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ANALYSIS AND DESIGN
SIGNIFICANCE OF NOZZLE
INTERFACE SEAL LEAKAGE
TEST RESULTS

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INTRODUCTION

The interface seal between the inner reflector cylinder and the nozzle flange prevents coolant flow from bypassing the reflector system and core and flowing directly from the reflector inlet plenum to the core exit. Its effectiveness is important to both the performance and structural integrity of the reactor.

The seal, shown in figure 1, is made of two flexible U-shaped inconel rings welded together over a central stiffening ring. At assembly, the insertion of the nozzle against the seating force of the inner reflector axial pre-load springs compresses the seal within the confines of the machined groove on the nozzle end of the inner reflector cylinder. During reactor operation, the full pressure drop from the reflector inlet to core exit is exerted on the inner faces of the U-shaped rings, forcing them against the seating surfaces of the inner reflector cylinder and nozzle flange. Coolant leaking through the seal passes to the core exit plenum through the interface between the inner reflector cylinder and the nozzle flange or, more likely, passes through twenty-four 0.100 inch diameter pressure relief holes drilled in the inner reflector cylinder. These low impedance holes are drilled at an angle to direct the low temperature leakage into the flow path of the high temperature lateral support coolant. This aids in mixing the two flows and prevents the low temperature leakage from impinging on the peripheral support block surfaces.

To determine the effectiveness of the seal, flow tests were conducted in the WANL Engineering Mechanics and Fluid Flow laboratories. The results of the tests are reported in separate documents.^{1,2} This report, in fulfilling NRX-A2 prerequisites^{3,4},

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- 1 WANL-TME-867, Nozzle Interface Seal Test-Mechanical Loading and Seal Leakage
 - 2 WANL-TME-865, Flow Rate Pressure Drop Characteristics of an Inconel X-750 Nozzle Interface Seal
 - 3 WANL-TME-728, Component Testing Prerequisites to NRX-A2 Power Testing
 - 4 AGC Letter 775:NSD:445 Prerequisite Component Testing and Analysis for NRX-A2; April 8, 1964

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Figure 1. Nozzle Interface Assembly

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analyzes the significant test results and evaluates the effectiveness and flow characteristics of the seal.

CONCLUSIONS

Analysis of the results of tests on the nozzle interface seal reveals that the seal is effective and that the leakage past the seal has no significant detrimental effect on reactor performance. The leakage rate past the seal is no more than four percent of the lateral support system coolant flow at full power operation. A four percent leakage rate would result in a bulk temperature change in this coolant of less than 50 R.

It is therefore concluded that the nozzle interface seal will perform in a satisfactory manner from the thermal and fluid flow standpoint in the NRX-A2 reactor at all power levels up to and including full power.

DISCUSSION

GENERAL

The two series of nozzle interface seal leakage flow tests, conducted in the WANL Engineering Mechanics and Fluid Flow Laboratories, utilized production - type seals but different test methods.^{1, 2}

ENGINEERING MECHANICS LABORATORY (EML) TESTS

Tests in the Engineering Mechanics Laboratory were performed as an adjunct to the permeability tests on the ND215 impregnated inner reflector cylinder. The seal leakage was calculated from the difference between the porous flow rates measured with the seal

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installed and effective, and the porous flow rates measured with the seal installed but with the seating surfaces sealed with Silastic sealing compound. The tests used hydrogen and nitrogen at room temperature; a separate report¹ describes the apparatus, method and results.

The significant leakage results from the EML series of tests are plotted in figure 2 as leakage flow rate versus the product of seal inlet density and pressure differential. Inspection of figure 2 indicates that the functional relationship of the data is of the form:

$$w = m(\rho \Delta P)^n \quad (1)$$

where,

$$\begin{aligned} w &= \text{leakage flow rate in lb } M/\text{sec} \\ \rho &= \text{seal inlet density in lb } M/\text{ft}^3 \\ \Delta P &= \text{seal pressure differential in lb } F/\text{ft}^2 \\ m &= 2.34 \times 10^{-6} \\ n &= 0.715 \end{aligned}$$

Since the leakages were calculated from differences instead of being measured directly, the possible error in the results is between 10 percent and 20 percent. Considering this margin, the hydrogen and the nitrogen data correlate well with Equation 1.

FLUID FLOW LABORATORY (FFL) TESTS

To date, two series of seal leakage tests have been conducted in the Fluid Flow Laboratory (FFL). In the first, an Inconel seal was installed between a simulated aluminum inner reflector cylinder and simulated aluminum nozzle flange. In the second series of tests the reflector cylinder was simulated by a ring of impregnated H4LM graphite; the other components were the same. A separate report² describes the test setup, methods, and results in detail.

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Figure 2. Nozzle Interface Seal Leakage Flow Characteristics
Obtained From EML Tests

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In figure 3 (first test series) and figure 4 (second test series) leakage flow results are plotted as a function of the product of seal inlet density and seal pressure differential ($\rho \Delta P$). As both curves show, the leakage flow rate increases with increasing $\rho \Delta P$, but tends to level off at the high values. This leveling off is attributed to a change in shape in the seal with increase in pressure differential. As the pressure differential increases, the "U" shaped rings of the seal "belly out" and increase the areas of contact (as well as the contact force) between the sealing surfaces, thereby increasing the flow resistance.

This hypothesis was tested to a limited extent with data obtained at two different values of ΔP . As figure 5 shows, two separate curves are obtained when the data is plotted separately for the two values of ΔP . These curves can be expressed by:

$$w = 3.1 \times 10^{-4} (\rho \Delta P)^{0.5} \text{ for } \Delta P = 35 \text{ to } 40 \text{ psi} \quad (2)$$

and,

$$w = 2.1 \times 10^{-4} (\rho \Delta P)^{0.5} \text{ for } \Delta P = 120 \text{ to } 125 \text{ psi} \quad (3)$$

On the basis of this limited data it appears that the seal acts like an orifice (witness the exponents of Equations 2 and 3) with an area restriction that varies with pressure differential. Testing at constant pressure differential and varying pressure level, over the entire range of seal pressure differentials should be performed if this conclusion is to be confirmed.

A comparison of figures 3 and 4 reveals that the leakage flow rate through the fixture using a graphite ring to simulate the reflector cylinder is approximately twice that of the flow rate through the test fixture using an aluminum simulated cylinder. The poorer surface geometry and permeability of the graphite probably accounts for part of the difference but, as noted in the report² of these tests, although the apparatus leak tested negative before the tests were run, it was found to leak after the tests were completed. The leakage rates obtained, then, cannot be established as truly representing seal leakage when a graphite reflector is used. They can only be considered as upper limits. Additional testing should be performed to determine whether the difference in leakage rates between the

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Figure 3. Nozzle Interface Seal Leakage with Simulated Aluminum Heating Surfaces

Figure 5. Nozzle Interface Seal Leakage Characteristics of Constant Pressure Differential

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graphite and aluminum sealing surfaces is of this magnitude.

COMPARISON OF TEST RESULTS

The results obtained from the three series of tests are replotted in figure 6 and the curves extrapolated to the NRX-A full power condition. As shown, at a $\rho \Delta P$ corresponding to full power condition, the three sets of data differ over a range of a factor of five. At lower values of $\rho \Delta P$, the range increases to as high as a factor of twenty-five.

The differences between the results of the EML tests and the FFL tests are largely due to differences in the configurations of the test fixtures. The EML reflector cylinder was not drilled with the twenty four 0.100 inch diameter pressure relief holes and the flush fit of the reflector cylinder in contact with the simulated nozzle flange acted as an additional seal against leakage. Although the combined effect of this flush fit seal and the interface seal was to reduce leakage flow rate significantly, elimination of the pressure relief holes in the design would reduce the margin of safety of the inner reflector seating force on the nozzle.

As described above, the variance in data from the two series of FFL tests is attributed to possible leakage in the test apparatus during the simulated graphite reflector cylinder tests, to the difference between the graphite and aluminum surface qualities, and to the graphite permeability. Since the apparatus leakage flow rates may be included in the test results, the results can be considered only as an upper limit for interface seal leakage.

DESIGN SIGNIFICANCE OF INTERFACE SEAL LEAKAGE

In its effects on reactor operation, the interface seal leakage flow rate can be compared to the flow rate calculated for the lateral support seal system at the exit of the eighteenth seal. This flow rate is about 0.35 lb/sec at full power operation, assuming no radial stepping gap between adjacent filler strips and no support seal seat leakage. Figure 6 shows the upper limit of the interface seal leakage flow rate to be 0.015 lb/sec,

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Figure 6. Comparison of Interface Seal Leakage Test Results and Application to NRX-A

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only 4 percent of the eighteenth seal exit flow rate. Since some radial stepping between filler strips is likely, and since significant support seal seat leakage is also likely⁵, the 4 percent figure would probably be reduced in actual operation.

The decrease in the bulk fluid temperature of the lateral support system flow due to the interface seal leakage is small. At 100 percent power the bulk temperature of the support system coolant (flow at 0.35 lb/sec) is about 1345 R. Assuming the interface seal leakage is 0.015 lb/sec at a bulk temperature corresponding to 162 R (reflector inlet temperature), the resulting decrease in the bulk temperature of the coolant entering the nozzle inlet plenum from the seal region is less than 50 R.

It is concluded that the nozzle interface seal is effective, and that the leakage from this seal into the lateral support system at the exit of the eighteenth seal will not significantly change the thermal and fluid flow performance of the NRX-A lateral support seal system and the core periphery.

5 WANL-TME-655, Analysis and Design Significance of the B-3, Single Seal, High Pressure, Isothermal Test Data, January 1964

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