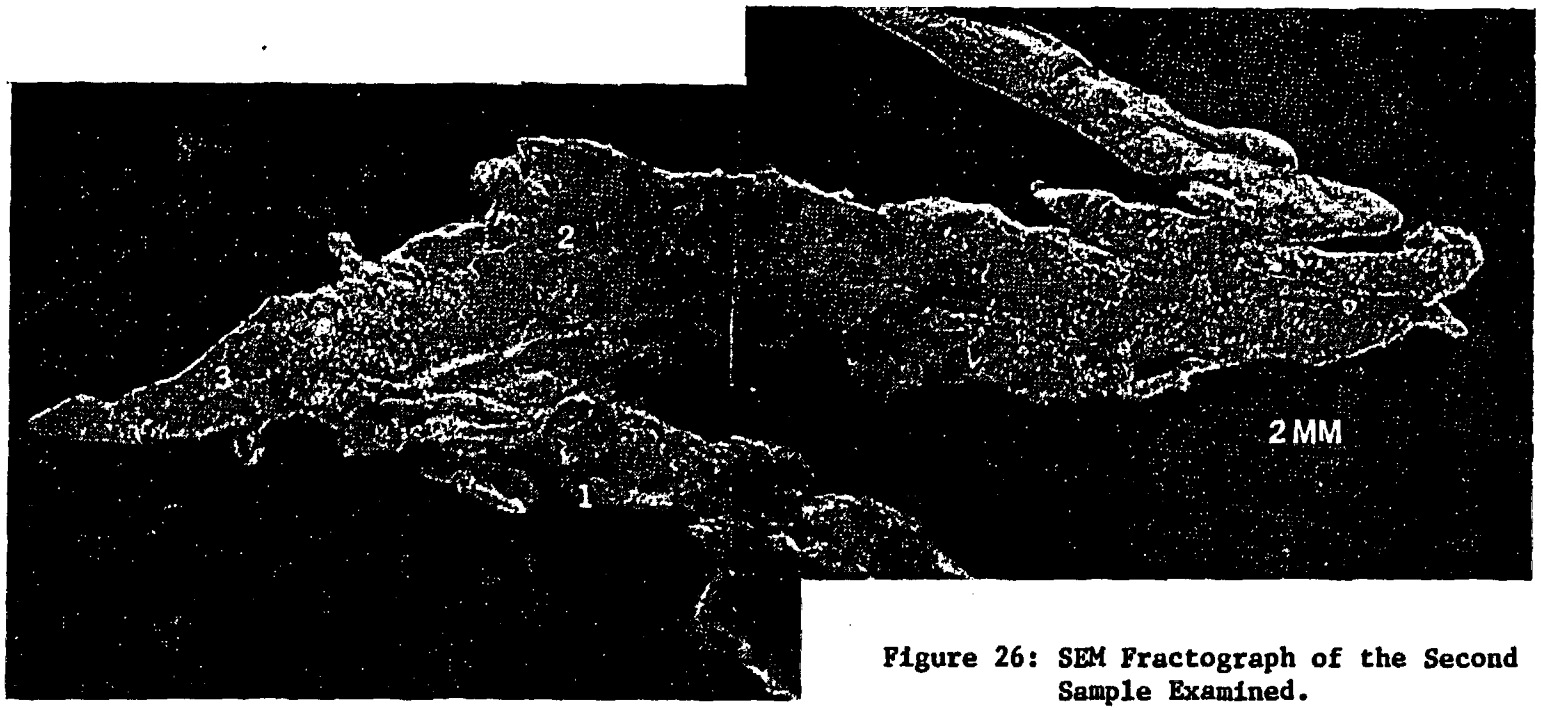


Figure 26: SEM Fractograph of the Second Sample Examined.

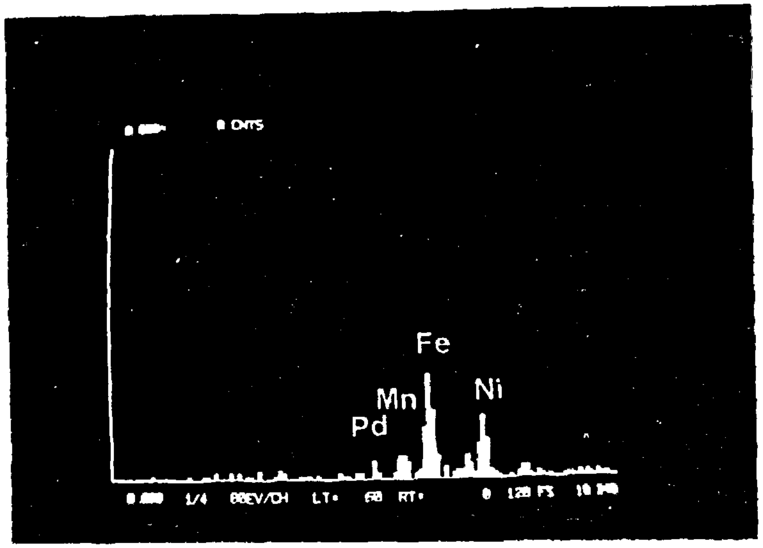


Figure 26a: EDS Scan of Area 1 for Constituents.

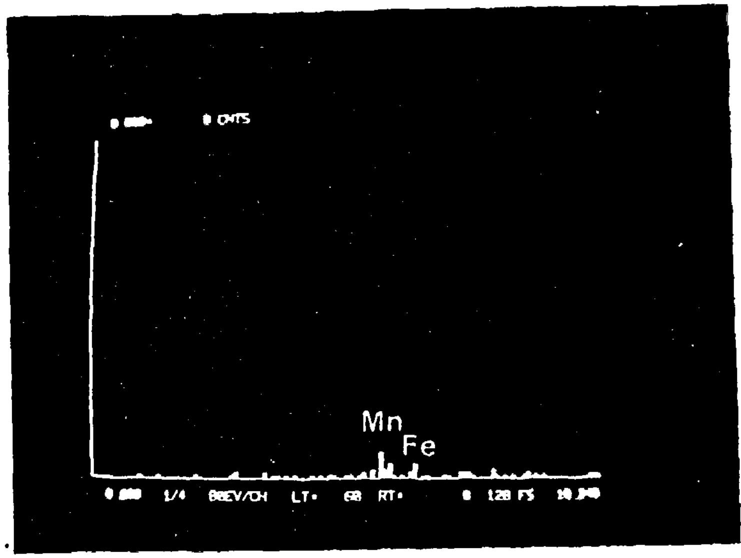


Figure 26b: EDS Scan of Area 2 for Constituents.

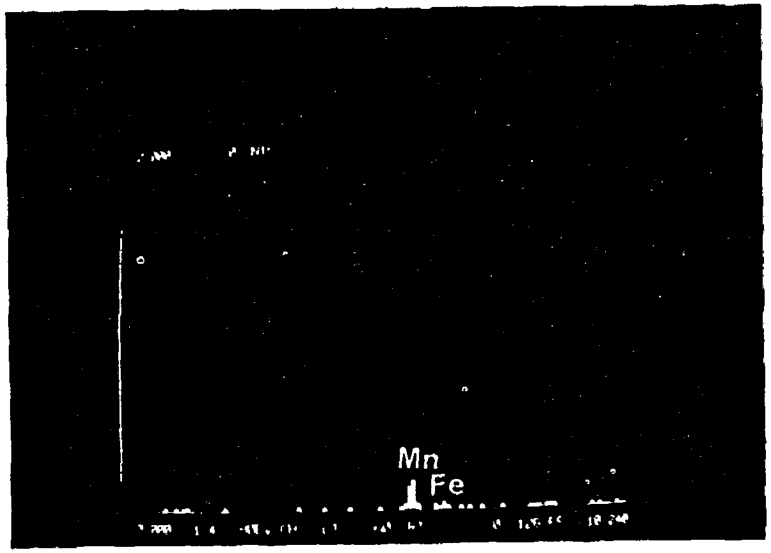


Figure 26c: EDS Analysis of Area 3.

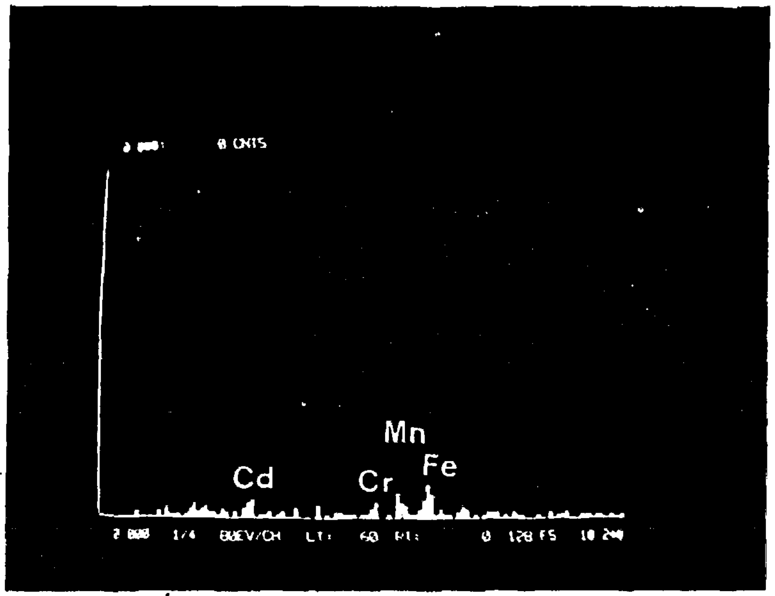


Figure 27: EDS Scan of Double Delta Seal.

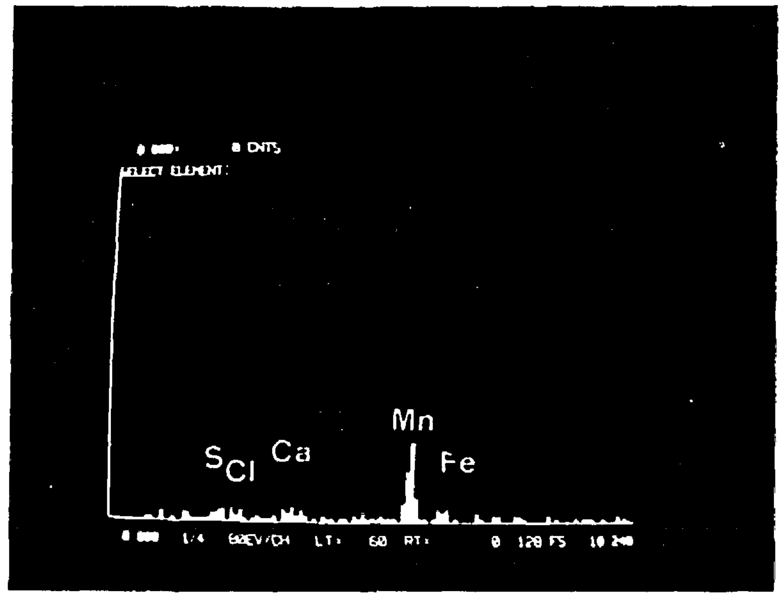


Figure 28: EDS Scan of "O" Ring Seal.

4.3 Interim Conclusions

The visual examination of all service exposed seals and in-depth examinations of the two selected seals lead to the following interim conclusions:

- the visual examination disclosed no evidence of metal fragments or metal wear,
- there was no gross evidence of contamination by foreign material on the seals,
- SEM of the channel seal shows significant thinning of the seal, which subsequently damaged the O-ring seal,
- there was significant cracking of channel and O-ring seals which presumably allowed excessive leakage,
- significant wear of the channel seal and the O-ring might have been caused by heat generated due to rubbing action and mechanical stresses due to O-ring "roll up,"
- chemical analysis (EDS and radiochemical) of crud taken from the channel/O-ring area of the No. 1 seal indicates normal metallic elements from reactor coolant, but none from seal metal wear. The chemical analysis did reveal O-ring material in the crud, and
- The antirotation pin fracture surface was so badly scoured that further examination was precluded. Further examination on root causes of this failure should be considered.

5. CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations presented in this section are preliminary, and are based on the limited scope of the study. Conclusions are categorized into several areas which contributed to the IP2 seal failures. These include, design and manufacturing processes, instrumentation at the plant, starting and operational procedures followed by the utility, and the maintenance program and philosophy. Recommendations are based on these conclusions and data available to BNL for this study. However, additional research is needed in order to develop more specific recommendations for alleviating the seal failure problems at IP2.

5.1 Conclusions

The interim conclusions from Chapters 2, 3, and 4 have been synthesized and the results are contained in the following four areas of investigation:

a) Design and Manufacturing

- Although no significant evidence of surface wear was found, improvement of seal face material from aluminum oxide to silicon nitride should further minimize surface wear.

- Chrome carbide on all rubbing steel surfaces against the nonmetallic seal components may alleviate the channel and O-ring wear, as well as the No. 2 and 3 runner insert problems. However, the seals examined at the BNL hot lab were of the older type without chrome carbide cladding.

- New channel seal material (gray tetralon 720) should limit the seal wear and roll-up problems.

- Degradation of nonmetallic components such as O-ring, channel seals, and gaskets may be the primarily remaining root cause of seal failures. It is expected that new seal material may alleviate seal degradation problems under normal operation.

b) Instrumentation

- Improved No. 1 seal flow meter (orifice type), flow meter in No. 2 seal leakoffs, and a check valve in the No. 2 leak off to prevent back flow will help monitor the leakage rates.

c) Startup and Operational Procedures

- Most early IP2 RCP seal failures are attributed to the No. 1 seal due to improper seal water injection. However, present seal injection practices should preclude this from causing future problems.

- Improved administrative controls should minimize any human errors during pump startup.

d) Maintenance

- Installation of seals in the past have affected overall seal performance. However, with proper training and the use of a seal assembly mockup, this should not cause future problems. The cartridge seals are definitely better suited for preventive maintenance.
- Replacement of complete seal assemblies at every second outage does not seem to be warranted.
- A scheduled inspection on all seal surfaces for nose heights, seal face conditions, and crud buildup, with channel/O-ring replacement as required, should be made at every second refueling outage.

5.2 Recommendations

- Improved monitoring and instrumentation should be implemented so that a condition monitoring program can be established to identify incipient seal degradation.
- Con Ed should investigate the feasibility of using the cartridge seals for easier maintenance.
- A better procedure to assure absolute flushing of contaminants from seal areas prior to starting the pump should be considered. (One such procedure is available from Westinghouse.)
- Pump seals should be examined every other refueling outage for seal face surface wear, nose height wear, and crud buildups. All nonmetallic components should be replaced each time the pump is disassembled for examination, with other parts only replaced as necessary.
- Pump No. 23 should be studied in detail since it has exhibited somewhat more failures than the other three pumps, and appears to have an inherent vibration problem.

6. FUTURE WORK

As continuation of this project, the remaining service exposed seals at IP2 will be examined and analyzed to obtain root causes of failure. To better understand these failure causes and the mechanisms leading to a failure, future in-depth seal examinations will be performed on seal components with known failure history.

If necessary, a three dimensional thermo-hydraulic analysis will be performed for the normal operating conditions. This would simulate the temperature, pressure, and flow conditions inside the seals. This would also help understand the cocking mechanism which might have been occurring as a result of an asymmetric pressure distribution on the No. 1 seal ring assembly around the pump shaft. Furthermore, the temperature distribution in the No. 2 seal would be considered in its transition from a rubbing face to a film riding seal in the event of No. 1 seal failure.

Once the failure modes, mechanisms and causes are identified, final recommendations for instrumentation and a condition monitoring program can be made to provide feedback on seal performance. The operating and maintenance procedures will be reviewed in relation to seal performance.

Thus, the BNL effort will continue to assess the seal performances in each of the four areas; design and manufacturing, instrumentation, startup and operating practices, and maintenance.

In order to achieve these goals, it is important that the following information be made available to BNL in future research activities:

- Design dimensions of seal components to measure the seal faces and fretting surfaces, and to study the thermo-hydraulic or dynamic models under normal operating condition.
- Complete maintenance history on each known failed seals to determine failure modes and mechanisms.
- Complete operating records including startup and plant transients experienced by the subject seal to correlate with the failure mode, if any.
- Complete details on the symptoms or failure modes exhibited by instrumentation. This would help establishing the root cause of each seal failures and the remedial actions to prevent this in the future.

7. REFERENCES

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2. Boardman, T., et al., "Leak Rate Analysis of the Westinghouse Reactor Coolant Pump," NUREG/CR-4294, 85-ETEC-DRF-1714, July 1985.

3. Kittmer, C.A., et al., "Reactor Coolant Pump Shaft Seal Behavior During Station Blackout," NUREG/CR-4077, EGG-2365, April 1985.

4. Azarm, M.A., Boccio, J.L., and Mitra, S., "The Impact of Mechanical and Maintenance-Induced Failures of Main Reactor Coolant Pump Seals on Plant Safety," NUREG/CR-4400, BNL-NUREG-51928, December 1985.

5. Luckas, W.J., et al., "Reactor Coolant Pump Seal Related Instrumentation and Operator Response: An Evaluation of Adequacy to Anticipate Seal Failures," Draft Report, November 1985.

6. Metcalfe, R. and Wensel, R., "The Significance of Eccentric Mountings and Elastomer Resistance in Main Coolant Face Seals," EPRI NP-3714, October 1984.

7. Wensel, R.G., "Factors Affecting Wear Damage to Elastomer Seals in Main Coolant Pump Face Seals," EPRI-NP-4245, September 1985.

8. Letter from Mr. R. Ament of Westinghouse to Mr. J.M. Makepeace of Con Ed, dated October 11, 1983

9. Internal Memo from John Taylor, "RCP Seals - Ginna Station," May 14, 1986.

APPENDIX A

PHYSICAL EXAMINATION OF SERVICE EXPOSED SEALS FROM IP2

(FIRST BATCH OF SIX CANISTERS)

Legends to Accompany Photographs

Hot cell at BNL where drums were unloaded (CN3-438-86).
The 6 drums that have been received are arranged along the side wall of the hot cell. These drums have been numbered from 1 through 6 in the left-to-right order seen in the photograph. A technician is unwrapping a number 2 seal housing that had been removed from drum #1.

Number 1 Seal Runner Assembly (BNL #3A-CN3-555-86 and BNL #3A-CN3-552-86).
The number 1 seal is a hydrostatically-balanced, film-riding, face seal in which a non-rotating ring assembly rides axially on a thin film of water that separates its faceplate from the faceplate of a runner assembly that rotates with the shaft. A runner assembly consists of a lower runner support to which the faceplate is clamped by means of the hydrostatic ring clamp. This assembly appears to be undamaged. The faceplate is stained a deep amber color. Smudges on the faceplate are probably the result of handling during and subsequent to removal of the assembly from the pump. Those surfaces of the runner support and the ring clamp that were exposed to water in the seal chamber are stained dark brown with oxide and crud.

Number 1 Seal Runner Assembly (BNL #5A-CN3-825-86 and BNL #5A-CN3-831-86).
The faceplate is missing from this assembly and it seems likely that it was destroyed as the result of a contact between the rotating runner faceplate and the stationary ring faceplate. Deep, circumferential scratches in the surface of the runner support that was beneath the faceplate, a sheared anti-rotation pin in the righthand, rear quadrant of this surface, and the torn O-ring in the groove in this surface all indicate that the faceplate had been forcably rotated against the support surface. The absence of oxide and crud buildup on the surfaces exposed to water in the seal chamber suggest that the event that destroyed the faceplate probably occurred shortly after startup. Whitish deposits, probably of borate, are visible on the inner circumference of the runner support.

Number 1 Seal Runner Assembly (BNL #5D-CN3-823-86 and BNL #5D-CN3-834-86).
This assembly appears to be undamaged. The faceplate has been stained yellow in color, and the runner surfaces that were exposed to water in the seal chamber show only a light buildup of oxide and crud. Smudges on the faceplate were most likely the result of handling during or subsequent to removal of the runner from the pump.

Number 1 Seal Runner Assembly (BNL #6A-CN3-817-86 and BNL #6A-CN3-819-86).
Unlike other number 1 seal faceplates, which are uniformly colored, the faceplate in this runner shows an uneven distribution of color. Westinghouse engineers indicated that this could have been the result of uneven drying of liquid on the surface of the faceplate. Only a light crud and oxide staining is evident on runner surfaces that had been exposed to water in the seal chamber. The white plastic pieces that flank the runner are part of a cover that is used to protect the faceplate during shipping and handling.

Number 1 Seal Stationary Ring Assembly (BNL #1A-CN3-445-86 and BNL #1A-CN3-447-86).
Like the number 1 runner assembly, the number 1 stationary ring assembly consists of a ring support to which the faceplate is clamped by means of the hydrostatic ring clamp. A protective cover is in place over the faceplate, and only a tiny sector of the faceplate is visible. The hydrostatic ring clamp and that portion of the ring support which was outside of the number 1 seal housing is stained dark reddish-brown by oxide and crud, but that portion of the ring support that was within the housing is purplish-black in color. The double-delta channel seal, which makes a sliding contact with the insert from the number 1 seal housing, is not present. The channel it occupied can best be seen on the inner circumference of the ring support in photograph BNL #1A-CN3-445-86. Deposits of material are visible both above and below this channel.

Number 1 Seal Stationary Ring Assembly (BNL #4A-CN3-828-86 and BNL#4A-CN3-829-86).
This is the seal that has been selected for a detailed examination of the double-delta channel seal and of the material deposited along the seal channel. The faceplate is dark yellow or amber in color. Deposits of grease on the faceplate probably originated from handling during or subsequent to the removal of the ring assembly from the pump. Four small chips are visible in photograph BNL #4A-CN3-828-86 on the rim of the outer circumference of the hydrostatic ring clamp. Two dents are visible in photograph BNL#4A-CN3-829-86 on the rim of the outer circumference of the ring support. The difference in color between those portions of the ring assembly that were inside and those that were outside the number 1 seal housing, which were noted earlier, are evident in the photographs of this assembly. The double-delta channel seal is present. It can best be observed in photograph BNL #4A-CN3-829-86 where it can be seen to be partially dislodged from its channel. Deposits of material are visible on the inner circumference of the ring support close to the double-delta channel.

Number 1 Seal Stationary Ring Assembly (BNL #4B-CN3-830-86 and BNL #4B-CN3-836-86).
This assembly appears to be undamaged. The faceplate is yellow in color, and the smudges on the surface are probably the result of handling during or subsequent to removal of the ring from the pump. Color differences between those portions of the assembly that were inside and those that were outside the seal housing, which were noted earlier, are evident in these photographs. The double-delta channel seal is missing, but there are some deposits of material in the vicinity of the double-delta channel.

Number 1 Seal Stationary Ring Assembly (BNL #5C-CN3-822-86 and BNL #5C-CN3-832-86).
This assembly appears to be undamaged. Overall this assembly is more heavily stained with oxide and crud than was component BNL #4B. The faceplate is deep amber in color, and shows very little smudging on the surface. Color differences between those portions of the assembly that were inside and those that were outside the seal housing, which were noted earlier, are evident in these photographs. The double-delta channel seal is missing, but there are some deposits of material in the vicinity of the double-delta channel. The number 1 seal housing insert designated as component BNL #5B was found inserted into the ring support side of this ring assembly in the position it would have occupied in the pump.

Number 1 Seal Housing Insert (BNL #5B-CN3-824-86 and BNL #5B-CN3-833-86).
As noted earlier, this piece was found inserted into the ring support side of component BNL #5C. The double-delta channel seal on the number 1 seal stationary assembly slides against the outer surface of the collar seen on the lower surface of the insert. Black marks on this surface show where this sliding contact occurred. In this piece, this surface is polished stainless steel, but in newer versions of the insert the rubbing surface has been coated with chrome carbide.

Miscellaneous seal components (BNL #2-CN3-484-86).
This photograph shows two aluminum oxide number 1 seal faceplates, a number 2 seal ring assembly, a shattered graphitar insert from a number 2 seal ring assembly, and several discarded O-rings. The aluminum oxide faceplates are nearly white in color and are, therefore, relatively new. Light brown stains on the surface of the lefthand faceplate trace the pattern of grooves and of the O-ring channel that occur on the support surface underlying the faceplate. Also visible on this faceplate is the depression into which the an anti-rotation pin, located on the support surface, fits. Smudges on the surface of the other faceplate are probably the result of handling during or subsequent to its removal from the assembly. The source of the shattered graphitar insert is unknown.

Graphitar Insert from a Number 2 Seal Stationary Ring Assembly (BNL #2-CN3-482-86).
This is the same set of graphitar pieces shown in photograph BNL #2-CN3-484-86. It is not known which number 2 ring assembly this insert came from.

Number 2 Seal Runner Assembly (BNL #2D-CN3-478-86 and BNL #2D-CN3-479-86).
The number 2 seal is a rubbing face seal in which the nosepiece on the graphitar insert in a non-rotating ring assembly rubs against an insert in a runner assembly that rotates with the shaft. In older versions of the runner assembly, such as that pictured here, the runner insert is made of aluminum oxide, but in more recent versions the aluminum oxide has been replaced by a chrome carbide rubbing surface. Black deposits on the aluminum oxide insert show where rubbing contact occurred. Two O-rings are visible in channels on the inside circumferential surface of the assembly. Unless the aluminum oxide insert is worn, this assembly appears to be undamaged.

Number 2 Seal Stationary Ring Assembly (BNL #2A-CN3-481-86 and BNL #2A-CN3-483-86).
The black graphitar insert and its nosepiece can be seen in photograph BNL #2A-CN3-481-86. The inner surface of the ring assembly cowl that encloses the graphitar ring is stained dark reddish-brown with oxide and crud, but the outer surface is relatively free of such staining. The double-delta channel seal is still intact and can best be seen just above the graphitar insert in photograph BNL #2A-CN3-483-86. The upper rim of the double-delta channel seal appears to be fretted.

Number 2 Seal Housing (BNL #1B-CN3-442-86 and BNL #1B-CN3-446-86).
Except for discolorations around the O-ring channels on the outside circumference of the housing and on the outside circumference of the inner housing skirt, this piece looks almost new. The discoloration on the outside surface of the inner housing skirt is in the area where the double-delta channel seal of the number 2 stationary ring assembly slides against the housing. In older versions of the housing, such as the piece pictured, the contact surface for the double-delta channel seal was stainless steel, but in more recent versions this surface is coated with chrome carbide. Also, in the newer versions, the one piece construction of the housing has been replaced by a two-piece construction in which the housing section that contacts the double-delta channel seal can be replaced independently of the rest of the housing.

Number 3 Seal Stationary Ring Assembly (BNL #1C-CN3-443-86 and BNL #1C-CN3-444-86).
The number 3 seal, like the number 2 seal, is a rubbing face seal in which the nosepiece of a graphitar insert on a non-rotating stationary ring rubs against an insert on a seal runner that rotates with the shaft. In older versions of the seal, such as those pictured in this report, the runner insert was aluminum oxide, but in newer seals the aluminum oxide has been replaced by chrome carbide. Examination of the graphitar insert with a hand lens revealed the presence of at least three places where the nosepiece is chipped. Also the nose piece appears to be much worn, especially in the front, lefthand quadrant. Considerable deposits of borate can be seen on the inside circumference of the ring assembly. An O-ring can be seen in a groove on the outer circumferential surface of the assembly.

Number 3 Seal Stationary Ring Assembly (BNL #5E-CN3-821-86 and BNL #5E-CN3-835-86).
This assembly is still packaged for shipping.

Number 3 Seal Stationary Ring Assembly (BNL #6B-CN3-815-86 and BNL #6B-CN3-816-86).
The rim of the inner circumference of the graphitar insert has a chipped area in the rear, righthand quadrant, and there appears to be a groove in the nosepiece in the front, righthand quadrant. Along the left side of the graphitar insert, the graphitar appears to be either worn down to expose an underlying metallic surface, or to be more highly polished and reflective than elsewhere along the insert. An O-ring can be seen in a groove on the outer circumferential surface of the assembly.

Number 3 Seal Runner Assembly (BNL #3B/C/D-CN3-554-86 and BNL #3B/C/D-CN3-556-86). The runner is flanked by two lock washers from the top of the seal assembly. Photographic enlargement is not sufficient to allow a close examination of the aluminum oxide insert on the runner. The lower surface of the runner assembly is deeply stained with oxide and crud.

Number 3 Seal Runner Assembly (BNL #3E-CN3-553-86 and BNL #3E-CN3-557-86). Photographic enlargement is not sufficient to allow a close examination of the aluminum oxide insert on the runner. Smudged areas on the insert surface are probably a result of handling during or subsequent to removal of the runner from the pump. The lower surface of the runner assembly is deeply stained with oxide and crud. A protective cover for a number 1 seal faceplate also appears in the photographs.

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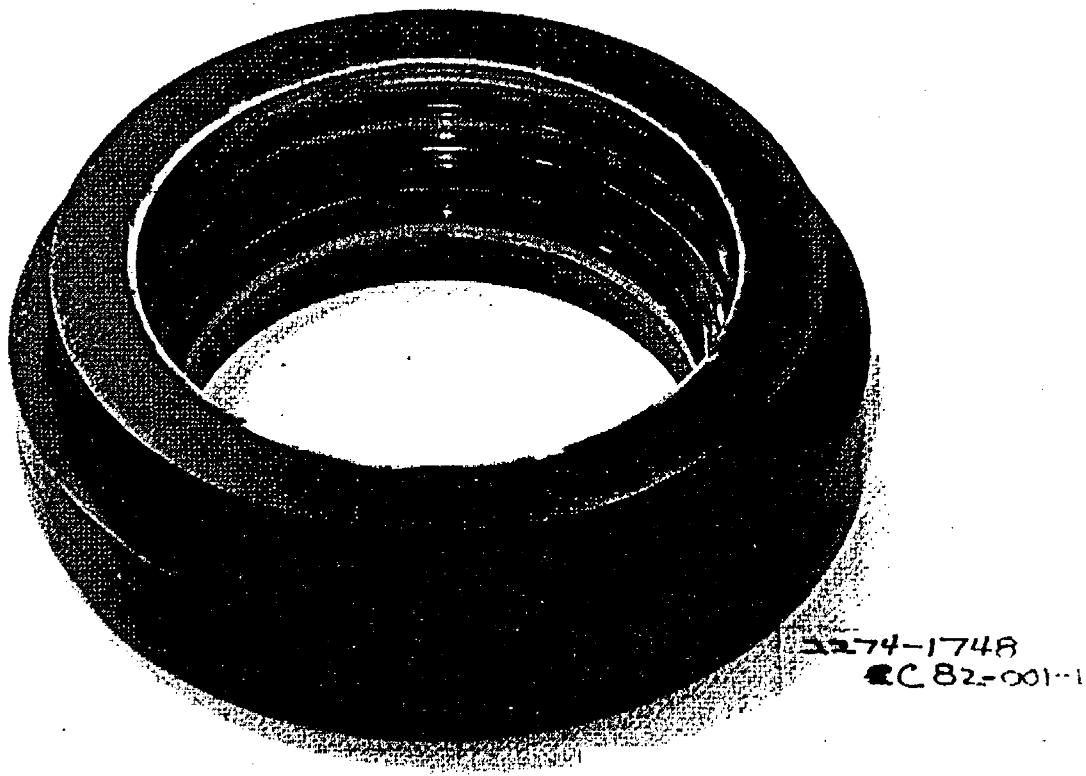
DRUMS RECEIVED FROM CONED



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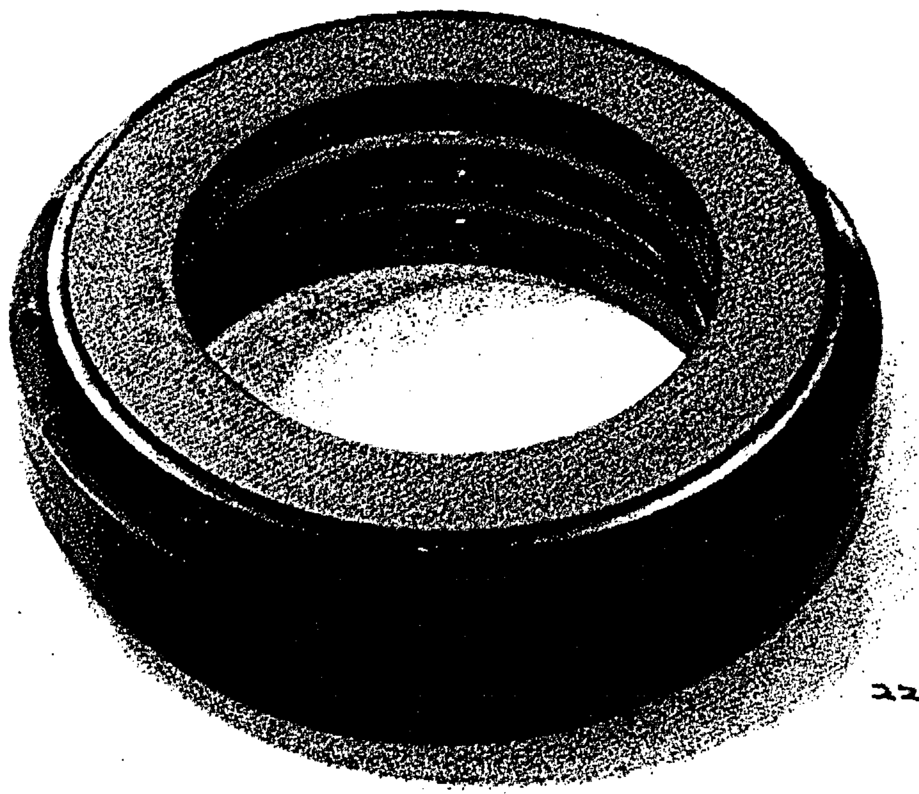
NO. 1 SEAL RUNNER: OPPOSITE FACE

A-7



2274-1748
C 82-001-1

BNL ID: 3A-CN3-552-86

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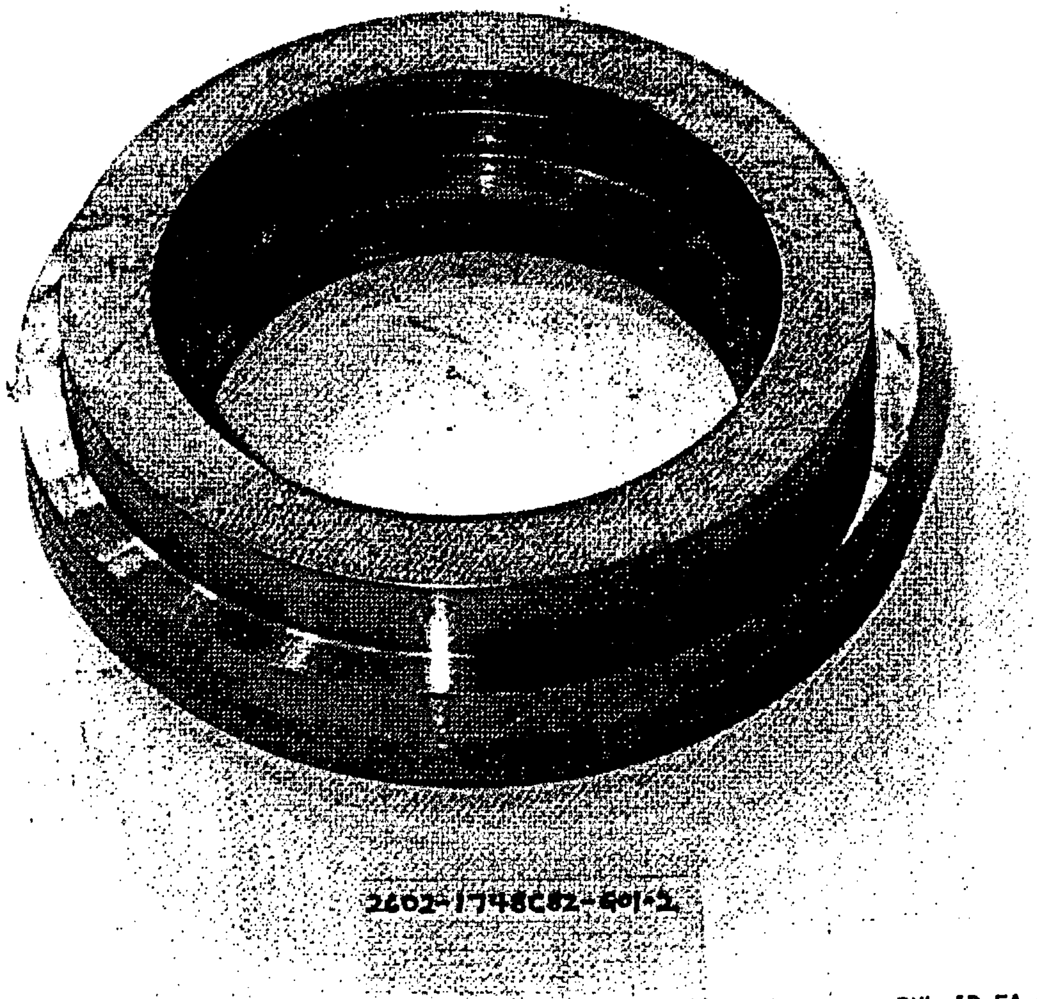

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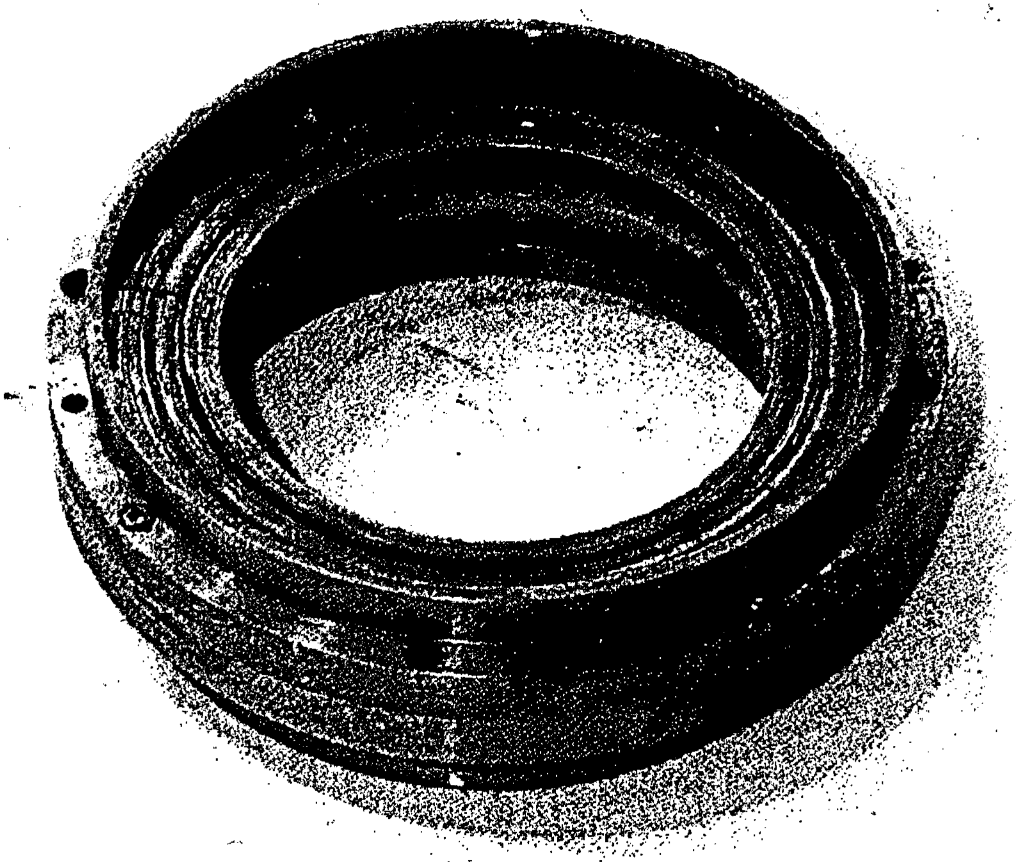
NO. 1 SEAL RUNNER



2602-1748C82-601-2

BNL ID: 5A-CN3-831-86

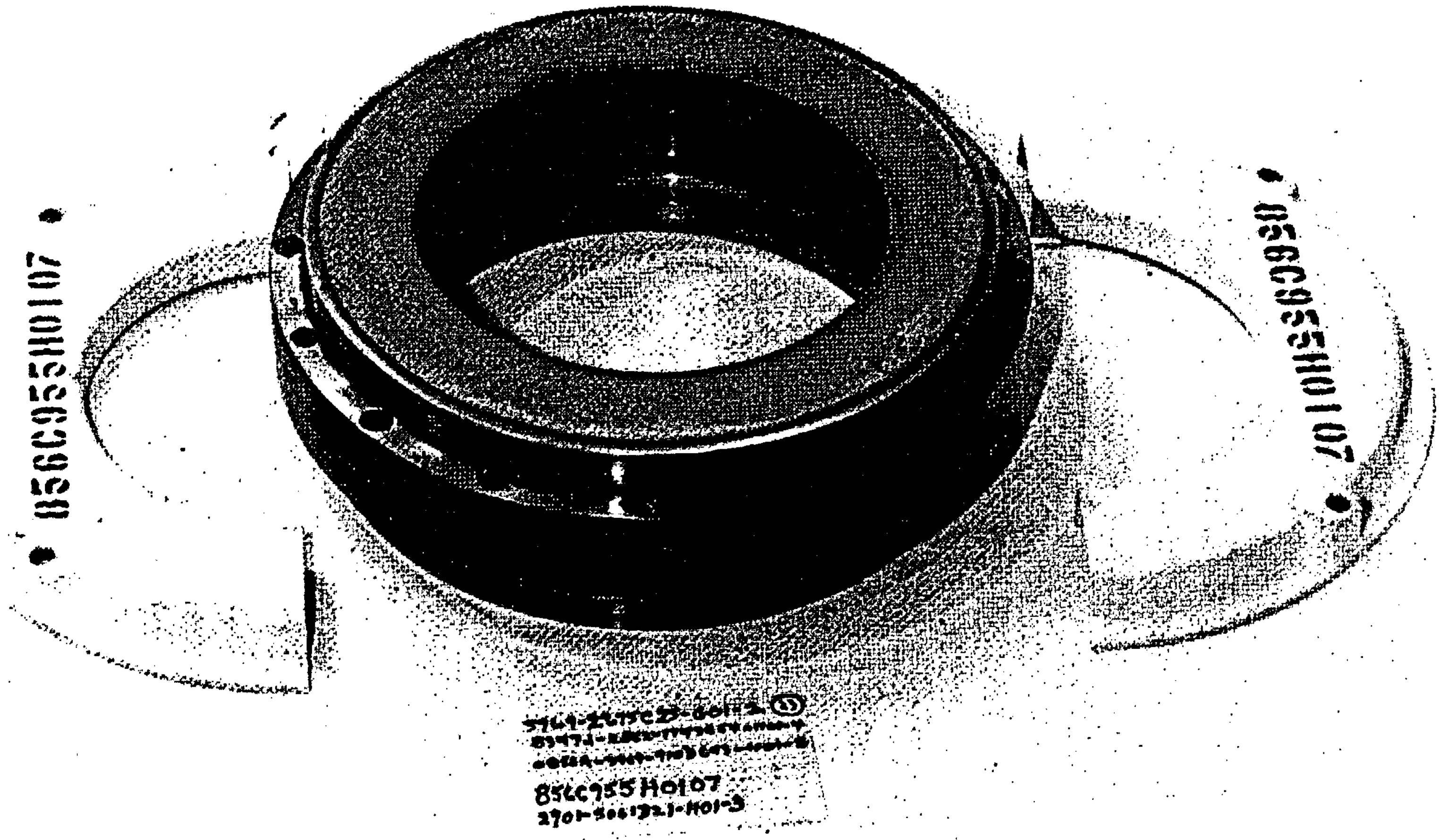
NO. 1 SEAL RUNNER

BNL ID: 5D-CN3-823-86

NO. 1 SEAL RUNNER: OPPOSITE FACE

BNL ID:5D-CN3-834-86

NO. 1 SEAL RUNNER: SEAL FACE



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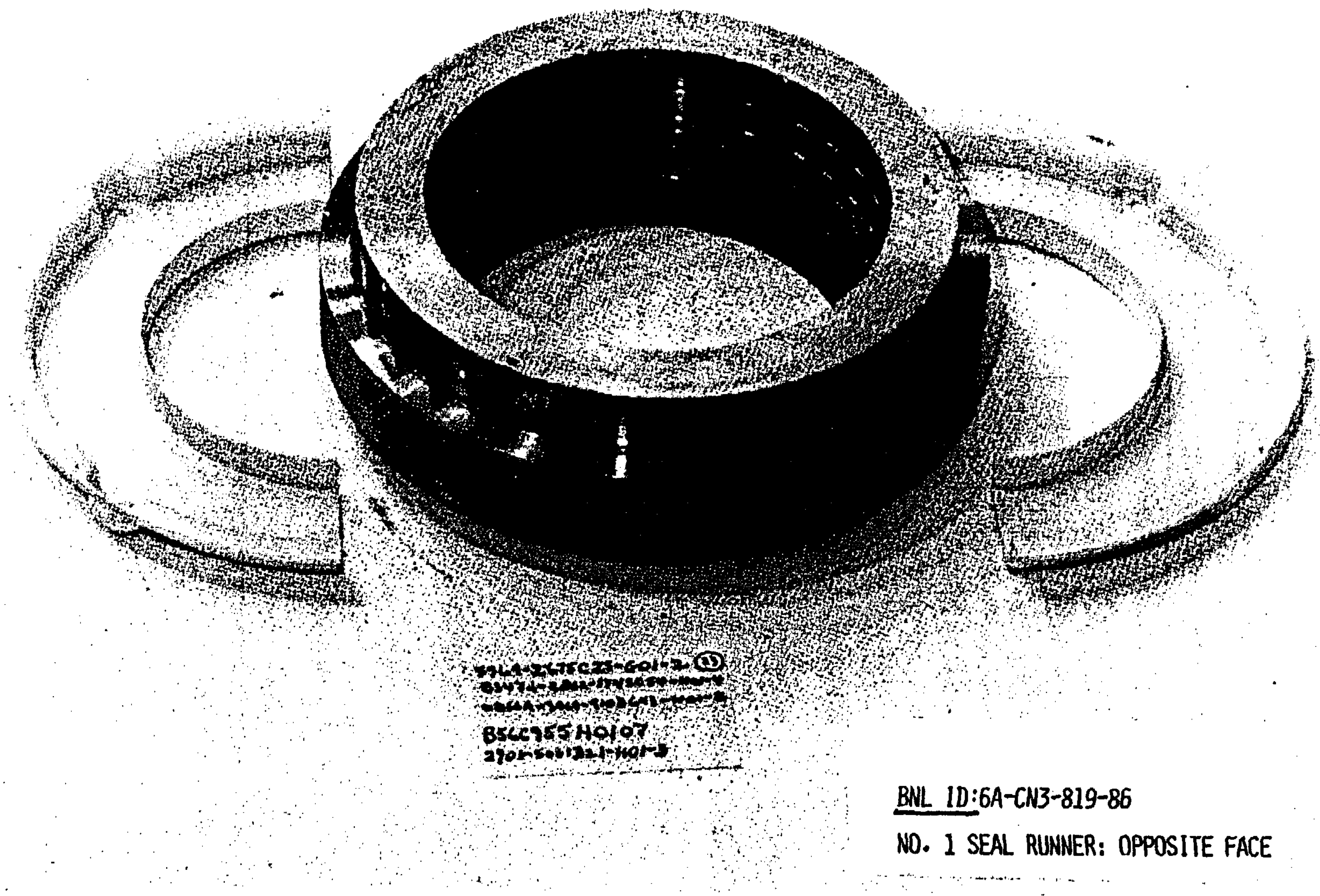

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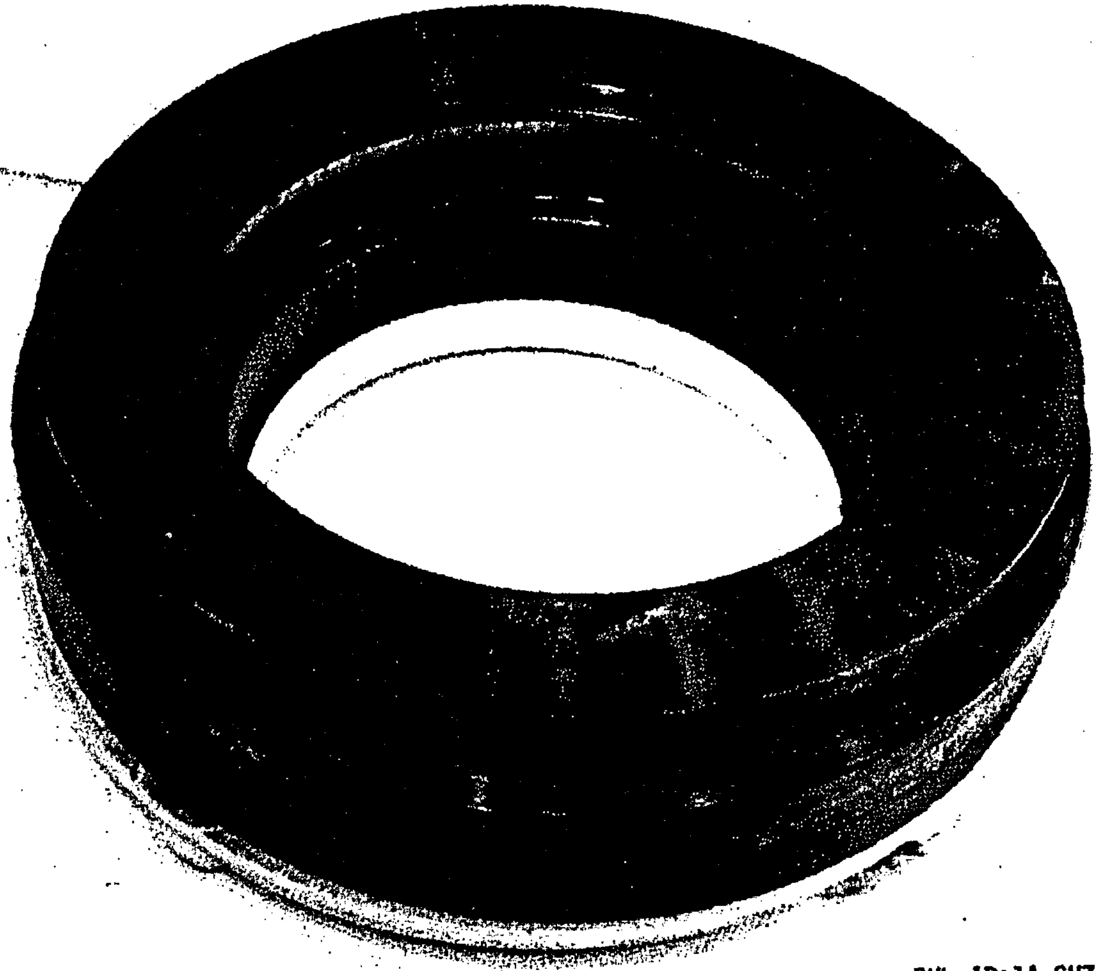
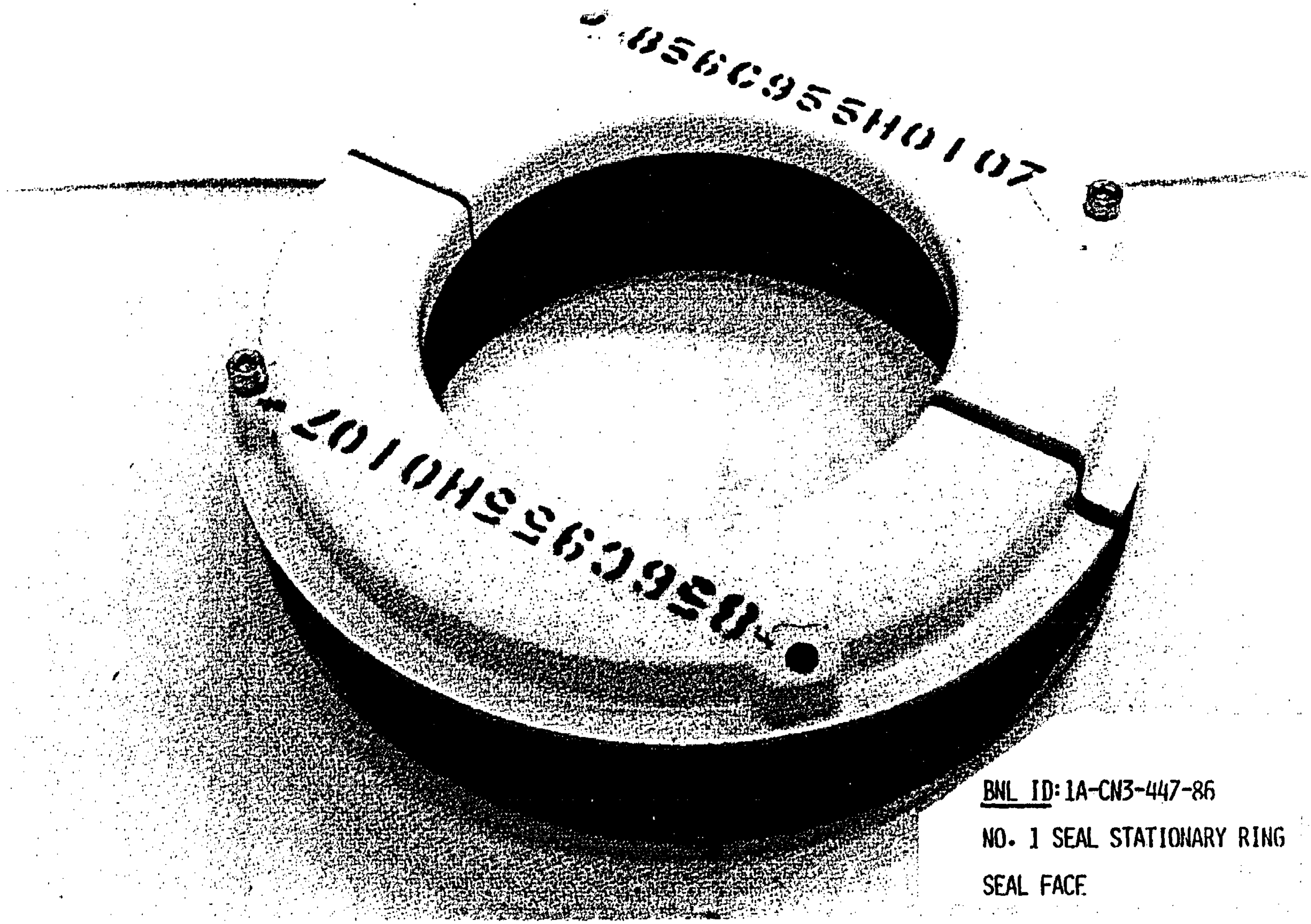


BNL ID: 1A-CN3-445-86

NO. 1 SEAL STATIONARY RING, OPPOSITE FACE



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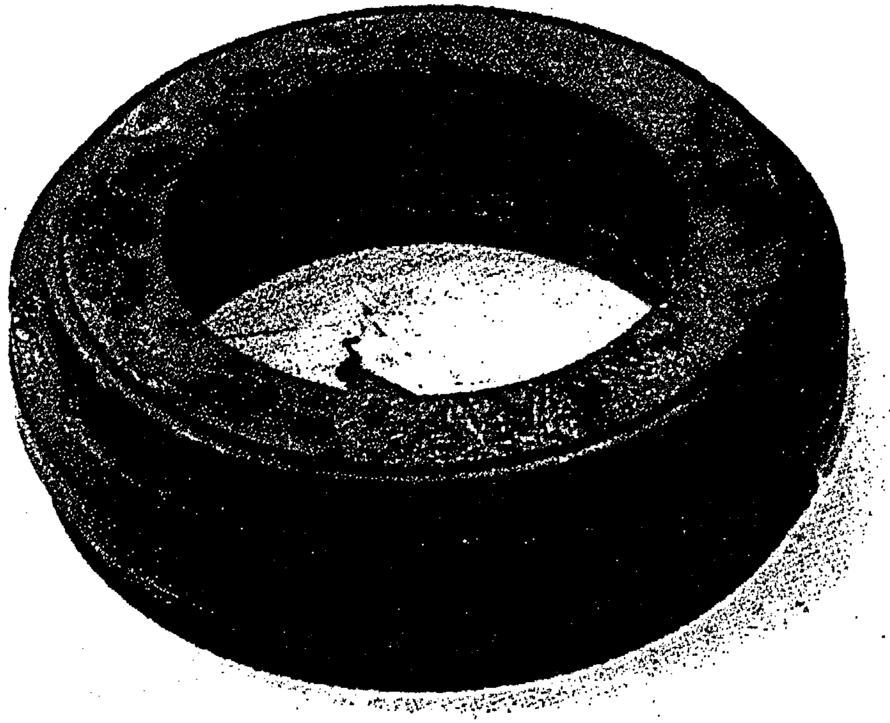
NO. 1 SEAL STATIONARY RING

SEAL FACE



1919-5059D52-
G01-3
1182-910D611-H01-10

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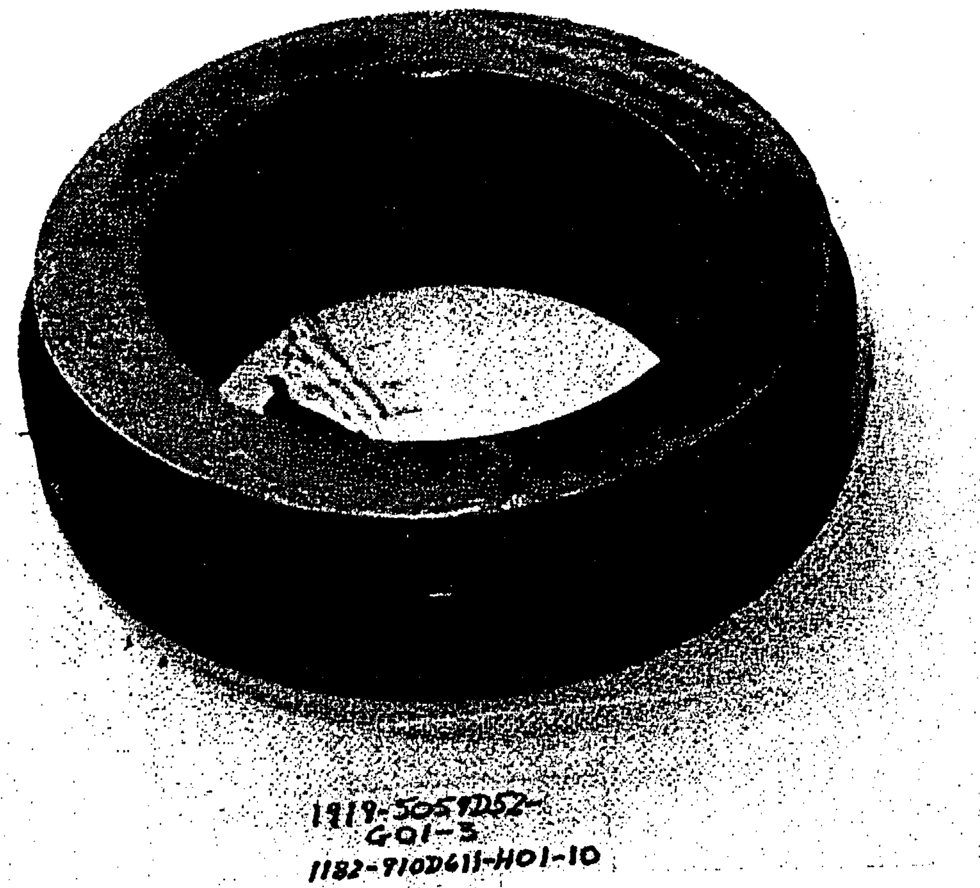

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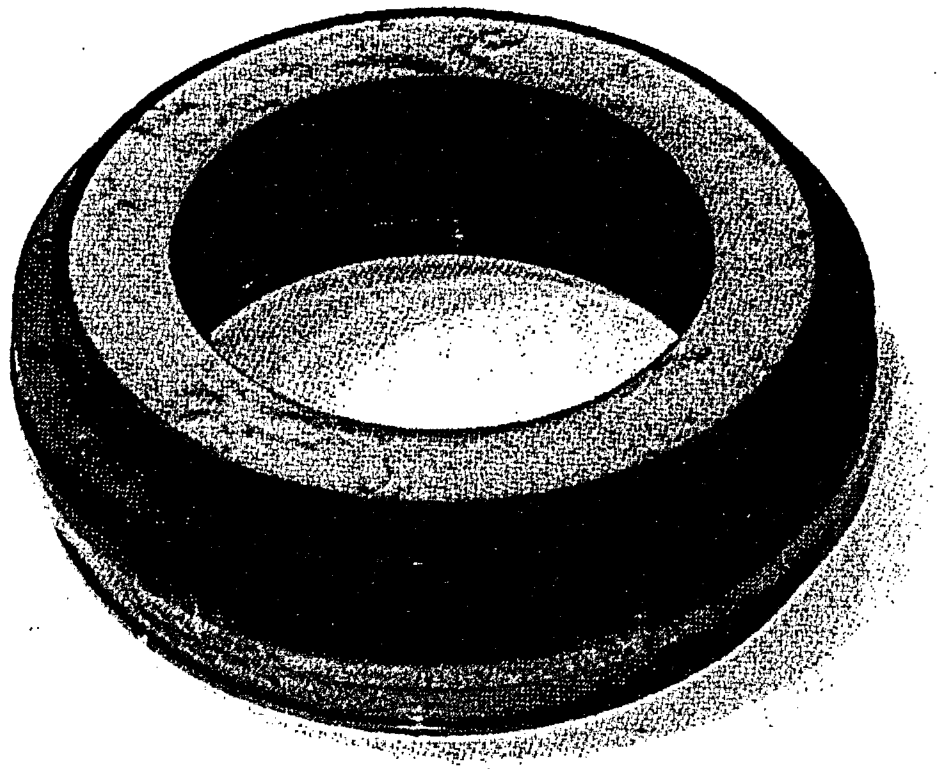
NO. 1 SEAL STATIONARY RING: OPPOSITE FACE



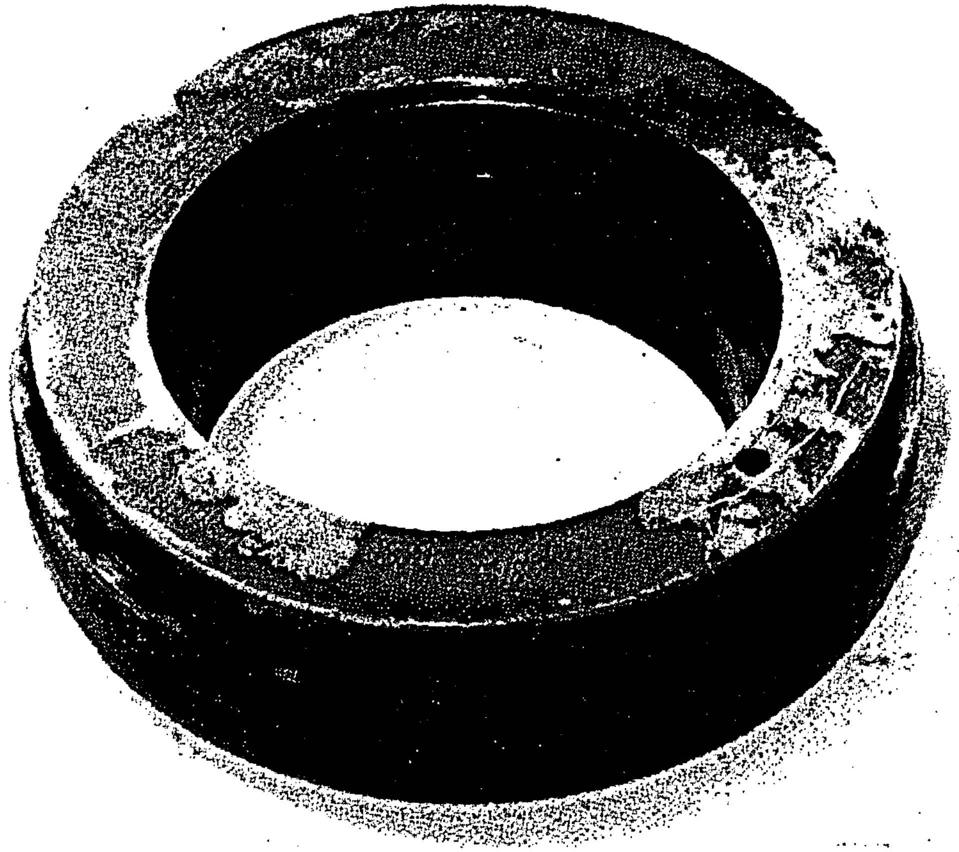
4285-5059D52-G01-2
1689-910D611-H01-810

BNL ID: 4B-CN3-830-86

NO. 1 SEAL STATIONARY RING: SEAL FACE

BNL ID:4B-CN3-836-86

NO. 1 SEAL STATIONARY RING: OPPOSITE FACE



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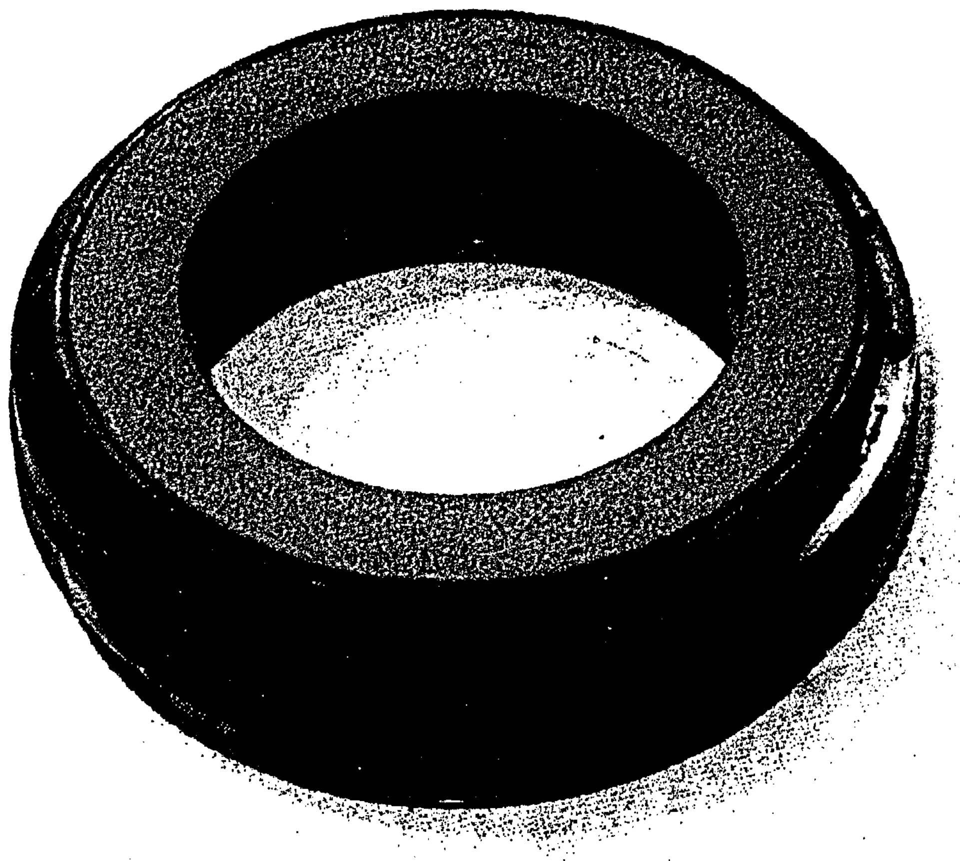

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BNL ID:5C-CN3-832-86

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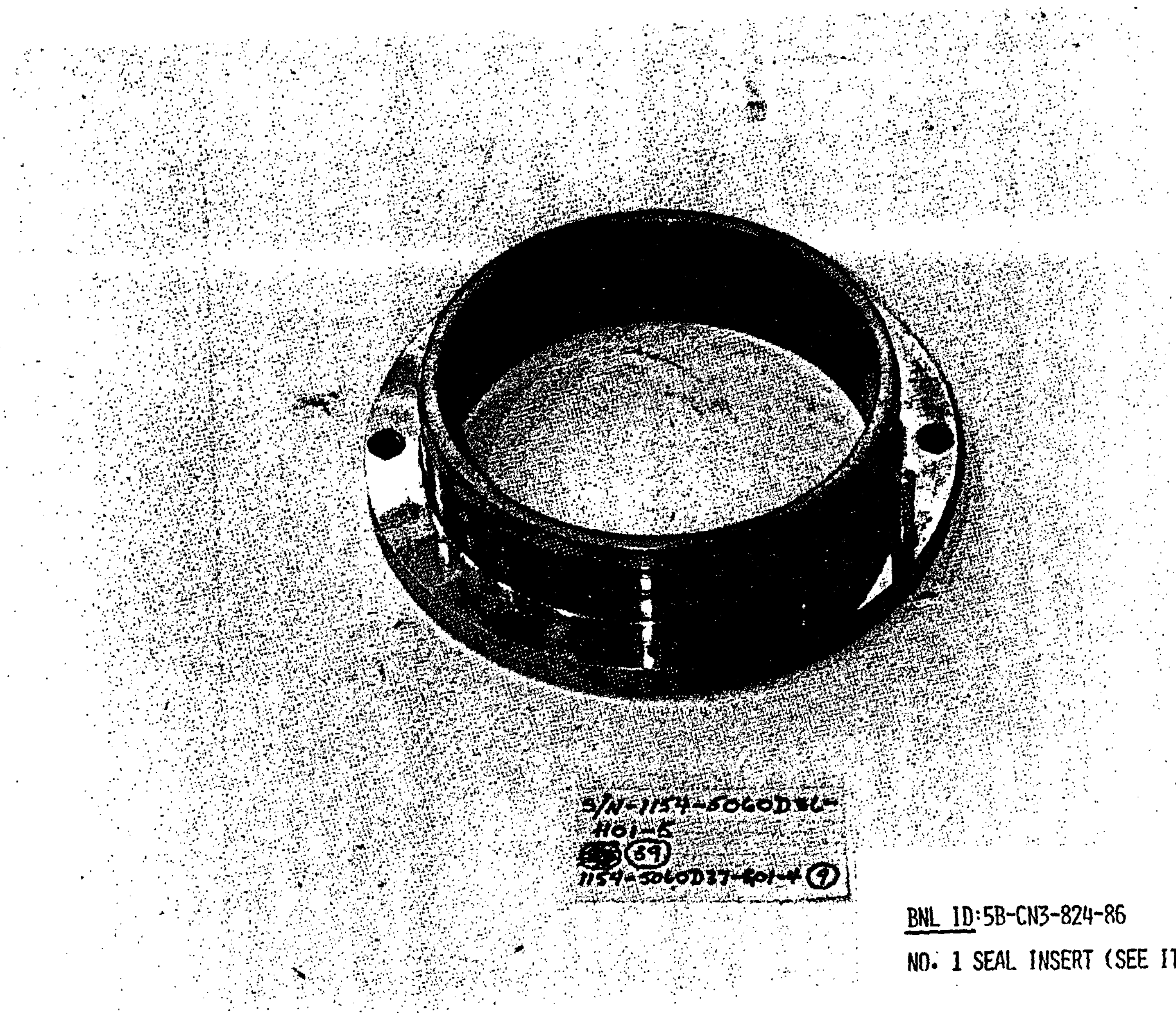

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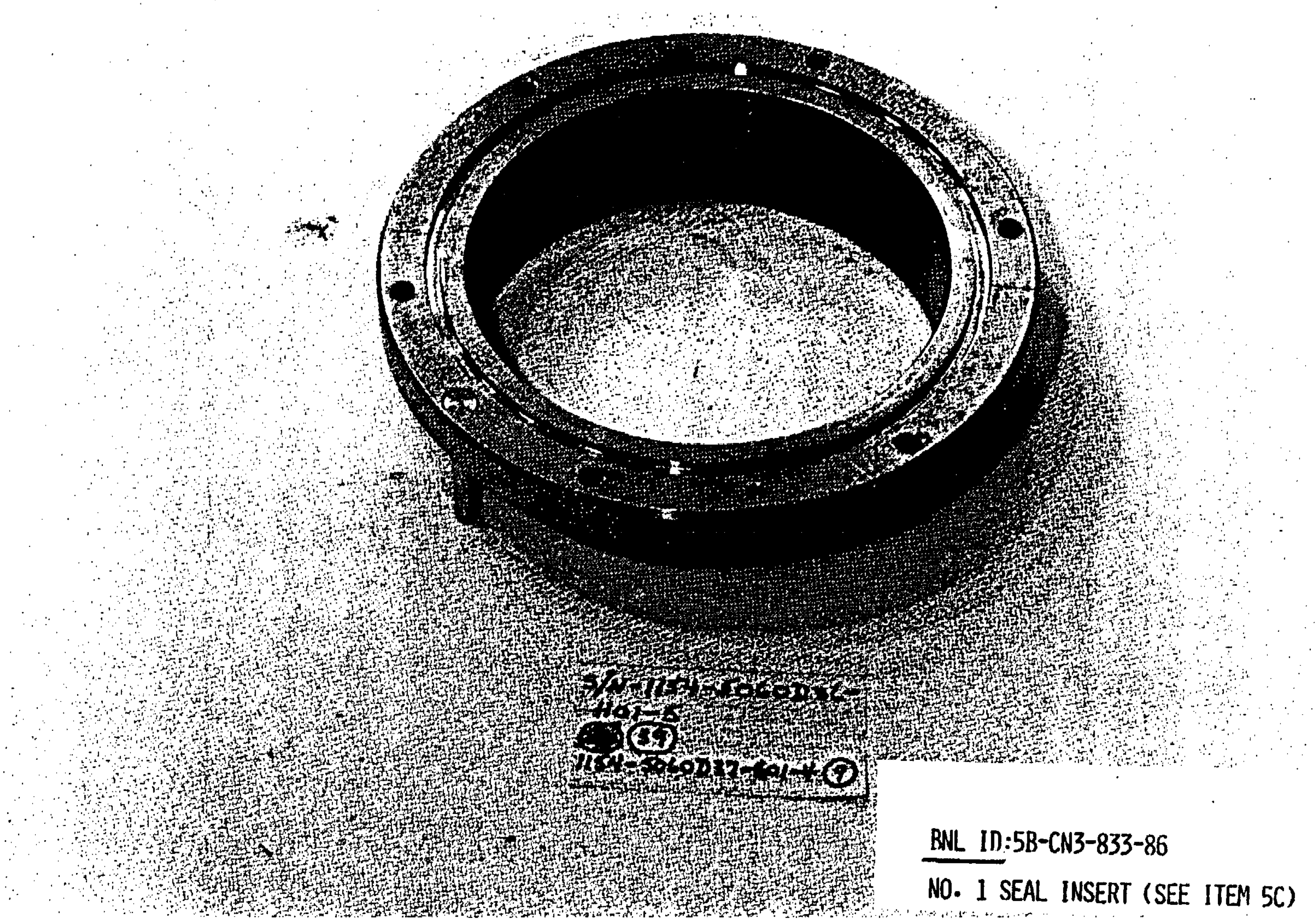
NO. 1 SEAL INSERT (SEE ITEM 5C)



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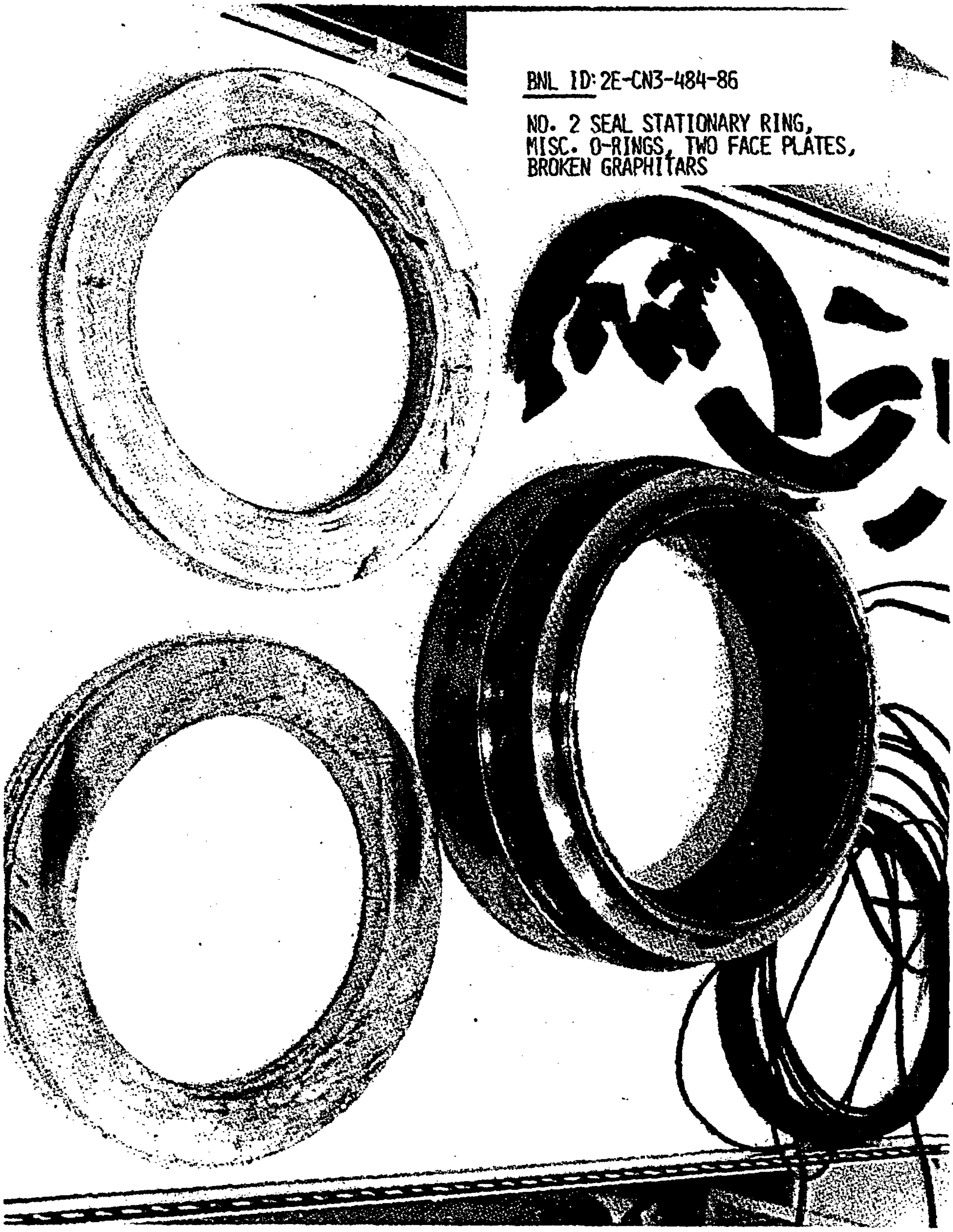
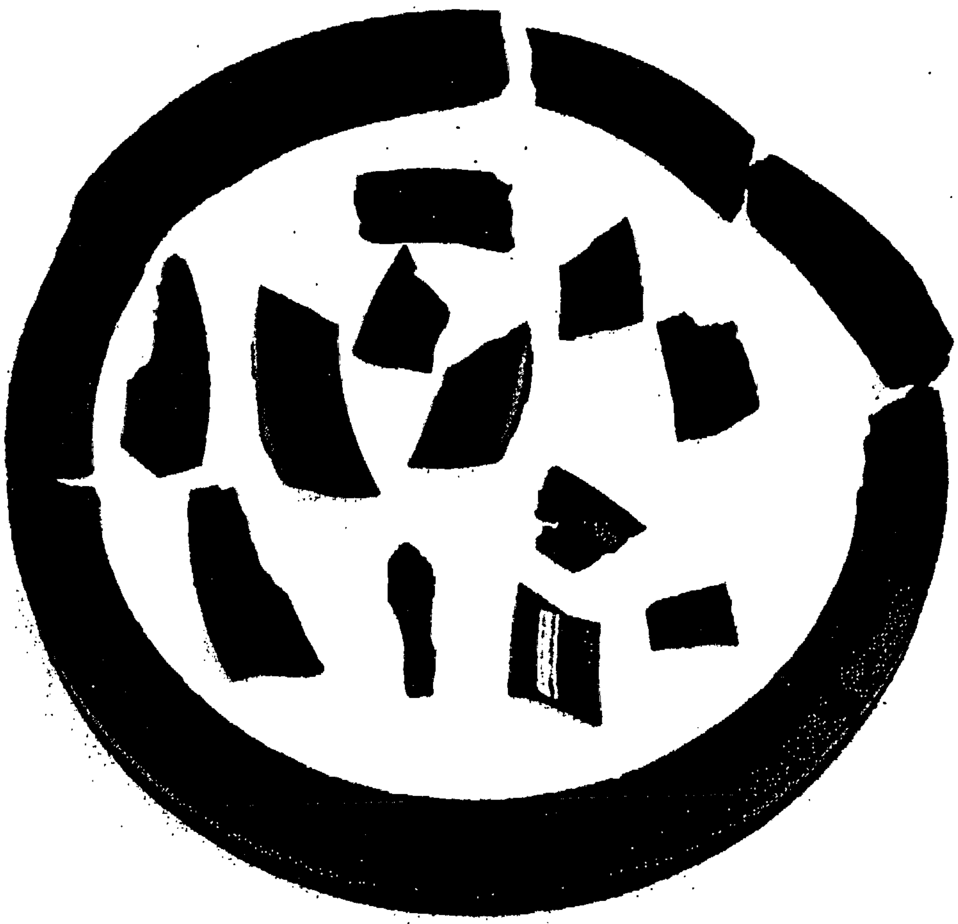

BNL ID: 2E-CN3-484-86
NO. 2 SEAL STATIONARY RING,
MISC. O-RINGS, TWO FACE PLATES,
BROKEN GRAPHITARS



BNL ID: 2B-CN3-482-86

BROKEN GRAPHITAR RING

6354D1133-
910DGM1101-
5 (45)

BNL ID: 2D-CN3-478-86

NO. 2 SEAL RUNNER

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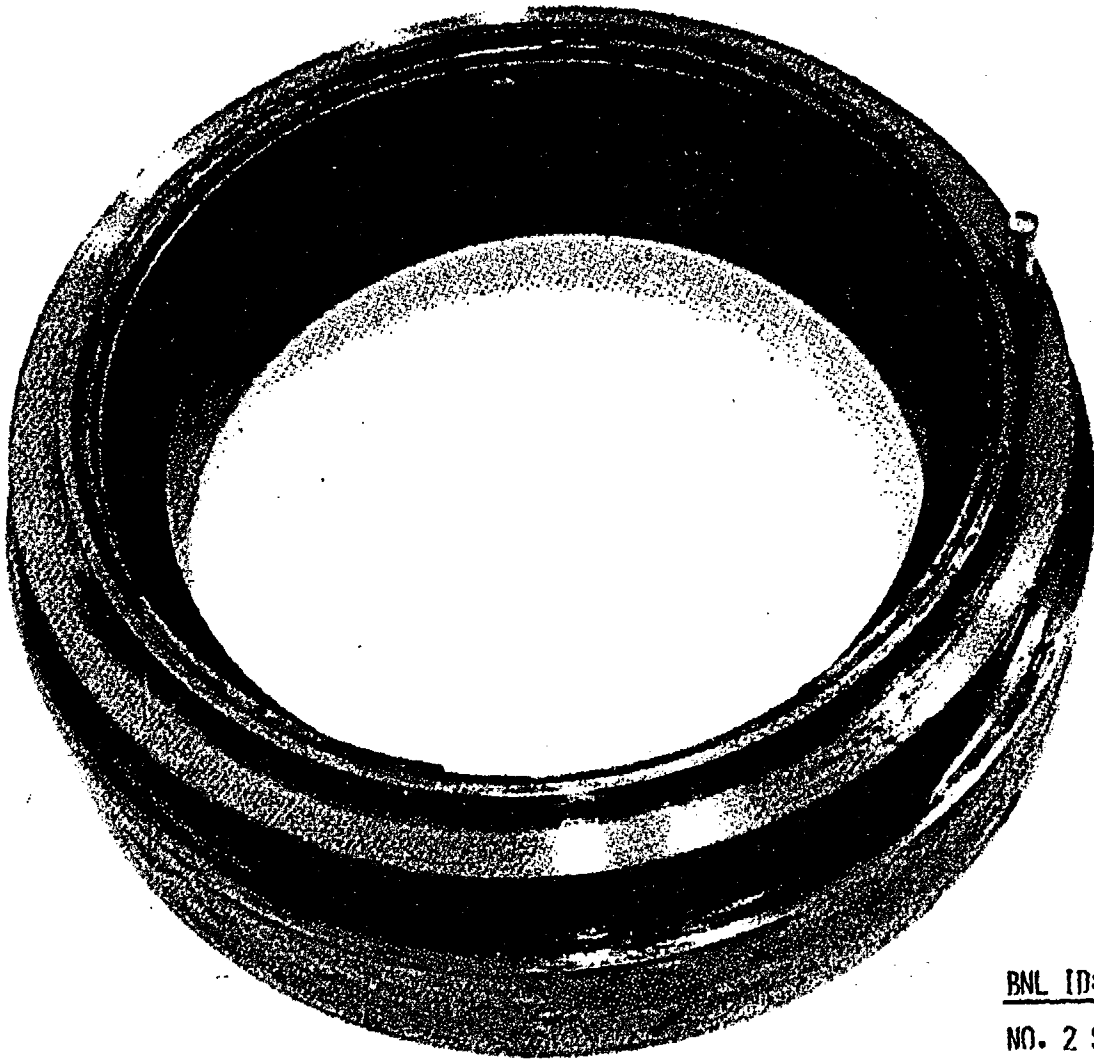
BNL ID: 2D-CN3-479-86

NO. 2 SEAL RUNNER



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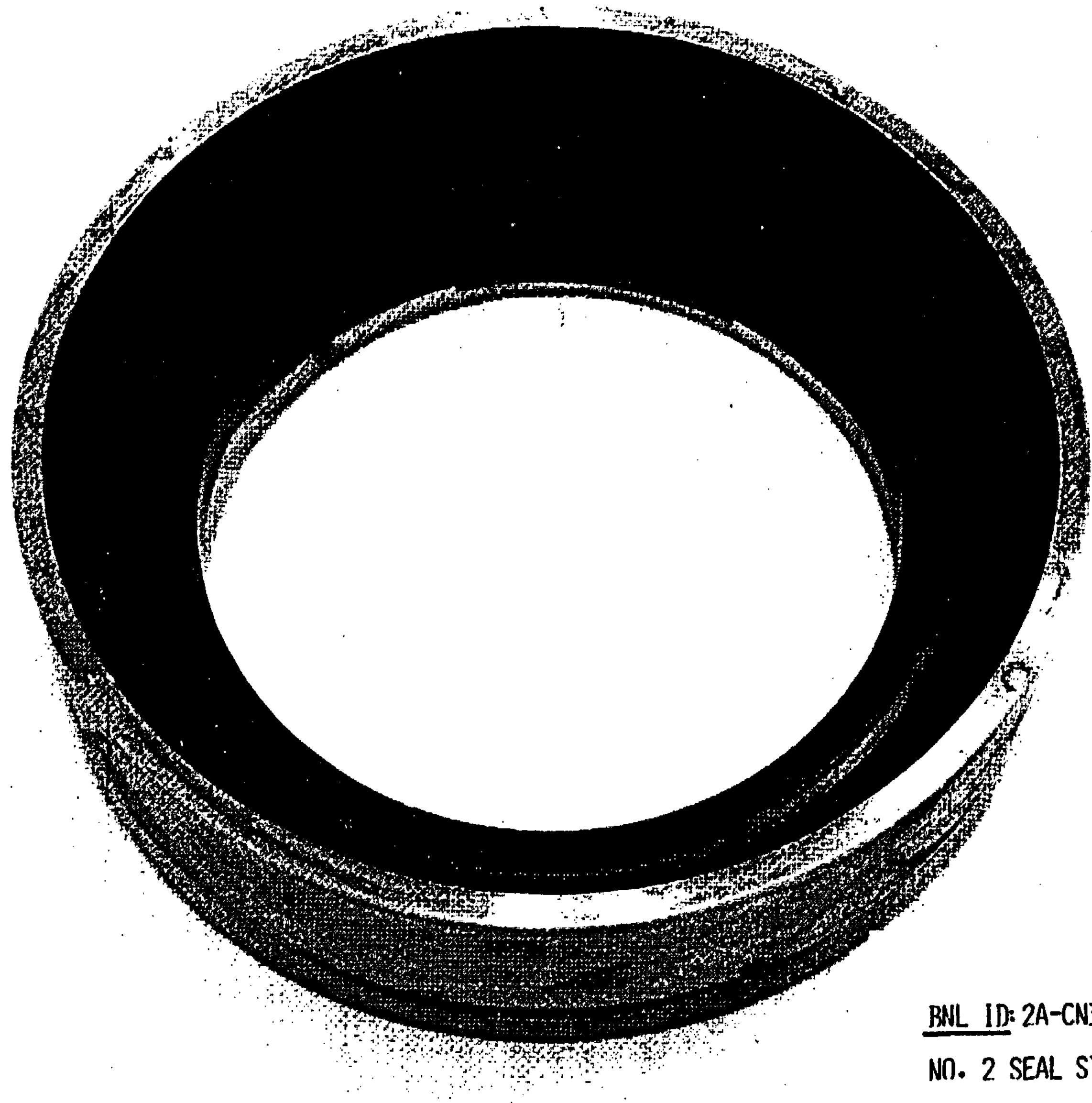

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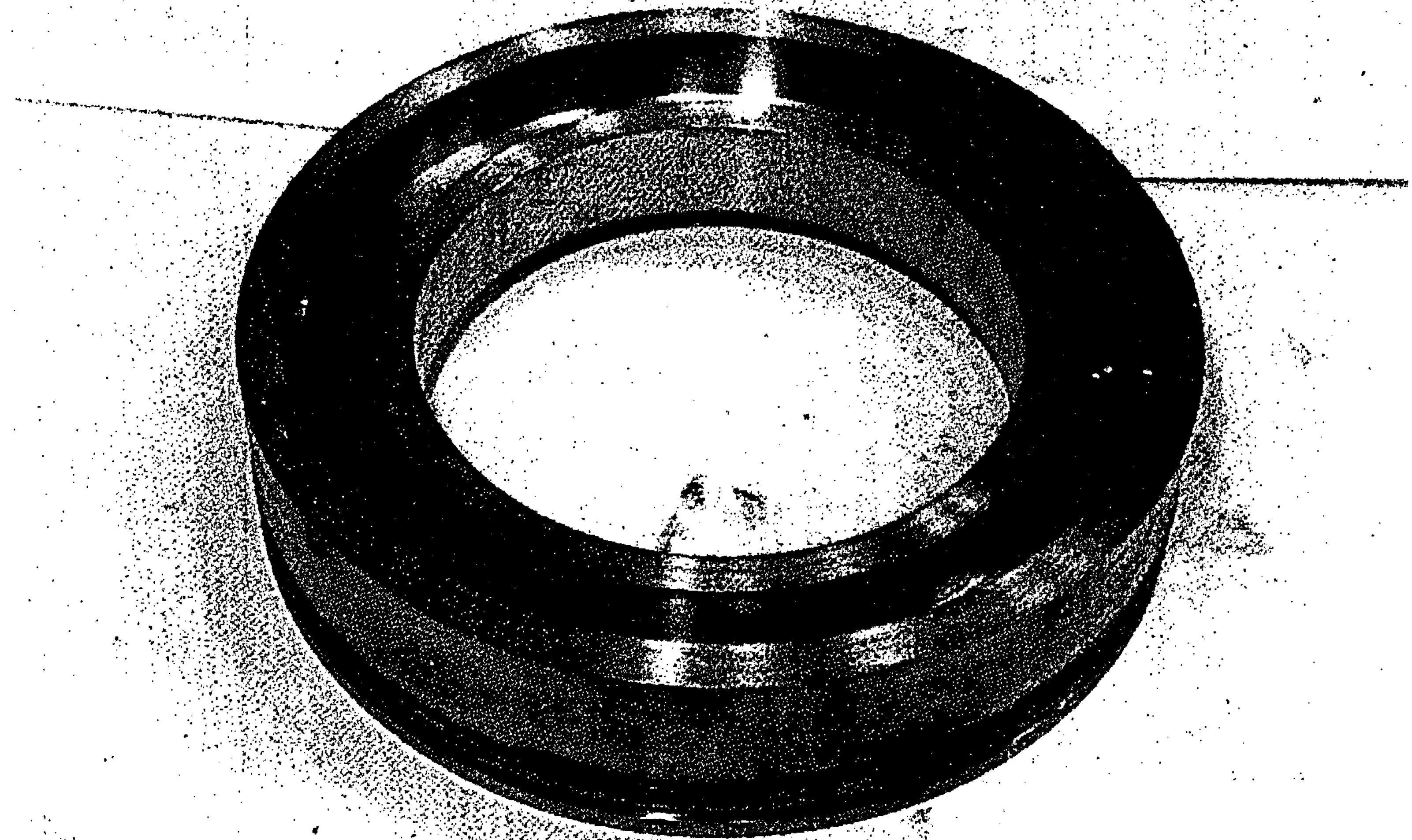

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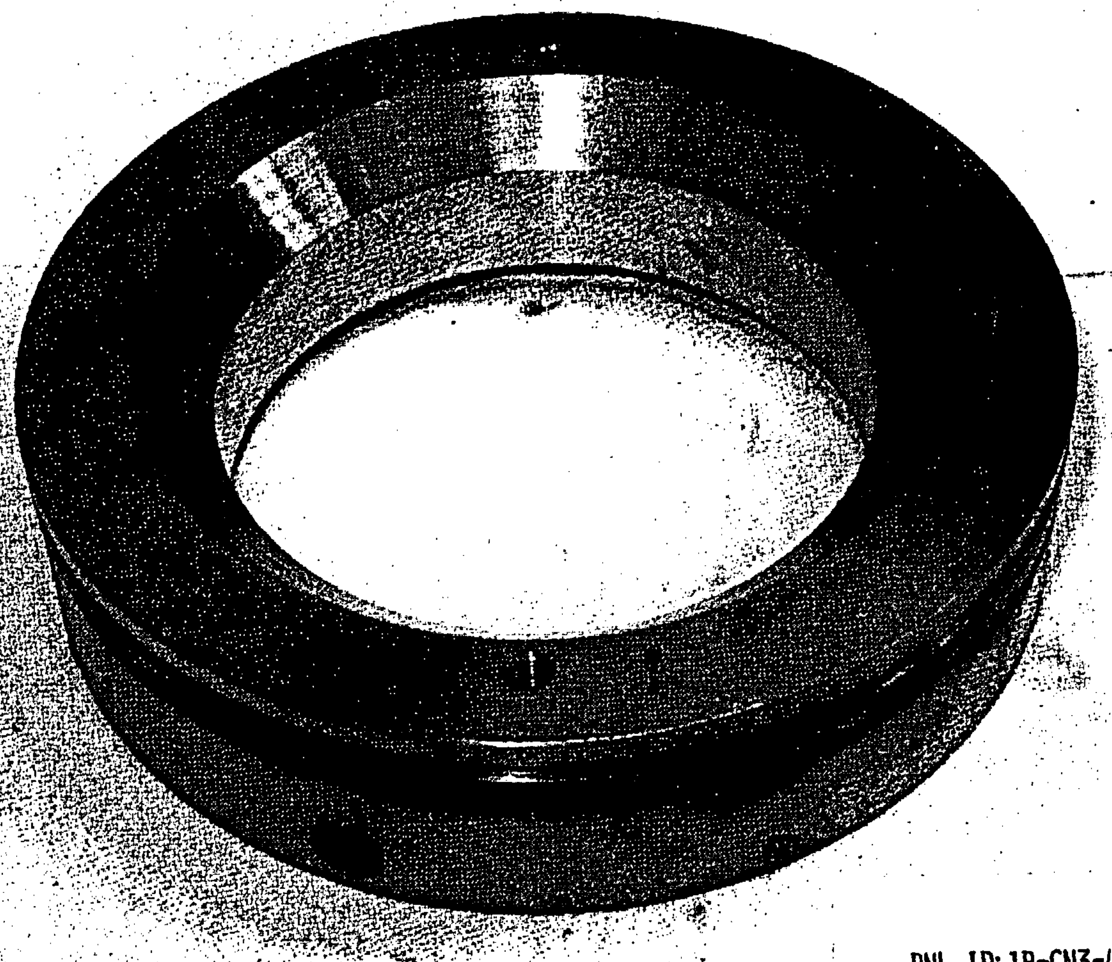

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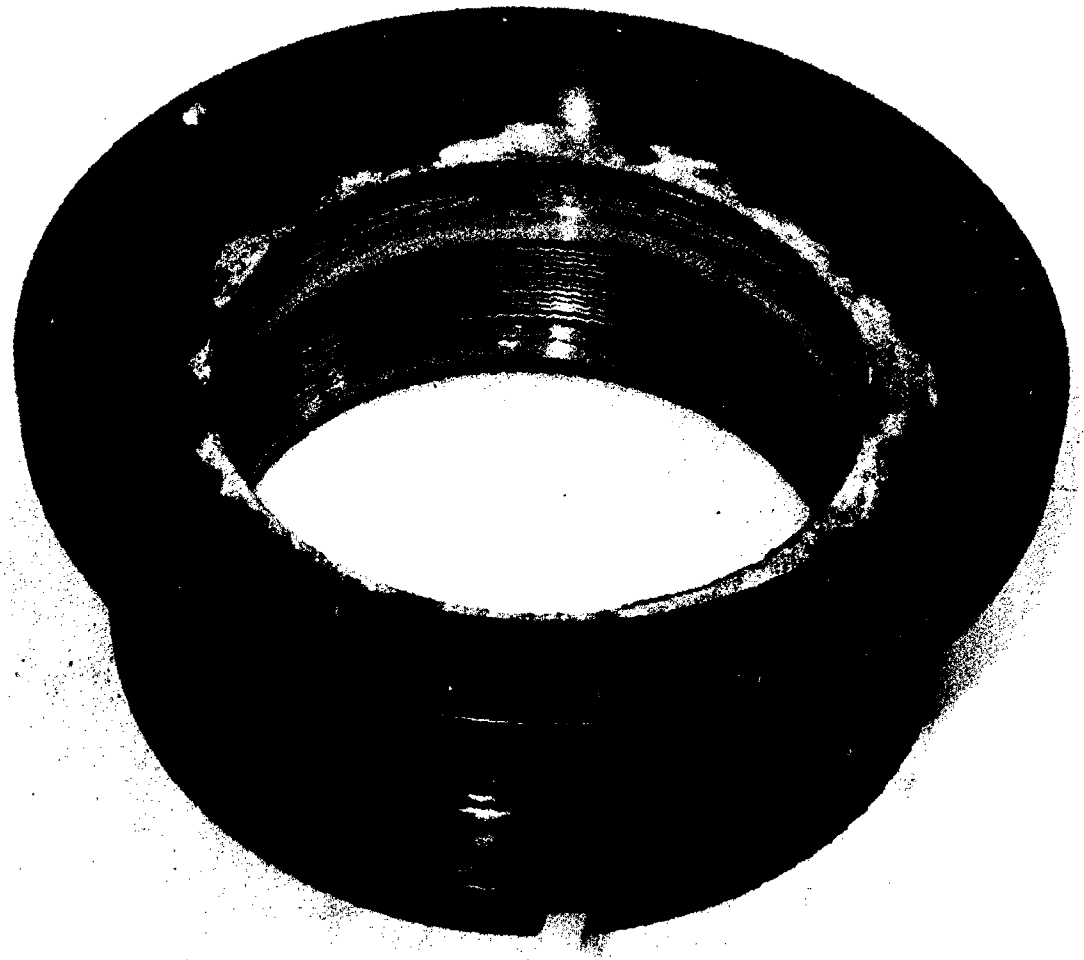

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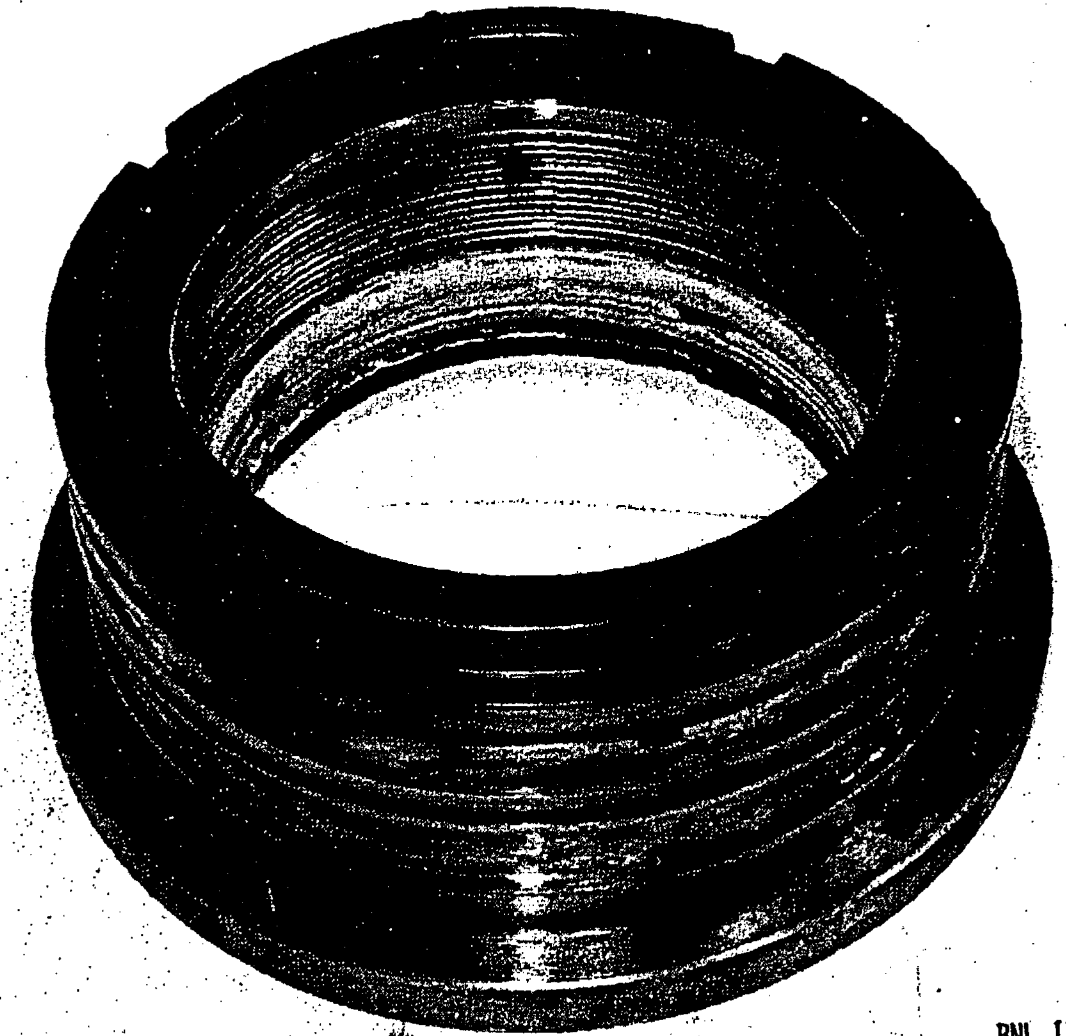

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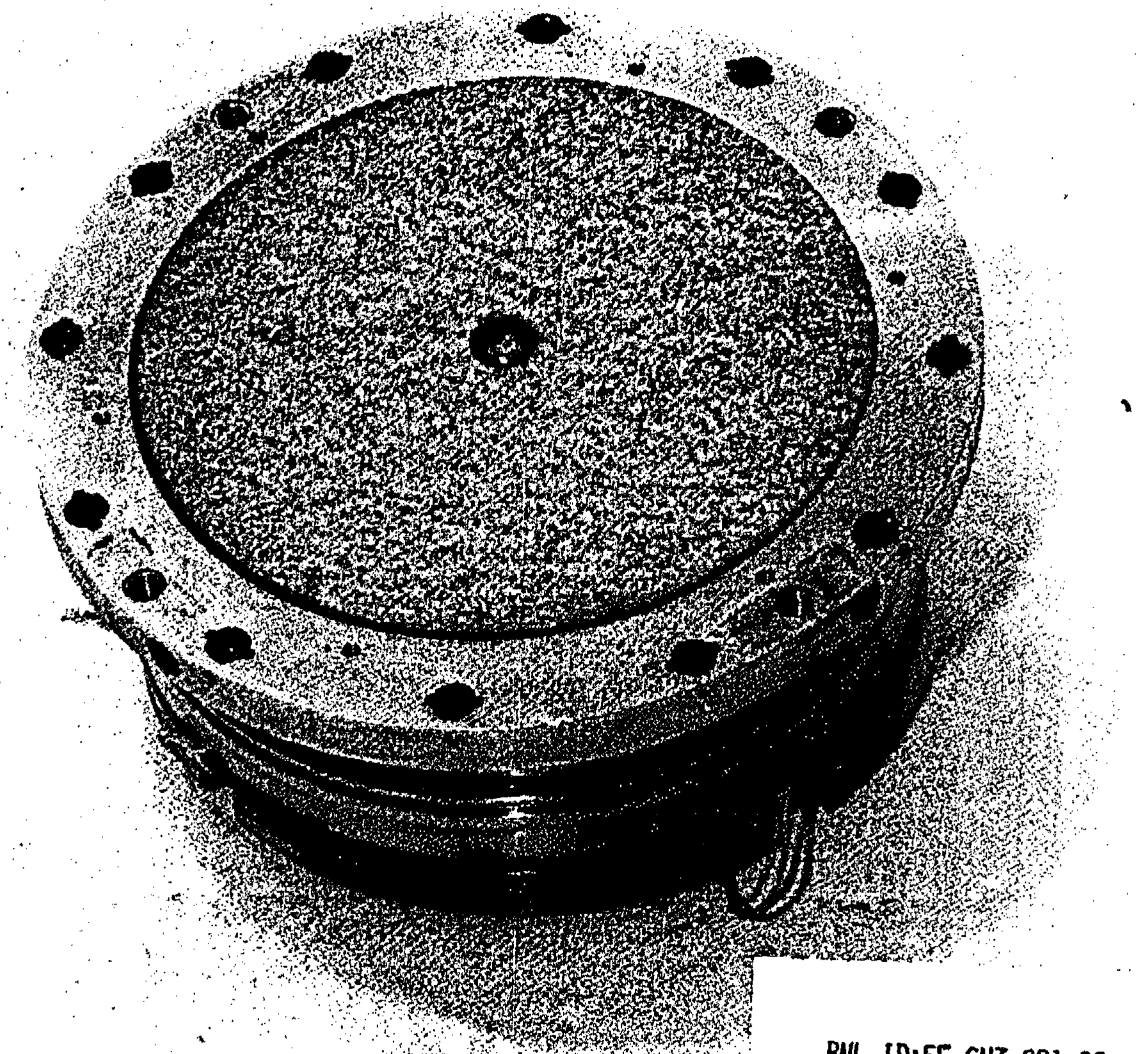

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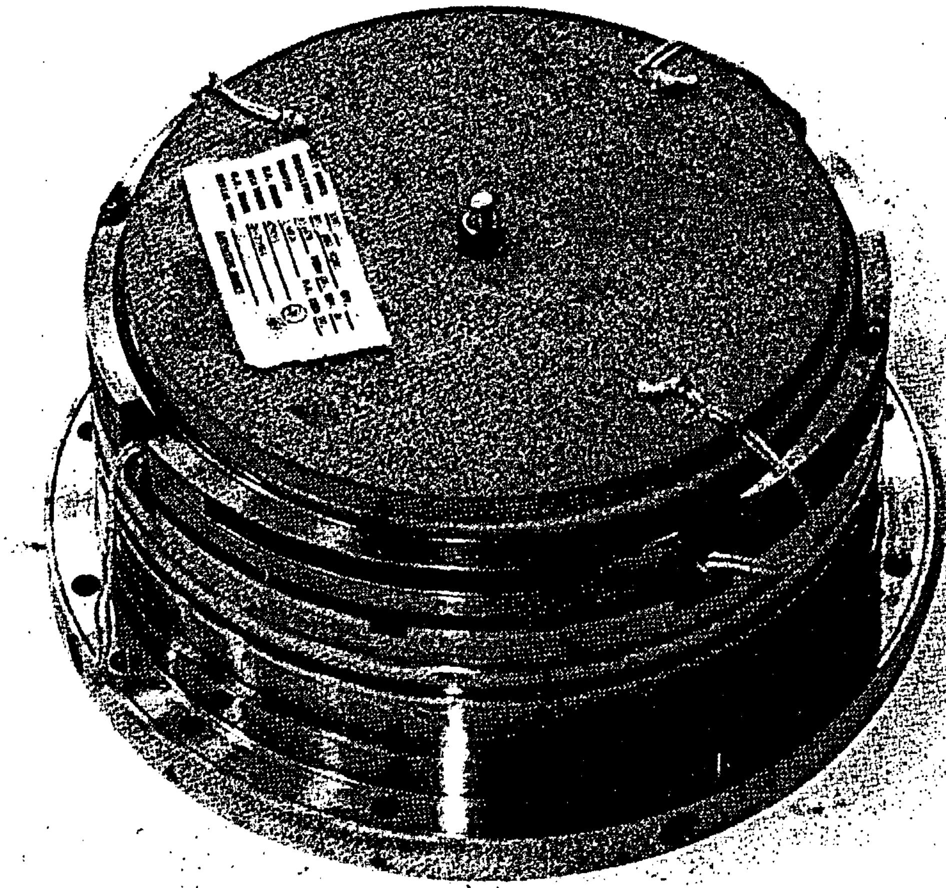

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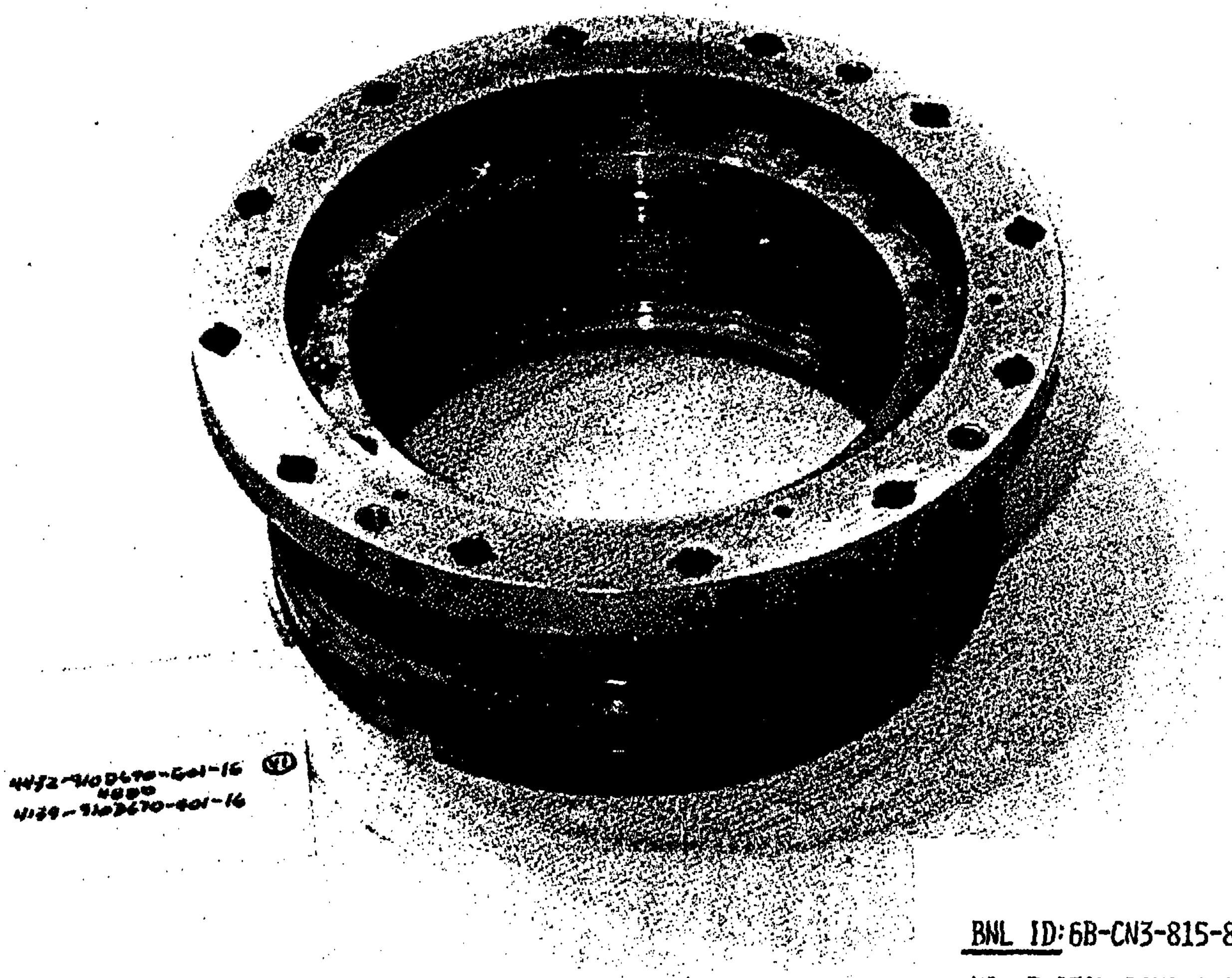

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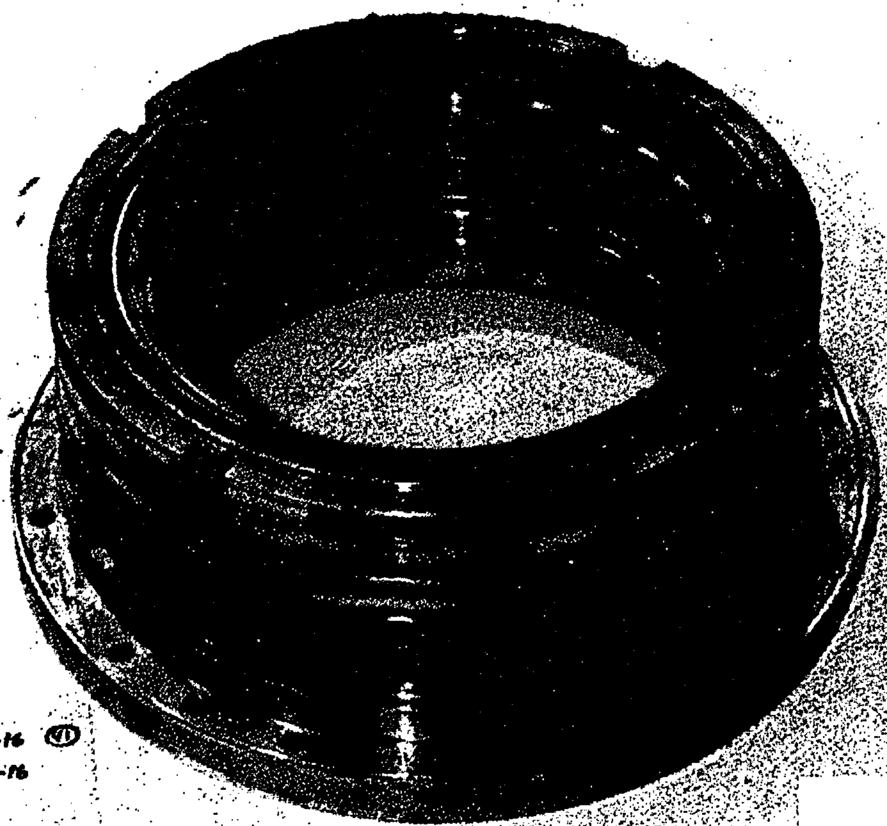

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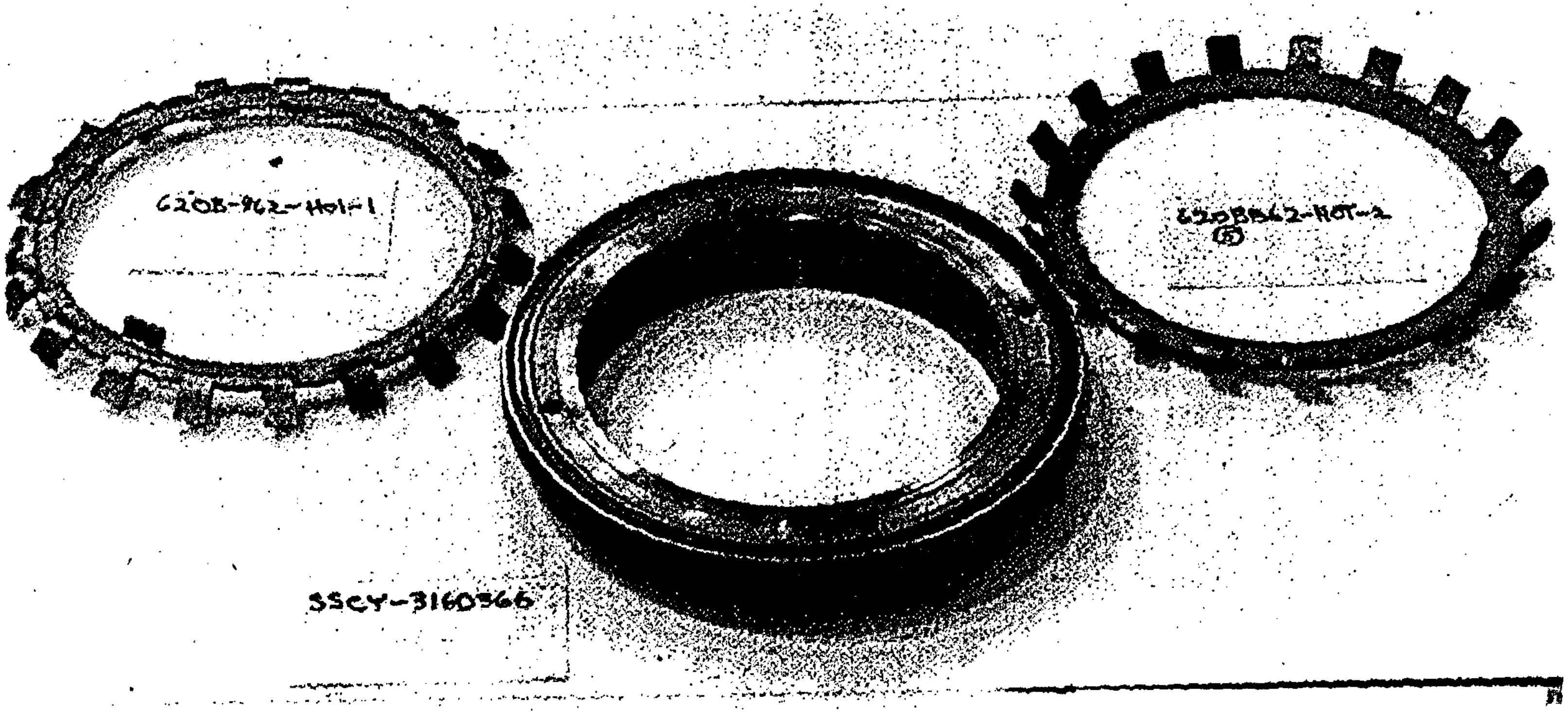

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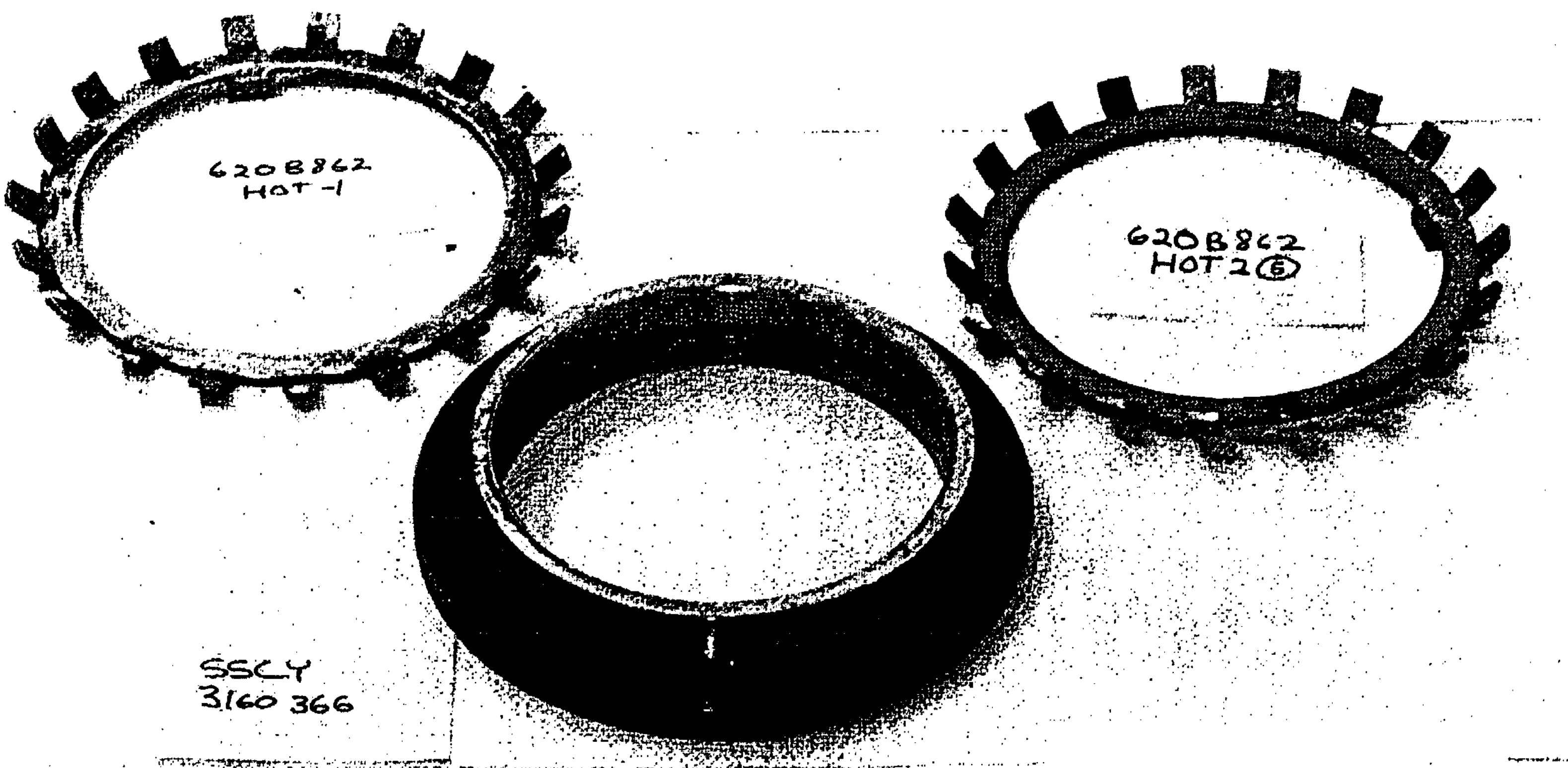
NO. 3 SEAL RUNNER AND
TWO LOCK WASHERS



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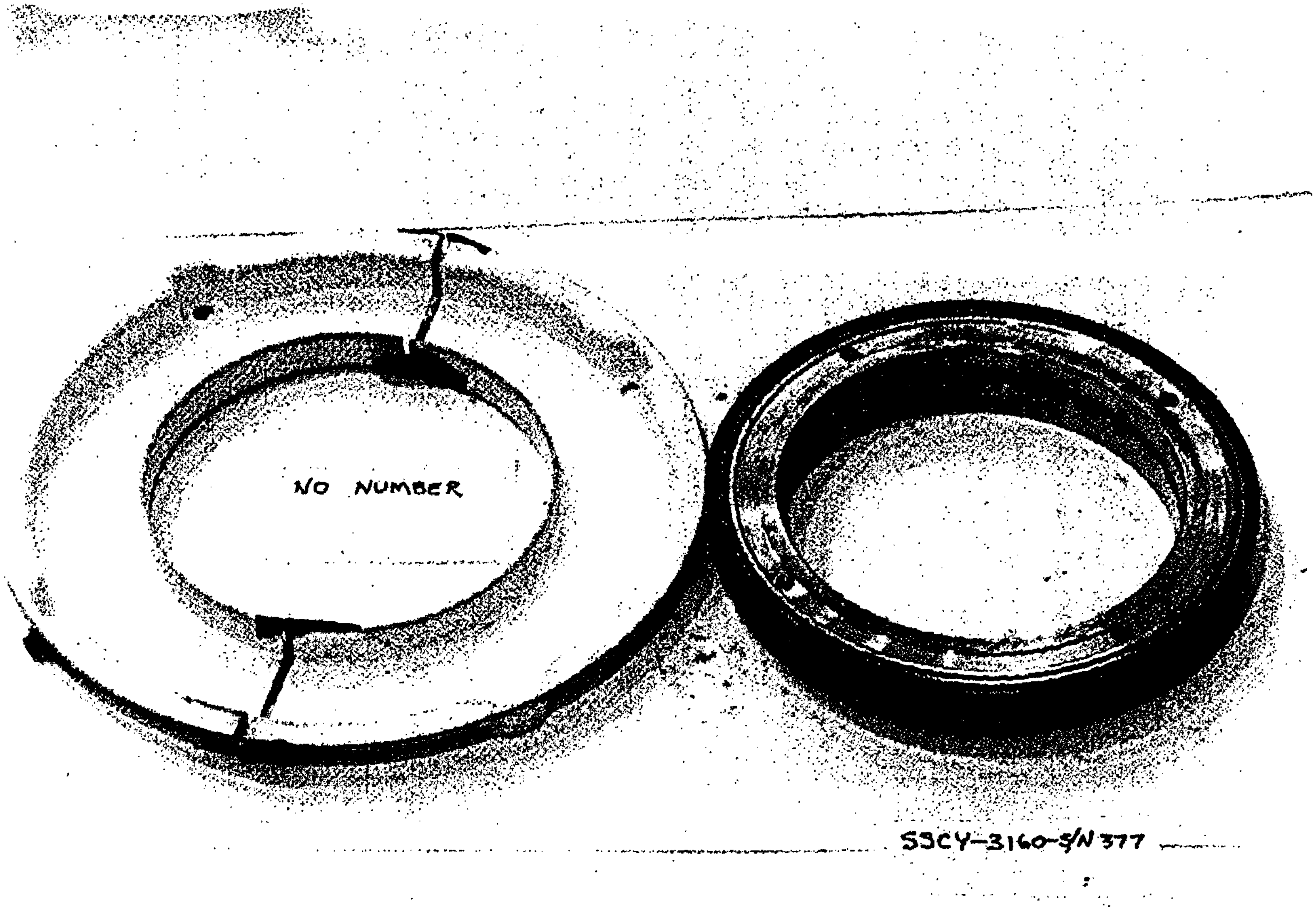

BNL ID:3E-CN3-553-86

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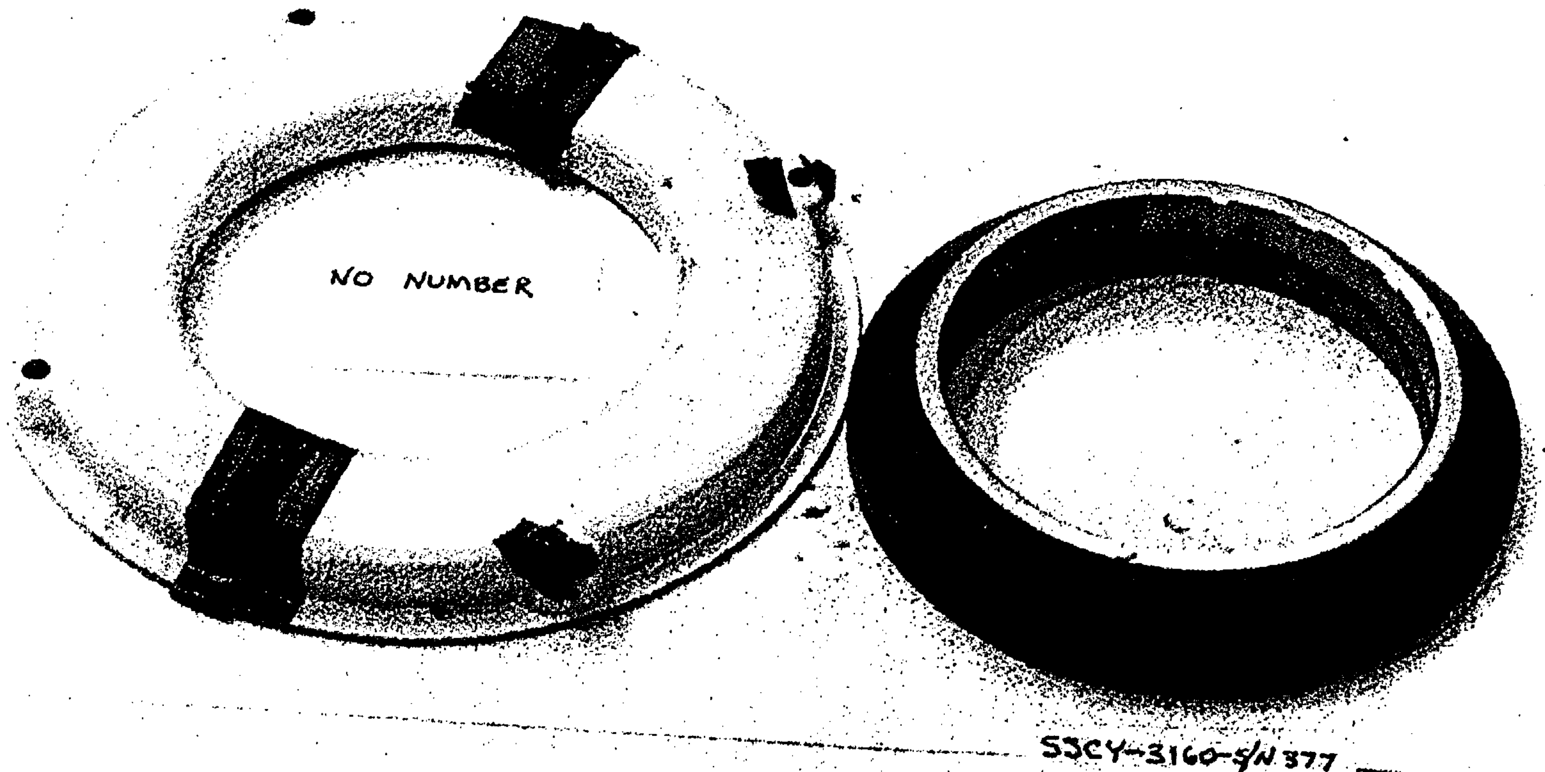

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NO. 3 SEAL RUNNER: SEAL FACE

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This report summarizes the findings on Westinghouse Reactor Coolant Pump Seal Performance at the Indian Point 2 Nuclear Power Station. The study was conducted under the joint sponsorship of Consolidated Edison of New York and the U.S. Nuclear Regulatory Commission Office of Research. The conclusions and recommendations herein are based on the review of the plant operational and maintenance data on seals, consultation with Westinghouse and Utilities, review of prior studies, and visual as well as in-depth examination of service exposed seals received from the plant.

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Failure Analysis

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