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Astronuclear

WANL-TME-655
January, 1964

MASTER

~~Group 1~~
~~Excluded from Automatic D~~
~~and Declassification~~

(23)

SUBMITTED BY:

WESTINGHOUSE ELECTRIC CORPORATION

ASTRONUCLEAR LABORATORY

PITTSBURGH 36, PENNSYLVANIA

Classification cancelled (~~or changed to~~ ________)
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by H. T. C. TIC, date SEP 12 1973

INFORMATION CATEGORY
~~Confidential RD~~
~~K L Rieke 1/20/64~~
Authorized Classifier Date

Prepared By:

K L Rieke
K. L. Rieke, Supervisor

A. I. Miller
A. I. Miller

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ANALYSIS AND DESIGN SIGNIFICANCE OF THE B-3, SINGLE SEAL, HIGH PRESSURE, ISOTHERMAL TEST DATA

(TITLE UNCLASSIFIED)

Approved By:

F. D. Retallick
F. D. Retallick, Manager

SPECIAL REREVIEW
FINAL
DETERMINATION
Class: U

Reviewer	Class.	Date
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ABSTRACT

This report analyzes the available B-3, single seal, high pressure, isothermal test data in compliance with the NRX-A1 Cold Flow Test pre-requisite requirements. The results of the comparison of test data with analytical results indicate that the analytical methods used to predict unheated seal flow characteristics for the NRX-A reactors is satisfactory. Data from the tests reported here, and future seal testing will allow further refinement of the analytical model.

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1.0 INTRODUCTION

Test Specification B-3 of WANL-TNR-095(1)* outlines a series of tests designed to furnish experimental data on the performance of NRX-A, Block I, Lateral Support and Seal System. In broad terms, the objectives of these tests are:

(a) Determination of the loss coefficients for the lateral support and seal system.

(b) Determination of the adequacy of the mechanical and thermal design of the lateral support and seal system and related parts of the core periphery (seal segments, plungers, springs, inner reflector, filler strips).

(c) Verification of the analytical methods used in the design of the NRX-A1, Block I, reactor lateral support and seal system.

The test series include (1) graphite permeability tests, (2) single seal, low pressure, isothermal tests, (3) single seal, high pressure, isothermal tests, (4) multiple seal, high pressure, isothermal tests, (5) single seal, heated graphite tests, and (6) full scale, circular, heated tests.

The results of permeability tests, performed as part of the B-3 test series, on virgin H4LM graphite have been analyzed and reported(4). These data along with the permeability data obtained on the ND215 inner reflector cylinder as initially fabricated indicated that the permeability of the NRX-A1 inner reflector cylinder is more nearly that of virgin H4LM graphite than effectively impregnated H4LM(4). This

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* References listed at the end of report.

permeability has been accounted for in the NRX-A1 test predictions using a correlation derived from the available permeability test data, including that obtained under this test specification.

The single seal, low pressure, isothermal tests performed under this specification were completed, and data reported and analyzed in September, 1963⁽²⁾, ⁽³⁾. The tests were performed on a plexiglas model of a single seal, with low pressure, ambient temperature air. The results of this test were of a purely qualitative nature, due to excessive extraneous leakage within the model, and tended to confirm some of the basic analytical assumptions; namely, that (a) when the seal is seated, with no seal gaps, the leakage flow past the radial seat between the seal segment and the reflector block was much less than the other leakage flows within the model, and (b) the seal restriction acts much like any other turbulent flow restriction device in that its performance can be characterized by a loss coefficient, CL, dependent upon a flow Reynolds Number, N_{Re}.

Initial test results have now been obtained on the flow characteristics of a single flat seal with high pressure hydrogen at ambient temperatures (third series of B-3 tests). This test is designed to model a 1/12th segment of an effective single seal ring of the total of 18 seal rings (16 effective, 2 ineffective) which comprise the NRX-A, Block I, seal system. The more detailed objectives of this single flat seal test include:

(a) Determination of leakage flow characteristics of a seal with no machined grooves or filler gaps for use as a base configuration.

(b) Determination of the flow characteristics of a single seal with axially machined grooves in the seal segment of a depth of $0.007 {}^{+0.001}_{-0.000}$ inches, $0.009 {}^{+0.001}_{-0.000}$ inches, and $0.011\,^{+0.001}_{-0.000}$ inches and a uniform width of $0.440\,^{+0.005}_{-0.000}$ inches, as is designed into the NRX-A, Block I, reactor lateral support and seal system.

(c) Determination of the effect of the filler strip gap, ranging in width from 0.0005 inches to 0.007 inches, on the flow characteristics of a single seal segment.

(d) Determination of the effect of radial steps between adjacent filler strips on the flow characteristics of a single seal.

In addition to these detailed test objectives, an analysis of the high pressure single seal tests is required as a pre-requisite to the running of the NRX-A1 cold flow test. This pre-requisite is stated in WANL-TME-490(7), Page 2, as follows: "Verification of hydraulic design of the nuclear subsystem; in particular, the pressures and flow rates in the numerous paths pertinent to the lateral support region and core periphery." For the NRX-A1 non-nuclear test this consists of verification of the B-3 (lateral support and seal) isothermal flow tests on single and multiple seal systems. For the B-3 multiple seal system, a substitute of the A-11(1) component test data has been made and is analyzed for pre-requisite purposes in a separate report(6).

This report analyzes the available B-3, single seal, high pressure data in compliance with the pre-requisite requirement. The data covers the seal leakage flow characteristics for a seal configuration with no machined seal grooves or filler gaps (Base Configuration) and the seal flow characteristics of a seal segment with a nominal 7 mil machined seal groove ($0.007\,^{+0.001}_{-0.000}$ inches by $0.440\,^{+0.005}_{-0.000}$ inches) over 63.5% of its length. The latter configuration is that of seal rings 12-16 and 18 in the NRX-A1 reactor with the exception that the seal land (i.e., the surface of the seal segment in contact with the filler strip) had a constant width as compared to the variable circumferential width in the reactor design. However, the constant seal land width used in the model corresponds to an effective average seal land circumferential width as would occur in the NRX-A, Block I, seal segment design. In addition, the test model, for this series of tests, used a solid filler block (i.e., no filler strip gap).

The test rig, shown schematically in Figure 1, and described in detail in Test Specification B-3(1), is designed so that flow rates w_1, w_2, w_3, and w_4 and pressure differentials, ΔP_{1-2}, ΔP_{1-3}, and ΔP_{1-4}, across the seal segment, plunger pin, and filler strips, respectively, can be varied over the ranges expected within the reactor. The model of the seal segment differs from a seal segment of the NRX, Block I, design principally in that it is flat. The end restraints on the model seal segment are transmitted through scarf joints similar to the reactor design, as shown in Figure 2.

2.0 CONCLUSIONS

The test results on a single seal with no machined seal grooves indicate that the magnitude of the leakage past the radial seal seat (see Figure 1) and/or the scarf joint (see Figure 2) is equivalent to approximately a 0.001 inch gap all around the core periphery. The analysis of the lateral support and seal system has heretofore assumed that this radial seat was completely effective and no leakage occurred. The addition of this 0.001 inch gap results in a negligible change in seal pressure distributions and will, therefore, not significantly affect any of the NRX-A1 test analyses. However, the small increment in seal flow rate which results could affect the seal temperature distributions slightly during powered operation. Additional tests will be performed with the greater depth seal grooves and with various sizes of filler strip gap, and the effect of the seat leakage will be determined over the complete range of flow geometries as expected within the NRX-A, Block I, reactors under all operating conditions. Incorporation of the effect of radial seat leakage into multi-seal analyses must await the results of these further tests and is a pre-requisite to nuclear powered operation of the reactor.

Due to the present uncertainty as to the actual source of this leakage - past the radial seat or through the seal segment scarf joint - additional analytical and experimental investigations should be pursued to establish the nature of the source.

The initial test results on a nominal 7 mil seal gap configuration (seal groove dimensions $0.007^{+0.001}_{-0.000}$ inches deep by $0.440^{+0.005}_{-0.000}$ inches wide) with no filler strip gap have been reviewed and compared with analytical predictions. This comparison shows good correlation (± 20%, within the spread of the experimental data) between test data and analytical results if the estimated radial seat leakage is added to the analytically predicted seal groove flow rate. On the basis of this correlation between the initial test data and analytical results, it appears that the analytical methods used and assumptions made to predict the unheated single seal flow characteristics are reasonable, and may be used with confidence for the NRX-A1 flow conditions.

3.0 DISCUSSION

3.1 Experimental Data

The initial test results available encompass the two flow configurations previously described - the base configuration and the nominal 7 mil seal groove configuration. Although no detailed dimensional inspection of the machined grooves was made, spot checks indicated that the depth of the machined groove in the second configuration was probably close to 0.008 inches rather than the nominal 7 mil groove.

Test results for three separate tests on the base configuration and two tests on the nominal 7 mil seal gap configuration are plotted in Figure 3 as mass flow rate versus the product of inlet density and pressure differential across the seal segment.

The experimental data shown plotted in Figure 3 was obtained with unimpregnated H4LM graphite components. However, porous flow effects were minimized by maintaining the spring chamber pressure and the core side filler strip pressure equal to the upstream seal pressure. This eliminated any porous flow into the upstream seal chamber. Thus, porous flow could only occur axially through the seal segment and through the downstream portions of filler block and reflector block as porous bypass of the radial seal seat. A check on the magnitude of the axial porous flow through the seal segment and the porous bypass of the radial seal seat using a previously developed porous flow correlation(4) for H4LM graphite, showed values from 50 to 100 times less than the measured inlet flow rates. The porous flow which could occur through the downstream side of the filler strip block and the reflector block should not significantly effect the flow characteristics of the seal itself.

Initial test results for two separate tests on the nominal 7 mil seal gap configuration are also plotted in Figure 3. These data indicate flows about twice the base configuration leakage flow and having approximately the same functional relation between flow rate and the product of density and seal pressure differential.

3.2 Data Analysis

3.2.1 Base Configuration (No Machined Seal Grooves, No Filler Strip Gaps)

The data plotted in Figure 3 for the base configuration indicates that leakage flow exists when the seal has no machined grooves and is firmly butted against a solid filler block and the radial seal seat of the reflector block. The possible sources of this leakage are as follows:

(a) Extraneous test rig leakage,
(b) Leakage through the seal segment joints,
(c) Leakage under the circumferential seat,
(d) Leakage through the radial seat.

Although the possibility of the existance of extraneous test rig leakage cannot be definitely ruled out, it can be said that its likelihood is extremely small. The testing personnel have accomplished this by using well-established test model design and testing techniques, all tending to minimize any extraneous leakage.

The leakage path through the seal segment joint is a complex one as shown by Figure 2. However, a crude estimate of this leakage has been made based upon a 0.006 inch gap betweenthe angled faces of the joint. The calculation, for the two joints in the test rig, showed a flow rate which was at least one order of magnitude less than the measured flow rates of the base case. Due to the crudeness of this original estimate, further analytical and experimental investigation of the order of magnitude of this potential seal bypass flow is being pursued.

Thus, it appears that the great bulk of the leakage flows measured went through the radial seat between the seal segment and reflector block (see Figure 1a) and under the circumferential seat between the filler strips and the seal segment (see Figure 1b). Although both of these seats are theoretically area seats, it is likely, because of perpendicularity variations between mating surfaces, that only a line contact exists at both interfaces.

The data points plotted in Figure 1 show that the relationship between the leakage flow rate, w, and the product of the density, ρ, and pressure drop, ΔP, is of the turbulent flow type, i.e.,

$$w \propto \sqrt{\rho \, \Delta P} \tag{1}$$

With the assumptions that the line contact at both interfaces acts like an orifice restriction with an effective discharge coefficient of 0.65, and that an equal quantity of flow passes both seats in parallel, an effective gap width of approximately 1 mil can be calculated. Considering the nature of the machined graphite surfaces, ("nominal" surface finish of 63 μ in. with large voids scattered throughout) this is not an unreasonable value.

3.2.2 Nominal 7 Mil Machined Seal Groove

An analysis has been performed on the nominal 7 mil machined groove seal test configuration using the same methods as are normally employed in the lateral support and seal analysis. These methods, which are embodied in the SCAP(5) computer program, were applied to the single unheated seal of the test configuration. A relation between the flow rate passing through the machined seal grooves and the product of the density and seal pressure differential was determined for two groove sizes - 0.0075 inches x 0.4425 inches and 0.008 inches x 0.445 inches - representing expected average nominal design dimensions and the maximum design dimensions, respectively. As noted previously, a cursory dimensional inspection of the test specimens indicated that the actual seal groove size was close to the maximum design value. The calculated seal flow characteristics are plotted as curves A and B, respectively, on Figure 3. Since the analysis does not include any of the leakage flow through the radial seal seat and circumferential seal seat shown in Figure 1, the calculated seal flow rates fall below the experimental data. The effect of leakage past the radial seal seat and past the circumferential seat at the seal lands can be obtained from the base configuration data. Two possibilities have been considered - leakage occurs only past the radial seat (i.e., there is no leakage under the seal lands) and leakage occurs past both the radial seat and the seal lands. In the former case, half the leakage flow has been added to calculated seal flow at a given value of $\rho \, \Delta P$, and in the latter case, $0.685 \left[0.5 + 0.5 \, (1-0.635)\right]$ of the leakage flow has been added to the calculated seal flow. These total flows are also plotted respectively as curves C, D, and E in Figure 3. As shown, the addition of the leakage flow brings the calculated values into good agreement with the experimental data.

In an actual NRX-A, Block I, core build-up, there are gaps between adjacent filler strips and radial stepping gaps between the filler strips and the seal segments in addition to the machined seal grooves. For the NRX-A reactors assembled to date, ND101 and ND201, the magnitude of the nominal average filler gap and the equivalent average stepping gap, evaluated from "as-assembled" dimensional inspections, were in the ranges of 0.00082 - 0.00103 inches and 0.00240 - 0.00273 inches maximum, respectively. The flow under the seal segment lands will be governed by the radial stepping gap rather than by the interface with the filler strips. Thus, only the leakage passing the radial seat is applicable to the NRX-A design.

The radial seat leakage has been estimated to be equivalent to an average peripheral gap of about 0.001 inches. In terms of total seal flow area (groove + filler gap + stepping gap + radial seat leakage gap) this is only slightly more than 10% for the minimum depth seal groove and decreases to about 7% for the maximum depth seal groove. Additional seal flow areas above this magnitude and greater have been considered in design analyses of seal tolerance build-up.

Typical results of these analyses are shown in Figures 4 and 5 where the seal pressure distributions and seal flow rates are plotted for the NRX-A1 configuration with and without the equivalent seat leakage area (1 mil) at an ambient hydrogen flow rate of 25 lbs/sec. The detailed dimensions for the configurations are as follows:

Dimensions (inches)

Seal No. and Slot Depth			Slot	Filler	Plunger	Filler Strip
2-6	7-4	12-16, 18	Width	Strip Gap	Clearance	Radial Step
0.012	0.010	0.008	0.440	0.00103	0.00033	0

Total Flow Areas (square inches)

	Seal No.		
	2-6	7-11	12-16, 18
No seat leakage	.940	.798	.655
With seat leakage through equivalent area of 1 mil x core circumference	1.065	.923	.780

The total flow area includes that for the seal segment groove plus the filler strip gap (plus the equivalent leakage flow area in the second case above).

The above dimensional data indicates that the inclusion of the equivalent seat leakage flow area results in a seal flow area increase varying from 13% at the first five seals to 19% for the last six seals. Comparison of the pressure distributions show only a maximum difference of 1/2 psi (0.3%). Thus, the additional 1 mil gap, resulting from radial seat leakage, has only a small effect on the seal pressure distribution. However, the addition of this equivalent 1 mil leakage gap increases the inlet seal flow rate by about 6% and the accumulated flow at exit by about 2%.

Incorporation of this additional leakage area is not deemed necessary for NRX-A1 test analyses since it will have a negligible effect on the pressure distribution. However, its incorporation into the NRX-A2 reactor analyses must be evaluated when additional test data becomes available, since the increased seal flow rate may effect the temperature distributions in the seal regions slightly.

4.0 REFERENCES

(1) WANL-TNR-095 - NRX-A Component Test Program.

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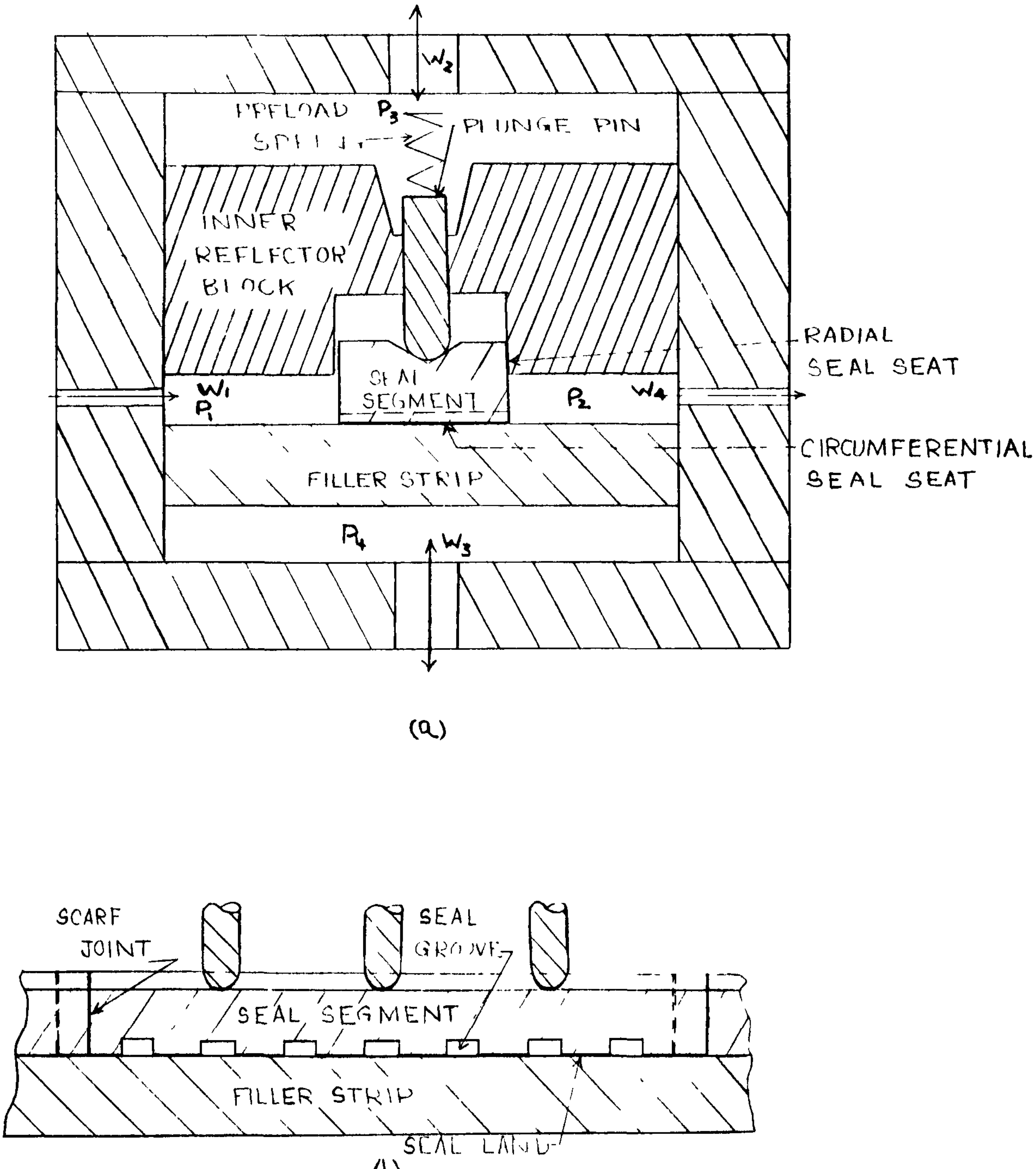
(5) WANL-TNR-045 - A Single Channel Analysis Program (SCAP) for the Temperature Distribution in an Internally-Cooled Heat Generating Solid Cooled by a Compressible Gas - B. L. Pierce, February, 1962.

(6) WANL-TME-630 - Analysis and Design Significance of A-11, Flow Induced Vibration Test, Phases I and III - O. P. Gormley, K. L. Rieke, A. I. Miller.

(7) WANL-TME-490 - Prerequisites for Full Scale Reactor Tests - W. H. Arnold, August 19, 1963.



(a)

(b)

SCHEMATIC OF SINGLE SEAL, HIGH PRESSURE, ISOTHERMAL TEST RIG

FIGURE 1

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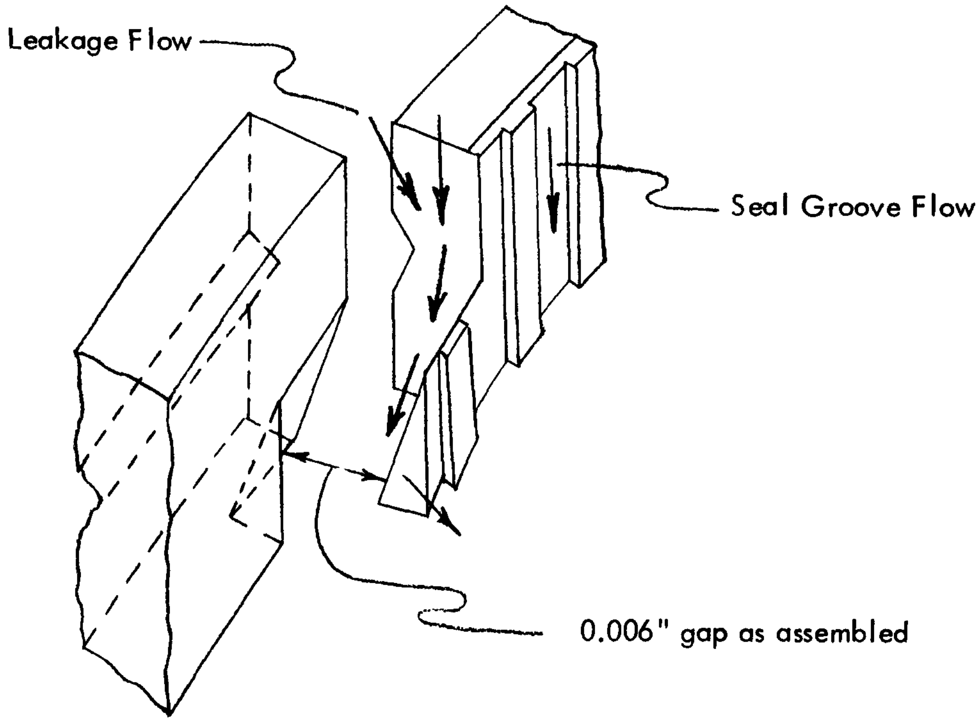

SCARF JOINT OF SEAL SEGMENT

FIGURE 2

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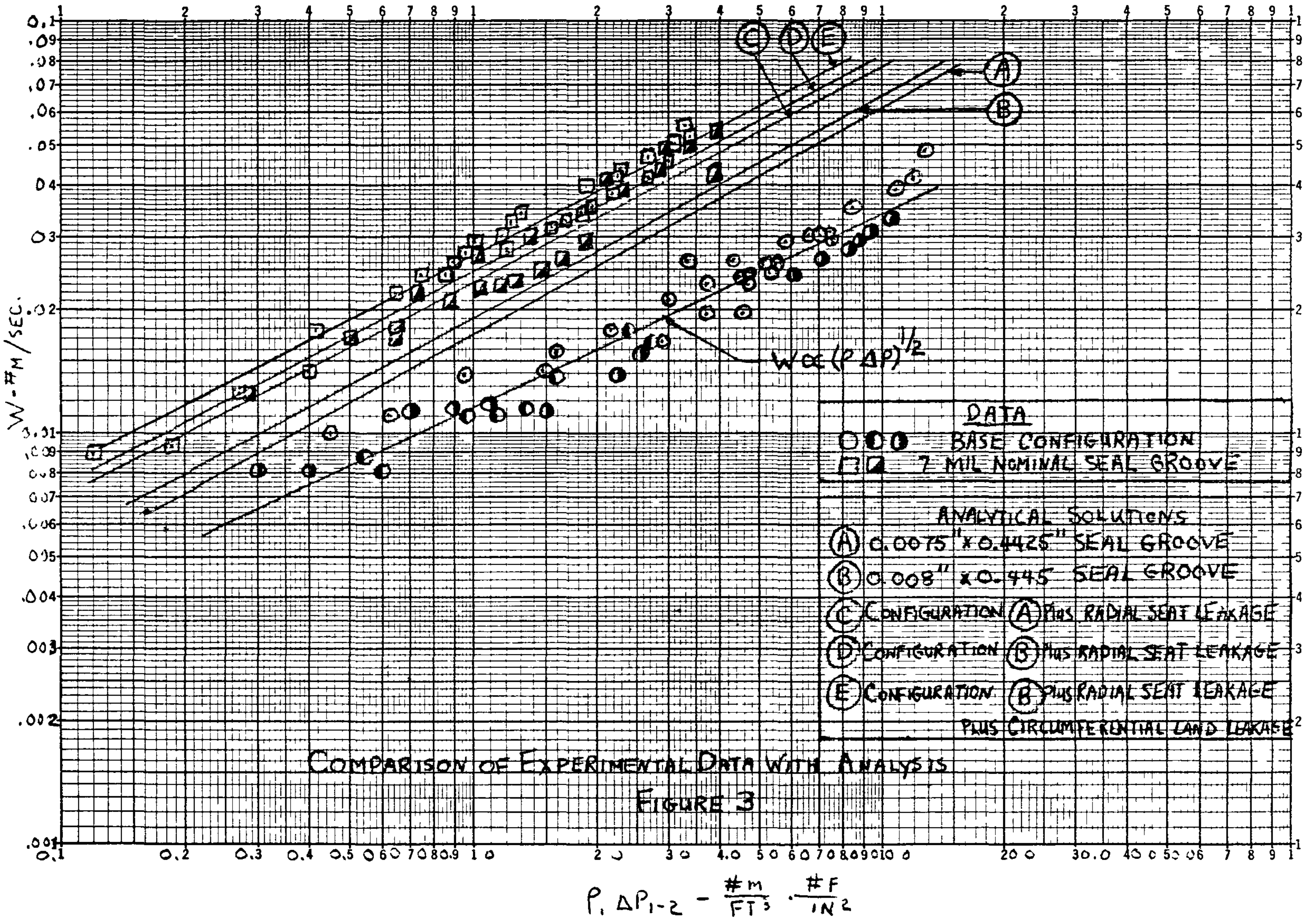

COMPARISON OF EXPERIMENTAL DATA WITH ANALYSIS

FIGURE 3

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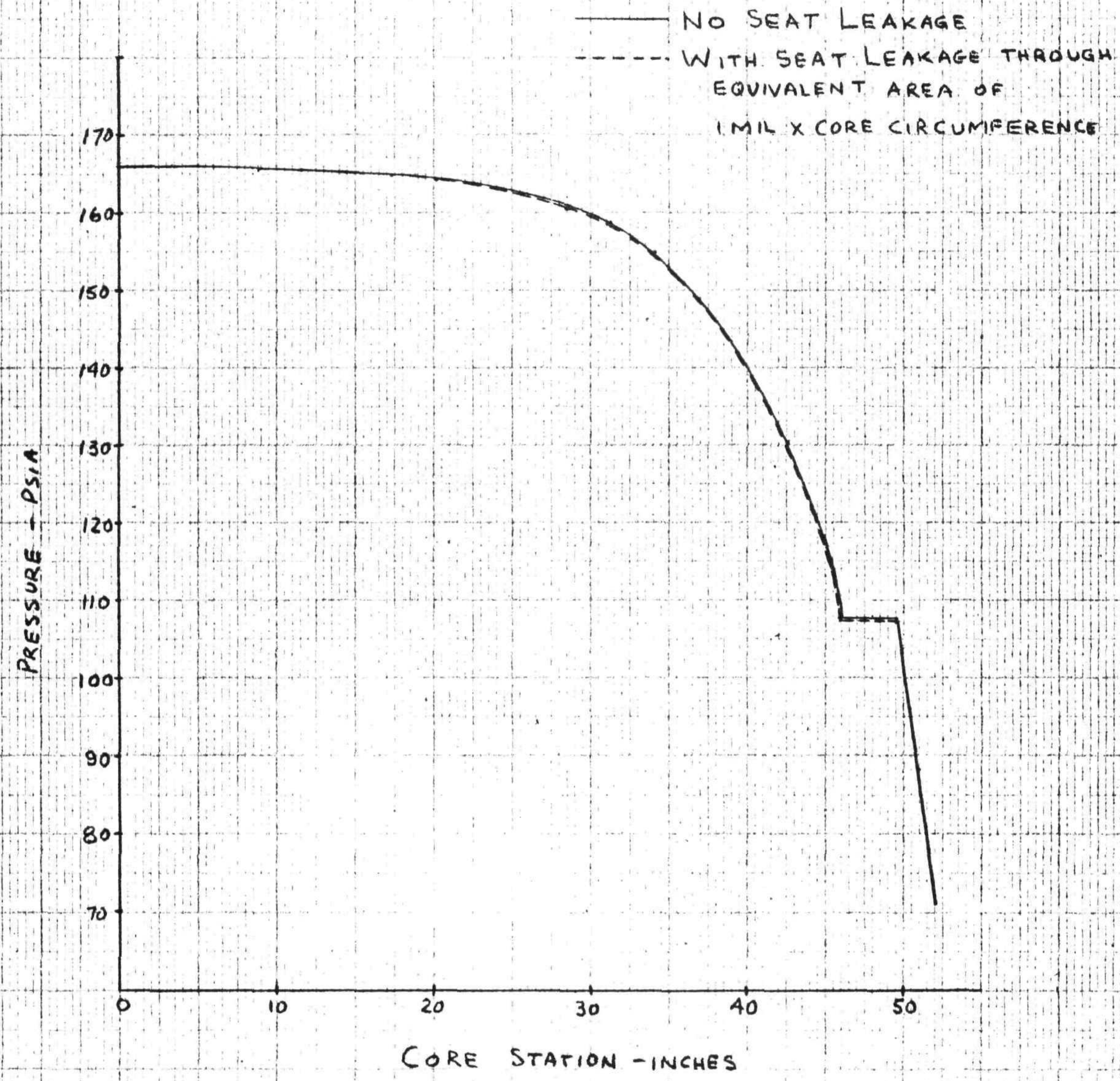

EFFECT OF RADIAL SEAT LEAKAGE ON PRESSURE DISTRIBUTION

FIGURE 4

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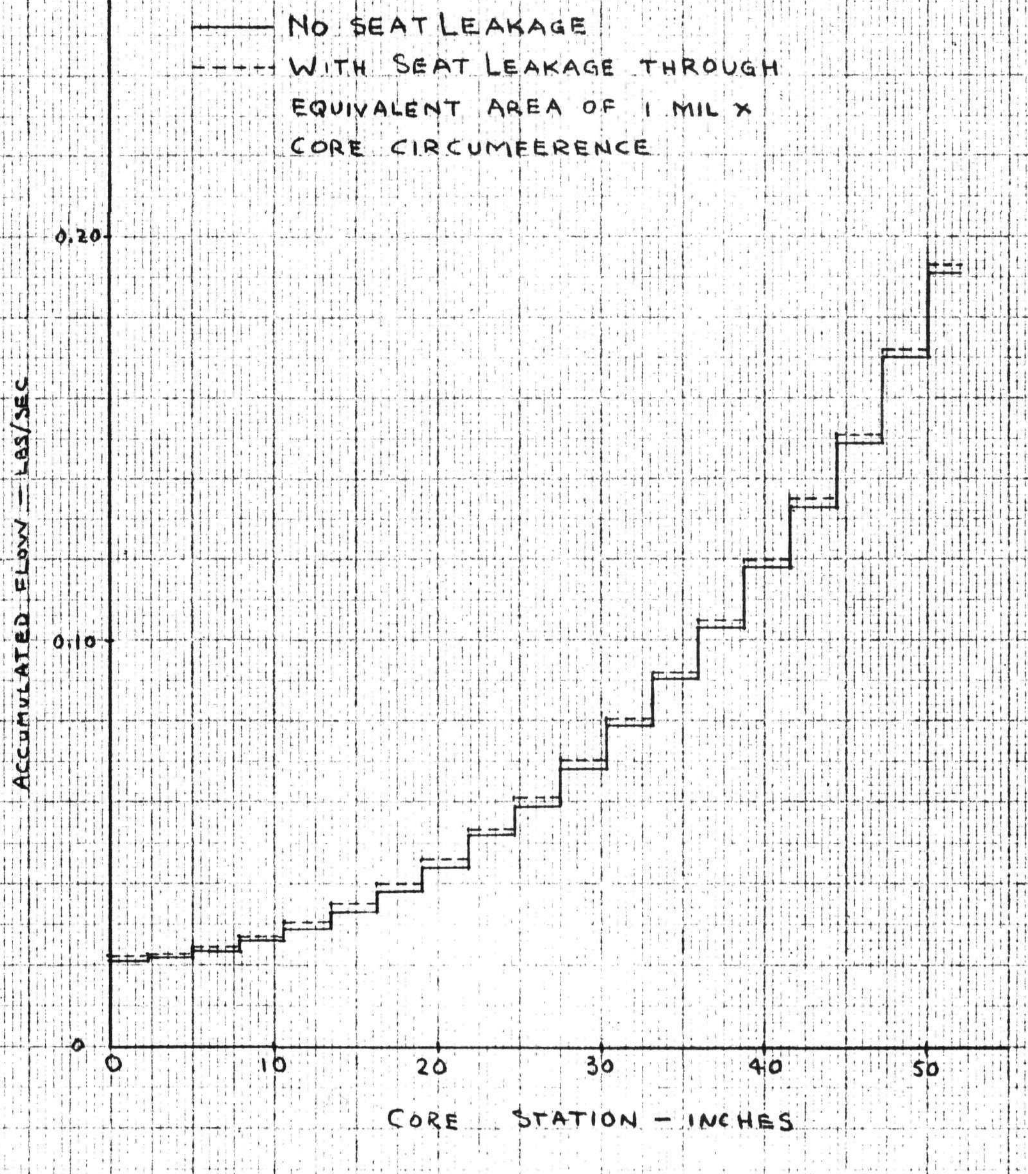

EFFECT OF RADIAL SEAT LEAKAGE ON ACCUMULATED SEAL FLOW

FIGURE 5

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