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MASTER

Program: Cover Gas Seals

AEC Task: 11 - FFTF-LMFBR Seal Test Program

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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) develop and demonstrate these FFTF seals or new seal configurations to provide acceptable fission product and cover gas retention capabilities at LMFBR Demonstration Plant operating environmental conditions other than radiation, and (3) develop improved seals and seal technology for the LMFBR demonstration plants 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 is 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 Demonstration 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 seal will be conducted.

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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.

Permeation-solubility testing has been completed on 18 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 is in progress.

Test fixtures were designed for static inflatable seal and molded-in-metal static seal tests, and the design of the Instrument Tree inflatable seal feature test fixture was completed.

A permeation test of the IVHM inflatable seal was started, and then stopped because of leakage in the fixture seals. The fixture was repaired, and the permeation test was started again. Development Activity Description, D. A. D. 32.06, for conducting tests on IVHM inflatable seals under Demonstration Plant conditions, was received from Westinghouse.

A plan for evaluating sodium vapor effects on reciprocating seals was prepared, and a plan for conducting a comparison of HEDL and AI leakage measurements was started. Fabrication of the AI-HEDL comparative seal test fixture was started. Buildup of the gauges, valves, plumbing, etc was completed.

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 long term. 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 this quarter, containing seals as noted in Table 1, are continuing without evidence of gross leakage.

b. Information Test No. 7

Test No. 7, containing Buna N seals, as noted in Table 2, completed ~390 hr of testing (6460 cycles) with no evidence of gross leakage. The system was disassembled, and the seals were removed. Examination revealed all seals to be in good condition.

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	1436 (1080 cycles)
	T seals (3), Buna N Parker Seal	10	8			
No. 4	Quad rings (3), EPR Minnesota Rubber	10	8	150	DC55M	1436 (1080 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. 7	T seal (2), Buna N Greene Tweed	5	16	150	DC55M	8,590 (6,460 cycles)	Test completed. No gross leakage observed. Seals appeared in good shape.
	Q ring (1), Buna N Parker Seal	5	16				
	T seal (1), Buna N Parker Seal	20	16				
	Quad ring (2), Buna N Minnesota Rubber	20	16				
No. 8	T seal (1), EPR Parker Seal	5	16	150	DC55M	10,850 (8,153 cycles)	Test completed. No leakage observed, except at end bellows.
	Quad rings (2), EPR Minnesota Rubber	5	16				
	Q ring (1), EPR Parker Seal	20	16				
	T rings (2), EPR Greene Tweed	20	16				

c. Information Test No. 8

This test completed 10,850 ft of travel with no evidence of seal leakage, although a leak in the bellows was noted near the end of the test (Table 2). This test was continued beyond the normal scheduled cycling to obtain additional gas chromatographic data. Examination of the seals revealed all seals to be in good condition, although the chromatographic data showed high leakages of hydrogen at both the 5 and 20% compressions. The equivalent krypton and xenon leakage was lower than expected. This same phenomenon had been noted in an earlier test (Demonstration Test No. 1), which also contained EPR seals. These data are discussed in more detail in Section III-A-3.

2. Rotating Seal Tests

a. Demonstration Test No. 1

Test No. 1, containing seals as shown in Table 3, completed ~31,000 ft of travel (WDTRS 1.25 requirement 28,000 ft) without evidence of gross leakage. Examination of the seals showed negligible wear.

b. Demonstration Test No. 2

Test No. 2, containing seals as shown in Table 3, was run in parallel with Test No. 1, and completed ~31,000 ft of travel with no evidence of gross leakage. A post-test examination revealed no excessive wear on the seals which lost <23 mg weight during the test (compared to Test No. 1 seals, which lost up to 32 mg each during the test).

c. Demonstration Tests No. 3 and No. 4

Tests No. 3 and No. 4, containing Buna N seals, as noted in Table 3, have completed ~14,000 ft of travel with no gross leakage observed.

d. Demonstration Tests No. 5 and No. 6

Tests No. 5 and No. 6, also containing Buna N seals, as shown in Table 3, have completed ~9900 ft of travel with no observed leakage.

e. Information Tests No. 6, 7, 11, and 12

Tests numbered 6, 7, 11, and 12, containing Buna N seals, as shown in Table 4, completed the test cycles (62,300) in late October without evidence of gross leakage. The tests were disassembled, and the seals were examined. Little or no wear was observed.

TABLE 3
ROTATING SEAL DEMONSTRATION TESTS

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (°F)	Lubricant	Seal Travel (ft)	Comments
No. 1	Q rings (4), EPR Parker Seal	10	8	150	DC55M	31,060 (59,395 cycles)	Test completed. No significant leakage observed.
No. 2	O rings (4), EPR Minnesota Rubber	10	8	150	DC55M	31,060 (59,395 cycles)	Test completed. No significant leakage observed until after required number of cycles were completed.
No. 3	Quad rings (4), Buna N Minnesota Rubber	10	8	150	DC55M	23,380 (44,700 cycles)	Test in progress. No indication of gross leakage.
No. 4	O rings (4), Buna N Parker Seal	10	8	150	DC55M	23,380 (44,700 cycles)	Test in progress. No indication of gross leakage.
No. 5	Q rings (4), Buna N Parker Seal	10	8	150	DC55M	9,900 (18,550 cycles)	Test in progress. No indication of leakage.
No. 6	O rings (4), Buna N Minnesota Rubber	10	8	150	DC55M	9,900 (18,550 cycles)	Test in progress. No indication of leakage.

TABLE 4
ROTATING SEAL INFORMATION TESTS

Test	Seals	Compression (%)	Shaft Finish (rms)	Temperature (° F)	Lubricant	Seal Travel (ft)	Comments
No. 6	Quad rings (2), Buna N Minnesota Rubber	5	4	150	DC55M	32,580 (63,300 cycles)	Test terminated 10-31-73. No indication of gross leakage.
	O rings (2), Buna N Parker Seal	5	4				
No. 7	Q rings (2), Buna N Parker Seal	20	4	150	DC55M	32,580 (62,300 cycles)	Test terminated 10-30-73. No indication of gross leakage.
	O rings (2), Buna N Minnesota Rubber	20	4				
No. 8	Quad ring (1), EPR Minnesota Rubber	5	16	150	DC55M	27,680 (52,930 cycles)	No indication of gross leakage.
	O rings (2), EPR Parker Seal	5	16				
No. 9	Q rings (1), EPR Parker Seal	20	16	150	DC55M	10,000 (19,100 cycles)	No indication of gross leakage. High friction forces. Test stopped.
	O rings (2), EPR Minnesota Rubber	20	16				
No. 10	O rings (1), Silicone Parker Seal	5	4	300	DC55M	27,680 (52,930 cycles)	Suspected leak.
	Quad rings (2), Silicone Minnesota Rubber	5	4				
No. 11	O rings (1), Buna N Minnesota Rubber	5	16	150	DC55M	31,304 (59,855 cycles)	Test terminated 10-30-73. No indication of gross leakage.
	Q rings (2), Buna N Parker Seal	5	16				
No. 12	O ring (1), Buna N Parker Seal	20	16	150	DC55M	31,304 (59,855 cycles)	Test terminated 10-30-73. No indication of gross leakage.
	Quad rings (2), Buna N Minnesota Rubber	20	16				
No. 13	Q ring (1), Silicone Parker Seal	20	4	300	DC55M	27,680 (52,930 cycles)	Suspected leak.
	O ring (2), Silicone Minnesota Rubber	20	4				

f. Information Tests No. 8, 9, 10, and 13

These tests have reached the midpoint of the test period. As noted in Table 4, the two tests with ethylene propylene rubber seals show no evidence of leakage, but both silicone seal tests (No. 10 and 13) indicate leakage. These two tests will be continued until leakage is definitely established.

Test No. 9 was stopped when the friction forces increased, shearing the safety rod which protects the torque transducer from damage. A torque wrench was attached to the shaft, a breakaway force of 110 in.-lb and a running force of 190 in.-lb were measured, which are equivalent to ~ 4.4 and 7.6 in.-lb/in. of seal, respectively. This test will be continued to obtain additional gas chromatographic data.

3. Leakage Calculations

Refinement of the leakage calculations continue. Several of the earlier information tests did not have sufficient data points to properly define the leakage, and a comparative graph plotting technique, using the information and demonstration data has been used to obtain more correct answers. Table 5 lists leakage values ($L_{Kr} = \text{std cc/sec/linear inch of seal/atm } \Delta P \text{ of Kr} \times 10^{-8}$) 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 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 8 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.

*All calculated values are based on a static O-ring seal, and are only shown for comparison. Seals of differing geometry may ultimately be found to exhibit consistently higher, or consistently lower, leakages than on 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	Test in progress
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	Test in progress
Q	Buna N	PS	RoD-5	10	8	DC55M	25	20	Test in progress
O	Buna N	PS	RoI-6	5	4	DC55M	10	23	
O	Buna N	MR	RoI-7	20	4	DC55M	24	26	
O	Buna N	MR	RoI-11	5	16	DC55M	12	38	
O	Buna N	PS	RoI-12	20	16	DC55M	18	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	23	23	
Quad	Buna N	MR	RoI-12	20	16	DC55M	16	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 or K_r
 $\times 10^{-8}$

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	Test in progress
T	Buna N	PS	ReD-3	10	8	DC55M	-	20	
Quad	Buna N	MR	ReD-2	10	8	DC55M	28	33	Test in progress
Q	Buna N	PS	ReD-3	10	8	DC55M	-	20	
T	Buna N	PS	ReI-5	5	4	DC55M	-	23	†H2 value only
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	-	38	
Quad	Buna N	MR	ReI-4/7	20	16	DC55M	380†/38	26	
Q	Buna N	PS	ReI-7	5	16	DC55M	98†	23	
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
 $Kr \times 10^{-8}$

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	265†	170	† K_r value only
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	130†	130	† K_r value only
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	-	150	Test in progress
O	EPR	MR	RoI-9	20	16	DC55M	-	130	Test in progress
Q	EPR	PS	RoI-1	5	4	DC55M	75	150	
Quad	EPR	MR	RoI-5	20	4	DC55M	68	130	
Quad	EPR	MR	RoI-8	5	16	DC55M	-	190	Test in progress
Q	EPR	PS	RoI-9	20	16	DC55M	-	96	Test in progress

EPR = Ethylene
*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
 $K_r \times 10^{-8}$

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	Test in progress
T	EPR	PS	ReD-4	10	8	DC55M	170	130	
Quad	EPR	MR	ReD-4	10	8	DC55M	59	170	Test in progress
Q	EPR	PS	ReD-1	10	8	DC55M	14	130	
T	EPR	GT	ReI-4	5	4	DC55M	172	140	†Hz value only
T	EPR	PS	ReI-5	20	4	DC55M	-	96	
T	EPR	PS	ReI-8	5	16	DC55M	1270†	150	
T	EPR	GT	ReI-8	20	16	DC55M	42	96	
Quad	EPR	MR	ReI-8	5	16	DC55M	-	190	
Quad	EPR	MR	ReI-5	20	4	DC55M	380	130	
Q	EPR	PS	ReI-4	5	4	DC55M	244	150	
Q	EPR	PS	ReI-8	20	16	DC55M	230	96	

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

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 8 will 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 a indication of the extent of seal leakage.

4. Lubricant Evaluation

The program for evaluating candidate lubricants continued, in order to select a second lubricant for the seal test program. Friction test data, obtained on the Lubricant Evaluation Fixture (Figures 1a and b) and tabulated in the last Quarterly Progress Report (AI-AEC-13113), are shown graphically in Figure 2. Each test was run initially at room ambient, and then heated to 150° F. Of the five lubricants tested (some lubricants were dropped during earlier screening tests), only DC55M, WSX-8788, and SWS-295 exhibited low friction forces.

Similar friction tests were run at ~220° F on Parker Silicone O rings with the WSX-8788 and the DC55M lubricants, as shown in Figure 3. Examination did not reveal any significant wear of the O ring.

The fixture was reassembled, using the same O ring as run with DC55M earlier. The seal was regreased, and the test run until failure, as shown on Figure 4, at 99,161 ft of travel. This second portion of testing was run with the seal heated to 300° F.

Specimens of Buna N (No. N741-75), silicone (No. S684-70), ethylene propylene (No. E692-75) and urethane (No. P648-90) elastomer O rings were exposed to various greases at 150° F for 1000 hr (Figure 5). At the end of the test period, the elastomer specimens were removed, wiped free of grease, and their weights and hardnesses measured. Table 9 shows the results of these measurements.

a. Fixture

b. Fixture Installed on Lathe

Figure 1. Lubricant Evaluation Fixture

73-025-56-56A

Figure 2. Friction Force vs Lubricant — Buna N O Ring Friction Test
[Run on Parker Buna N O rings (Compound N741) (Size 345)
at 10% compression and 48 rpm continuous at 150°F]

9006-40132

Figure 3. Maximum Friction Force vs Lubricant on Silicone O Rings
 (Temperature = 220°F, speed = 48 rpm on 4.0-in. diameter O ring)

9006-40133

Figure 4. Friction Force vs Travel (Dow Corning DC 55M on Parker Silicone Compound S684, Size 345)

9006-40120

Figure 5. Elastomer-Grease Compatibility Test
(1000 hr, 150°F)

TABLE 9
ELASTOMER-GREASE COMPATIBILITY TESTS
(1000 hr, 150°F)

Grease	Elastomer							
	Buna N		Silicone		EPR		Urethane	
	Weight Change (%)	Hardness Change (%)	Weight Change (%)	Hardness Change (%)	Weight Change (%)	Hardness Change (%)	Weight Change (%)	Hardness Change (%)
DC55M	+4	<5	+23	-20	+9	-12	-	<5
SWS-295	-5	<5	+16	-13	-2	<5	-1	<5
WSX-8788	+5	<5	+2	<5	+1	<5	-	<5

Shore A Hardness

Parker Seal Buna N (N741-75)	72-75
Parker Seal Silicone (S684-70)	73-74
Parker Seal EPR (E692-75)	71-74
Parker Seal Urethane (P648-90)	91-94

DC55M grease softened the silicone and ethylene propylene elastomers, and caused noticeable increases in weight by dissolving in the elastomer. The SWS-295 also softened the silicone elastomer, and caused a weight gain. This behavior was anticipated, since it is known that silicone greases, like DC55M and SWS-295, dissolve in and soften the silicone elastomers. These tests were with elastomers immersed in grease, whereas only a light coat is applied for installation in components.

The WSX-8788 grease did not appear to affect the four elastomers significantly.

Since only these two greases (SWS-295 and WSX-8788) remained as candidates after the various screening and friction tests, the polyester-type grease, WSX-8788 was tentatively selected as the second lubricant because of its lack of solubility in the elastomers.

Additional compatibility testing to two silicone elastomers vs DC55M and WSX-8788 was begun, since the silicone elastomers are generally not compatible with silicone greases. Table 10 summarizes the weight, hardness, and dimensional changes of the silicone elastomers produced by exposure to lubricant, and to air at 200 and 300°F for 3 days. Significant swelling, increases in weight, and softening were noted for both silicone elastomers exposed to DC55M, whereas little or no effect was noted upon exposure to air or to WSX-8788.

The test was restarted, and DC11 grease was added to the test matrix to verify the usefulness of this grease, which has been selected by Westinghouse for FFTF useage.

5. Elastomer Aging and Shelf Life*

Deterioration with time or aging relates to the nature of the elastomer molecule, a long chain-like structure consisting of many smaller molecules joined together. At least three principle types of reactions are associated with aging. They usually occur concurrently, but in varying degrees.

- 1) Scission — The molecular bonds are cut, dividing the chain into smaller segments. Ozone, ultraviolet light, and radiation cause degradation of this type.

*Parker Seal Co. "Seal Compound Manual," (December 1971)

TABLE 10
EFFECT OF TWO LUBRICANTS ON SILICONE RUBBER SEALS*

Temperature (°F) Environment Time (days)	200 Air 3	200 DC55M 3	200 WSX8788 3	300 Air 3	300 DC55M 3	300 WSX8788 3
<u>Weight (gm)</u>						
Parker Seal						
Pre	1.420	1.430	1.465	1.419	1.438	1.423
Post	1.419	1.713	1.505	1.414	1.741	1.476
Change	<-1%	+20%	+3%	<-1%	+21%	+3%
Minnesota Rubber						
Pre	1.805	1.727	1.675	1.772	1.753	1.711
Post	1.788	1.986	1.680	1.742	2.033	1.725
Change	<-1%	+15%	<+1%	-2%	+16%	<+1%
<u>Diameter (in.)</u>						
Parker Seal						
Pre	0.213	0.211	0.213	0.213	0.212	0.214
Post	0.206	0.224	0.209	0.209	0.225	0.210
Change	-3%	+6%	-2%	-2%	+6%	-2%
Minnesota Rubber						
Pre	0.212	0.213	0.214	0.213	0.215	0.213
Post	0.210	0.220	0.211	0.210	0.220	0.213
Change	-1%	+3%	-1%	-1%	+2%	0
<u>Hardness (Shore)</u>						
Parker Seal						
Pre	72	70	70	720	70	72
Post	72	60	66	62	55	67
Change	0	-10	-4	-10	-15	-5
Minnesota Rubber						
Pre	71	71	71	71	71	71
Post	71	56	65	76	55	70
Change	0	-15	-6	+5	-16	-1

*Parker Seal Co. compound No. S684-70 and Minnesota Rubber Co. compound No. 71417-70

- 2) Cross Linking — An oxidation process, whereby additional inter-molecular bonds are formed. This process may be a regenerative one. Heat and oxygen are principle causes of this type attack.
- 3) Modification of Side Groups — A change in the complex, weaker fringe areas of the molecular construction due to chemical reaction. Moisture, for example, could promote this activity.

Note that all mechanisms by which rubber deteriorates with time are attributable to environmental conditions. It is environment then, not age, that is significant to seal life, both in storage and actual service.

Normal procedure throughout the seal industry is to indicate the date of cure on the seal package by quarter and calendar year (e. g., 1 Q 73 would indicate the first quarter of 1973). Thus, the elastomer seal user is informed of the age of the seals at the time of receipt.

b. Shelf Life

Shelf life varies with the resistance of each synthetic elastomer to normal storage conditions. Military Handbook 695 (MIL-HDBK-695) sorts synthetic elastomers into three groups, according to "age resistance generally associated with products fabricated from various rubbers." These groups consist of materials suitable for periods of storage as noted in Table 11.

Where the non-age-sensitive elastomers, mentioned in Table 11, in 10 or 20 year categories, are involved, considerable storage life without detectable damage is common, even under adverse conditions. For materials mentioned in the 2 to 5 year category, which are subject to deterioration, the following conditions are suggested for maximum life:

- 1) Ambient temperature not exceeding 120° F (49° C)
- 2) Exclusion of air (oxygen)
- 3) Exclusion of contamination
- 4) Exclusion of light (particularly sunlight)
- 5) Exclusion of ozone generating electrical devices
- 6) Exclusion of radiation.

Generally, polyethylene bags stored in larger cardboard containers or polyethylene-lined craft paper bags insure optimal storage life. However, in normal warehousing conditions, life of even the relatively age-sensitive elastomers is considerable.

TABLE 11
SHELF LIFE OF ELASTOMERIC MATERIALS

Type Rubber	Common or Trade Name
	Maximum (Up to 20 years)
Fluorosilicone	Silastic LS
Polyacrylate	Acrylate
Polysulfide	Thiokol
Silicone	Silastic, Silicone
	Average (5 to 10 years)
Chlorosulfonated polyethylene	Hypalon
Ethylene-propylene-diene	Ethylene propylene terpolymer
Fluorocarbon	Fluorel, Viton
Isobutylene-isoprene	Butyl, GR-1
Polychloroprene	Neoprene, GR-M, Chloroprene
Polyvinyl chloride	Vinyl, Poly (vinyl chloride)
Polyurethane	Urethane
	Minimum (2 to 5 years)
Butadiene-acrylonitrile	Nitrile, Buna N
Butadiene-styrene	CR-S, Buna S
Cis polybutadiene	Stereo polybutadiene
Natural	Pale crepe, smoked sheets

In order to minimize the deterioration of elastomer seals used in the Seal Test Program, all seals are currently stored in airtight, friction-top steel containers. Whenever quantities of seals are procured and immediate use is not planned, it is recommended that adequate storage be provided.

B. STATIC TESTING

1. 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 100, 150, and 300°F, respectively (Figure 6). The preliminary leakage data appear to be in the order of permeation-type, calculated for a seal under 50% compression.

b. Information Tests

Static information tests were set up with Parker Seal Co. and Minnesota Rubber Co. Buna N, EPR, and silicone elastomer rings under 10 and 20% compression. Table 12 shows the status of all static tests.

2. Leakage Calculations

As described in the preceeding section, the leakage values can be calculated, knowing the seal geometry, % compression, temperature, and material permeability. Table 13 compares these calculated values with currently running seal tests, where sufficient data exists, to establish the measured leakage value. Reasonably good agreement is seen with the Buna N and EPR elastomers, although the one silicone data point does not agree. These tests are in progress, and it can be expected that the data will change as the test progresses.

3. Compression Set Tests

Compression set data were plotted on an Arrhenius-type graph of log time (weeks) vs $1000/T^{\circ}K$, in an effort to more accurately predict the maximum temperature for a 5-year useful life. Figures 7 through 10 show the graphical results. Urethane (522FX), Buna N (N-219), EPR (E692), and Silicone (S684) exhibit maximum-use temperatures (5-year life) of 133, 106, 189, and 189°F, respectively, at a 90% compression set limit. Lowering the compression set limit to 80% decreases the maximum-use temperature by 15°F or less. It is interesting to note that, in each figure, the data points at the high-temperature test conditions depart from the straight line, indicating that some physical change is occurring in the elastomer, causing a deviation from the linear.

Figure 6. Static Seal Test Fixtures

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TABLE 12
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	2000	Test progressing. No observed leakages.
Demonstration No. 2	EPR (E692) Parker Seal Co.	50	16	150		1700	
Demonstration No. 3	Silicone (S684) Parker Seal Co.	50	16	300		1700	
Information 1A	Buna N (366Y) Minnesota Rubber Co.	10	8	150		1100	
Information 1B	Buna N (N741-75) Parker Seal Co.	10	32	150		1100	
Information 1C	Buna N (N741-75) Parker Seal Co.	20	8	150		1100	
Information 1D	Buna N (366Y) Minnesota Rubber Co.	20	32	150		1100	
Information 2A	EPR (E692) Parker Seal Co.	10	8	150		300	
Information 2B	EPR (559N) Minnesota Rubber Co.	10	32	150		300	
Information 2C	EPR (559N) Minnesota Rubber Co.	20	8	150		300	
Information 2D	EPR (E692) Parker Seal Co.	20	32	150		300	
Information 3A	Silicone (71417) Minnesota Rubber Co.	10	8	300		300	
Information 3B	Silicone (S684) Parker Seal Co.	10	32	300		300	
Information 3C	Silicone (S684) Parker Seal Co.	20	8	300		300	
Information 3D	Silicone (71417) Minnesota Rubber Co.	20	32	300	DC55M	300	Tests progressing. No observed leakages.

TABLE 13

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}		Comments
							Measured	Calculated	
O	Buna N	PS	Sta-D-1	50	16	DC55M	6	6	All tests in progress
O	Buna N	MR		50	16	DC55M	-	10	
O	Buna N	MR	Sta-I-1A	10	8	DC55M	25	33	
O	Buna N	PS	Sta-I-1B	10	32	DC55M	10	20	
O	Buna N	PS	Sta-I-1C	20	8	DC55M	12	16	
O	Buna N	MR	Sta-I-1D	20	32	DC55M	7	26	
O	EPR	PS	Sta-D-2	50	16	DC55M	24	38	
O	EPR	MR		50	16	DC55M	-	48	
O	EPR	PS	Sta-I-2A	10	8	DC55M	-	130	
O	EPR	MR	Sta-I-2B	10	32	DC55M	-	170	
O	EPR	MR	Sta-I-2C	20	8	DC55M	-	130	
O	EPR	PS	Sta-I-2D	20	32	DC55M	-	96	
O	Silicone	PS	Sta-D3	50	16	DC55M	82	1700	
O	Silicone	MR		50	16	DC55M	-	2400	
O	Silicone	MR	Sta-I-3A	10	8	DC55M	-	8000	
O	Silicone	PS	Sta-I-3B	10	32	DC55M	-	6000	
O	Silicone	PS	Sta-I-3C	20	8	DC55M	-	4500	
O	Silicone	MR	Sta-I-3D	20	32	DC55M	-	6000	

EPR = Ethylene Propylene Rubber
PS = Parker Seal
MR = Minnesota Rubber

Sta = Static
I = Information
D = Demonstration

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

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Figure 7. Estimation of Seal Useful Life at 80 and 90% Compression Set - Minnesota Rubber Urethane O Ring (522FX)

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Figure 8. Estimation of Seal Useful Life at 80 and 90% Compression Set - Parker Seal Buna N O Ring (N-219)

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Figure 9. Estimation of Seal Useful Life at 80 and 90% Compression Set – Parker Seal Ethylene Propylene O Ring (E692)

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Figure 10. Estimation of Seal Useful Life at 80 and 90% Compression Set – Parker Seal Silicone O Ring (S684)

Preliminary compression set data have been obtained on Minnesota Rubber Co. Buna N (366Y), ethylene propylene (559N), and silicone (71417) elastomer O rings at 200 and 250°F (Figures 11 to 13). The Minnesota Rubber EPR appears to have a higher compression set than the Parker Seal EPR. The Minnesota Rubber silicone rubber appears to have almost the same compression set properties as the Parker Seal silicone rubber. Testing will continue until 32 weeks is reached, or until the set exceeds 90%.

Compression set testing of the Parker Seal Buna N (N741-75) O rings was interrupted when it was found that the O rings were cracked after 1 week of testing at 150 and 200°F under 50% compression. Figure 14a shows the two seals, and Figure 14b shows a close-up of the crack in the 150°F seal. The test was repeated with two new seals, which cracked after 2 weeks of testing. The vendor was contacted on the problem, and the tentative conclusion was that the compression was too high for the high-modulus and high-hardness rubber (Shore A 75). (Note: About 50% compression is used in selected IVHM applications to minimize seal leakage-permeation.)

Earlier, this elastomer (Buna N N741-75) had been recommended to replace butyl rubber seals in the FFTF, because of the poorer radiation resistance of the butyl rubbers. On the basis of this latest information, however, it is now recommended that the alternate composition, Minnesota Rubber Buna N (366Y), be used in place of the Parker Buna N, at least for high seal compression applications. The Minnesota Rubber Buna N is slightly softer, and has completed over 2 months of testing at 150 and 200°F without evidence of damage.

The Parker Seal Buna N (N741-75) elastomer is still in test at 100°F and 50% compression; after 8 weeks with no evidence of damage, it appears that, if the seal temperature is kept at ~100°F, the material is still useable.

C. PERMEABILITY TESTS

Permeability tests were continued on slab samples of elastomer compounds from which the test seals were fabricated. The permeability data were treated with the same computerized "least squares" calculational method as used for the earlier data. Plots of log permeability vs $1/T$ (°K) for a Minnesota Rubber

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Figure 11. Compression Set of Minnesota Rubber O-Ring Seals, Buna N (366Y)

Figure 12. Compression Set of Minnesota Rubber O-Ring Seals, EPR (559N)

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Figure 13. Compression Set of Minnesota Rubber O-Ring Seals, Silicone (71417)

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a. Seals Tested at 150 and 200°F

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b. Close-up of Crack in 150°F Seal

Figure 14. Parker Seal Buna N (N741-75) O-Ring Seals
After 1 Week Under 50% Compression

polyacrylic elastomer (335GA), a Parker Seal polyacrylic elastomer (A607), a Parker Seal Buna S (G244), and a Parker Seal urethane (P642) are shown in Figures 15 to 18. All of these elastomers exhibit permeabilities greater than the Buna N elastomers.

Table 14 lists the solubilities of these elastomers for the four test gases - hydrogen, argon, krypton, and xenon.

D. GAS BOUNDARY LEAKAGE CALCULATIONS

FFTF units for which leakage calculations will be made are those containing reactor gases during normal reactor operation. Excluded are maintenance and storage units, such as the CLEM and Loop Preparation Equipment. The complete list of 17 units for leakage calculation, subject to verification by Westinghouse, is tabulated in Table 15. These units account for ~160 seal installation details for leakage calculation.

Leakages for the four gases of interest (i. e., hydrogen, argon, xenon, and krypton) have been calculated for the IVHM Chain Hoist and IVHM Arm Support System, based on a unit value for partial pressure. These leakages will be updated when more precise values of partial pressure are provided by Westinghouse. Also pending from Westinghouse are assembly and detail drawings affecting six of the units. Of these, leakage calculations have not as yet been started on five of the units, because of insufficient design information.

E. INSTRUMENT TREE INFLATABLE SEAL TESTS

The purchase order has still not been accepted by B. F. Goodrich, as they are reviewing the terms and conditions. Westinghouse Drawing H4-23128 is needed to provide the material callout for the comparable part in the test rig. All other parts of the test rig are being fabricated. The Test Plan was drafted, and is being typed.

F. COMPARATIVE LEAK TEST

Fabrication of the Static O-ring test fixture in the AI shop is ~90% completed. Setup of the gauges, valves, plumbing, etc is completed and awaiting

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Figure 15. Log $\bar{P}$ vs $1/T$ (°K) for H₂, Ar, Kr, and Xe for Minnesota Rubber Polyacrylic (335GA)

Figure 16. $\log \bar{P}$ vs $1/T$ (°K) for H₂, Ar, Kr, and Xe for Parker Seal Polyacrylic (A607)

Figure 17. $\log \bar{P}$ vs $1/T$ (°K) for H₂, Ar, Kr, and Xe for Parker Seal Buna S (G244)

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Figure 18. Log $\bar{P}$ vs $1/T$ (°K) for H₂, Ar, Kr, and Xe for Parker Seal Urethane²(P642)

TABLE 14
SOLUBILITIES OF ELASTOMERS TO THE
TEST GASES H₂, Ar, Kr, AND Xe

Gas	Parker Seal Co. Polyacrylic (A607) Range 100-307°F	Parker Seal Co. Buna S (G244) Range 101-251°F	Minnesota Rubber Co. Polyacrylic (335GA) Range 99-301°F	Parker Seal Co. Urethane (P642) Range 103-202°F
	Solubility (cm ³ gas/cm ³ elastomer)			
H ₂	0.97 - 1.53	0.10 - 0.46	0.19 - 1.41	0.40 - 0.45
Ar	0.08 - 0.21	0.02 - 0.16	0.047 - 0.21	0.07 - 0.15
Kr	0.36 - 0.69	0.08 - 0.23	0.20 - 0.64	0.08 - 0.35
Xe	0.53 - 0.93	0.04 - 0.31	0.31 - 1.14	0.14 - 0.52

TABLE 15
UNITS FOR GAS LEAKAGE CALCULATIONS

IVHM Chain Hoist System
IVHM Arm Support System
IVHM Orientation System
Instrument Tree
Low-Level Flux Monitor
Closed Loop In-Reactor Assembly
Control Rod Drive Mechanism
Fuels Open Test Assembly
Core Restraint Actuator Plug
Reactor Vessel Head
Closure Head Assembly
Temperature and Liquid Level Port Plug
Temperature and Liquid Level Port Instrumentation
Fuel Transfer Port and Floor Valve Adapter
Toe Adjust Drive Assembly
IVHM Top Assembly
P&I Argon System

delivery of the test fixture. The test gas (argon, argon + 1% hydrogen, and argon + 1% krypton) have been received. Preparation of the Test Procedure is underway.

G. SEALS IN SODIUM VAPOR

Approval of the Test Plan for exposing a reciprocating shaft to sodium vapor as it wipes through the seal has not yet been received, and is thereby delaying initiation of test fixture fabrication.

H. ROTATING PLUG SEAL FEATURE TEST

The reassembled IVHM inflatable seal test rig with the inner seal replaced was checked out, and the 200-hr permeation test was started. The test report to cover testing applicable to the IVHM was begun.

The Test Plan to support the CRBRP inflatable seal design, by running the seals at higher speeds than previously run to a total of 80,000 ft travel, was initiated. The test will be run in the present setup, and the permeation test mentioned previously will establish a baseline value for this test. The rig with the brand new inner seal has an outer seal with ~28,000 ft of travel accumulated during the IVHM test run at 2 ft/min. A revised Development Activity Description, DAD 32.06, was received from Westinghouse, but the Test Plan and Test Procedure cannot be completed until the detailed development requirements specification is received.

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.

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 various seal types and materials will be continued in the ongoing dynamic and static seal tests. Permeation tests, being run to establish basic permeation rates for various elastomer materials, will continue. The long-term feature test of the inflatable seal under Demonstration Plant conditions will be initiated. Gas boundary leakage calculations for the many FFTF seals will proceed. Test fixtures will be fabricated, and Test Plans and Test Procedures will be prepared to support the sodium vapor effects tests, the comparative tests, and the Instrument Tree seal test programs. Testing on one or more of these is expected to begin; however, current activity is being hampered by lack of information and/or approvals from Westinghouse, and this will have a corresponding effect on the scheduling of the program activities. Preparation of RRD Standards and Ordering Instructions for seals is expected to begin during the next quarter.

VI. SCHEDULE

A schedule showing the anticipated program activities and milestones is shown in Figure 19.

Figure 19. Schedule and Milestones, FTF-LMFBR Seal Test Program