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MASTER

Program: Cover Gas Seals

AEC Task: 1 - FFTF-LMFBR Seal Test Program

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I. PROJECT OBJECTIVES

The objectives of the general seal test program are to: (1) conduct static and dynamic tests to demonstrate or determine the mechanical performance of full-size (cross-section) FFTF fuel transfer machine and reactor vessel head seals intended for use in a sodium vapor - inert gas environment, (2) demonstrate that these FFTF seals or new seal configurations provide acceptable fission product and cover gas retention capabilities at Clinch River Breeder Reactor Plant (CRBRP) operating environmental conditions other than radiation, (3) develop improved seals and seal technology for the CRBRP to support the national objective to reduce all atmospheric contaminations to low levels, and (4) publish a Design Guide for reactor seals along with Ordering Data.

Testing of the FFTF Instrument Tree inflatable seal to demonstrate its performance is to be conducted. Also the IVHM inflatable seal is to be tested to CRBRP conditions to provide design information for the CRBRP.

Design analysis and testing of proposed CRBRP dip seal configurations to determine an acceptable configuration and generate performance data will be conducted.

An additional objective will be to develop advanced seal geometries and materials to overcome deficiencies in permeation rate, compression set and high temperature use of commercially available seals.

II. MAJOR PROGRESS DURING REPORT PERIOD

A. GENERAL SEAL DEVELOPMENT

Testing of seals to FFTF requirements per WDTRS 1.25 continued through this period with emphasis on testing urethane seals which were added to the test

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matrix late in FY 74. Program redirection from ARD resulted in shutdown of the rotary and static demonstration tests. Table 1 shows the status of reciprocating seals demonstration tests Nos. 5 and 6. No changes in performance or leakage have been noted. These tests will be completed in mid-December.

The status of rotating seals demonstration tests Nos. 7 through 10 at shutdown is shown in Table 2, and the status of static seal demonstration tests Nos. 4, 5, and 6 at shutdown is shown in Table 3. All were showing satisfactory performance when stopped. Permeation and compression set calculations for these tests are being made.

Compression set data continues to be taken for nitrile at 100°F, EPR at 150°F and 200°F; and urethane (from two suppliers) at 100, 150, and 200°F. The 32-week tests will be completed in January 1975.

The writing of a Design Guide for use in designing seals for LMFBR's was started. It is based on findings from this program.

B. INFLATABLE SEAL TESTS

1. Instrument Tree Inflatable Seal Test

Preparation for the Instrument Tree inflatable seal test is continuing with the checkout and assembly of the seal fixture and support plumbing. Construction of a thermal shroud and hot-air heating system is underway. A detailed test procedure is also being written. Preliminary tests will be conducted with a thin-wall plastic cylinder, simulating the Instrument Tree arm, to permit observation of the seal during inflation and rotation of the fixture.

The silicone seals, one of two materials to be tested, were delivered to AI in September. Procedures for installing the seal, which will be on a vertical surface, are being developed. Present plans are to use Dow Corning 1200 primer and DC731 RTV adhesive. Adhesive recommendations for installation of the EPDM seal have been made by B. F. Goodrich. However, tests with this second seal material, EPDM (ethylene propylenediene monomer), will not be started for several months and work with these adhesives will be deferred until later.

TABLE 1
RECIPROCATING DEMONSTRATION SEAL TEST

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (°F)	Lubricant	Seal Travel (ft)	Comments
5	T seals (3) Urethane Parker Seal	10	8	100	DC55M	3680 (2755 cycles)	No significant changes or leakage noted
	T seals (3) Buna N Greene Tweed	10	8	100	DC55M	3680 (2755 cycles)	
6	T seals (3) Urethane Parker Seal	10	8	150	WSX8788	3880 (2906 cycles)	No significant changes or leakage noted
	T seals (3) Buna N Greene Tweed	10	8	150	WSX8788	3880 (2906 cycles)	

TABLE 2
ROTATING SEAL DEMONSTRATION TESTS

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (°F)	Lubricant	Seal Travel (ft)	Comments
7	Quad rings (3) EPR Minnesota Rubber*	10	8	150	DC55M	40,700 (77,820 cycles)	Test shut down, no indication of leakage
8	O-rings (3) EPR Parker Seal*	10	8	150	DC55M	40,700 (77,820 cycles)	Test shut down, no indication of leakage
9	O-rings (3) Urethane Parker Seal	10	8	100	DC55M	24,400 (26,540 cycles)	Test shut down, no indication of leakage
10	O-rings (3) Urethane Parker Seal	10	8	150	DC55M	24,400 (26,540 cycles)	Test shut down, no indication of leakage

*Parker Seal Buna N (N741) outer seal to reduce end losses

TABLE 3
STATIC DEMONSTRATION TESTS
(O-rings only)

Test	Seals	Com- pres- sion (%)	Gland Finish (rms)	Tem- pera- ture (°F)	Lubri- cant	Comments
4	Urethane (P642) Parker Seal Co.	50	16	100	DC55M	Tests shut down after 3294 hr, no leakage
5	Urethane (522FX) Minnesota Rubber	50	16	100	DC55M	Tests shut down after 3294 hr, no leakage
6	Urethane (P642) Parker Seal Co.	50	16	150	DC55M	Test shut down after 941 hr, no leakage observed

2. CRBRP Rotating Plug Seal Development

The specification for installation and removal of the IVHM inflatable seal using Chemlok 304 epoxy adhesive was issued. In addition, a specification for the installation, removal and cleanup of the IVHM seal installed with Dow Corning 140 RTV adhesive was issued.

Tests to evaluate the effectiveness of elastomer-to-steel adhesives were continued.

Pull-test specimens of IVHM seal sections cemented to steel plates with 140 RTV and smeared with DC55M or Exxon 5182 grease continued on long term soak in air at 150°F. Samples will be removed at various times and pull tested to determine the shear strength of the adhesive bond and thus determine whether the DC55M grease that is being absorbed by the adhesive affects the bond strength.

Pull-test specimens of IVHM seal sections cemented to carbon steel and stainless steel plates with Chemlok 304 and smeared with DC55M or Exxon 5182 grease continue, as above, to soak at 150°F.

Metal coupons of carbon steel with 32-, 64-, and 125- μ in. surface roughness were cemented together using Chemlok 304 adhesive. Pull tests were then conducted to determine the effect of metal surface finish on adhesive bond shear strength. The direction of the finish was in the direction of the pull. Figure 1 shows the test results. Even though some scatter of data points is evident, all

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Figure 1. Chemlok Bond Strength

test samples show bond shear strength in excess of 8,000 psi with some stronger bonds at the rougher finishes. The mode of failure was a clean separation of the metal epoxy interface. The results show no consistent dependence on finish but the rougher finishes should be favored.

Two series of tests have been performed on the IVHM inflatable seal to CRBRP operating conditions. The first series was conducted per AI, DTP 707-810-008, and continued through 88,849 ft of seal travel or two seal-design lifetimes. These tests were followed by a second test series, per direction of WARD, and continued through 180,263 ft of seals total travel. The seal test setup is shown in Figure 2.

Performance mapping conducted during the initial tests of the first series resulted in selection of 7.5 psig for the seal inflation pressure for operation and dwell tests. System pressures were: buffer gas, $P_b = 1.0$ psig; reactor pressure, $P_r = 10$ in. of water; and head pressure, $P_h = 0$ psig. The seal temperature was 150°F throughout the program, except for periods during fixture heatup and cooldown when seal drag data were measured. Nominal seal speed was 15 fpm. The seal fixture was assembled to provide ± 0.060 in. of vertical movement. Measurements taken at the end of the tests when the fixture was opened showed a seal-to-track radial displacement of ± 0.020 in. The outer seal had 57.4 gm while the inner seal had 27.4 gm of DC55M grease. The travel was accumulated in approximate 10,000-ft increments with a duty cycle of 1.5 revolutions clockwise, a 1-min dwell, 1.0 revolution counter clockwise followed by another 1-min dwell, etc. After each 10,000-ft increment, the seal was permitted to dwell up to 24 hr.

For this portion of the program (the first double lifetime), testing of the IVHM to CRBRP conditions was conducted to the test sequence shown in Table 4. The data were reduced and preliminary curves and tabulations were given to Westinghouse for use in formulating the test sequence for the next phase of the test program. Figure 3 is a summary of the test results showing the measured seal drag and total drag variation (excursion) during each travel increment plus the varying dwell durations. The drag became more uniform and lower as travel was accumulated. Figure 4 shows the starting drag after the various dwell periods and indicates an increase in drag as dwell time is lengthened.

Figure 2. CRBRP Inflatable Seal Test Setup

TABLE 4
CRBRP INFLATABLE SEAL TEST SEQUENCE — FIRST, DOUBLE LIFETIME SERIES

Test	Temperature (°F)	Seal Speed (fpm)	Buffer Gas Pressure (psig)	Inflation Pressure (psig)	Seal Travel* (ft)	Remarks
Run In	Room	15	1.0	15	437	
Drag vs Temperature	Room to 150	15	1.0	15	2,565	
Drag and Buffer Gas Dynamic Leakage vs Inflation Pressure	150	15	1.0	0-25	1,399	
Buffer Gas Static Leakage vs Inflation Pressure	150	0	0-21	0-25	0	
Drag vs Dwell	150	15	1.0	7.5	291	Dwell to 200 ⁺ hr
Drag and Buffer Gas Leak- age at Nominal Conditions	150	15	1.0	7.5	1,225	
Drag vs Speed	150	2-20	1.0	7.5	699	
Life Cycle	150	15	1.0	7.5	70,833	
Lube Effectiveness	150	15	0	7.5, 0 0, 7.5 0, 0	5,190	11 tests through- out test program
Repeat Tests						
Drag vs Inflation Pressure					6,210	
Leakage vs Inflation Pressure						
Drag vs Speed						
Permeation Test	150	0	1.0	7.5	0	185 hr; 98% Ar, 1% Xe, 1% H ₂
Maintenance Simulation and Buffer Gas Leakage	Room	0	1.0	to 22.1	0	Raised seal track 3/16 and 1/4 in.
Disassembly of Seal Fixture and Visual Inspection	Room	0	0	0	0	

*Total Seal Travel = 88,849

Figure 3. CRBRP Inflatable Seal Double Lifetime Travel Summary

Figure 4. CRBRP Inflatable Seal Starting Drag vs Dwell

The effect of inflation pressure on drag was measured and is plotted in Figure 5 for data taken in the middle and at the end of the test. Figure 6 defines the threshold of buffer gas pressures at which buffer gas leakage can be detected for various inflation pressures. The effect of seal speed on drag is shown in Figure 7 at two periods during the first, double time test.

The apparent effect on drag from the different amounts of lubricant applied to each seal is shown in Figure 8. After each $\sim 10,000$ -ft increment of test, the seal drag was recorded while the seals were alternately deflated to 0 psig and then with both seals deflated. The seal with less lubricant had higher drag, as expected. The final seal drag test at room temperature, following the permeation measurement of 150°F , showed a significant increase.

While the assembly was still at 150°F , a measurement of permeation through the outer seal was made. Using a gas mixture of 98% argon and 1% each of hydrogen and xenon in the simulated reactor cavity, permeation leakages of 0.35×10^{-6} and 0.71×10^{-6} (std cc)/(sec, ft of seal, cm Hg ΔP) were measured for hydrogen and xenon, respectively. Permeation leakage through the elastomer seal can be expressed by:

$$R = \bar{P} \times K_{H/T} \times L \times \Delta P$$

where

R = permeation rate (cc/sec)

$\bar{P}$ = permeation coefficient of the elastomer (cc-cm/sec-cm²-atm)

$K_{H/T}$ = cross section coefficient of the seal (cm/cm)

L = length of seal (cm)

ΔP = differential partial pressure of the gas (atm)

The $K_{H/T}$ value was determined using the R and ΔP observed during this test, plus the measured seal length, L , and the permeation coefficient, $\bar{P}$, measured previously under controlled laboratory conditions for the B. F. Goodrich 139-PC-12 seal material. With $K_{H/T}$ determined, permeation of the various reactor cover gas species can be determined using the gas specie partial pressure and $\bar{P}$. The values of $K_{H/T}$ determined were

Figure 5. CRBRP Inflatable Seal Drag vs Inflation Pressure

Figure 6. Buffer Gas Static Leakage Threshold vs Seal Inflation Pressure

Figure 7. CRBRP Inflatable Seal Running Drag vs Seal Speed

Figure 8. CRBRP Inflatable Seal Lubrication Effectiveness

$K_{H/T} = 4.1$, hydrogen basis

$K_{H/T} = 4.5$, xenon basis.

While ideally these values should be identical, the agreement was very good and well within the expected experimental error.

When the rig was cooled to room temperature, a maintenance simulation test was conducted. The seal runner was uniformly displaced away from the seal by 0.25 in. This gap, in addition to the ± 0.060 in. originally set in the fixture, produced a 0.31-in. gap at one point on the circumference. A seal inflation pressure of 22.1 psig was not sufficient to prevent leakage from the seal buffer cavity under this condition. The runner was then uniformly lowered toward the seal to a position providing 0.19 in. maximum gap at one point on the periphery. A 12.8-psig seal inflation pressure then successfully sealed the buffer gas cavity for zero leakage at a cavity pressure of 1.0 psig and simulated reactor and head pressures of 0 psig.

The test rig was then opened and the seals examined visually. No seal wear was detected, although the light-colored DC55M grease was darkened.

After reviewing the test results, a second double lifetime test was conducted to 170,263 ft of seal travel. The seals were first wiped clean of grease and relubricated with 60 gm of DC55M per seal. A test regime was initiated in which 20,000-ft test increments were followed by long dwells with 15 psi inflation pressure, with subsequent operation at 4, 5, or 5.7 psi inflation pressure. The test sequence for this second double lifetime series is summarized in Table 5.

During heatup to 150°F, data were taken to establish a drag vs temperature curve (Figure 9). Drag vs inflation pressure at various speeds at 150°F is shown in Figure 10.

The upper plot in Figure 11 shows the seal drag measured during the second double lifetime tests, and the lower bar plot shows the duration of the dwell times between the tests. As shown in Figure 4 for the first double lifetime test, the tendency for drag to increase, during a long period of continuous operation, is repeated. Seal drag greater than the final drag for a given test interval was observed during every test, and the high-low values during a test sequence are plotted on Figure 11 with vertical dashed lines to show the range of drag values.

TABLE 5
CRBRP INFLATABLE SEAL TEST SEQUENCE – SECOND, DOUBLE LIFETIME SERIES

Test	Tem- pera- ture (°F)	Seal Speed (fpm)	Buffer Gas Pressure (psig)	Inflation Pressure (psig)	Seal Travel* (ft)	Remarks
Drag vs Temperature Speed and Inflation Pressure	Room to 150	5 to 15	1.0	3, 5, 7.5	3,906	4 tests during tempera- ture increase
Lube Effectiveness	Room to 150	0	0	5, 0 0, 5 0, 0	2,274	
Cycling	150	15	1.0	5	22,936	
Dwell Start	150	15	1.0	5	150	
Cycling	150	15	1.0	4, 5, 5.7	54,024	48-hr minimum dwell period
Dwell Start and 1.0-hr Run	150	15	1.0	4, 5, 5.7	3,926	
Lube Effectiveness	150	15	1.0	4, 5, 5.7	1,517	
Drag vs Temperature, Speed and Inflation Pressure	150 to Room	5, 10, 15	1.0	3, 5, 7.5	1,748	3 tests
Lube Effectiveness	Room	15	1.0	5	933	

*Total Seal Travel = 91,414 ft;
Accumulated Total for 2 Test Series = 180,263 ft

Figure 9. CRBRP Inflatable Seal Running Drag vs Temperature at Various Speeds and Inflation Pressures

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Figure 10. CRBRP Inflatable Seal Running Drag vs Inflation Pressure at Various Speeds

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Figure 11. CRBRP Inflatable Seal Life Cycle Summary - Second Double Lifetime Test

The location of the plots of these drag excursions on the abscissa is not intended to identify the exact point in the sequence that the high or low drag condition occurred. One explanation for this increasing drag behavior during a sequence would be that lubricant between the seal and track tends to be wiped away during continuous operation, and slowly flows back to the seal-track interface when there is no rotation and a sufficiently long dwell. Note that the very short dwell between the first and second test increment was not long enough for the relubrication to occur. The seal inflation pressures during the dwell periods are noted on the lower bar plot of Figure 11.

The lubrication effectiveness plot (Figure 12) shows the drag on the inner seal to be significantly higher than on the outer seal. This was unexpected, since in this second double lifetime test, both seals had 60 gm of lubricant, whereas in the first test (which also showed significant differences in drag), the lubricant on the inner seal was only half of that on the outer seal (Figure 8). This suggests that some factor other than lubricant quantity is contributing to the higher drag on the inner seal. An explanation for this anomaly will be sought when the seal fixture is disassembled at a future date and the seals and seal runners can be examined for finish, wear, surface irregularities, concentricity, vertical runout, etc.

Figure 13 shows an increase in seal starting drag with increased dwell time, similar to that of Figure 4 for the earlier tests. In all cases, the seal drag drops at least 15 lb/ft of seal within 3 sec as the seal fixture rotation continues.

Figure 14 shows the effect of temperature on seal drag. The upper curves are for increasing temperature and the lower curves are for decreasing temperature (note arrows) after the second double lifetime test at 150°F. The lower curves reflect the decrease in drag as travel is accumulated which is consistent with the trends in Figures 3 and 11.

During all the second double lifetime tests, the inflation pressure was above the threshold of leakage per Figure 6 and no leakage was observed on the flow-meter.

When the test program was completed, the entire seal housing assembly was removed by separation at the keyed drive shaft and moved to a storage

Figure 12. CRBRP Inflatable Seal Lubrication Effectiveness - Second Double Lifetime Test

Figure 13. CRBRP Inflatable Seal Drag vs Dwell Time - Second Double Lifetime Test

Figure 14. CRBRP Inflatable Seal - Seal Drag vs Temperature for Various Seal Speeds, Inflation Pressures and Accumulated Feet of Seal Travel - Second Double Lifetime Test

location. No disassembly and inspection was performed at this time. The oven is being rebuilt around the assembly and it will be held at 150°F with 15-psi inflation pressure for several months while tests of the Instrument Tree inflatable seal are in progress on the test rig drive. Following these tests, the assembly will be reinstalled on the drive rig with inflation pressure maintained. Operation of the seals at 150°F following the many months dwell will be observed at that time.

The final tests planned will evaluate lateral misalignment or eccentricity between runner and seal of ± 0.080 in.

Some preliminary observations from the testing are:

- 1) The seal drag decreases significantly with increase in temperature.
- 2) The seal drag increases significantly with increase in inflation pressure.
- 3) Wear was insignificant during the first double lifetime travel.
- 4) Drag decreased as travel life increased for both the double lifetime tests.
- 5) Measurable leakage above the threshold inflation pressures was zero. For the reactor and buffer gas pressures for CRBRP, the 5-psi or higher inflation pressures were above the threshold for leakage.
- 6) The permeation measured was consistent with that which can be calculated from the basic permeation measurements on a slab of the seal elastomer.
- 7) Running drag after a long dwell period increases with length of dwell period. For short dwells, up to 20 min, no change was noted.

C. SEAL MATERIAL IMPROVEMENT

A listing of property requirements, performance goals, and operating conditions for elastomers used as LMFBR seals, formed a basis for inquiries about advanced materials. Based on replies to these inquiries, polymer groups that have been further investigated include modified flexible thermoplastics, inorganic elastomers, modifications of basic elastomers (EPDM), and research

and development stage polymers. Of these, the inorganic nonhalogenated polyphosphazene shows the most promise. Purchase requisitions have been issued to obtain experimental batches of both the polymer raw stock and of molded O-ring seals for gas permeation/leakage and compression set testing. Two private research organizations and a government-sponsored research institute have been contacted in this regard. Because of the extreme hydrolytic sensitivity during processing, and the instability of the Si-N bond for most elastomer applications, the original candidate material, silazane polymer, is no longer considered as a candidate for LMFBR seal applications.

In addition to an AI literature search for material improvements, custom literature surveys were ordered from the Rubber Division of the American Chemical Society in Akron, Ohio, and from an information distribution service of the National Academy of Sciences. These searches are in progress. Also, major polymer research and development organizations have been requested to supply information on performance and availability of any elastomer materials which may adhere to the specified LMFBR seal criteria.

D. ADVANCED SEALS AND GEOMETRY

A variety of seal assemblies and composite forms has been considered to provide adequate gas permeation and compression set resistance to meet LMFBR seal requirements. The assemblies actively being developed include:

- 1) Stainless steel E-seals which have been ordered to test their ability to provide an impermeable barrier to radioactive gases as face seals in static applications. The contact surface of the seal with the test gland is protected by a soft indium metal plating or an elastomer gasket bonded to the seal contour. EPDM, urethane, and nitrile adhesives and sheeting have been ordered for gasket material evaluations. (See Figure 15a.)
- 2) For dynamic applications, a compressed helical spring, elastomer jacketed assembly was chosen to provide a compensating force to overcome compression set failures of common elastomer O-rings. RFQ's have been issued for molding of the nitrile and EPDM elastomer jackets needed to complete the seal assembly. (See Figure 15b.)

Figure 15. Advanced Seal Configurations

- 3) Also, for dynamic applications, an elastomer-jacketed, stainless-steel, C-shaped spring was selected to test the sealing ability and to reduce gas permeation and compression set tendencies. This seal has been ordered with both EPDM and nitrile-based jackets for subsequent seal evaluations. (See Figure 15c.)
- 4) Soft metallic plated elastomer O-ring seals were ordered to test the metallic film resistance to gas permeation. The elastomer resiliency is expected to provide compression set resistance. Quotes have been requested for plating EPDM and nitrile O-ring seals with indium and silver metal. Electrolysis and vacuum deposition processes are being considered. (See Figure 15d.)
- 5) For rotary applications, a FERROMETIC[®] seal (a colloidal liquid suspension of coated ferrite particles held by a magnetic field) has been proposed to provide a barrier to the reactor gases. The performance of such a seal is being considered for evaluation in a special test fixture. Permeation rates would be determined at various temperature ranges. Also, resistance to sodium vapor will have to be determined. An upper temperature limit is imposed on this seal due to the characteristic vapor pressure of the fluid and the decomposition of the ferrite particle coatings at higher temperatures. (See Figure 16.)

E. TOP SHIELD DIP SEAL CONFIGURATION CHARACTERIZATION

Liquid sodium dip seals will be used to seal the circular gaps between rotating plugs and between a rotating plug and the stationary ring, as shown in Figure 17. The primary function of the dip seal is to impede the diffusion of radioactive gases into the upper annulus region. The dip seal also prevents sodium vapor and aerosols in the cover gas from being transported into the annular gap by convection, diffusion, or both. By virtue of inleakage of buffer and seal pressurization gas (argon) through the inner elastomeric seal, the sodium level in the buffer leg of the dip seal could frequently be at the level of the bottom of the dip seal blade, as shown in Figure 17. Hence, if the cover gas pressure decreases, gas will be bubbled from the buffer leg to the cover gas leg. If the rate of cover gas pressure decrease is high, as during a reactor scram, the

Figure 16. Magnetic Fluid Seal (FERROMETIC®)

Figure 17. Dip Seal Installation

rate at which gas bubbles across the dip seal will be high and could cause some of the sodium to be ejected out of the cover gas leg. An experimental investigation has been initiated to determine the effect of dip seal configuration, particularly the dip seal blade configuration, on the amount of sodium that would be lost from the dip seal during the gas bubbling condition described above.

Testing continues in progress on a special screening test device which permits rapid preliminary determination of the stability of various dip seal configurations. The bench-scale device (Figure 18) consists of a transparent plastic box, 4 in. by 4 in. inside dimensions, placed with its open side downward in a rectangular glass tank. Adjustable legs are provided on the plastic box to permit the space between the bottom of the box and the tank bottom to be varied. Each vertical side of the plastic box can serve as the dip seal blade. Hence, four different dip seal blade configurations can be tested. The low-pressure-side dip seal channel is formed by placing the dip seal blade configuration to be tested adjacent and parallel to an end-wall of the glass tank. Baffles and skirts are attached on the plastic box, as shown in Figure 18, to restrict water and gas flows to the appropriate areas. After the tank is filled with water to the desired level, the screening test is initiated by pumping gas into the plastic box until the condition of incipient gas flow across the dip seal blade is reached, at which point the water levels on the two sides of the dip seal blade are measured. Gas flow is then re-initiated at the desired rate, and the maximum, local increase in the water level in the low-pressure side of the blade is measured by means of a height-adjustable electrode. The maximum, local increase in water level in the low-pressure channel was taken to be the level reached by the water not less than 4 times/min and not more than 6 times/min. This local increase in water level is taken to be an indication of the relative amount of sodium that would be lost from the dip seal. The assumed proportionality is approximate inasmuch as it does not take into consideration possible variations in lateral spacing and sharpness of the local increase in liquid level for the different dip seal blade configurations.

The variables in these screening tests are:

- 1) Dip seal blade configuration — Figure 19 shows the various dip seal blade configurations that have been investigated to date in the screening test device.

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Figure 18. Transparent, Bench-Scale Device for Dip Seal Configuration Screening Tests

a. 1 in. THICK, PLAIN BLADE

b. BEVELED-EDGE BLADE

NOTCH SPACING = 12 in.

c. BLADE WITH NOTCHES

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Figure 19. Dip Seal Blade Configurations

- 2) Low-pressure channel gap — Data have been obtained at gaps ranging from 1/2 in. to 3 in.
- 3) Liquid level difference (ΔH) in the two dip seal channels at the conditions of incipient gas flow across the dip seal blade. Data have been obtained at $\Delta H = 2\text{-}1/4$ in. and $3\text{-}3/4$ in. H_2O .
- 4) Gas flowrate across the dip seal — Data have been obtained at gas flowrates ranging from 0.12 to 1.26 cfm/ft of blade length. The gas flowrate that could occur across the Small Rotating Plug-Intermediate Rotating Plug (SRP-IRP) dip seal and across the Intermediate Rotating Plug-Large Rotating Plug (IRP-LRP) dip seal during a cover gas pressure transient of -0.2 psi/sec and under uniform circumferential flow distribution is 0.12 cfm/ft of blade length. The corresponding gas flowrate across the Large Rotating Plug-Stationary Ring (LRP-SR) dip seal is 0.40 cfm/ft of blade length. If the gas flow is not distributed uniformly around the circumference as would be the case if the rotating plugs are not perfectly level, the gas flowrates that could occur across these dip seals would be greater.

Most of the data obtained to date in the screening tests are shown in Figures 20 through 23.

Figures 20 and 21 show the maximum local increase in water level in the low-pressure channel at $\Delta H = 2\text{-}1/4$ in. H_2O for all blade configurations shown in Figure 19, except the 1-in.-thick plain blade, at gas flowrates of 0.42 and 1.26 cfm/ft of blade length, respectively. The following observations are made from the results shown in Figures 20 and 21:

- 1) The maximum, local increase in water level decreases with increase in the low-pressure channel gap up to a gap of about 1-1/2 in. in the case of the 1/2-in.-thick plain blade and up to a gap of about 3/4 in. in the case of the beveled edge blade.
- 2) The maximum, local increase in water level is generally lower for the beveled edge blade than for the 1/2-in.-thick, plain blade.
- 3) The maximum, local increase in water level generally tends to increase somewhat with increase in the low-pressure channel gap for the blades with holes or notches.

Figure 20. Screening Test Results of Gas Flowrate of 0.42 cfm/ft of Blade and $\Delta H = 2\frac{1}{4}$ in. H_2O

Figure 21. Screening Test Results of Gas Flowrate of 1.26 cfm/ft of Blade and $\Delta H = 2\frac{1}{4}$ in. H_2O

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Figure 22. Screening Test Results for 1-in. Thick, Plain Blade and Beveled-Edge Blade at $\Delta H = 2\text{-}1/4$ in. H_2O

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Figure 23. Screening Test Results for 1-in. Thick, Plain Blade and Beveled-Edge Blade at $\Delta H = 3\text{-}3/4$ in. H_2O

- 4) The difference in performance between the blade with holes and the blade with notches is fairly small.
- 5) The maximum, local increase in water level is generally higher for the beveled edge blade than for the blades with holes or notches when the low-pressure channel gap is smaller than about $3/8$ in. to $1/2$ in. The reverse is true when the low-pressure channel gap is greater than about $3/8$ to $1/2$ in.
- 6) Increasing the gas flowrate across the blade increases the maximum, local increase in water level.

Figures 22 and 23 show the maximum, local increase in water level in the low-pressure channel at $\Delta H = 2-1/2$ in. and $3-3/4$ in. H_2O , respectively, for the 1-in.-thick plain blade and the beveled-edge blade. Data for gas flowrates of 0.12 and 0.40 cfm/ft of blade length are plotted. Data were also obtained at a gas flowrate of 0.27 cfm/ft of blade length. Figures 22 and 23 show the following in the range of conditions covered:

- 1) The maximum local increase in water level in the low-pressure channel is lower for the beveled-edge blade than for the 1-in.-thick plain blade, and this difference generally increases with increase in gas flowrate.
- 2) The maximum local increase in water level in the low-pressure channel increases with increase in gas flowrate. This is shown more specifically in Figure 24 for the 1-in.-thick plain blade.
- 3) The maximum local increase in water level in the low-pressure channel tends to increase (slightly) with increase in low-pressure channel gap in the case of the 1-in.-thick plain blade, whereas this is generally not so in the case of the beveled-edge blade.

A comparison of Figures 22 and 23 shows that increasing ΔH from $2-1/4$ in. H_2O to $3-3/4$ in. H_2O results in a decrease in the maximum local increase in water level in the low-pressure channel. A possible explanation for this is that the gas bubbles have a greater opportunity to disperse when ΔH is large.

The following conclusions are drawn from the results shown in Figures 20 through 24 for the dip seal blade configurations tested:

- 1) For low-pressure channel gaps greater than about $3/8$ to $1/2$ in., the preferred dip seal configuration is the beveled-edge blade.
- 2) The optimum, low-pressure channel gap for the beveled-edge blade is about $3/4$ in.
- 3) The maximum, local increase in fluid level in the low-pressure channel increases with increase in gas flowrate across the dip seal, and decreases with increase in ΔH .

The actual loss of liquid (water) from a dip seal during cover gas pressure transients was measured for the dip seal configuration shown in Figure 25. Data were obtained for two blade configurations: a $1/2$ -in.-thick plain blade, and a $1/2$ -in.-thick notched blade. In the latter blade, the notches were the same as those shown in Figure 19, but were spaced 12 in. apart.

The test procedure was as follows: The dip seal trough was initially filled with enough water so that at incipient gas flow across the blade, the low-pressure channel was filled to capacity, i. e., the water level in this channel was at the height of the wall of this channel. The pressures in the two channels were then equalized. Gas flow was then initiated and continued for a specified period of time. The amount of water remaining in the dip seal at the end of the run was measured. This procedure was repeated for various time periods.

The results are given in Figure 26 for gas flowrates of 0.12 and 0.87 cfm/ft of blade. As shown, at a gas flowrate of 0.12 cfm/ft of blade, less water is lost with the notched blade than with the $1/2$ -in.-thick plain blade. Also, at this gas flowrate, essentially no water will be lost from the dip seal if the amount of water in the seal is such that at the condition of incipient gas flow across the blade, the water level in the low-pressure channel is more than 1.4 in. below the top of the wall of this channel in the case of the notched blade, and more than 1.6 in. in the case of the $1/2$ -in.-thick plain blade. At a gas flowrate of 0.87 cfm/ft of blade, the $1/2$ -in.-thick plain blade performs better than the notched blade. The performance of the notched blade could undoubtedly be improved by increasing the number of notches per unit length of blade. A resonance

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Figure 24. Effects of Gas Flow Rate for 1-in. Thick, Plain Blade

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Figure 25. Cross-Sectional View of Transparent Dip Seal Model

Figure 26. Loss of Water From Dip Seal (Shown in Figure 25) During Gas Flow Across Blade

effect, which probably degrades performance, occurs under certain conditions with the notched blade. This suggests that it may be desirable to space the notches unevenly.

The amount of loss of water from the dip seal shown in Figure 25, when the dip seal is initially at the incipient gas flow condition, was determined by simply subtracting out the time required for the dip seal to go from the equilibrium condition to the incipient gas flow condition. The results are shown in Figure 27. At a gas flowrate of 0.12 cfm/ft of blade, which is the rate that could occur across the SRP-IRP and IRP-LRP annulus dip seals during a cover gas pressure transient of -0.2 psi/sec, the notched blade performs better than the 1/2-in.-thick plain blade. If the duration of this -0.2 psi/sec gas pressure transient is 6.5 sec (a duration of ARD concern), the reduction in the low-pressure channel water level, at the incipient gas flow condition, would be 0.26 in. and 0.39 in. for the notched, and 1/2-in.-thick plain blades, respectively. At gas flowrates of 0.57 and 0.87 cfm/ft of blade, the performance of the 1/2-in.-thick plain blade is better than that of the notched blade.

The effort on the redesign of the sodium dip seal/deposition test article to incorporate the dip seal/annulus configuration per ED SK 346645 D, Sheet 4, and to make the dip seal blade rotatable to permit investigation of mechanical cleaning of the dip seal is continuing.

The test plan has been revised and updated (TP-707-230-002, Rev A).

A layout of the transparent model of the WARD dip seal (ED SK 346645 D, Sheet 4), which will be full scale in cross section, is being completed.

III. IMPACT ON LMFBR PROGRAM

The initial phase of the test program, which was scheduled to specifically support seal selection for all FFTF applications, has supplied invaluable seal data to support selection of seal materials and configurations for the FFTF Program. This same information has direct and important application to the LMFBR industry, has advanced the state of the art, and has led or will lead to the generation of RDT seal standards for use by the industry.

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Figure 27. Loss of Water From Dip Seal (Shown in Figure 25) During Gas Flow Across Blade, Dip Seal Initially at Incipient Gas Flow Condition of $Y = 0$

Current test activities are proving the feasibility of specialized seal concepts, i. e., the CRBRP inflatable seal, FFTF Instrument Tree inflatable seal, and the CRBRP dip seal. The results of these programs will be of great benefit to future LMFBR's employing these seal concepts by providing test performance and reactor system design guidance.

Special investigations of new seal materials and seal geometries will continue to provide data which will be needed to develop sealing under the unique and demanding environmental conditions which will be present in future LMFBR's.

IV. NEXT REPORT PERIOD ACTIVITIES

The remaining reciprocating seal tests will be concluded. Data on these tests plus the rotary and static tests recently shut down will be analyzed and reported. The design guide based on all data to date will be written and final reports on the testing in WDTRS 1.25 will be started.

The Instrument Tree silicone inflatable seal test will be performed and preliminary data sent to Westinghouse for evaluation.

The dip seal performance tests in the larger scale model will be started.

Seals and materials of advanced designs will be received and started into permeation and compression set testing.

V. SCHEDULE

The scheduled activities for the seal program in FY 1975 (as proposed in the 189 submission) are shown in Figure 28.