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MASTER

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Program: Cover Gas Seals			
AEC Task: 11 — FFTF-LMFBR Seal-Test Program			
Program Manager: G. W. Meyers		**Project Manager:** J. S. Asquith	
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I. PROJECT OBJECTIVES

The objectives of this 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 configuration provide acceptable fission product and cover gas retention capabilities at LMFBR Clinch River Plant operating environmental ~~conditions other than radiation, and (3) develop improved seals and~~ seal technology for the LMFBR Clinch River Plant to support the national objective to reduce all atmospheric contaminations to low levels.

The leakage and/or permeation of reactor cover gas into the FFTF head cavity through elastomer seals will be calculated for each seal. Examination of head-region penetrations and evaluation of the designs are currently underway. The material permeation measurements and/or seal permeation measurements generated on this program will be used for the calculations.

An additional objective will be to conduct a feature test on the IVHM inflatable seals to: (1) verify acceptable operational performance under environmental conditions anticipated in FFTF service, and (2) demonstrate satisfactory long-term operation (80,000 linear feet of travel) for the seals at the anticipated Clinch River Plant rotating plug speed. The effects of sodium vapor on seals will be evaluated, and a feature test to assess the performance of the FFTF Instrument Tree inflatable seals will be conducted.

A special test will be conducted by AI and the Hanford Engineering Development Laboratory (HEDL), wherein the permeation of a set of elastomer seals

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will be measured by AI and the leakage of a metallic seal measured by HEDL. The test fixtures and gases will be exchanged between the two facilities, and the tests repeated, to compare the measuring techniques of the two laboratories.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1974

Reciprocating and rotary dynamic testing of seals generated considerable new test data concerning the leakage, compression set, and wear characteristics of various seal types and materials under specific conditions of compression, temperature, lubrication, travel, and surface finish. Both short-term (information tests) and longer-term (demonstration tests) are being conducted.

Compression set testing of O-ring seals yielded additional long-term data on Buna N, urethane, ethylene propylene, and silicone materials. (These tests have established some maximum operating temperature-time relationships for the materials.)

Permeability-solubility testing has been completed on 20 elastomer samples. This information is now being used as a basis for evaluating the leakage performance of seals under the dynamic test program.

Assembly and checkout of all static O-ring test fixtures were completed, and all are now on test.

A review of various lubricants was conducted to select a backup lubricant for evaluation in the seal test program. The evaluation included lubricant-elastomer compatibility, friction-temperature performance, and temperature-time stability.

A comprehensive survey of the gas boundary leakage in the FFTF has been completed, and the report is being prepared. Test fixtures were designed for static inflatable seal and molded-in-metal static seal tests. The fabrication of the Instrument Tree inflatable seal feature test fixture was started, and the Test Plan was issued for comments.

A permeation test of the IVHM inflatable seal was completed. Compatibility and bond strength tests, to determine the seal bond failure mode, were started. Development Requirements Specification, DRS 32.06, for conducting tests on

IVHM inflatable seals under Clinch River Plant conditions, was received from Westinghouse, the AI Test Plan was written and commented on by Westinghouse.

A plan for evaluating sodium vapor effects on reciprocating seals was approved; the test apparatus was designed, and fabrication for the test was started. The test procedure for the AI-HEDL Comparative Seal test was approved. Fabrication of the AI-HEDL comparative seal test fixture was completed, and the Comparative Seal Test was begun using two Buna N O rings (Compound 366Y).

An interim report, TI-707-810-013, was prepared, summarizing the seal test data generated to date, and recommending seal materials and types, temperature limitations, seal gland sizes, percent compression, etc for use in FFTF design and fabrication.

III. PROGRESS DURING REPORT PERIOD

A. DYNAMIC TESTING

Testing is continuing on all phases of the dynamic seal test program, following the guidelines of the statistical test matrix which were derived to provide meaningful test data on a time schedule consistent with FFTF and LMFBR program requirements. Two types of seal tests are being run in the program — demonstration tests and information tests. The demonstration tests are evaluating the performance of various seal types when tested under conditions representative of those specified for FFTF seal design conditions. Testing will generally be about 6 months in duration for each group of test seals. Information tests are measuring the short-term performance of various seal types under broader ranges of seal application conditions, to determine appropriate new guidelines and/or seal standards for use in the design of current or future reactor systems.

Individual tests which were completed or initiated are discussed in the following sections.

1. Reciprocating Seal Tests

a. Demonstration Tests No. 3 and 4

These two reciprocating seal tests, which were started last quarter, containing seals as noted in Table 1, are continuing without evidence of gross leakage.

b. Information Test No. 9

Reciprocating Test No. 9, containing urethane seals as noted in Table 2, has completed ~10,000 cycles with no evidence of leakage. (Note: Only 2100 ft are required by the WDTRS 1.25 document, but the test was extended to obtain longer-term leakage data.)

c. Information Test No. 10

Reciprocating Test No. 10, containing silicone seals as noted in Table 2, was set up; but, during the checkout of the system, a leak was observed in one of the bellows when the system was evacuated. This leak was confirmed by a healium leak check. Two additional bellows, ordered earlier, were received, and the defective bellows replaced. The test was begun, and has completed 530 cycles, as shown in Table 2.

2. Rotating Seal Tests

a. Demonstration Tests No. 3 and 4

Rotating Demonstration Tests No. 3 and 4, containing Buna N seals as noted in Table 3, have completed 6 months of testing (~31,380 ft of travel) with no evidence of gross leakage. The test was stopped. Post-test examination revealed all seals to be in excellent condition.

b. Demonstration Tests No. 5 and No. 6

Rotating Demonstration Tests No. 5 and 6, containing Buna N seals as noted in Table 3, have completed ~23,378 of travel with no evidence of gross leakage.

c. Demonstration Tests No. 7 and 8

Rotating Demonstration Tests No. 7 and 8, containing seals as noted in Table 3, were started, and have completed ~2244 ft of travel with no evidence of gross leakage.

TABLE 1

RECIPROCATING DEMONSTRATION SEAL TEST

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (°F)	Lubricant	Seal Travel (ft)
No. 3	Q rings (3) Buna N Parker Seal	10	8	150	DC55M	4800 (3600 cycles)
	T seals (3) Buna N Parker Seal	10	8			
No. 4	Quad rings (3) EPR Minnesota Rubber	10	8	150	DC55M	4800 (3600 cycles)
	T seals (3) EPR Parker Seal	10	8			

TABLE 2

RECIPROCATING INFORMATION SEAL TEST

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (°F)	Lubricant	Seal Travel (ft)	Comments
No. 9	T seal (1) Urethane No. 379 Greene Tweed	5	16	100	DC55M	13,300 (10,000 cycles)	Required number of cycles completed; no leakage observed.
	Q rings (2) Urethane No. P648 Parker Seal	5	16				
	Quad ring (1) Urethane No. 522FX Minnesota Rubber	20	16				
	T seals (2) Urethane No. P648 Parker Seal	20	16				
No. 10	T seal (1) Silicone No. 407 Greene Tweed	5	16	300	DC55M	706 (530 cycles)	
	Q rings (2) Silicone No. S684 Parker Seal	5	16				
	Quad ring (1) Silicone No. 71417 Minnesota Rubber	20	16				
	T seals (2) Silicone No. S684 Parker Seal	20	16				

TABLE 3

ROTATING SEAL DEMONSTRATION TESTS

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (°F)	Lubricant	Seal Travel (ft)	Comments
No. 3	Quad rings (4) Buna N Minnesota Rubber	10	8	150	DC55M	31,380 (60,000 cycles)	Test completed; no indication of leakage.
No. 4	O rings (4) Buna N Parker Seal	10	8	150	DC55M	31,380 (60,000 cycles)	Test completed; no indication of leakage.
No. 5	Q rings (4) Buna N Parker Seal	10	8	150	DC55M	23,378 (44,700 cycles)	Test in progress; no indication of leakage.
No. 6	O rings (4) Buna N Minnesota Rubber	10	8	150	DC55M	23,378 (44,700 cycles)	Test in progress; no indication of leakage.
No. 7	Quad rings (3) EPR Minnesota Rubber*	10	8	150	DC55M	2,244 (4,290 cycles)	
No. 8	O rings (3) EPR Parker Seal*	10	8	150	DC55M	2,244 (4,290 cycles)	

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

d. Information Tests No. 14, 15, 16, and 17

Two of these four tests were stopped — No. 14 because of leakage across the seals, and No. 17 because of high friction forces, as noted in Table 4. Leakage measurements were continued on No. 17, even though the rotary action was stopped to obtain the additional permeation data. The remaining two tests were stopped at the end of the planned test period. No wear was noted in any of the tests, except Information Test No. 17. Figure 1 is a close-up view of the D seal (outer containment seal, urethane Q-ring). This seal apparently rotated in the groove, where there is a minimum of lubrication, and subsequently produced a high torque. This wear was not observed in any of the other seals.

e. Information Tests No. 18, 19, 20, and 21

Four new urethane seal tests were started, as shown in Table 4. The No. 19 test developed high torque forces after several hours of running, and the cycling was discontinued temporarily to replace the sheared linkage pin. When the test was restarted, the linkage pin did not shear, and the test is operating satisfactorily.

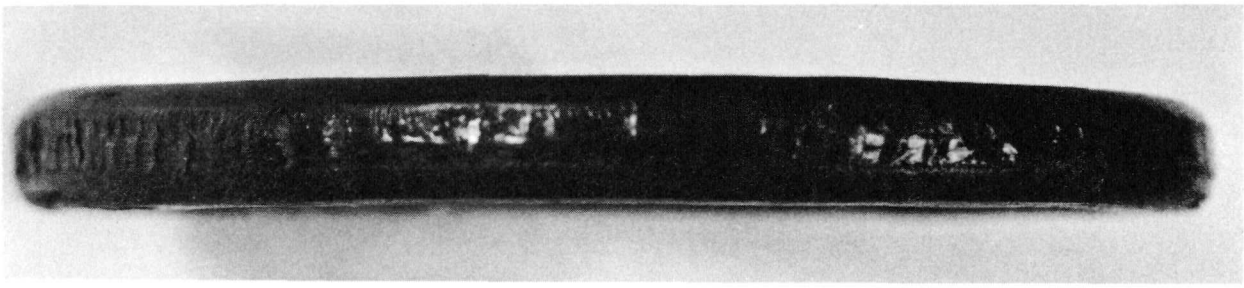

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Figure 1. Rotary Information Test No. 17, Urethane Q Ring, Showing Wear

3. Leakage Calculations

Leakage calculations continue on the tests. Table 5 lists leakage values (L_{Kr} = std cc/sec/linear inch of seal/atm ΔP of Kr x 10^{-8}) for four rotary demonstration tests and four information tests with Buna N seals.

An estimation of leakage can be calculated, knowing the seal geometry, % compression, temperature, and material permeability. Table 5 lists the values

TABLE 4
ROTATING SEAL INFORMATION TESTS

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (°F)	Lubricant	Seal Travel (ft)	Comments
No 14	O ring (1) Silicone Minnesota Rubber	5	16	300	DC55M	32,150 (61,484 cycles)	Test stopped, leakage noted across seals
	Q rings (2) Silicone Parker Seal	5	16				
No. 15	Quad ring (1) Silicone Minnesota Rubber	20	16	300	DC55M		Test completed
	O rings (2) Silicone Parker Seal	20	16				
No. 16	O ring (1) Urethane Parker Seal	5	4	100	DC55M		Test completed
	Quad rings (2) Urethane Minnesota Rubber						
No. 17	Q ring (1) Urethane Parker Seal	20	4	100	DC55M	16,420 (31,400 cycles)	Test stopped. Friction forces too high.
	O rings (2) Urethane Minnesota Rubber						
No. 18	O ring (1) Urethane Minnesota Rubber	5	16	100	DC55M	(16,630 cycles)	
	Q rings (2) Urethane Parker Seal	5	16				
No. 19	Quad ring (1) Urethane Minnesota Rubber	20	16	100	DC55M		
	O rings (2) Urethane Parker Seal	20	16			(15,130 cycles)	
No. 20	O ring (1) Urethane Minnesota Rubber	5	4	100	WSX-8788		
	Q rings (2) Urethane Parker Seal	5	4			(16,630 cycles)	
No. 21	Quad ring (1) Urethane Minnesota Rubber	20	4	100	WSX-8788		
	O rings (2) Urethane Parker Seal	20	4			(16,630 cycles)	

calculated for static Buna N O-ring seals, for comparison with the measured rotary seal values. In most cases, the agreement between the two is very good, indicating that these slowly moving rotary seals function basically as static seals.

Tables 6 through 10 list the measured and calculated L_{Kr} values for the remaining rotating and reciprocating seal tests. All of the measured values are preliminary, and some values are from tests currently running. In general, the leakages of reciprocating seals of a given material do not show the same good agreement with calculated values* as do the leakages of the rotary seals. This phenomena is not unexpected, since the reciprocating type of seal should, by its very nature, exhibit higher and variable leakages, as the seal is continually exposed to a new surface to seal, and is, in addition, exposed to alternating lateral forces which tend to alter the seal shape.

Tables 5 through 10 include new data, generated this month, and will continue to be updated, and the L_{Kr} values changed, as new test data are obtained, and the data refinement progresses. As such, these data should only be used, at this time, as an indication of the extent of seal leakage.

The measured values of L_{Kr} (seal leakage based upon Kr gas) for EPR and silicone are, in nearly all cases, much lower than the values calculated from permeation data. It is believed that these low values are caused by unaccounted for trace gas losses through the outer containment seal. The calculational method is being reviewed and revised to account for these losses.

4. Lubrication Evaluation

Three friction tests were completed on urethane, silicone, and EPR elastomer O rings, lubricated with one of several greases, as shown in Figures 2 to 4. The urethane seals showed low uniform friction forces for both DC-55M and WSX-8788 greases.

The Stauffer 295, silicone-base grease (now dropped from the evaluation program) produced high forces with a silicone O ring, and sheared the safety

*All calculated values are based on static O-ring seals, and are only shown for comparison. Seals of differing geometry may ultimately be found to exhibit consistently higher, or consistently lower, leakages than an O-ring seal. Likewise, dynamic seals should be expected to exhibit higher leakages than static seals.

TABLE 5

ROTATING BUNA N SEALS TABULATION OF L_{Kr} VALUES FROM ELASTOMER SEAL LEAKAGE TESTS

Seal Type	Elastomer	Supplier	Test Type	Compression (%)	Finish (rms)	Lubricant	Leakage, L_{Kr}		Comments
							Measured	Calculated	
O	Buna N*	PS	RoD-4	10	8	DC55M	18	20	
O	Buna N	MR	RoD-6	10	8	DC55M	25	33	Test in progress
Quad	Buna N	MR	RoD-3	10	8	DC55M	15	33	
Q	Buna N	PS	RoD-5	10	8	DC55M	25	20	Test in progress
O	Buna N	PS	RoI-6	5	4	DC55M	19	23	
O	Buna N	MR	RoI-7	20	4	DC55M	26	26	
O	Buna N	MR	RoI-11	5	16	DC55M	7	38	
O	Buna N	PS	RoI-12	20	16	DC55M	28	16	
Quad	Buna N	MR	RoI-6	5	4	DC55M	38	38	
Q	Buna N	PS	RoI-7	20	4	DC55M	15	16	
Q	Buna N	PS	RoI-11	5	16	DC55M	14	23	
Quad	Buna N	MR	RoI-12	20	16	DC55M	25	26	

*150°F
PS = Parker Seal
MR = Minnesota Rubber

Ro = Rotary
I = Information
D = Demonstration

L_{Kr} = Std cc/sec/linear inch of seal/atm ΔP of Kr x 10^{-8}

TABLE 6

RECIPROCATING BUNA N SEALS TABULATION OF L_{Kr} VALUES FROM ELASTOMER SEAL LEAKAGE TESTS

Seal Type	Elastomer	Supplier	Test Type	Compression (%)	Finish (rms)	Lubricant	Leakage, L_{Kr}		Comments
							Measured	Calculated	
T	Buna N*	GT	ReD-2	10	8	DC55M	10	13	
T	Buna N	PS	ReD-3	10	8	DC55M	7	20	Test in progress
Quad	Buna N	MR	ReD-2	10	8	DC55M	28	33	
Q	Buna N	PS	ReD-3	10	8	DC55M	16	20	Test in progress
T	Buna N	PS	ReI-5	5	4	DC55M	68	23	
T	Buna N	GT	ReI-4	20	4	DC55M	18	10	
T	Buna N	GT	ReI-7	5	16	DC55M	59	16	
T	Buna N	PS	ReI-7	20	16	DC55M	160	16	
Quad	Buna N	MR	ReI-5	5	4	DC55M	700 †	38	†H_2 value only
Quad	Buna N	MR	ReI-4/7	20	16	DC55M	380†/38	26	†H_2 value only
Q	Buna N	PS	ReI-7	5	16	DC55M	98 †	23	†H_2 value only
Q	Buna N	PS		20	4	DC55M	--	16	

*150 °F
PS = Parker Seal
MR = Minnesota Rubber

Re = Reciprocating
I = Information
D = Demonstration

L_{Kr} = Std cc/sec/linear inch of seal/atm ΔP of Kr x 10^{-8}

TABLE 7

ROTATING EPR SEALS TABULATION OF L_{Kr} VALUES FROM ELASTOMER SEAL LEAKAGE TESTS

Seal Type	Elastomer	Supplier	Test Type	Compression (%)	Finish (rms)	Lubricant	Leakage, L_{Kr}		Comments
							Measured	Calculated	
O	EPR**	MR	RoD-2*	10	8	DC55M	143	170	
O	EPR	PS		10	8	DC55M	-	130	To be tested
Quad	EPR	MR		10	8	DC55M	-	170	To be tested
Q	EPR	PS	RoD-1	10	8	DC55M	78	130	
O	EPR	MR	RoI-1	5	4	DC55M	70	190	
O	EPR	PS	RoI-5	20	4	DC55M	50	96	
O	EPR	PS	RoI-8	5	16	DC55M	42	150	
O	EPR	MR	RoI-9	20	16	DC55M	28	130	
Q	EPR	PS	RoI-1	5	4	DC55M	75	150	
Quad	EPR	MR	RoI-5	20	4	DC55M	51	130	
Quad	EPR	MR	RoI-8	5	16	DC55M	62	190	
Q	EPR	PS	RoI-9	20	16	DC55M	26	96	

**EPR = Ethylene Propylene Rubber
*150°F
PS = Parker Seal
MR = Minnesota Rubber

Ro = Rotary
I = Information
D = Demonstration

L_{Kr} = Std cc/sec/linear inch of seal/atm ΔP of Kr x 10^{-8}

TABLE 8

RECIPROCATING EPR SEALS TABULATION OF L_{Kr} VALUES FROM ELASTOMER SEAL LEAKAGE TESTS

Seal Type	Elastomer	Supplier	Test Type	Compression (%)	Finish (rms)	Lubricant	Leakage, L_{Kr}		Comments
							Measured	Calculated	
T	EPR**	GT	ReD-1*	10	8	DC55M	135	130	
T	EPR	PS	ReD-4	10	8	DC55M	11	130	Test in progress
Quad	EPR	MR	ReD-4	10	8	DC55M	59	170	Test in progress
Q	EPR	PS	ReD-1	10	8	DC55M	168	130	
T	EPR	GT	ReI-4	5	4	DC55M	172	140	
T	EPR	PS	ReI-5	20	4	DC55M	14	96	
T	EPR	PS	ReI-8	5	16	DC55M	20	150	
T	EPR	GT	ReI-8	20	16	DC55M	42	96	
Quad	EPR	MR	ReI-8	5	16	DC55M	1270†	190	†H_2 value only
Quad	EPR	MR	ReI-5	20	4	DC55M	400†	130	†H_2 value only
Q	EPR	PS	ReI-4	5	4	DC55M	244†	150	†H_2 value only
Q	EPR	PS	ReI-8	20	16	DC55M	230†	96	†H_2 value only

**EPR = Ethylene Propylene Rubber
*150°F

PS = Parker Seal
MR = Minnesota Rubber
GT = Greene Tweed

Re = Reciprocation
I = Information
D = Demonstration

L_{Kr} = Std cc/sec/linear inch of seal/atm ΔP of Kr x 10^{-8}

TABLE 9

ROTATING URETHANE AND SILICONE SEALS TABULATION OF L_{Kr} VALUES FROM ELASTOMER SEAL LEAKAGE TESTS

Seal Type	Elastomer	Supplier	Test Type	Compression %	Finish RMS	Lubricant	Leakage, Meas.	L_{Kr} Calc	Comments
O	Urethane*	PS	RoI-16	5	4	DCSSM	2.3	2.5	
O	Urethane	MR	RoI-16	20	4	DCSSM		5	
O	Urethane	MR		5	16	DCSSM		8	
O	Urethane	PS		20	16	DCSSM		1.5	
Quad	Urethane	MR	RoI-16	5	4	DCSSM	5	8	
Q	Urethane	PS	RoI-16	20	4	DCSSM		1.5	
Q	Urethane	PS		5	16	DCSSM		2.5	
Quad	Urethane	MR		20	16	DCSSM		5	
O	Silicone**	PS	RoI-16	5	4	DCSSM	400	6800	
O	Silicone	MR	RoI-16	20	4	DCSSM	590	6000	
O	Silicone	MR	RoI-16	5	16	DCSSM	428	9000	
O	Silicone	PS	RoI-16	20	16	DCSSM	370	4600	
Quad	Silicone	MR	RoI-16	5	4	DCSSM	100	9000	
Q	Silicone	PS	RoI-16	20	4	DCSSM	390	4600	
Q	Silicone	PS	RoI-14	5	16	DCSSM	225	6800	
Quad	Silicone	MR	RoI-15	20	16	DCSSM	151	6000	

*100 °F
**300 °F

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I = Information
D = Demonstration
L_{Kr} = Std cc/sec/linear inch of seal/atm ΔP of Kr x 10^{-8}

TABLE 10

RECIPROCATING URETHANE AND SILICONE SEALS TABULATION OF L_{Kr} VALUES FROM ELASTOMER SEAL LEAKAGE TESTS

Seal Type	Elastomer	Supplier	Test Type	Compression %	Finish RMS	Lubricant	Leakage, Meas.	$L_{Kr_{Calc}}$	Comments
T	Urethane*	PS		5	4	DCSSM		2.5	
T	Urethane	GT		20	4	DCSSM		4.5	
T	Urethane	GT	ReI-9	5	16	DCSSM	40	7	
T	Urethane	PS	ReI-9	20	16	DCSSM	42	1.5	
Quad	Urethane	MR		5	4	DCSSM		8	
Q	Urethane	PS		20	4	DCSSM		1.5	
Q	Urethane	PS	ReI-9	5	16	DCSSM	25	2.5	
Quad	Urethane	MR	ReI-9	20	16	DCSSM	22	5	
T	Silicone**	PS		5	4	DCSSM		6800	
T	Silicone	GT		20	4	DCSSM		3100	
T	Silicone	GT		5	16	DCSSM		4500	
T	Silicone	PS		20	16	DCSSM		4600	
Quad	Silicone	MR		5	4	DCSSM		9000	
Q	Silicone	PS		20	4	DCSSM		4600	
Q	Silicone	PS		5	16	DCSSM		6800	
Quad	Silicone	MR		20	16	DCSSM		6000	

*100 °F
**300 °F

PS = Parker Seal
MR = Minnesota Rubber
GT = Greene Tweed

Ro = Rotary
Re = Reciprocating

I = Information
D = Demonstration
L_{Kr} = Std cc/sec/linear inch of seal/atm ΔP of Kr x 10^{-8}

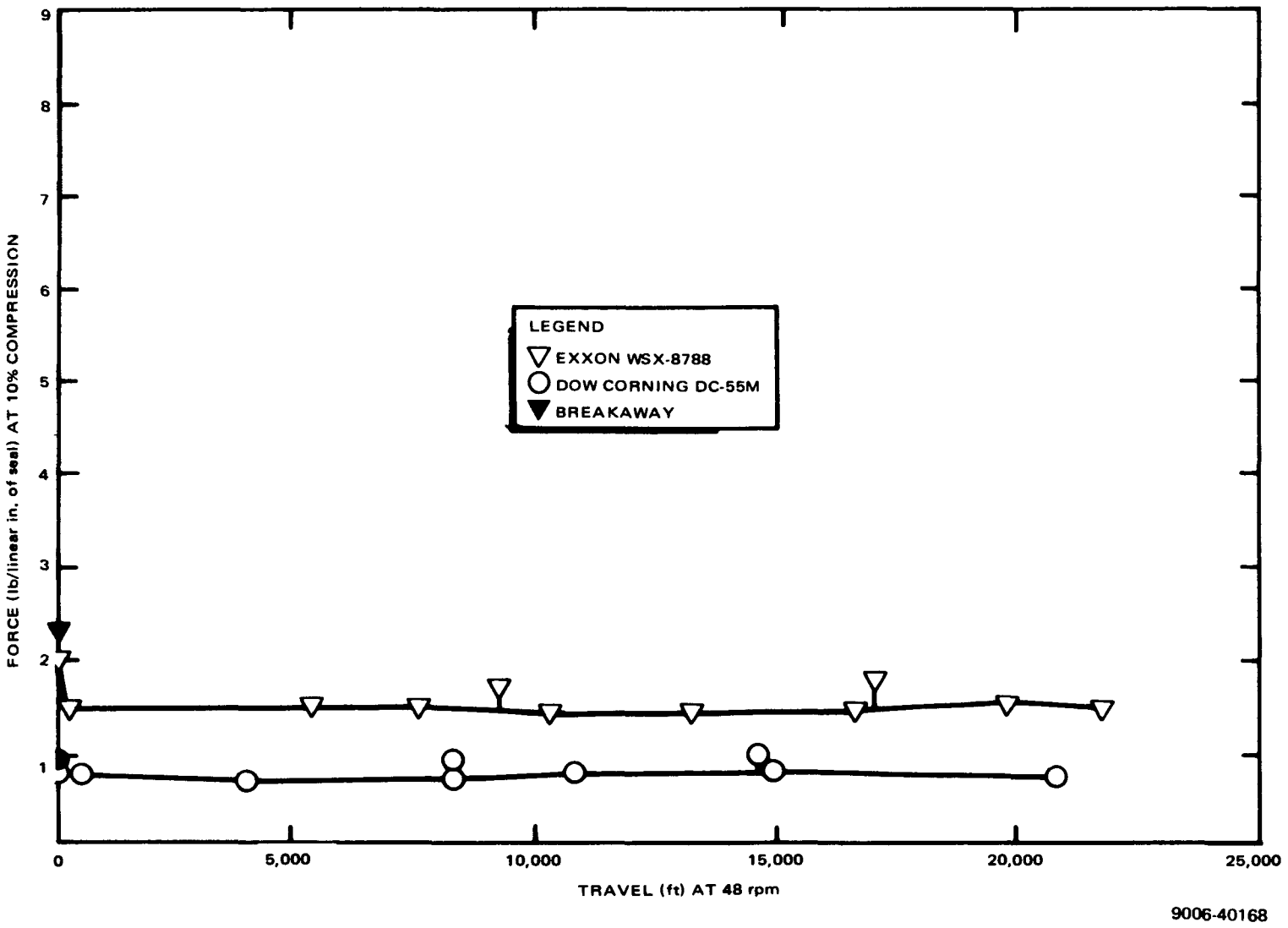


Figure 2. Friction Force vs Travel — Parker Urethane O Rings (Compound No. P648) at 100°F

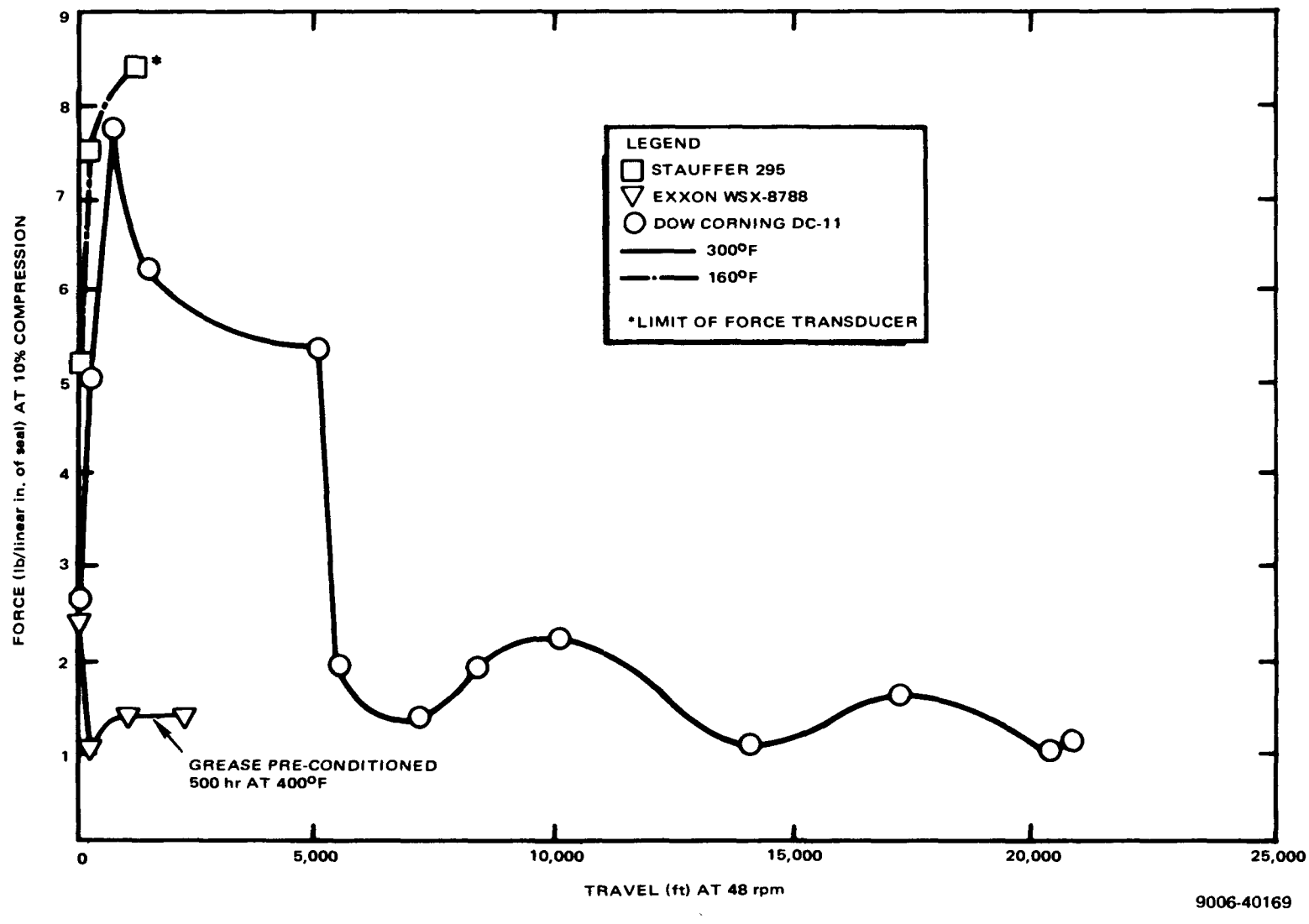


Figure 3. Friction Force vs Travel — Parker Silicone O Rings (Compound No. S684)

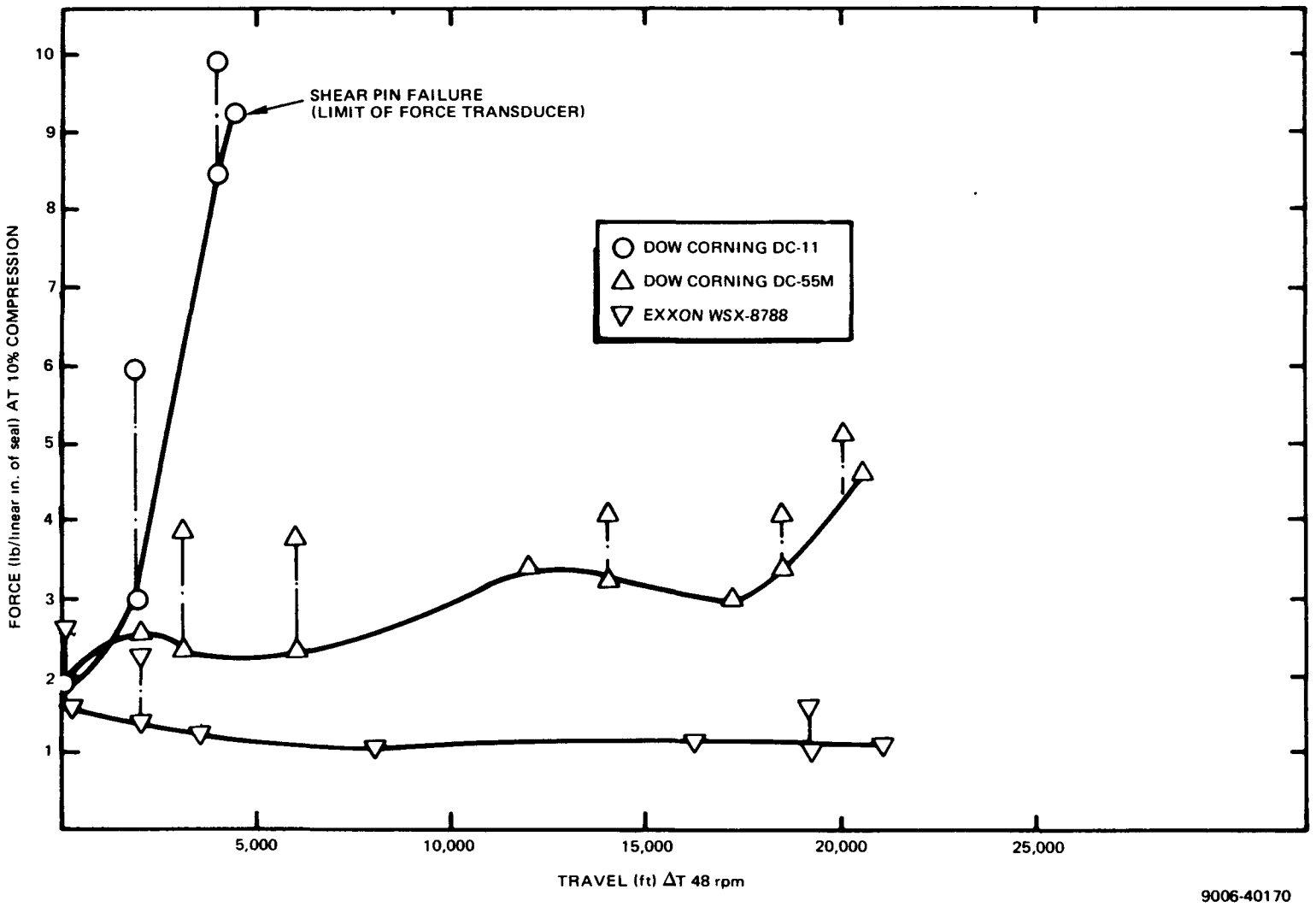


Figure 4. Friction Force vs Travel — Parker EPR O Rings

linkage which protects the transducer. Initially, DC-11 grease on the silicone O ring produced high forces but these forces dropped off to a low, but variable, value.

A small amount of WSX-8788 was removed from one of the thermal stability tests, and was used to lubricate a silicone O-ring, to determine any change in lubricity. As shown in Figure 3, the pre-conditioned grease showed about 1-lb force/linear inch of seal, which was the same as the friction force of the as-received material.

Figure 5 shows a bar chart summary of all friction tests run. The tests with Buna N elastomers were run initially, and resulted in the elimination of the two greases, SWS-290 and Super-O-Lube, whose friction force exceeded the limit of the transducer. Tests conducted on silicone elastomers at 220°F eliminated the SWS-295 grease. Tests on EPR at 100°F showed excessive friction for the DC-11, and long-term tests on silicone at 300°F showed excessive friction for the reference DC-55M grease. The EXXON WSX-8788, a polyester-base grease, showed the best overall results, and has been selected as the alternate lubricant in the test program, and is recommended specifically for the lubrication of the silicone elastomer seals.

Material compatibility tests are continuing. Table 11 shows the results of silicone elastomers exposed to Dow Corning DC-11, DC-55M, and EXXON WSX-8788 for 572 and 1200 hr at 200 and 300°F. As expected, the silicone greases, DC-11 and DC-55M are less compatible and result in greater swelling of the silicone elastomers than the polyester-base WSX-8788. Most of the reaction or swelling occurred during the initial 72 hr.

Weight loss of original specimens continuing on test is shown in Table 12, which expands on data presented last month. The WSX-8788 at 350°F still shows considerable weight loss, and has lost a significant degree of lubricity. Duplicate sets of thermal stability lubricant specimens have been placed on test at 300, 350, and 400°F, using DC-11, DC-55M, and WSX-8788 greases. Visual examination of the 400°F specimens shows WSX-8788 has the tendency to evaporate the low boiling point esters, while the DC-55M separated into a pool of oil, probably the base DC-510 silicone oil, and the heavier oil and thicker portions of the grease. While the 350 and 400°F temperatures exceed the expected use temperature, they provide insight into the behavior of the compound.

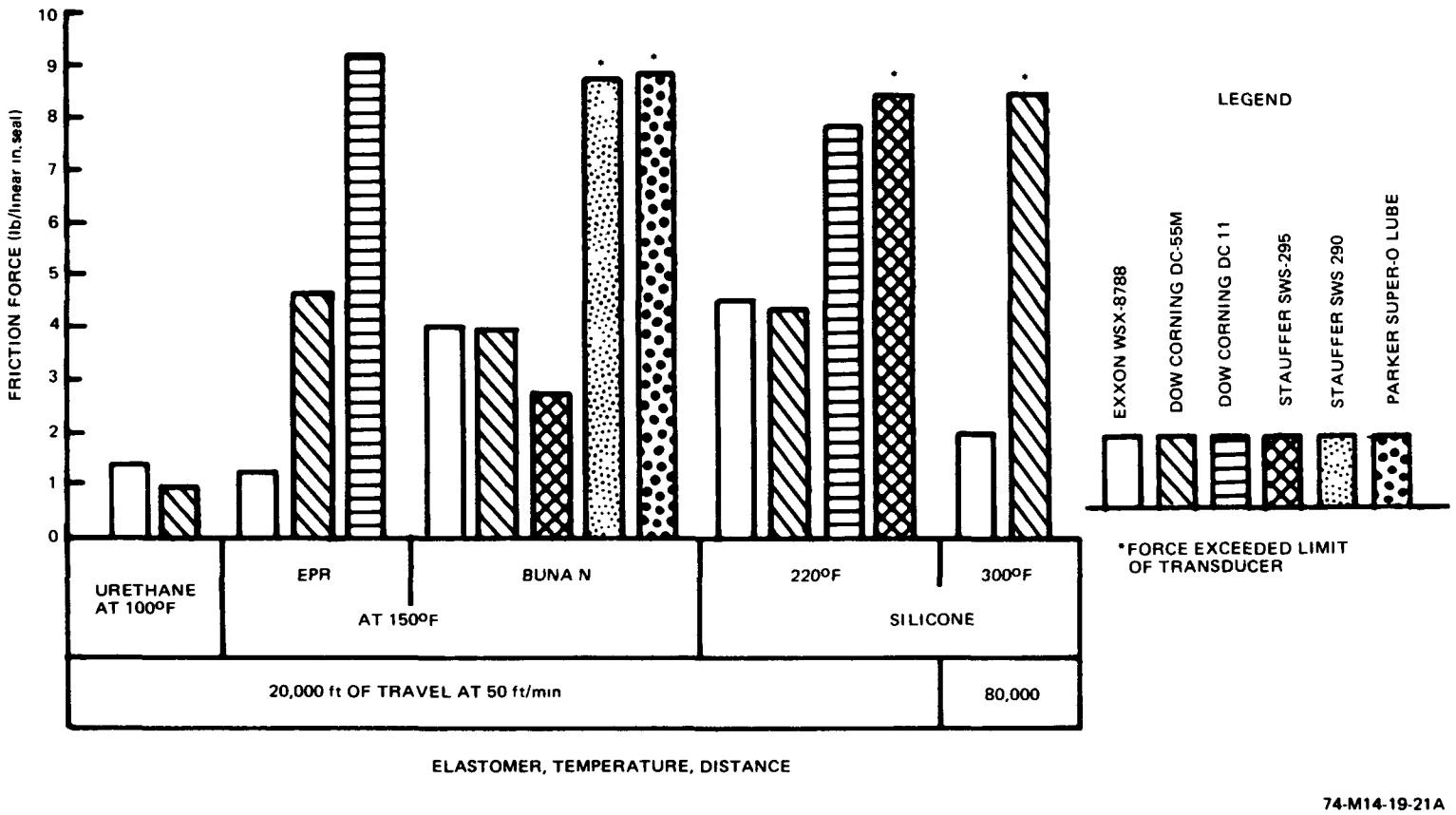


Figure 5. Friction Force vs Material Elastomer - Lubricant Combinations as a Function of Temperature and Distance

TABLE 11

LUBRICANT EFFECT ON SILICONE SEALS

Parameter	Vendor	% Change Through 572 hr*							
		200°F†				300°F			
		Dry	WSX	DC-11	55M	Dry	WSX	DC-11	55M
Weight	Parker	-0.2	+3.9	+7.9	+23.6	-0.5	+5.8	+7.8	+26.8
	Minn.	-0.8	+1.5	+7.3	+17.9	-1.5	+0.1	+5.1	+18.2
Diameter	Parker	-3.3	+1.9	+1.4	+ 7.1	-2.4	+1.4	+1.9	+ 7.0
	Minn.	-0.4	-1.4	+2.4	+ 5.7	-0.4	-	+1.4	+ 3.2
Hardness	Parker	-	-1	-7	-14	-	>1	-7	-20
	Minn.	-	-7	-4	-20	+7	-	-3	-21
		% Change Through 1200 hr							
		200°F†				300°F†			
		Dry	WSX	DC-11	DC-55M	Dry	WSX	DC-11	DC-55M
Weight	Parker	-<1	3.9	9.8	26.6	-<1	+5.2	10.0	28.6
	Minn.	-<1	+<1	8.7	16.1	-1.3	-<1	6.5	18.8
Hardness	Parker	1.0	3.0	-9.5	-15.6	1.4	2.9	-9.7	-21.4
	Minn.	-3.0	7.0	-7.0	-21.0	6.0	-	1.4	-20.7
Diameter	Parker	-3.3	-1.4	+2.4	+6.2	-1.4	1.0	1.9	5.7
	Minn.	-2.4	-2.3	+2.3	+3.8	-1.4	-1.4	-1.4	2.8

*DC-1 = 500 hr †Immersed in the test lubricant

TABLE 12

LUBRICANT THERMAL STABILITY (Weight Loss) TEST

Temperature (°F)	Lubricant	Weight Loss (%) Total Time at Temperature (hr)						Comments
		500	1000	1500	1800	2500	3000	
300	DC-55M(1)	ND	32.7	6.2	–	1.3	1.1	Light skin, darkened
300	DC-55M(2)	20.1	4.0	1.8	–	0.9	0.9	Light skin
300	WSX-8788	11.0	5.3	4.3	–	0.8	2.14	Darkened
300	SWS-295	3.2	1.7	4.3				Light skin
300	SWS-290	3.4	0.3	0.3				High friction results
300	Super-O	0.1	0.1	0.3				High friction results
300	761	23.0	37.3					High friction results
300	B645	10.1	2.0	4.1				Very stiff
300	MO-40	10.4						Rock hard
300	DC-44	1.5	4.6	0.9	–	4.9	0.2	High friction results
300	DC-11	1.1						
350	DC-55M	24.6	12.4	–	0.8	3.6	2.3	Light skin, darkened
350	WSX-8788	12.4	13.7	–	3.2	22.7	20.5	Black, gummy, best at 1800 hr
350	SWS-295	3.4	2.1	–	1.0	3.5	1.9	Light skin
350	SWS-290	3.6	0.6	–	0.2			High friction results
350	Super-O	0.1	0.6	–	0.1			High friction results
350	761	32.8						High friction results
350	B645	9.9	20.0	–	7.2			Very stiff
350	MO-40	18.1						Rock hard
350	DC-11	1.5						
400	DC-55M	~30	*					Light skin, darkened
400	WSX-8788	27.4	*					Darkened
400	SWS-295	16.0	*					Light skin
400	DC-11	2.0						

*Test Terminated

B. STATIC TESTING

1. Static Seal Tests

Table 13 summarizes the status of all current static seal tests.

a. Demonstration Tests

Three static demonstration tests (No. 1, 2, and 3) were assembled with pairs of Buna N, EPR, and silicone elastomer O-ring seals, and static leakage testing begun at 150, 150, and 300°F, respectively. The preliminary leakage data for the Buna N seals appear to be of the same order of magnitude as permeation-type, calculated for a seal under 50% compression, but the leakage values for the EPR and silicone seals appear to be low. These low values have been attributed to the high losses through the outer, containment seal. These losses are not accounted for in the current method of calculation, although correction for these losses will be made.

To reduce these losses to a more acceptable level, Demonstration Tests No. 2 and 3 were shut down, and Buna N seals installed in the outer, containment seal gland. These tests are continuing.

b. Information Tests

Static information tests were set up with Parker Seal Company and Minnesota Rubber Company Buna N, EPR, and silicone elastomer rings under 10 and 20% compression. Static Information Tests No. 2A-D and 3A-D also showed lower than anticipated leakage values. Test No. 3 was shut down, and the outer, containment removed and replaced with a Buna N seal. Test No. 2 was not interrupted for a seal replacement, as discussed in the next section. As shown in Table 13, the Buna N and EPR tests were ended after 3459 and 2154 hr, respectively.

2. Leakage Calculations

As described in the preceding section, the leakage values can be calculated, knowing the seal geometry, % compression, temperature, and material permeability. Table 14 compares these calculated values with currently running seal tests, where sufficient data exist, to establish the measured leakage value. Reasonably good agreement is seen only with the Buna N seals.

TABLE 13

STATIC SEAL TESTS
(O rings only)

Test	Seals	Compression (%)	Gland Finish (rms)	Temperature (°F)	Lubricant	Time (hr)	Comments
Demonstration No. 1	Buna N (N741-75) Parker Seal Co.	50	16	150	DC55M		Test completed
Demonstration No. 2	EPR (E692) Parker Seal Co.	50	16	150		1637	
Demonstration No. 3	Silicone (S684) Parker Seal Co.	50	16	300		1637	
Information 1A	Buna N (366Y) Minnesota Rubber Co.	10	8	150		3459	
Information 1B	Buna N (N741-75) Parker Seal Co.	10	32	150		3459	Test completed
Information 1C	Buna N (N741-75) Parker Seal Co.	20	8	150		3459	
Information 1D	Buna N (366Y) Minnesota Rubber Co.	20	32	150		3459	
Information 2A	EPR (E692) Parker Seal Co.	10	8	150		2154	
Information 2B	EPR (559N) Minnesota Rubber Co.	10	32	150		2154	Test completed
Information 2C	EPR (559N) Minnesota Rubber Co.	20	8	150		2154	
Information 2D	EPR (E692) Parker Seal Co.	20	32	150		2154	
Information 3A	Silicone (71417) Minnesota Rubber Co.	10	8	300		1073	
Information 3B	Silicone (S684) Parker Seal Co.	10	32	300		1073	Test completed
Information 3C	Silicone (S684) Parker Seal Co.	20	8	300		1073	
Information 3D	Silicone (71417) Minnesota Rubber Co.	20	32	300	DC55M	1073	

TABLE 14

STATIC O-RING SEAL TESTS – TABULATION OF L_{Kr} VALUES FROM ELASTOMER SEAL LEAKAGE TESTS

Seal Type	Elastomer	Supplier	Test Type	Compression (%)	Finish (rms)	Lubricant	Leakage, L_{Kr}	
							Measured*	Calculated
O	Buna N	PS	STA-D-1	50	16	DC-55M	6	6
O	Buna N	MR		50	16	DC-55M		10
O	Buna N	MR	STA-1-1A	10	8	DC-55M	25	33
O	Buna N	PS	STA-1-1B	10	32	DC-55M	10	20
O	Buna N	PS	STA-1-1C	20	8	DC-55M	12	16
O	Buna N	MR	STA-1-1D	20	32	DC-55M	8	26
O	EPR	PS	STA-D-2	50	16	DC-55M	14	38
O	EPR	MR		50	16	DC-55M		48
O	EPR	PS	STA-1-2A	10	8	DC-55M	29	130
O	EPR	MR	STA-1-2B	10	32	DC-55M	48	170
O	EPR	MR	STA-1-2C	20	8	DC-55M	62	130
O	EPR	PS	STA-1-2D	20	32	DC-55M	43	96
O	Silicone	PS	STA-D-3	50	16	WSX-8788	227	1700
O	Silicone	MR		50	16	DC-55M		2400
O	Silicone	MR	STA-1-3A	10	8	DC-55M	575	8000
O	Silicone	PS	STA-1-3B	10	32	DC-55M	365	6000
O	Silicone	PS	STA-1-3C	20	8	DC-55M	250	4500
O	Silicone	MR	STA-1-3D	20	32	DC-55M	355	6000

EPR = Ethylene propylene rubber
PS = Parker Seal
MR = Minnesota Rubber
STA = Static
I = Information
D = Demonstration
L_{Kr} = Std cc/sec/linear in. of seal/atm P of Kr x 10^{-8}
*Listed values not yet corrected for permeation leakage through outer fixture seal

As may be seen in Table 14, the L_{Kr} values for the EPR seals are only 1/2 to 1/4 of the calculated values, and the L_{Kr} values(calculated from the H_2 data point only, the L_{Kr} value calculated from the Kr data point is even lower) for the silicone seals are 1/15 to 1/25 of the calculated value. It had been recognized, early in the test program, that the loss of gas by permeation through the outer, containment O-ring seal would produce a low L_{Kr} value, but that this loss would be corrected to produce a more accurate L_{Kr} value.

To reduce the size of the correction, an attempt is being made first to reduce the loss through the outer seal by replacing the outer silicone and EPR O rings with Buna N O rings. (Although Buna N is not normally used at 300°F, it is believed that, in this static application, it will provide a satisfactory "one-time" seal.) The calculated L_{Kr} for the Buna N O ring at 300°F is $\sim 2 \times 10^{-6}$ Std cc/sec/linear in. of seal/atm ΔP, compared to an L_{Kr} of 1.7×10^{-5} for the silicone O ring at the same temperature (i. e., $\sim 1/8$ as much Kr should permeate through the Buna N as with the silicone seal).

On the basis of the first few chromatograph readings, with the Buna N containment seal, the L_{Kr} for the silicone O ring in Static Demonstration Test No. 3 increased from 82 to 227×10^{-8} Std cc/sec/linear in. of seal/atm ΔP, compared to the calculated value of 1700×10^{-8}. Additional mathematical corrections for the loss through the less permeable Buna N seal are now expected to give a very realistic L_{Kr} value for the silicone seals at 300°F and 50% compression.

The outer containment seal in Static Demonstration Test No. 2 (EPR O rings, 150°F, 50% compression) was also replaced with a Buna N seal. No significant change in the L_{Kr} for EPR has been seen in these early readings, since the difference between the L_{Kr}'s of EPR and Buna N is much less than the difference between the L_{Kr}'s of silicone and Buna N.

3. Special Observations

When Static Demonstration Test No. 3 was disassembled to remove the Silicone O rings, it was found that the plates were tightly stuck together, and a wedge had to be used to force the plates apart. It was found that the silicone O rings were firmly attached to the stainless steel plates, causing small pieces

of seal to tear off as the plates were separated. The seal was stuck more firmly to the top plate than to the seal gland. As the seal was pulled from the top plate, the seal tore partially in several places, and, at one place, tore completely across the cross section. A post-test photograph of the seals is shown in Figure 6. Pieces of seal, stuck to and remaining in the seal glands, are evident in the photo of the fixture, Figure 7.

The fixture plates were cleaned, and new seals installed (two Parker silicone test O rings, one Minnesota Rubber Buna N containment O ring). It was decided not to use the DC-55M lubricant on these seals, but to use the WSX-8788 lubricant. The test was reassembled, and the leakage measurements begun.

When Static Information Tests No. 3A-D was disassembled to replace the outer seals, the silicone O rings were found to be adhering to the steel plates in the same manner as when Static Demonstration Test No. 3 was disassembled.

The inner test silicone seals were not found to be stuck to the plates, probably because these seals were compressed only 10 and 20%. All seals were removed, measured, etc. The compression set of these seals was calculated, and the data are presented in the following section.

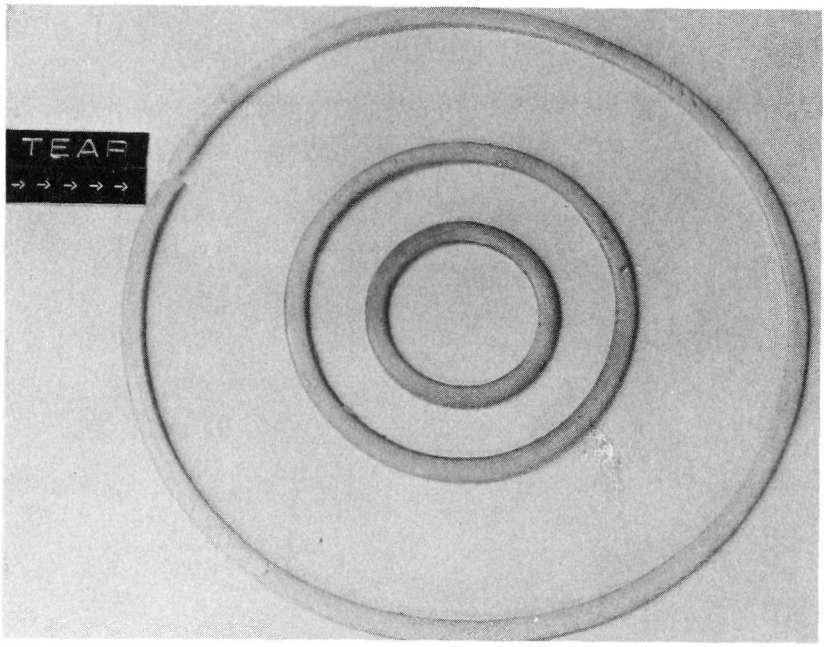
4. Compression Set

Compression set testing continues on several elastomer O rings, and is into the last 16 weeks of the 32-week test (readings are taken at 1, 2, 4, 8, 16, and 32 weeks).

The Parker Seal Buna N seal after 16 weeks at 100°F shows no damage, and has experienced only 20.1% set.

Testing was begun on a new elastomer material (Parker Seal EPR Compound E529). Table 15 summarizes the current data on this compound. The percent compression set is much greater for the softer, Compound E529 (Hardness Shore 65) than for the previously tested Parker Seal EPR (Compound E692, Hardness 80).

The 300°F compression set values for the 12 silicone seals removed from Static Information Tests No. 3A-D were determined from the seal dimensions. Table 16 shows the compression set values, and the pre- and post-test hardness



9006-40155

Figure 6. Silicone Test Seals, Static Demonstration Test No. 3 (Park Seal silicone O ring, Dow Corning 55M, 3 months, 300°F)

9006-40153

Figure 7. Seal Particles Torn From Test Seals, Static Demonstration Test No. 3

TABLE 15

COMPRESSION SET AND HARDNESS OF PARKER SEAL EPR O RING (Compound E529)

Time (hr)	Temperature (°F)	Compression Set (%)	Hardness (Shore A)
0	Ambient	-	62-63
168	250	54.3	63-64
336	250	62.3	63-65
672	250	72.0	68-70

TABLE 16

COMPRESSION SET AND HARDNESS OF SILICONE O RINGS FROM STATIC INFORMATION TEST NO. 3 (1386 hr - 300°F)

Vendor	Seal Diameter (in.)	Compression (%)	Compression Set (%)	Hardness	
				Pre	Post
Minnesota Rubber Compound 71417	2	10	36.4	72	65
	4	10	31.6	71	65
	8	45	91.5	72	59
	2	20	20.9	65	59
	4	20	37.3	70	54
	8	45	98	75	52
Parker Seal Compound S684	2	10	61.5	75	66
	4	10	68.5	75	68
	8	45	100	75	70
	2	20	74.4	76	65
	4	20	83.8	74	65
	8	45	99	74	69

values. It can be seen that the Parker Seal silicone O rings exhibited significantly greater set than the Minnesota Rubber silicone O rings. These data confirm the observations at 200 and 250°F, which also showed the Minnesota Rubber Silicone compound to exhibit less set. It also is seen that the seals compressed at only 10 and 20% exhibited much less set than those seals compressed 45%. Earlier test data had shown that no difference in % set could be seen between seals compressed 35 and 50%. It is possible that the amount of set is roughly proportioned to the % compression at lower compression, but is not proportional to the % compression after a certain level is reached.

Figure 8 shows the 300°F data point for the silicone elastomer (Compound S684) in relation to the % compression sets observed for other temperatures. Even though the observed set was ~100%, no leakage was observed across the test seal. The fact that the seal was well adhered to the steel would contribute to the nonleak observation.

The 150°F compression set values for the 12 EPR seals removed from Static Information Tests No. 2A-D were determined from the seal dimensions. Table 17 shows these compression set values and the pre- and post-test hardnesses. No significant difference was observed, in this case, between the % set at 10 and 20% compression and the % set at 45% compression. This is different from the data on silicone, where less set accompanied less compression. Figure 9 adds the 150°F data point to the EPR compression set curve.

C. PERMEABILITY TESTS

Permeability tests were continued on slab samples of elastomer compounds from which the test seals were fabricated, or which might have application for seal fabrication. Figures 10 to 12 show the permeability, $\overline{P}$, values for three elastomers: Parker Seal Butyl (B318), Parker Seal EPR (E529), and Minnesota Rubber Buna N (366Y, Los No. 2). The $\overline{P}$ values for the butyl rubber are not significantly different than the Buna N $\overline{P}$ values, confirming the earlier recommendation that Buna N seals could replace butyl seals with no increase in gas permeability.

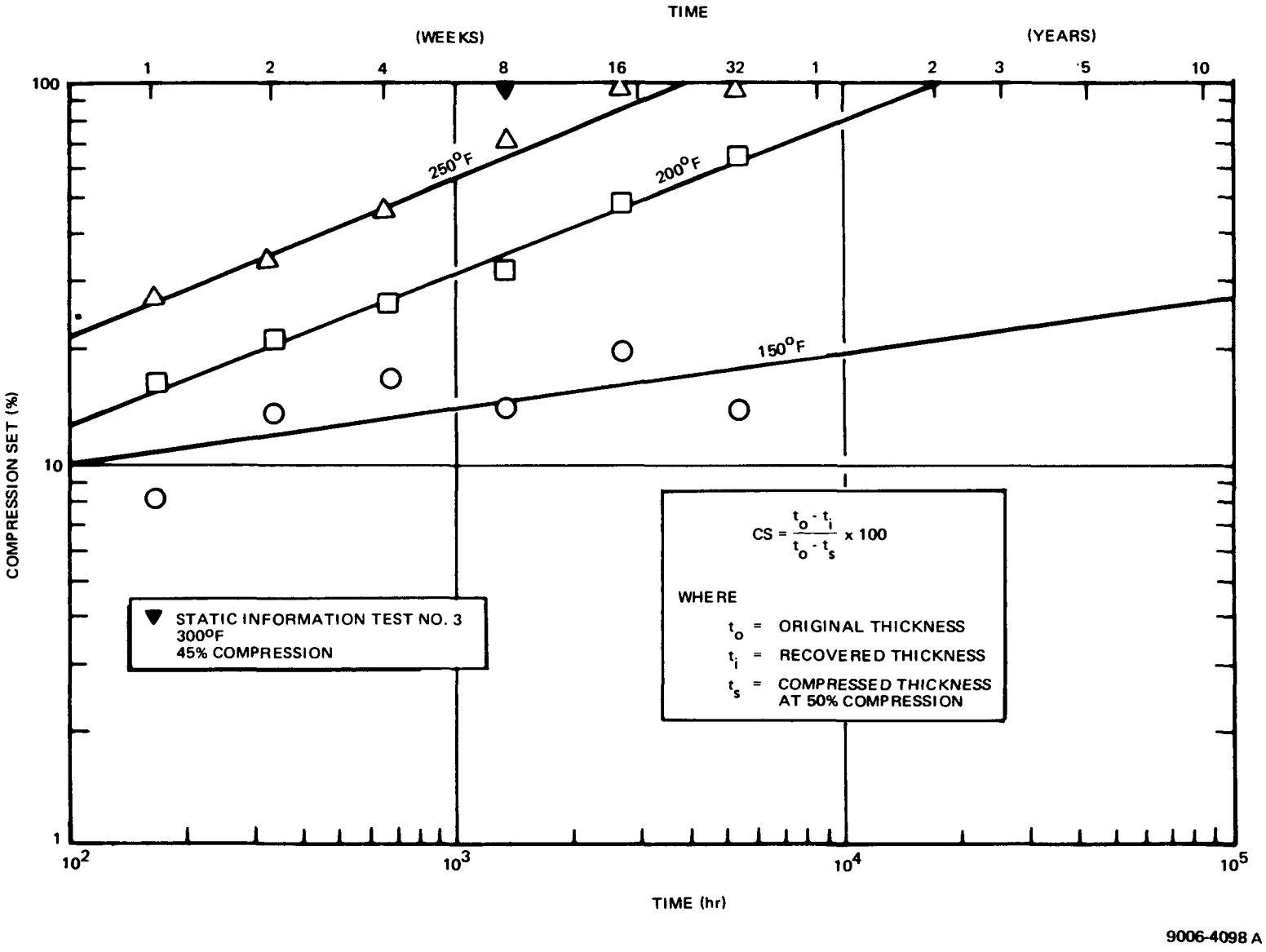


Figure 8. Compression Set of Parker Seal Silicone O Rings (Compound S684)

TABLE 17

COMPRESSION SET AND HARDNESS OF EPR O RINGS FROM STATIC INFORMATION TEST NO. 2 (2154 hr, 150°F)

Vendor	Seal Diameter (in.)	Compression (%)	Compression Set (%)	Hardness	
				Pre	Post
Parker Seal Compound E692	2	10	11.8	74	75
	4	10	33.3	76	75
	8	45	18.3	65	61
	2	20	16.7	76	76
	4	20	17.8	74	74
	8	45	20.2	65	63
Minnesota Rubber Compound 559N	2	10	20.0	68	69
	4	10	31.8	73	72
	8	45	15.8	70	70
	2	20	28.0	68	69
	4	20	20.0	71	73
	8	45	11.3	68	70

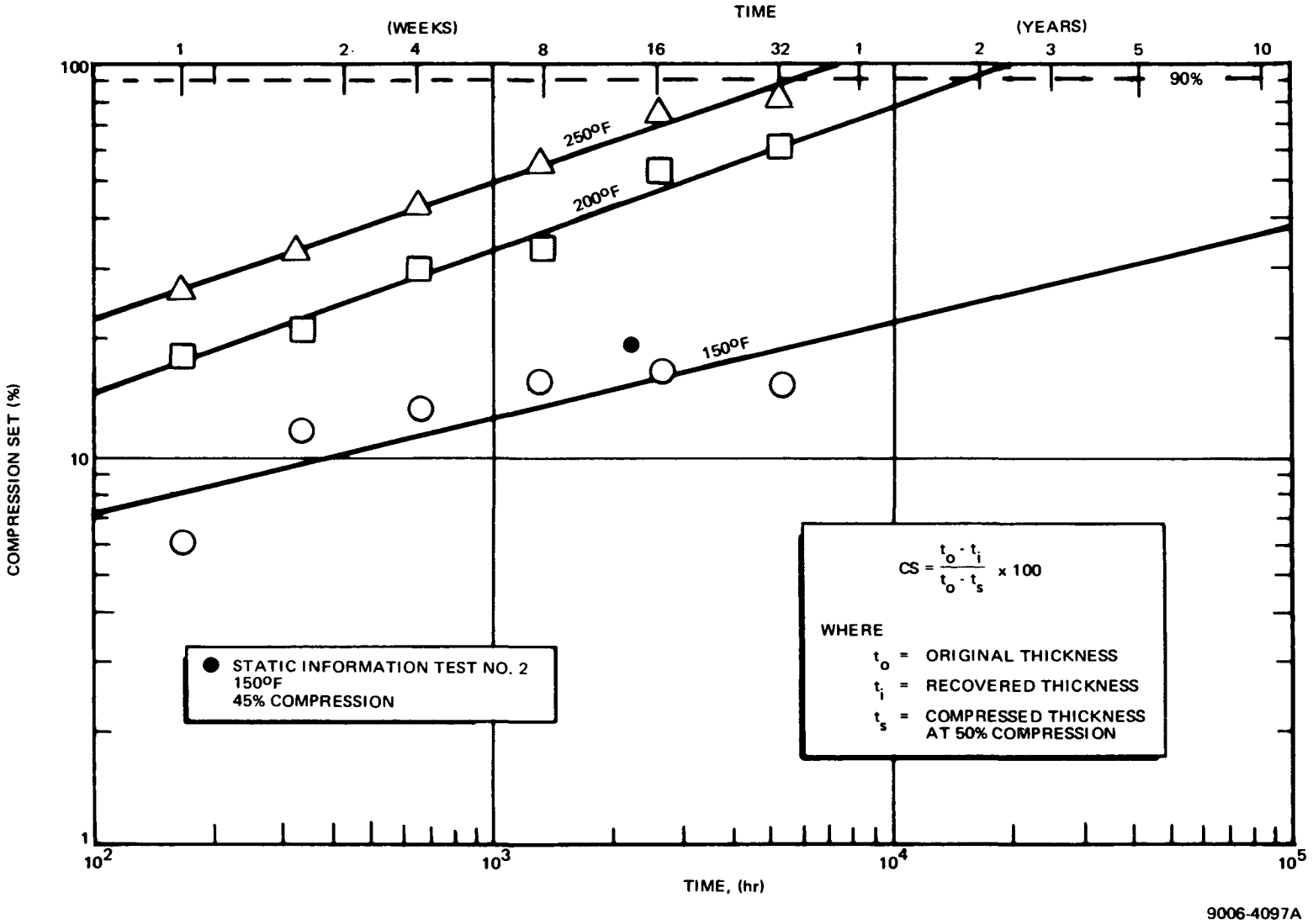
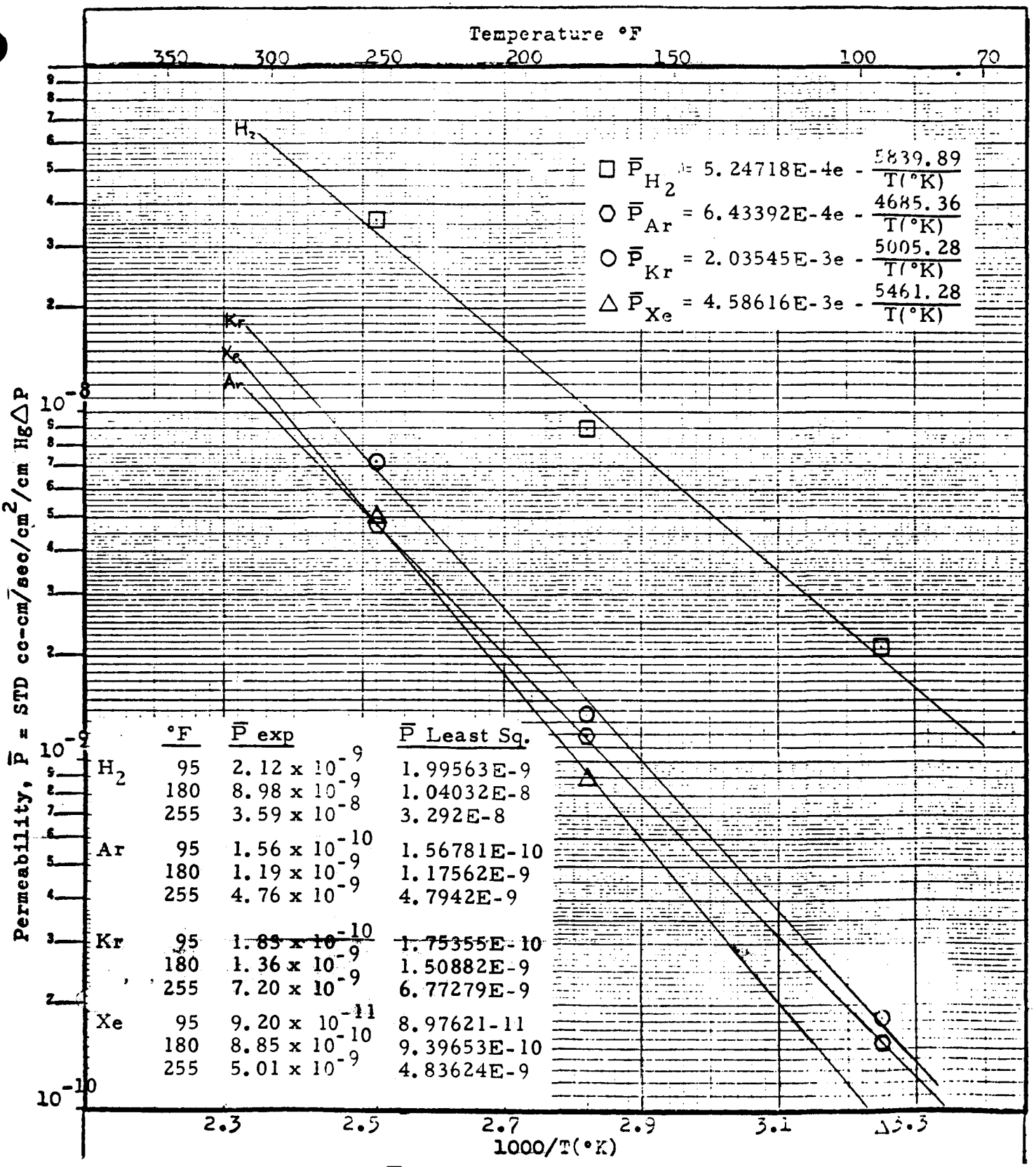


Figure 9. Compression Set of Parker Seal EPR O Rings (Compound E692)



	°F	$\bar{P}$ exp	$\bar{P}$ Least Sq.
H_2	95	2.12×10^{-9}	1.99563E-9
	180	8.98×10^{-9}	1.04032E-8
	255	3.59×10^{-8}	3.292E-8
Ar	95	1.56×10^{-10}	1.56781E-10
	180	1.19×10^{-9}	1.17562E-9
	255	4.76×10^{-9}	4.7942E-9
Kr	95	~~1.85×10^{-10}~~	~~1.75355E-10~~
	180	1.36×10^{-9}	1.50882E-9
	255	7.20×10^{-9}	6.77279E-9
Xe	95	9.20×10^{-11}	8.97621-11
	180	8.85×10^{-10}	9.39653E-10
	255	5.01×10^{-9}	4.83624E-9

Figure 10. Log $\bar{P}$ vs 1/T (°K) for H_2, Ar, Kr, and Xe for Parker Seal Butyl Rubber (B318-70)

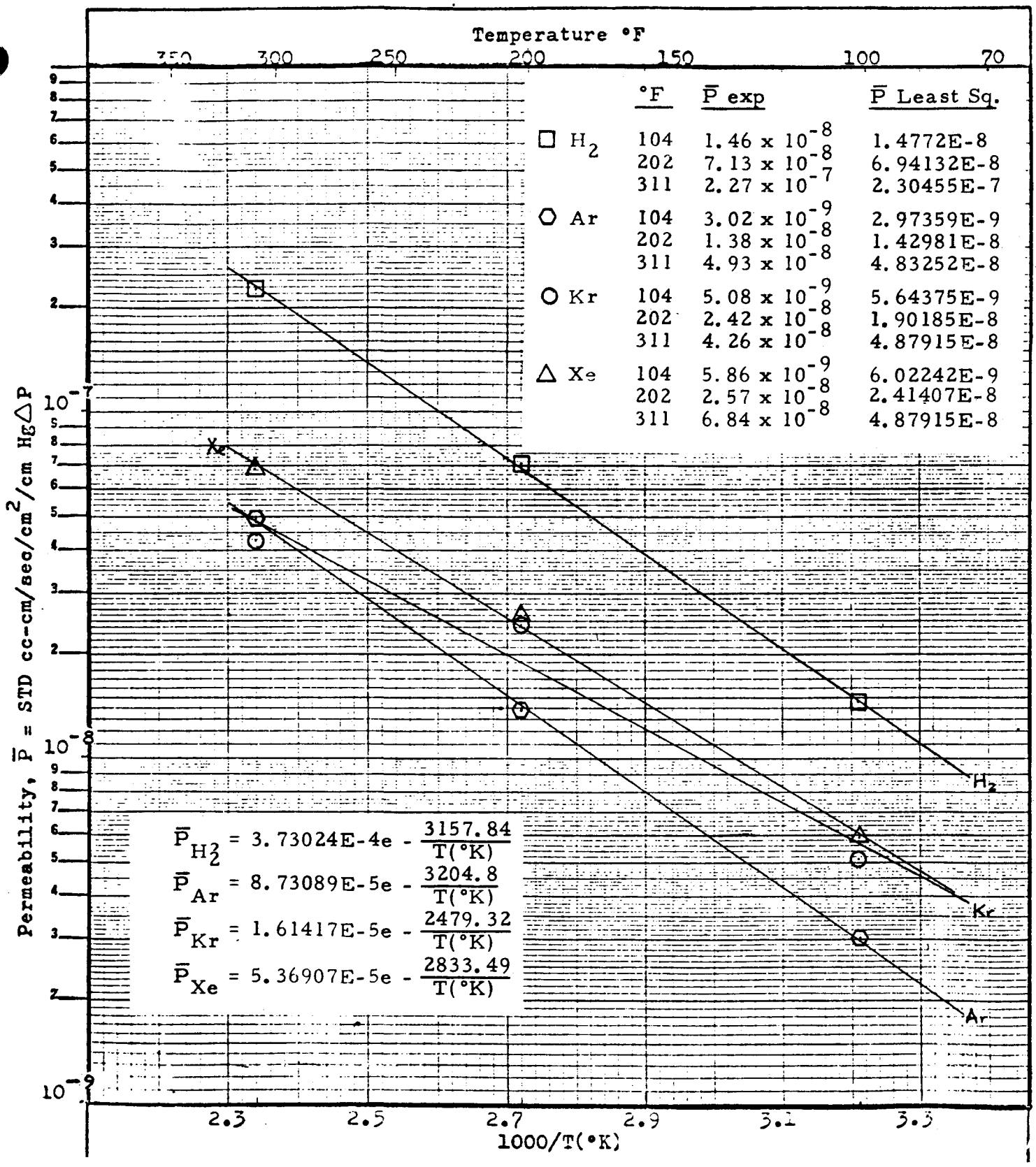
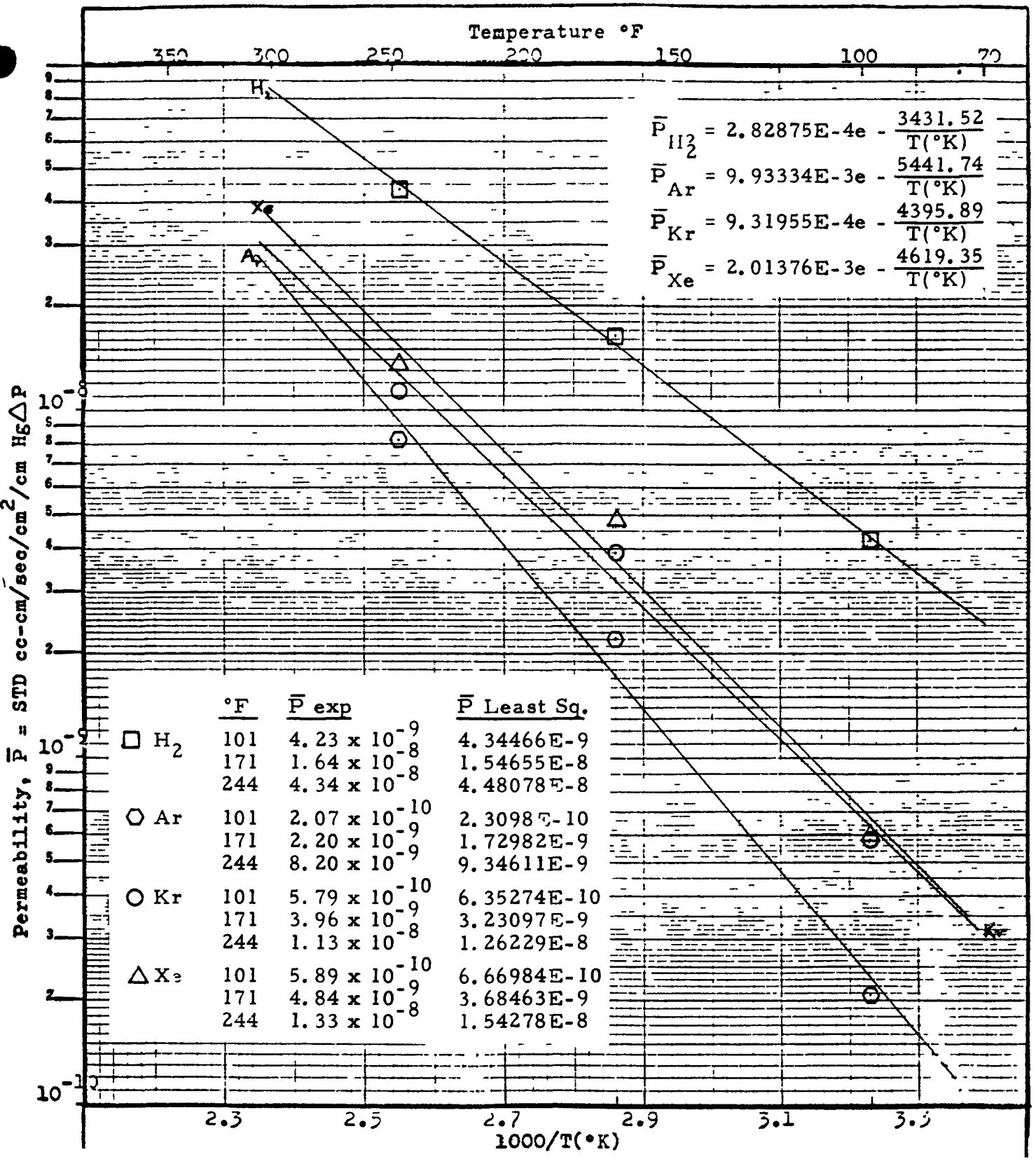


Figure 11. Log $\overline{P}$ vs 1/T (°K) for H_2, Ar, Kr, and Xe for Parker Seal EPR (E529)



	°F	$\bar{P}$ exp	$\bar{P}$ Least Sq.
□ H_2	101	4.23×10^{-9}	4.34466E-9
	171	1.64×10^{-8}	1.54655E-8
	244	4.34×10^{-8}	4.48078E-8
⬡ Ar	101	2.07×10^{-10}	2.30985E-10
	171	2.20×10^{-9}	1.72982E-9
	244	8.20×10^{-9}	9.34611E-9
○ Kr	101	5.79×10^{-10}	6.35274E-10
	171	3.96×10^{-9}	3.23097E-9
	244	1.13×10^{-8}	1.26229E-8
△ Xe	101	5.89×10^{-10}	6.66984E-10
	171	4.84×10^{-9}	3.68463E-9
	244	1.33×10^{-8}	1.54278E-8

Figure 12. Log $\bar{P}$ vs 1/T (°K) for H_2, Ar, Kr, and Xe for Minnesota Buna N (366Y, Batch 982, 2nd Lot)

The P values for the second lot of Buna N obtained from Minnesota Rubber (Figure 12) is not significantly different than the P from the first lot,* but does indicate the type of data variation which can be expected between lots of the same elastomer from one vendor.

The solubilities of the test gases, H_2, Ar, Kr, and Xe are obtained from the P test, and these data are presented in Table 18 for the three elastomers.

D. GAS BOUNDARY LEAKAGE CALCULATIONS

The preliminary leakage calculations for the LMFBR-FFTF reactor cover gas containment system were completed, and the report is in preparation. The calculated leakages are shown in Table 19.

These leakages are for reactor subassemblies exposed directly to cover gas during normal reactor operation, and assume 1.0% fuel failure. Not included are reactor service units, such as the CLEM, grapple adapters, and interim decay storage. Also not included are the inflation seal pressurization systems, buffer gas systems, and purge systems. There are no plans to calculate the leak rates of these systems at this time. No attempt was made to assess the effect of holdup time on leak rates. For neon, with a half-life of 38 sec, the effect would be significant.

The calculated krypton leak rate exceeds the allowable by a factor of 1.4, and hydrogen exceeds the allowable for neon by a factor of 840. Hydrogen was used in lieu of neon, per the seal test plan. (The similarity of the ionization potentials of neon and helium, the gas analyzer carrier gas, precluded the measurement of neon.) Limited information shows hydrogen to have twice the permeation rate of neon, through silicone rubber at 0°C.

The outstanding sources of leakage in the system occur through a set of EPR seals, operating at 167°F in the arm support subassembly of the IVHM, and through a set of silicone seals, operating at 300°F in the materials open test assembly.

*AI-AEC-13113 (Figure 19)

TABLE 18

SOLUBILITY OF H_2, Ar, Kr, AND Xe GASES IN BUTYL RUBBER (B318), BUNA N RUBBER (366X), AND ETHYLENE PROPYLENE RUBBER (E529)

Butyl Rubber		Buna N (Nitrile) Rubber		Ethylene Propylene Rubber	
Parker Seal Company No. B 318-70		Minnesota Rubber Company No. 366Y, Batch 982, 2nd Lot		Parker Seal Company No. E 529	
Temperature Range, 95-255°F		Temperature Range, 101-244°F		Temperature Range, 104-311°F	
Gas	Solubility (cm^3 gas/cm^3 elastomer)	Gas	Solubility (cm^3 gas/cm^3 elastomer)	Gas	Solubility (cm^3 gas/cm^3 elastomer)
H_2	0.29-0.69	H_2	0.40-4.19	H_2	0.60-0.85
Ar	0.08-0.12	Ar	0.04-0.11	Ar	0.11-0.19
Kr	0.14-0.23	Kr	0.18-0.22	Kr	0.07-0.43
Xe	0.11-0.21	Xe	0.29-0.33	Xe	0.27-0.64

TABLE 19

PRELIMINARY LEAKAGE CALCULATION — LMFBR-FFTF REACTOR COVER GAS

Reactor Subassembly	Number of Seals per Unit		Number of Units per FFTF	Leakage (STP cc/sec)(2)			
				Kr	H_2	X_e	Ar
				Partial Pressures (atm)			
	Elastomer	Metal		0.467-7(3)	0.0025-7	2.54-7	0.086-10
1. IVHM Assembly	2	0	3	0.976-13	0.102-13	30.2-15	0.59-16
2. IVHM Arm Support	63	0	3	250.9-13	4.00-13	2133.6-15	36.9-16
3. IVHM Orientation System	14	0	3	5.6-13	0.11-13	35.8-15	0.7-16
4. IVHM Chain Hoist	30	0	3	9.4-13	0.22-13	41.1-15	2.01-16
5. Fuel Transfer Point	4	0	3	0.17-13	0.002-13	0.91-15	0.008-16
6. Instrument Tree	20	8	3	36.7-13 0.1-13	0.90-13 0.0004-13	239.2-15 0.414-15	5.9-16 0.01-16
7. Fuels Open Test Assembly	4	2	3(1)	487.0-13 0.1-13	4.96-13 0.0003-13	2910.8-15 0.36-15	32.3-16 0.01-16
8. Control Rod Drive Mechanism Assembly	0	4	18	- 17.7-13	- 0.09-13	- 96.0-15	- 3.25-16
9. Temperature and Liquid Level Port Plug and Instrumentation	0	4	3	- 0.06-13	- 0.0003-13	- 0.34-15	- 0.011-16
10. Closed Loop in Reactor Assembly	0	1	3(1)	- 0.03-13	- 0.0002-13	- 0.16-15	- 0.005-16
11. Proximity Test Plug	0	2	3(1)	- 0.002-13	- 0.00001-13	- 0.01-15	- 0.0004-16
12. Low-Level Flux Monitor	0	1	3	- 0.05-13	- 0.0003-13	- 0.30-15	- 0.01-16
13. Closure Head Assembly	0	2	1	45.5-13	0.24-13	248.0-15	8.4-16
				853.8-13 or 8.5-11	10.38-13 or 1.0-12	5753.2-15 or 5.8-10	84.3-16 or 8.4-15
				6.0-11	Ne = 8.4-14	9.6-10	2.4-4

Allowable leakage for reactor head compartment per Table I of ARD Memo FD 545, Roderick, 3-28-72(5)

NOTES:

(1) The OTA, CLIRA, and proximity Test Plug ports total 9
(2) STP is 1 atm pressure and 0°C
(3) 0.467-7 means 0.467×10^{-7}
(4) H_2 was used for permeation measurements, because of test equipment limitations. Partial pressure is for neon.
(5) The leak rate values in the referenced Table I are in units of (scc)/(sec, in.). The allowable values listed above are leak rates per 1000 ft of seal which is the length assumed for the reactor in paragraph 4 of the reference memo.

The large silicone shaped seal on the arm support system, and the inflatable seals on both the arm support system and instrument tree are part of a system of seals in parallel and series during normal reactor operation. As a result, their relatively high leak rates are reduced by other seals in the same leak paths. Consequently, the total effective leakage of these seals is low.

E. INSTRUMENT TREE INFLATABLE SEALS TEST

The test fixture fabrication is completed, except for the part containing the seal cavities, which is being chromium plated. The Buna N and silicone seals were scheduled for delivery in early April, but the delivery is now indefinite, pending settlement of a labor dispute in the supplier's plant. The test plan was issued, and sent to Westinghouse for comment.

F. COMPARATIVE LEAK TEST

The comparative leak test on Buna N O rings (Minnesota Rubber Co., Compound 366Y) has completed ~9 weeks at 70 ± 5°F. Table 20 shows the measured concentrations of trace gases in the test fixture and the preliminary calculation of the leakage values.

TABLE 20

LEAKAGE VALUES FOR BUNA N O RINGS IN THE COMPARATIVE LEAK TEST FIXTURE
(Compound 366Y, 70 ± 5°F)
(50% Compression, 16 rms Finish)

Hours	cc		L		L_{Kr}	
	H_2	Kr	H_2	Kr	Measured	Calculated
147	0.0035	0	13.8	0	2.1	0.9
582	0.0109	0	10.7	0	1.6	0.9
823	0.0164	0	11.27	0	1.7	0.9
977	0.0197	0	11.57	0	1.7	0.9
1175	0.0235	0	11.34	0	1.7	0.9

L = std cc/sec/linear in. of seal/atm $\Delta P \times 10^{-8}$
L_{Kr} = std cc/sec/linear in. of seal/atm ΔP of Kr $\times 10^{-8}$
(conversion of gases to their equivalent Kr leakage using measured values of permeability, etc.)

The values of 0.0035 and 0.0109 cc of H_2 are equivalent to $\sim$14 and 40 ppm of H_2, respectively. The lower limit of detection of the gases is $\sim$10 ppm, using the Trace Gas Analyzer in its current, derated condition, which permits readings up to $\sim$1% (10,000 ppm).

The calculated L_{Kr}, obtained in the same manner as described in Section III-A-3, for the Buna N O ring at 50% compression and 70°F is as shown in Table 20, 0.9×10^{-8} Std cc/sec/linear in. of seal/atm ΔP of Kr, whereas the measured values are $\sim 1.7 \times 10^{-8}$. This is exceptionally good agreement, considering that the values were obtained on two completely different text fixtures, one using an uncompressed sheet specimen and the other an O ring compressed 50%.

It is interesting to note that, at this low temperature (70°F), no krypton has been detected at greater than 10 ppm. The test will be ended at the end of March 1974, and the fixture and test gas shipped to HEDL. The metal O-ring test fixture has been received from HEDL.

G. SEALS IN SODIUM VAPOR

The Test Plan was approved by Westinghouse; the test fixture was designed, detailed, and released to the shop; and shop planning and material procurement was started.

H. IVHM INFLATABLE SEAL TEST

The IVHM post-test measurement of permeation through the inflatable seals was conducted, using 1% H_2 and 1% Xe trace gases in argon. The inflation pressure was 15 psig, the differential pressure was 2.5 psi, the temperature was 150°F, and the test duration was 384 hr. A gas chromatograph was used to measure the permeation of the trace gases through the seals.

Permeation leakage through the elastomer seal can be expressed by

$$R = \overline{P} \times K_{H/T} \times L \times \Delta P \qquad \ldots (1)$$

where

R = permeation rate (cc/sec)

$\overline{P}$ = permeation coefficient of the elastomer (cc-cm/sec-cm^2-atom)

$K_{H/T}$ = 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, along with the measured seal length (L) and the permeation coefficient measured previously (AI-AEC-13110, page 144, for B. F. Goodrich Nitrile No. 139-PC-12). With the $K_{H/T}$ determined, permeation of the various reactor cover gas species can be determined, using the gas specie partial pressure and $\overline{P}$. The values of $K_{H/T}$ determined are:

$$K_{H/T} = 1.42, \text{ hydrogen basis}$$

$$K_{H/T} = 2.30, \text{ xenon basis}$$

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

Following the completion of the formal IVHM Rotating Plug Seal Test, a special test, requested by Westinghouse personnel, was conducted to support troubleshooting of some IVHM problems at HEDL. The seal was operated at normal conditions of 100°F, 2 ft/min, with 8 psig inflation pressure. The torque recorder showed chatter; and, after 1.5 revolutions, the inflation pressure of the larger-diameter seal dropped to zero. The torque was within the normal range of 32 to 42 lb/ft. Examination of the seal revealed that the rubber was torn at the stem, due to movement of the seal with respect to the seal housing (Figure 13). This movement occurred because of a breakdown in the adhesive bond between the seal and seal gland. Failure Report No. 309 was issued. The mode of failure was very similar to the failure of the smaller-diameter seal, as noted in Failure Report No. 280, dated April 9, 1973, in which MEK solvent used in a rubber sealant for the test apparatus was suspected of degrading the effectiveness of the cement used to bond the seal to the steel housing.

A review of the materials involved in the seals installation and testing was conducted. The following listing summarizes the review:

1) The seal material is B. F. Goodrich Nitrile No. 139-PC-12.

2) The seal was installed per AI specification ST0620NA0087, which calls for cleaning the seal with methyl ethyl ketone (MEK) and the gland with denatured alcohol. Dow Silastic 140 RTV, a silicone-base adhesive, was used to cement the seal in the gland. Dow 705 silicone oil was used as original lubricant, but was absorbed by the rubber after 1 week, and Dow Corning 55M grease was applied, per the "A" change of the specification.

3) A leaky gasket in the test apparatus was plugged, using a liter of liquid rubber sealant with 50% MEK solvent.

4) The gasket was later removed and replaced with Permatix 2F which is a sealant/adhesive with 5% isopropyl alcohol in it.

A series of compatibility and adhesive-bond strength tests were started, to evaluate materials in the test setup and materials that are backup candidates. Reference materials are B. F. Goodrich Buna N No. 139-PC-12 rubber, 140 RTV adhesive, and DC-55M lubricant. Backup materials are Chemlock 304 adhesive

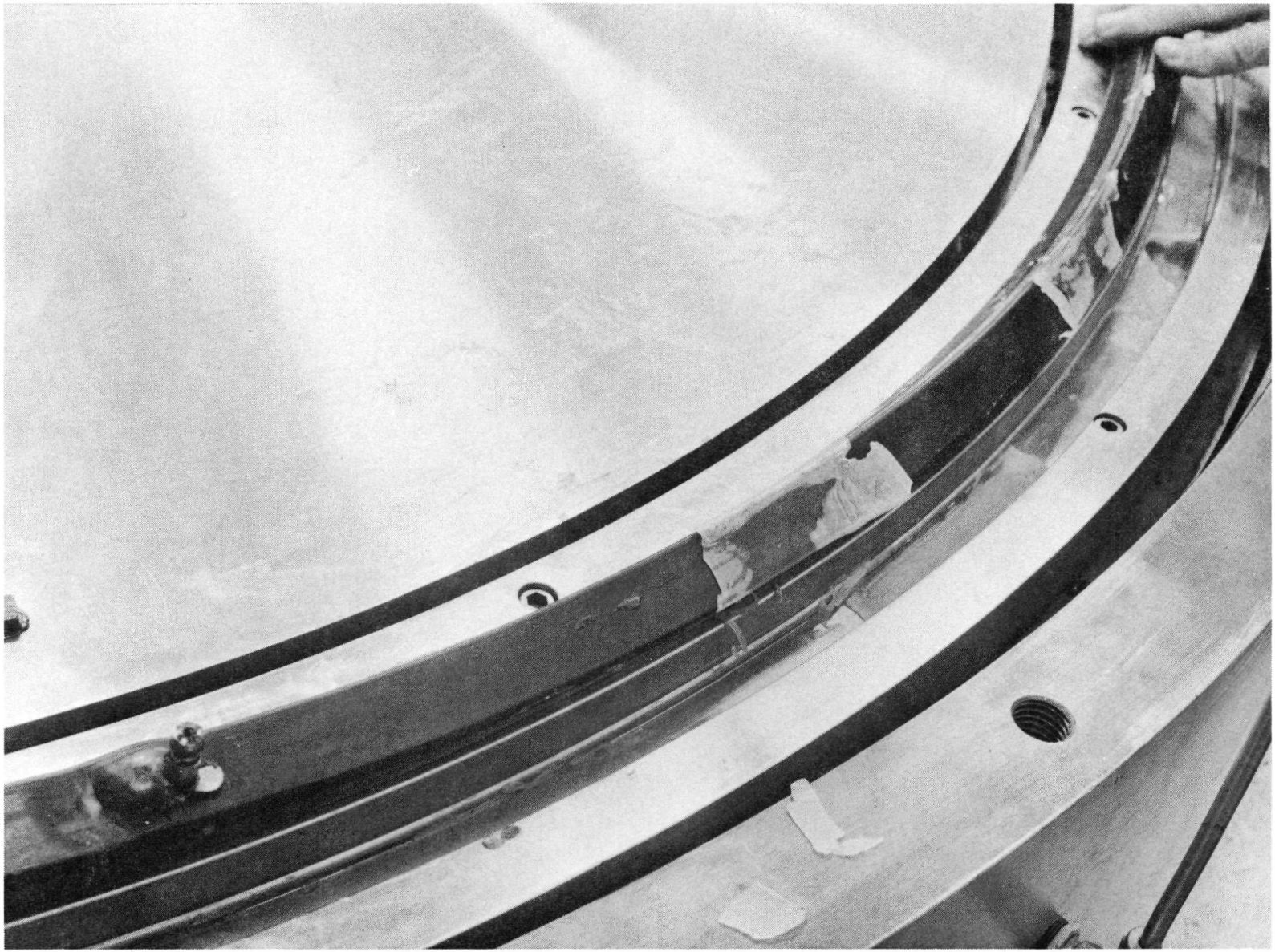


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Figure 13. IVHM Development Test Inflatable Seal — Adhesive Condition

and EXXON WSX-8788 lubricant. The effect of Permatex 2F sealant and MEK used in the test rig is also being evaluated.

Strips of rubber and each adhesive were smeared with each lubricant and soaked at 165°F. Periodically, samples were removed, wiped clean of lubricant, and weighed. Table 22 shows the test matrix of results to date, and future data points. The DC-55M silicone grease is seen to have undergone a considerable absorption by the 140 RTV silicone-base adhesive. The epoxy-base Chemlock 304 adhesive absorbs little of either grease. The rubber is shown to lose considerable weight, if left dry. It apparently either loses less when covered with lubricant, or absorbs lubricant and thereby counterbalances the weight loss of its own constituents. The absorption or drying effects appear to be leveling out.

A series of pull or shear tests is also being conducted, to determine whether there are interactions of the materials. Samples with a section of the seal bonded to a plate of stainless steel with 140 RTV and the backup cement, Chemlock 304 were prepared (Figure 14). Some were left "as prepared"; some were smeared with lubricant; and some were put in a can with either MEK or Permatex 2F. All were heated to 165°F in an oven, and samples were removed at intervals and pulled in a shear mode (Figure 15). Table 23 shows the resultant shear strengths noted to date. The Chemlock 304 appears unaffected by the greases, and was greater than the rubber strength, so that the rubber tore in all cases. While the 140 RTV bond strengths are considerably lower, none were near the 2 to 4 psi shear calculated to have been on the bond of the IVHM seals at the time of failure. Earlier trends in results have not continued, and the shear strengths of all bonds would be well in excess of that required to hold the IVHM seal.

I. CRBRP ROTATING PLUG SEAL FEATURE TEST

Information realized from the adhesive-elastomer lubricant studies discussed in the previous section and the results of seal lubrication studies reported in Section III-A-4, have direct application to the selection of adhesives and lubricants for the CRBRP inflatable seal. Tests in specific support of this program are now in progress on the most promising greases selected from

TABLE 22

RESULTS OF WEIGHT CHANGE TESTS ON SEAL ASSEMBLY MATERIALS

Specimen	Lubricant	Soak Time (days)				
		10	20	60	90	180
		Weight Change (%)				
140 RTV	DC-55M	+8.1	+32.0	+29.0		
140 RTV	WSX 8788	+2.0	+2.0	-1.5		
140 RTV	None	-0.4	-0.5	-0.5		
Chemlock 304	DC-55M	+1.5	+3.2	+3.6		
Chemlock 304	WSX 8788	1.3	1.8	2.2		
Chemlock 304	None	-0.03	-0.03	-0.02		
B. F. G. Rubber	DC-55M	-4.6	-6.8	-10.0		
B. F. G. Rubber	WSX 8788	-8.5	-9.1	-9.0		
B. F. G. Rubber	None	-11.0	-12.0	-13.2		

Strips of adhesive (140 TRV or Chemlock 304) or rubber were smeared with lubricant and held at 165°F in an air oven for time indicated.

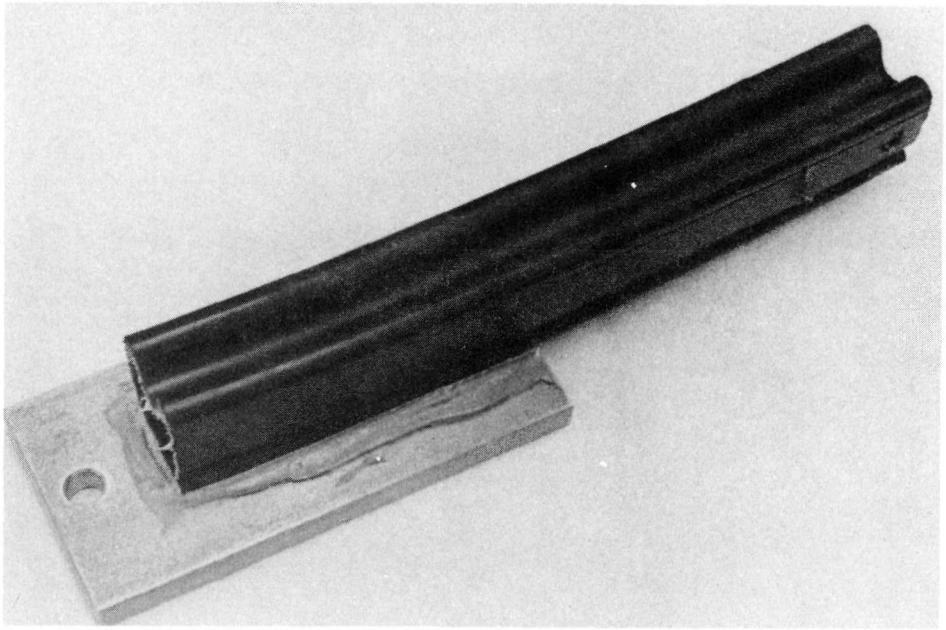

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Figure 14. Pull Test Coupon (Section of IVHM inflatable seal, cemented to Type 304 stainless steel with Dow Corning Silastic 140 RTV adhesive)

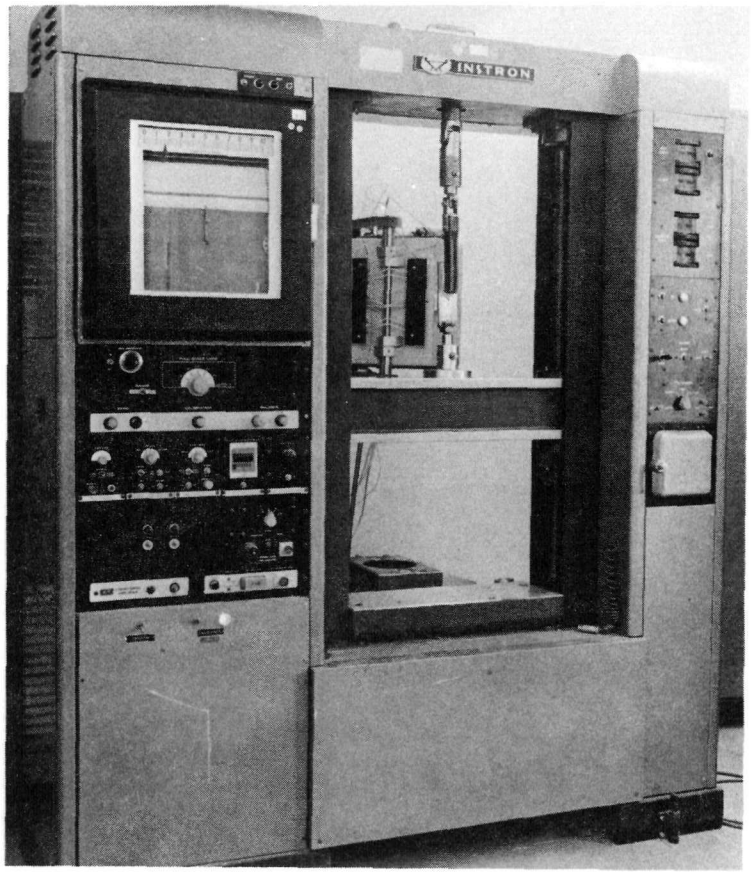

Figure 15. Pull Test Apparatus

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TABLE 23

RESULTS OF PULL TESTS ON IVHM SEAL-ADHESIVE-METAL BOND
(All specimens soaked at 165°F and pulled at room temperature)
(Specimens smeared with lubricant as indicated)

Adhesive	Lubricant	Test Results										
140 RTV	DC-55M	Specimen No.	1	12*	24	33	34	2	13*	25	26*	27*
	DC-55M	Soak Time (weeks)	2	2	2	2	2	6	5	5	3	6
	DC-55M	Shear Stress (psi)	25	44	63	59	62	28	34		20	
	WSX 8788	Specimen No.	35	8	16*	36	9	17*				
140 RTV	WSX 8788	Time (weeks)	2	3	3	4	8	12				
	WSX 8788	Stress (psi)	70	17	49		18					
	None	Specimen No.	20*	30	31	21*	X					
	None	Time (weeks)	2	2	4	6	†					
	None	Stress (psi)	60			55	42					
Chemlock 304	DC-55M	Specimen No.	5	14*	6	15*						
	DC-55M	Time (weeks)	3	3	9	12						
	DC-55M	Stress (psi)	80	>109	>73							
	WSX 8788	Specimen No.	10	18*	11	19*						
Chemlock 304	WSX 8788	Time (weeks)	3	3	8	12						
	WSX 8788	Stress (psi)	>113	>90	124							
	None	Specimen No.	7	22*	23*							
	None	Time (weeks)	1 day	3	12							
	None	Stress (psi)	>50	>105								
140 RTV in can with 1 cup Permatex 2F		Specimen No.	3	28	29	4						
		Time (weeks)	2	2	4	6						
		Stress (psi)	14	15		44						
140 RTV in can with 2 oz MEK		Specimen No.	32	MEK had fully evaporated and diffused out of can through cover								
		Time (weeks)										
		Stress (psi)										

>xx Rubber tore before adhesive sheared
X No specimen number assigned
*No cleaning with MEK during installation
†Set 4 months at room temperature with no lubrication

Samples prepared in groups at three times:
Group I, Specimens 1 to 11
Group II, Specimens 12 to 23
Group III, Specimens 24 to 36

those previous tests. Friction studies have been completed on DC-55M with 5% MoS_2, WSX 8788 with 5% MoS_2, a "dry" MoS_2 surface (created by spray coating a "bonded" layer of MoS_2 on metal), glycerin, and WSX 8788. The test apparatus is the same as used for the studies in Section III-A-4. The test conditions are more severe than for inflatable seals, in that the seal-metal interface pressure is 200 psi, while the comparable pressure in the inflatable seal is equal to the inflation pressure. The test does give a basis for comparison of lubricants, however. Table 24 is a summary of the results. All lubricants had an acceptable drag, initially. When WSX 8788 with 5% MoS_2 was used, the drag was <4 lb/in., up to 60,000 ft of travel; in the next 6,000 ft, the drag rose to cause shear of the pin. A travel of 103,000 ft was completed with DC-55M with 5% MoS_2.

The MoS_2 bonded film was evaluated dry to determine whether it could be used to extend seal life in the event a grease evaporated, or to reduce starting friction. It produced a low friction for 1025 ft, and then the friction increased rapidly. A retest, in conjunction with a grease, is being planned.

Glycerin was a good lubricant during steady running, but had excessive starting friction.

Plain WSX-8788 was run to 87,000 ft of travel. The drag at 68°F was 3.8 lb/in., but was below 2 lb/in. at 150°F.

The use of a mechanical holddown scheme to back up the adhesive has been suggested, and the sketches, Figures 16a, b, and c, show three approaches. The manufacturing and installation ramifications of these designs need further investigation.

The Test Plan for testing the IVHM seals to CRBRP reactor seal conditions, as outlined in Westinghouse Development Requirements Specification DRS 32.06, was released and sent to Westinghouse for review and comments.

IV. IMPACT ON LMFBR PROGRAMS

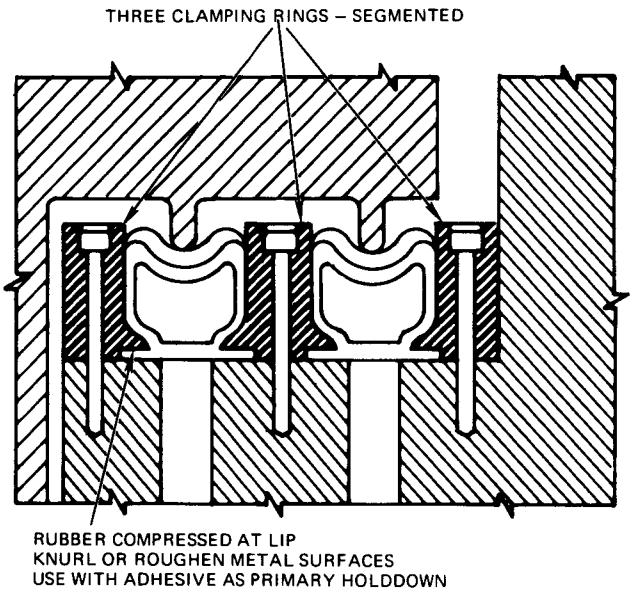
While the initial phase of this test program is being scheduled to specifically support seal selection for all FFTF applications, this first phase and the later programs will directly support the LMFBR industry, advance the state of the art, and lead to the generation of RDT seal standards for use by the industry.

TABLE 24

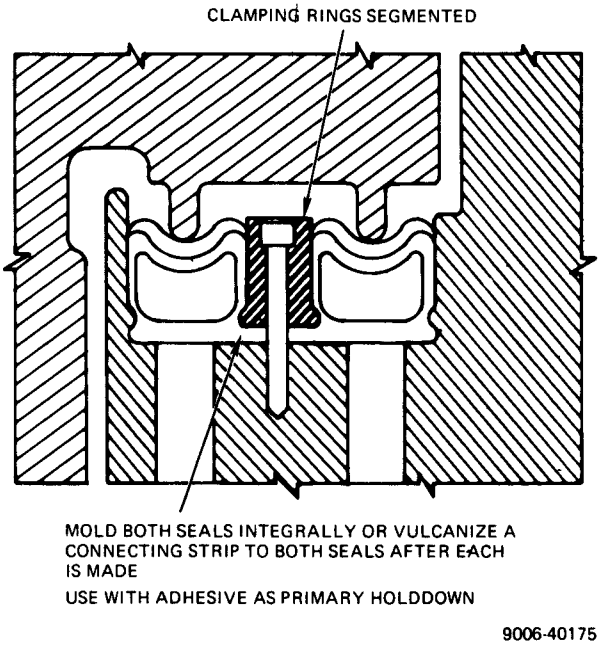
CRBRP LUBRICANT WEAR EVALUATION FOR INFLATABLE SEALS
(Nitrile O rings, 4 in. ID by 0.210 in. cross section, 50 fpm at 150°F, 10% squeeze on O rings, 80,000-ft life travel maximum)

Lubricant	Travel (ft)	Drag (lb/in.)	Weight Change (%)	O Ring	
				Radial ΔD (in.)	Longitudinal ΔD (in.)
WSX 8788 with 5% MoS_2	60,000	<4	+0.7	Negligible	+0.006
DC-55M with 5% MoS_2	103,000	<2.5	Negligible	+0.002	+0.002
MoS_2, Bonded Dry Lube (Perma Slick) 0.007 in.	1,025	2 to shear of pin*	+0.02	Negligible	Negligible
Glycerin					
Test 1	10,300	<2.0 †	Negligible	+0.001	+0.002
Test 2	86,355	2 to 3.5	Negligible	-0.001	+0.001
WSX 8788	87,000	<2.0**	+0.5	Negligible	+0.001

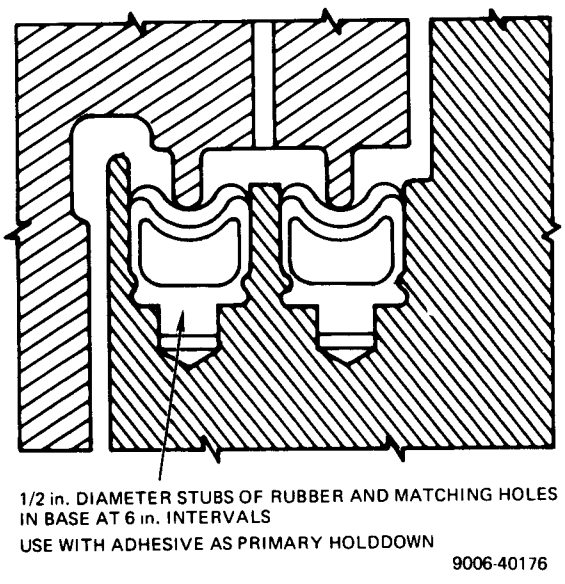
*A pin shears at >8 lb/in. drag
†Stopped over weekend. Pin sheared at 70°F on Monday
§Stopped for 2.5 hr. Pin sheared at 80°F
**Left at room temperature overnight. Pin sheared when restarted.



a. Approach No. 1



b. Approach No. 2



c. Approach No. 3

Figure 16. Mechanical Holddown for Inflatable Seals

The IVHM inflatable seal feature test is intended to prove the seal selection, or to recognize problems early in the program. Information gained will be of direct benefit to future LMFBR's employing the inflatable seal concept.

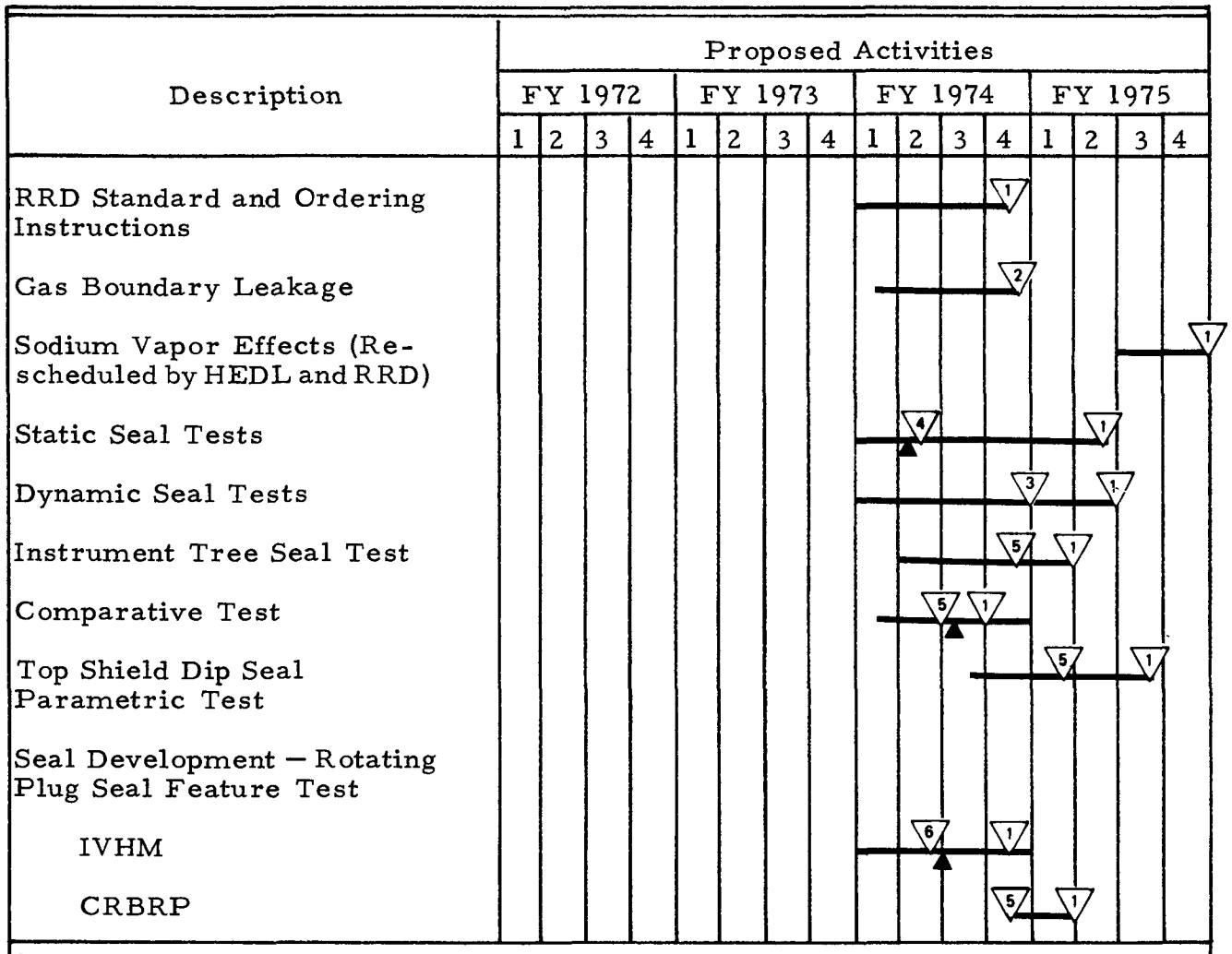
V. NEXT REPORT PERIOD ACTIVITIES

Evaluation of the various seal types and materials will be continued in the on-going static and dynamic seal tests. The remaining permeation tests will be completed, and the summary report prepared. The gas boundary leakage report will be completed. Preparation of the Seal Design Guide and Seal Ordering Data will be started.

The instrument tree inflatable seals of silicone and nitrile will be received, the comparative leak test will be completed, the IVHM inflatable seal report will be issued, and testing of the IVHM seals to CRBRP requirements will be started.

VI. SCHEDULE

A schedule showing the anticipated program activities and milestones is shown in Figure 17.



1. Final Report
2. Final Calculations
3. Reciprocating Data Report
4. Initial Static Seal Data
5. Begin Test
6. Complete IVHM Seal Test
7. Start Long-Term Feature Test

▲ Denotes completion

Figure 17. Schedule and Milestones, FFTF-LMFBR Seal Test Program