Westinghouse
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Laboratory

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WANL-TME-2732
SEPTEMBER 1970

DATA ITEM T-119

CLUSTER ATTACHMENT
SEAL LEAKAGE TEST

FINAL REPORT

MASTER

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Westinghouse Astronuclear Laboratory

Subcontract NP-1
CODE IDENT NO. 14683

WANL-TME-2732
SEPTEMBER 1970

DATA ITEM T-119

CLUSTER ATTACHMENT SEAL LEAKAGE TEST.

FINAL REPORT.

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APPROVED BY:

J. G. Gallagher
J. G. Gallagher, Manager
NERVA Design Engineering

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ABSTRACT

Three types of seals are used in the attachment of the cluster hardware to the support plate in order to contain the SSCA hydrogen flow. These O-rings, grafoil seals, and metal-to-metal seals were tested under varied laboratory conditions. Data obtained were used to predict the leakage for the NERVA reactor under rated conditions. The predicted leakage was compared with the Cluster Hardware Specification No. EC-677558 requirements for leakage. Each seal, when assembled to proposed reactor assembly conditions, was found to be capable of meeting the sealing requirements. Required seating forces or seating torques were determined for each seal.

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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1.0	INTRODUCTION	1-1
1.1	Test Identification	1-1
1.1.1	Type of Report	1-1
1.1.2	Applicable Scope of Test Document	1-1
1.1.3	Functional Category of Test	1-2
1.1.4	Contractor	1-2
1.1.5	Test Facility and Location	1-2
1.2	Purpose of Test	1-2
2.0	REFERENCES	2-1
2.1	Drawing List	2-1
2.2	Documentation	2-2
2.2.1	Procedures	2-2
2.2.2	Data Release Memorandums	2-3
2.2.3	Operating Test Directive	2-3
2.2.4	Test Scope	2-4
2.2.5	Photographs	2-4
3.0	DESCRIPTION OF THE TEST ARTICLE	3-1
3.1	Top "O"-Ring Seal (Seal A)	3-1
3.2	Metal-To-Metal Seal (Seal F)	3-1
3.3	Middle "O"-Ring Seal (Seal B)	3-6
3.4	Bottom "O"-Ring Seal (Seal C)	3-12
3.5	Upper Grafoil Seal (Seal D)	3-12
3.6	Lower Grafoil Seal (Seal E)	3-17

TABLE OF CONTENTS (CONTINUED)

<u>Section</u>		<u>Page</u>
4.0	SUMMARY OF TESTS	4-1
4.1	Narrative	4-1
4.1.1	General	4-1
4.1.2	Top "O"-Ring Seal (Seal A)	4-1
4.1.3	Irregular Closure Nut or Metal-to-Metal Seal (Seal F)	4-2
4.1.4	Bottom "O"-Ring Seal (Seal C)	4-5
4.1.5	Middle "O"-Ring Seal (Seal B)	4-14
4.1.6	Upper Grafoil Seal (Seal D)	4-16
4.1.7	Lower Grafoil Seal (Seal E)	4-21
4.2	Test Results	4-28
4.2.1	Top "O"-Ring Seal Leak Test Data	4-28
4.2.2	Metal-To-Metal Seal Leak Test Data	4-30
4.2.3	Bottom "O"-Ring Seal Leak Test Data	4-32
4.2.4	Middle "O"-Ring Seal Leak Tests	4-34
4.2.5	Upper Grafoil Seal Leak Test Data	4-37
4.2.6	Lower Grafoil Seal Leak Test Data	4-38
4.2.7	Discussion of Data	4-40
5.0	ANALYSIS	5-1
5.1	Analytical Model	5-1
5.2	Comparison of Predictions and Results	5-3
5.3	Post Test Comparison	5-17
6.0	CONCLUSIONS	6-1
	APPENDIX	
A	List of Seals Tested	A-1

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
3-1	Top "O"-Ring Seal A and Adaptor	3-2
3-2	Leak Test Fixture for Metal-To-Metal Seal F and Top "O"-Ring Seal A	3-3
3-3	Irregular Closure Nut Seal F	3-5
3-4	Middle "O"-Ring Seal B and Adaptor	3-7
3-5	Leak Test Fixture for Middle "O"-Ring Seal B	3-9
3-6	Leak Test Fixture for Middle "O"-Ring Seal B	3-11
3-7	Bottom "O"-Ring Seal C and Adaptor	3-13
3-8	Leak Test Fixture for Bottom "O"-Ring Seal C	3-14
3-9	Upper Grafoil Seal D Pre-Test Condition	3-15
3-10	Upper Grafoil Seal D Pre-Test Assembled Condition	3-16
3-11	Leak Test Fixture for Upper Grafoil Seal D	3-19
3-12	Leak Test Fixture for Upper Grafoil Seal D	3-21
3-13	Lower Grafoil Seal E Pre-Test Condition	3-22
3-14	Lower Grafoil Seal E Pre-Test Assembled Condition	3-23
3-15	Leak Test Fixture for Lower Grafoil Seal E	3-25
4-1	Percent Torque Required to Obtain Percent of Manufacturer's Recommended Compression of "O"-Rings	4-3
4-2	Seal H ₂ Leakage Vs. Seal Pressure Differential as a Function of Torque and Temperature (Top "O"-Ring Seal A)	4-4
4-3	Result of Torquing Steel Nut on Aluminum Sealing Surface	4-6
4-4	Effect of Torque on H ₂ Leak Rate (Metal-To-Metal Seal F)	4-7
4-5	Score Mark of "O"-Ring Weld Joint Plus Scoring of Aluminum Sealing Surface by Adaptor	4-9
4-6	"O"-Ring Weld Joint	4-10
4-7	Bottom "O" Ring Seal C	4-11

LIST OF ILLUSTRATIONS (CONTINUED)

<u>Figure</u>		<u>Page</u>
4-8	Bottom "O"-Ring Seal C	4-12
4-9	H ₂ Leakage Rate Vs. Seal Pressure Differential (Bottom "O"-Ring Seal B)	4-13
4-10	H ₂ Leakage Rate Vs. Seal Pressure Differential (Middle "O"-Ring Seal C)	4-15
4-11	Tested Upper Grafoil Seals (Seal D)	4-17
4-12	H ₂ Leakage Rate Vs. Seal Pressure Differential as a Function of Compressive Load (Upper Grafoil Seal D)	4-18
4-13	H ₂ Leakage Rate Vs. Seal Pressure Differential as Function of Compressive Load (Upper Grafoil Seal D)	4-19
4-14	Effect of Compressive Load on H ₂ Leakage Rate (Upper Grafoil Seal D)	4-20
4-15	Lower Grafoil Seal E, Pre-Test Condition	4-22
4-16	Lower Grafoil Seal E, Post-Test Condition	4-23
4-17	Lower Grafoil Seals E-6, E-7, E-8, and E-9, Post-Test Condition	4-24
4-18	H ₂ Leakage Rate Vs. Seal Pressure Differential as a Function of Compressive Load (Lower Grafoil Seal E)	4-25
4-19	H ₂ Leakage Rate Vs. Seal Pressure Differential as a Function of Axial Sliding of Liner Tube (Lower Grafoil Seal E)	4-26
4-20	H ₂ Leakage Rate Vs. Seal Pressure Differential as a Function of Perpendicular Liner Tube Bending (Lower Grafoil Seal E)	4-27
5-1	Cluster Attachment Seal Leakage Test, 58DT-151-4, Location of Seals	5-2
5-2	Plenum Pressures in Cluster Attachment Region for the R-1 Reactor Core, Nominal Conditions (Ref: State Point Information for Composite Core Dated July 1, 1970)	5-4

LIST OF ILLUSTRATIONS (CONTINUED)

<u>Figure</u>		<u>Page</u>
5-3	Cluster Attachment Seal Leakage Test-Top O-Ring Seal "A"	5-6
5-4	Cluster Attachment Seal Leakage Test-Middle O-Ring Seal "B"	5-7
5-5	Cluster Attachment Seal Leakage Test-Bottom O-Ring Seal "C"	5-8
5-6	Cluster Attachment Seal Leakage Test-Metal to Metal Seal "F"	5-9
5-7	Cluster Attachment Seal Leakage Test-Upper Grafoil Seal, Ambient Test	5-10
5-8	Cluster Attachment Seal Leakage Test-Upper Grafoil Seal, Cryogenic Test	5-11
5-9	Cluster Attachment Seal Leakage Test-Upper Grafoil Seal, Ambient Test, Seating Load 10 lbs.	5-12
5-10	Cluster Attachment Seal Leakage Test-Lower Grafoil Seal, Ambient Test, Seating Load 40 lbs.	5-13
5-11	Cluster Attachment Seal Leakage Test-Lower Grafoil Seal, Ambient Test Seating Load 100 lbs. and 140 lbs.	5-14
5-12	Cluster Attachment Seal Leakage Test-Effect of Sliding on Lower Grafoil Seal Performance	5-15
5-13	Cluster Attachment Seal Leakage Test-Effect of Bending on Lower Grafoil Seal Performance	5-16

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LIST OF TABLES

<u>Number</u>		<u>Page</u>
5-1	Summary Sheet of Seal Performance for Seals with Measurable Leakage	5-5
5-2	Thermal Cyclic Performance of Seals	5-18
6-1	Tentative Seating Force or Torque Recommended for Reactor Assembly	6-2
6-2	Comparison Matrix Between Measured and Allowable Reactor Assembly	6-3

1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

This report is a final report.

1.1.2 Applicable Scope of Test Document

The applicable Scope of Test Document Number is 58DT-151, Rev. 4, Cluster Attachment Seal Leak Test.

1.1.3 Functional Category of Test

This is a development test to determine seal leakage and optimum seating loads, under simulated reactor pressure and temperature conditions.

1.1.4 Contractor

The Westinghouse Astronuclear Laboratory (WANL/14683), under Subcontract NP-1, CY'70.

1.1.5 Test Facility and Location

These tests were performed at WANL Test Cell 7, 8, and 9, at Large, Pa.:
Test Period: March 5, 1970 to July 31, 1970.

1.2 PURPOSE OF TEST

The purpose of this test was to determine the sealing capability of the cluster attachment seals and to determine the optimum seating forces required for proper sealing.

2.0 REFERENCES

Section 2.0 is directed towards identifying related documents which influenced the procurement, design, assembly, disassembly, or operation of the test models.

This list includes drawings, procedures, operating test directives, test scopes, and interoffice memorandums.

2.1 DRAWING LIST

The following drawings describe the test articles and test fixtures.

<u>Drawing No.</u>	<u>Sheet No.</u>	<u>Title</u>
800C659	1	Seal, Grafoil Cluster Assembly
800C660	1	Seal, Grafoil Cluster Assembly
800C661	1	Seal, Grafoil Cluster Assembly
800C662	1	Seal, Grafoil Cluster Assembly
100E664	1	Seal Leakage Test, Upper
101E031	1	Lower Seal Leakage Test
711J865 Group 2 and 4	1	Top "O"-Ring - Irregular Closure Nut Cluster Attachment Assembly Leak Test
711J865 Group 1 and 3	1	Irregular Closure Nut - Top "O" Ring Cluster Attachment Assembly Leak Test
100E998 Group 1	1	Bottom "O"-Ring Seal Leak Test Cluster Attachment Assembly
100E998 Group 2	1	Middle "O"-Ring Seal Leak Test Cluster Attachment Assembly

2.2 DOCUMENTATION

2.2.1 Procedures

<u>Procedure No.</u>	<u>Date</u>	<u>Dep't.</u>	<u>Subject</u>	<u>Purpose</u>
TFLP-125	5/26/70	TFFL	Upper Grafoil Test Fixture Assembly Procedures.	To present the approved steps in assembling test fixture.
TFLP-126	5/26/70	TFFL	Lower Grafoil Test Fixture Assembly Procedure.	To present the approved steps in assembling test fixture.
TFLP-131	5/26/70	TFFL	Periphery Metal-to-Metal Seal Leak Test Assembly Procedure, Group 1.	To present the approved steps in assembling test fixture.
TFLP-142	5/26/70	TFFL	Periphery Metal-to-Metal Seal Leak Test Assembly Procedure, Group 3.	To present the approved steps in assembling test fixture.
TFLP-143	5/26/70	TFFL	Top "O"-Ring Seal Leak Test Fixture Assembly Procedure, Group 2.	To present the approved steps in assembling test fixture.
TFLP-144	5/26/70	TFFL	Top "O"-Ring Seal Leak Test Fixture Assembly Procedure, Group 4.	To present the approved steps in assembling test fixture.
TFLP-145	5/26/70	TFFL	Middle "O"-Ring Seal Leak Test Fixture Assembly Procedure.	To present the approved steps in assembling test fixture.
TFLP-146	5/26/70	TFFL	Bottom "O"-Ring Seal Leak Test Fixture Assembly Procedure.	To present the approved steps in assembling test fixture.

The preceding referenced assembly procedures are included in DRM 51360, Rev. A.

<u>Procedure No.</u>	<u>Date</u>	<u>Dept.</u>	<u>Subject</u>	<u>Purpose</u>
TFLP-123	4/13/70	TFFL	Seal Leak Test Run Procedures for Test Cell 7.	To present the approved steps for the proper operation of Test Cell 7 Seal Leak Test Experiments.
TFLP-115	3/17/70	TFFL	Seal Leak Test Run Procedures for Test Cell 8.	To present the approved steps for the proper operation of Test Cell 8 Seal Leak Test Experiments.
TFLP-124	6/9/70	TFFL	Seal Leak Test Run Procedures for Test Cell 9.	To present the approved steps for the proper operation of Test Cell 9 Seal Leak Test Experiments.

2.2.2 Data Release Memorandums

<u>DRM No.</u>	<u>Title</u>
51360	Test Fixture Assembly Procedures, 58DT-151-4 Cluster Attachment Seal Leakage Test Fixtures.
51357	Stress Calculations: 58DT-151-4 Test Fixtures.
51345	Operating Test Directive for 58DT-151-4, Cluster Attachment Seal Leak Test.

2.2.3 Operating Test Directive

DRM 51345, Rev. E, Operating Test Directive for 58DT-151-4, Cluster Attachment Seal Leak Test issued January 5, 1970.

2.2.4 Test Scope

58DT-151-4, issued January 1970. "Cluster Attachment Seal Leak Test".

2.2.5 Photographs

The photographs in this report, plus additional photos not shown, but acquired as a matter of procedure are controlled through the following number series.

70043 - 1 to 9

70051 - 2, 5, 6, 8, and 10

70073 - 2, 3, 11, 12, and 13

70087 - 1 to 7

70116 - 1 to 10

3.0 DESCRIPTION OF THE TEST ARTICLE

The test article consisted of six (6) individual configurations of seals located in the reactor support plate region and used to prevent leakage around the cluster attachment hardware. Location of these seals is given in Layout Drawing 939J698A (see Figure 5-1).

The nomenclature of DRM 51345, "Operating Test Directive for 58DT-151-4 Cluster Attachment Seal Leak Test," will be used in this report.

3.1 TOP "O"-RING SEAL (SEAL A)

The top "O"-ring seal is fabricated from type 321 stainless steel tube and is 1/32 inch diameter in cross-section having a 5 mil wall and a nominal 1.312 inches outside diameter. The "O"-ring is silver plated, and is of the self-energizing design. This "O"-ring is a standard United Aircraft Products, Inc., seal with a part number U-2105-01312 SEA and is shown on Figure 3-1.

The test fixture for this test series is presented on Drawing 711J865, Group 2, and shown on Figure 3-2. The adaptor, item 12 of the above drawing, used to compress the "O"-ring was fabricated to the "O"-ring manufacturer's specifications in regards to surface finish and dimensions directly related to seating the "O"-ring. The adaptor is shown in Figure 3-1 with the "O"-ring seal.

The test specimens were ordered on ERCO 16,594.

3.2 METAL-TO-METAL SEAL (SEAL F)

The metal-to-metal seal functions in the same location on the support plate as the top "O"-ring, and is used in the periphery region where the top "O" ring can not be used because of its size.

The seal is made by screwing the steel irregular closure nut shown on Figure 3-3 into the softer aluminum support plate. The closure nut, was fabricated to the "O"-ring manufacturer's specifications in regards to surface finish and dimensions directly related to the sealing surface.

Top "O"-Ring (U-2105-01313-SEA)

Top "O"-Ring Adaptor

Figure 3-1. Top "O"-Ring Seal A and Adaptor

GROUP 1
GROUP 2
SCALE 2/1

15.30 REF

TABLE I

GROUP NO	PART NO
1	711J865G01-
2	711J865G02-
3	711J865G03A
4	711J865G04A

TAG PART NO PER P294517 ! SEE TABLE I

GROUP 3
GROUP 4

REV'SONS			
NO	DATE	BY	APPROV
A	D3	ADDED GROUPS 3 & 4	5 8 10
		ADDED TEMS 16, 17 & 18	6 7 10
		D SPEC 751514 AJS	6/1/70

AR	AR	18	ELECTRODE	AL	ASTM E 4043
1	1	17	BASE PLATE	101E197C02	
1	1	16	SEAL BODY	101E187G01	
1	1	15	SPACER	100E952H06	
1	1	14	SPACER	100E952H05	
1	1	13	METAL O RING	U 2105 013145EA	
1	1	12	ADAPTER	100E952H04	
6	6	11	WASHER 500 STD		CRES COML
6	6	10	NUT HEX 500 13UNC 2B		CRES COML
6	6	9	SCREW CAP HEX 50C HD 500 13UNC 2A X 2 75 LG		CRES COML
6	6	8	SCREW CAP HEX 50C HD 500 13UNC 2A X 3 50 LG		CRES COML
1	1	7	BOLT SHOULDER EYE	946821 EB 37	STL
1	1	6	SEAL	978D790H25	
1	1	5	GASKET	100E675H07	
1	1	4	NUT IRREGULAR CLOSURE	100E952H03	
1	1	3	COVER	100E675G01	
1	1	2	BASE PLATE	100L952H02	
1	1	1	SEAL BODY	100E952H01	
G04	G03	G02	DI		
LIST OF MATERIAL					
Westinghouse Astronuclear Laboratory					
LEAK TEST IRREG CLOSURE NUT CLUSTER ATTACHMENT ASSEMBLY					
J 4683 711J865					

Figure 3-2. Leak Test Fixture for Metal-to-Metal Seal F and Top "O"-Ring Seal A

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Figure 3-3. Irregular Closure Nut Seal F

Five test specimens were fabricated and inspected under Work Order Number 20673.

The test fixture for this test series is presented on Drawing 711J865, Groups 1 and 3, and is shown in Figure 3-2.

3.3 MIDDLE "O"-RING SEAL (SEAL B)

The middle "O"-ring is fabricated from type 321 stainless steel tube and is 1/16 inch diameter in cross-section having a 10 mil wall thickness and a nominal 1.00 inch outside diameter. The "O"-ring is silver plated, and is of the self-energizing design. The self-energizing pressure ports on this "O"-ring are located on the outside diameter of the seal as contrasted to an I. D. location for the top and bottom "O"-rings. This "O"-ring is a standard United Aircraft Products, Inc., seal with a part number U-2210-0100SOA. The "O"-ring is shown in Figure 3-4, along with the adapter used to seat the seal. The test fixture for this test series is presented on Drawing 100E998, Group 2, and is shown in Figure 3-5. The adapter, item 7 of the above drawing, used to compress the "O"-ring was fabricated to the "O"-ring manufacturer's specifications in regards to surface finish and dimensions directly related to seating the "O"-ring.

The length of the seal body, and the support rod attached to the base flange, represent the dimensions found in the reactor design (Reference Drawing 939J689A). Materials are also compatible with the reactor design, and this coupled with the physical dimensions would show their effect on seal performance at liquid nitrogen temperatures (140°R). The "O"-ring and adapter as installed on the test fixture are shown in Figure 3-6.

The test specimens were ordered on ERCO 16,549.

Middle "O"-Ring Adaptor

Middle "O"-Ring (U-2210-01000-SOA)

Assembly of "O"-Ring on Adaptor

Figure 3-4. Middle "O"-Ring Seal B and Adaptor

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16.87 REF

1	1	14	SHOULDER EYEBOLT	94882	EB-37	STL		
6	6	13	WASHER 50 PLAIN			CRES	COML	
6	6	12	NUT 500-13UNC-2B HEX			CRES	COML	
6	6	11	SOC CYL HD CAP SCREW .500-13 UNC 2A x 5.00 LG			CRES	COML	
3	3	10	SOC CYL HD CAP SCREW .500 13UNC 2A x 1.00 LG			CRES	COML	
1	-	9	METAL O'RING	78943	U 2210-0100050A			
-	1	8	METAL O RING	78943	U-2210-012505EA			
1	-	7	ADAPTER		100EG75H06			
-	1	6	ADAPTER		100EG75H05			
2	2	5	SEAL		978D 790H25			
2	2	4	GASKET		100EG75H07			
1	1	3	BODY		100E996G01			
1	1	2	BASE FLANGE		100E997G01			
1	1	1	SEAL BODY		100E997H01			
G02	G01	BYB	ITER NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION
QTY	REQD							

UNLESS OTHERWISE SPECIFIED				CONTRACT NO. NP-1		Westinghouse Astronuclear Laboratory Pittsburgh, Pennsylvania	
INTERPRET DWG PER MIL-D-1000 DIM IN INCHES BASED ON 10:1				DATE OF DWG 12-23-69		RELAS 8 & 2	
TOLERANCES - DO NOT SCALE				CHECKED BY DESIGN 1-7-70		STRENGTH	
2PL DEC 3PL DEC ANGLES				ANALYSIS		BY SUPV	
2PL DEC 3PL DEC ANGLES				MAIL		BY SUPV	
NEXT ASSY USED ON P294517-1 IDENT				INFORMATION CATEGORY UNCLASSIFIED		DWG NO. 100E998	
APPLICATION SPECIFICATION TYPE				DWG NO. 14683		SCALE 2/1	
DWG CODE NO 3 DSPEC 751514AEA				AUTHORIZED CLASSIFIER DATE		WT ACT - WT CALC SHEET 1 OF 1	

Figure 3-5. Leak Test Fixture for Middle "O"-Ring Seal B

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Figure 3-6. Leak Test Fixture for Middle "O"-Ring Seal B

3.4 BOTTOM "O"-RING SEAL (SEAL C)

The bottom "O"-ring is fabricated from type 321 stainless steel tube and is 1/16 inch diameter in cross-section having a 10 mil wall thickness and a nominal 1.250 inches outside diameter. The "O"-ring is silver plated, and is of the self-energizing design. This "O"-ring is a standard United Aircraft Products, Inc., seal with a part number U-2210-01250SEA, and is shown in Figure 3-7.

The test fixture for this test series is presented on Drawing 100E998, Group 1, shown in Figure 3-5. The adaptor, item 6 of the above drawing, used to compress the "O"-ring was fabricated to the "O"-ring manufacturer's specifications in regards to surface finish and dimensions directly related to seating the "O"-ring, and is shown in Figure 3-7 with the "O"-ring seal.

The adaptor and "O"-ring, as installed on the test fixture, are shown in Figure 3-8.

The length of the seal body, and the support rod attached to the base flange, Figure 3-5, represent the dimensions found in the reactor design (Reference Drawing 939J689A). Materials are also compatible with the reactor design, and this coupled with the physical dimensions, would show their effect on seal performance at liquid nitrogen temperatures (140°R).

The test specimens were ordered on ERCO 16,549.

3.5 UPPER GRAFOIL SEAL (SEAL D)

The upper grafoil seal, which is shown on Figures 3-9, 3-10, and 5-1, is fabricated from grafoil and consists of two pieces with mating tapered conical surfaces. This seal has an interface with the support stem on the I. D., and the cluster nut on the O. D. The I. D. of this seal is 0.326 inch, and the O. D. is 0.499 inch. The conical surfaces have a basic taper of 0.3526 inch per inch of seal length.

During assembly the male and female halves of the seal are compressed together with an axial load forming the seal on three separate surfaces. The seal is mechanically fixed in place by a spring and a lock nut arrangement.

Bottom "O"-Ring Adaptor

Bottom "O"-Ring Seal (U-2210-01250-SEA)

Figure 3-7. Bottom "O"-Ring Seal C and Adaptor

Figure 3-8. Leak Test Fixture for Bottom "O"-Ring Seal C

DATE 4/9/70

sub: UNTESTED upper grafoil seals
INFORMATION CATEGORY UNCLASSIFIED

Figure 3-9. Upper Grafoil Seal D Pre-Test Condition

Figure 3-10. Upper Grafoil Seal D Pre-Test Assembled Condition

The test fixture for this test series is presented on Drawing 100E664 which is shown on Figure 3-11. The cavity into which the seal is installed is representative of the reactor design. The spring is a catalog item and is the same as specified for reactor use. The axial compressive load used to seat the seal was applied by means of a tool threaded into the body, item 1 of the above drawings. Photographs of the assembled and disassembled fixture are shown in Figure 3-12.

The test specimens were ordered on ERCO 16,549.

3.6 LOWER GRAFOIL SEAL (SEAL E)

The lower grafoil seal, which is shown on Figure 3-13, is fabricated from grafoil and consists of two pieces with mating tapered conical surfaces. It is similar to the upper grafoil seal in appearance. This seal has an interface between the liner tube on the I. D. and stem holder on the O. D. The I. D. of this seal is 0.406 inch, and the O. D. is 0.624 inch. The conical surfaces have a basic taper of 0.3526 inch per inch of seal length.

During assembly, the two halves of the seal are compressed together with an axial load forming the seal on three separate surfaces. When the seal is fully compressed, the threaded member used to apply the load is mechanically locked in place by tabs located on the stem holder. The two halves of the seal, as assembled, are shown in Figure 3-14.

The test fixture for this test series is presented on Drawing 101E031, which is shown on Figure 3-15. A photograph of the disassembled fixture is also shown on this figure. The cavity into which the seal is installed is representative of the reactor design. In addition, the fixture has the capability for moving the liner tube 0.125 inch axially with respect to the seal to simulate reactor axial movements. Also, the liner tube can be flexed .050 inch perpendicular to its centerline 3.5 inches below the seal to simulate reactor lateral movements.

The test specimens were ordered on ERCO 16,549.

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Figure 3-12. Leak Test Fixture for Upper Grafoil Seal D

Figure 3-13. Lower Grafoil Seal E Pre-Test Condition

Figure 3-14. Lower Grafoil Seal E Pre-Test Assembled Condition

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4.0 SUMMARY OF TESTS

4.1 NARRATIVE

4.1.1 General

The following environmental conditions were used in the seal leak tests.

<u>Seal Identification</u>	<u>High Side Pressure (PSIG)</u>	<u>Seal ΔP Range (PSID)</u>	<u>Seal ΔT Range ($^{\circ}$R)</u>
Top "O"-Ring (A)	1000	50 to 600	Ambient to 140 $^{\circ}$
Middle "O"-Ring (B)	1000	20 to 300	Ambient to 140 $^{\circ}$
Bottom "O"-Ring (C)	1000	50 to 600	Ambient to 140 $^{\circ}$
Upper Grafoil (D)	1200	20 to 300	Ambient to 140 $^{\circ}$
Lower Grafoil (E)	1000	20 to 300	Ambient - 1000 $^{\circ}$ - Ambient - 140 $^{\circ}$
Irregular Closure Nut (F)	1000	50 to 600	Ambient to 140 $^{\circ}$

All seals were tested maintaining the upstream seal pressure constant. The seal ΔP range was then applied by lowering the downstream pressure. Seals A, B, C, D, and F were leak tested at both ambient temperature and 140 $^{\circ}$ R. The Lower Grafoil Seal (E) was leak tested at ambient temperature then heated to 1000 $^{\circ}$ R, and then cooled to 140 $^{\circ}$ R where the seal was again leak tested. The seal was leak tested once again upon reaching ambient temperature.

4.1.2 Top "O"-Ring Seal (Seal A)

The top "O"-ring seals provide the seal between the support plate inlet plenum and the support stem inlet plenum. These "O"-rings were first seated in the fixture to manufacturer's recommended compression, which in this case is a nominal 8 mils. The torque necessary to obtain this amount of compression is listed in the following tabulation of data.

Seal No.	New"D"(in)	"Spent" "D"(in)	Compressed"D"(in)	Torque Req'd. (in-lbs)
A1	.032	.0246	.024	435
A2	.032	.0246	.024	415
A3	.032	.0243	.024	375
A4	.032	.0247	.024	340
A5	.032	.0246	.024	415

In all cases, the threaded parts were lubricated with Neolube. Possible explanations for the differences in torque values could be from variations in the "O"-ring itself, polishing of the aluminum threads from previous tests, and differences in micrometer readings.

Figure 4-1 is presented as a general observation of how all the metal "O"-rings (top, middle, and bottom) behaved during compression or seating. It can be seen that a large per cent of the torque required to seat the "O"-ring was applied before the "O"-ring wall yielded. This can also be determined from the measurements of the "spent" "O"-rings as tabulated above. The "spent" dimension is the thickness of the "O"-ring after it has once been compressed and the load relieved. The difference between the "spent" dimension and the compressed dimension is the "spring back".

Section 4.2, Test Results, shows that the top "O"-ring performed very well, only two of the five seals tested allowing leakage that could be measured. The maximum leakage observed at cryogenic conditions was allowed by Seal A4 and was 3.45×10^{-6} lbs/sec at the end of ten thermal cycles. Figure 4-2 shows the trend of leak rate versus applied seal ΔP for several seating loads and temperature conditions. The variation between leak rates at cryogenic and ambient conditions is due mainly to density changes with temperature.

4.1.3 Irregular Closure Nut or Metal-to-Metal Seal (Seal F)

The irregular closure nut seal is used in the same axial location as the top "O"-ring seal, but is located in the periphery area where space is not available for the top "O"-ring.

Figure 4-1. Percent Torque Required to Obtain
Percent of Manufacturer's Recommended Compression of "O"-Rings

Figure 4-2. Seal H₂ Leakage Vs. Seal Pressure Differential as a Function of Torque and Temperature (Top "O"-Ring Seal A)

The seal is formed by torquing the steel nut into the aluminum support plate. The sealing surface of the nut can be seen in Figure 3-3, and the effects of 250 in-lbs of torque on aluminum can be seen in Figure 4-3.

The tests on these seals began at a seating torque of 50 in-lbs. These tests were terminated because the measuring devices were over-ranged at very small seal pressure differentials. The measuring devices included an orifice meter with a maximum flow range of 1.0×10^{-3} lbs/sec. However, the sealing ability improved greatly with increasing torque, the maximum torque used being 250 in-lbs. The effect of torque on sealing ability is shown in Figure 4-4 for seal number F2.

Section 4.2, Test Results, presents a review of the performance of this seal. The maximum leakage observed at 250 in-lbs torque, cryogenic conditions, was 2.33×10^{-6} lbs/sec for seal F5, at the mid point of 10 thermal cycles.

4.1.4 Bottom "O"-Ring Seal (Seal C)

The bottom "O"-ring seal is located on the bottom of the support plate, and provides the seal between the support plate by-pass plenum and core inlet plenum. The stem holder, which is the reactor part that loads the "O"-ring, is fabricated from stainless steel and thus introduces a differential expansion with the aluminum support plate. Cooling the aluminum and steel to 140°R introduces a calculated difference of relative lengths of approximately 1.7 mils. This difference in contraction had a very great effect on the initial tests performed at cryogenic temperatures.

The first test of this series produced no observable leakage at ambient conditions. However, at cryogenic conditions, a pressure differential across the seal could not be established because of this difference in contraction. There was a literal gap between the "O"-ring and the aluminum as can be seen from the following tabulation of "O"-ring thicknesses after having been loaded to manufacturer's recommended compression. The difference between the "Spent" and Compressed dimensions is approximately 1.0 mil, which would leave 0.5 to 0.7 mils as a gap.

Figure 4-3. Result of Torquing Steel Nut on Aluminum Sealing Surface

Figure 4-4. Effect of Torque on H₂ Leak Rate (Metal-To-Metal Seal F)

Seal No.	New "D"(in)	"Spent" "D"(in)	Compressed "D"(in)	Torque Req'd. (in-lbs)
C1	.062	.0432	.042	365
C2	.062	.043	.042	365
C3	.062	.0432	.042	365
C4	.062	.043	.042	345
C5	.062	.043	.042	355

To accomplish testing at cryogenic conditions, it was necessary to strain or preload the steel member to compensate for the temperature effects. The amount of preload was an initial 150 in-lbs and was increased to 200 in-lbs over the torque required to seat the "O"-ring. This additional torque was responsible for deforming the flanges of the adaptor as can be seen from Figure 4-5 and probably formed a back-up seal to the "O"-rings. This is considered a reasonable assumption based on the metal-to-metal seal tests. Figure 4-5 also shows the effect of the "O"-ring weld joint on the aluminum sealing surface. The "O"-ring weld joint can be seen in Figure 4-6 along with the aluminum removed by the adaptor. The weld joint could be a possible source for leakage. Both the adaptor and aluminum sealing surfaces required redressing after each "O"-ring test. Figures 4-7 and 4-8 are 8x photos showing fixture tool marks impressed on the "O"-ring. The aluminum and steel surfaces were polished to finish.

Figure 4-9 is a plot of seal C1 data, leakage rate versus applied seal pressure differential at 515 in-lbs torque, cryogenic temperature conditions.

Section 4.2, Test Results, presents a review of the performance of this seal. Seal number C1, 515 in-lbs torque, cryogenic conditions, provided a maximum leak rate of 1.74×10^{-4} lbs/sec at 599 psi seal ΔP .

Figure 4-5. Score Mark of "O"-Ring Weld Joint Plus
Scoring of Aluminum Sealing Surface by Adaptor

Figure 4-6. "O"-Ring Weld Joint

Figure 4-7. Bottom "O" Ring Seal C

Figure 4-8. Bottom "O"-Ring Seal C

Figure 4-9. H_2 Leakage Rate Vs. Seal Pressure Differential
 (Bottom "O"-Ring Seal B)

4.1.5 Middle "O"-Ring Seal (Seal B)

The middle "O"-ring seal provides the seal between the support stem inlet plenum and the support plate mixing plenum. The same comments can be applied to this seal test as for the bottom "O"-ring test with a few exceptions.

Seal No.	New"D"(in)	"Spent" "D"(in)	Compressed"D"(in)	Torque Req'd. (in-lbs)
B1	.062	.0448	.042	185
B2	.062	.0446	.042	200
B3	.062	.0446	.042	200
B4	.062	.0446	.042	210
B5	.062	.0448	.042	218

The difference between the "Spent" and Compressed "D"s represents the amount of spring back for the seals.

A preload was required for this seal also, but the additional torque required was 250 in-lbs. Also, there was no evidence that the adaptor flange provided a back-up seal, probably accounting for the higher preload.

A review of the test data of Section 4.2 shows that the self-energizing feature of the "O"-ring began to take effect at a point in the applied seal pressure differential where an increase in seal ΔP produced lower leakage values. This was consistent for this seal design, but the bottom and top "O"-ring did not show this effect even though they are self-energizing. This effect can be seen in Figure 4-10 for seal B3, and may in part account for the greater spring-back seen in this seal.

Seal number B1, 435 in-lbs torque, cryogenic conditions provided the maximum leak rate of 9.19×10^{-6} lbs/sec at 300 psi seal ΔP .

Figure 4-10. H₂ Leakage Rate Vs. Seal Pressure Differential
(Middle "O"-Ring Seal C)

4.1.6 Upper Grafoil Seal (Seal D)

The test plan for this seal specified that the axial compressive load on the seal be increased as long as leak rate continued to decrease, for ambient temperature conditions. For all seals, the maximum load of 100 lbs was reached before the seal was tested at cryogenic conditions. The two tests where the seal was subjected to ten (10) thermal cycles were performed with a compressive load of 100 lbs on the seal. The compressive load was applied to the seal by means of a tool threaded into the fixture body.

A correlation between compressive load and torque was obtained by using coil springs of known rates, applying a torque and measuring the deflection. In this manner, values of torque were obtained for each value of compressive load.

A comparison between Figures 3-9 and 4-11 of the male half of the seal shows how the grafoil flows under the application of the compressive load.

Section 4.2, Test Results, presents a listing of the data available for this seal. The maximum observed leakage for this design at 100 lbs compressive load was 1.72×10^{-4} lbs/sec measured at 140°R with 300 psi seal ΔP for seal number D4 after ten thermal cycles.

Figures 4-12 and 4-13 are representative of how the upper grafoil seals behave as a function of compressive load and applied pressure differential. Figure 4-14 shows the effect of compressive load on leakage for seals D1, D2, and D3.

Figure 4-11. Tested Upper Grafoil Seals (Seal D)

Figure 4-12. H_2 Leakage Rate Vs. Seal Pressure Differential as a Function of Compressive Load (Upper Grafoil Seal D)

Figure 4-13. H₂ Leakage Rate Vs. Seal Pressure Differential as a Function of Compressive Load (Upper Grafoil Seal D)

Figure 4-14. Effect of Compressive Load on H₂ Leakage Rate
(Upper Grafoil Seal D)

4.1.7 Lower Grafoil Seal (Seal E)

The testing for this seal followed the same pattern as the upper grafoil seal in that the maximum compressive load was applied before the next sequence of testing was begun. After the first seal, the maximum compressive load was increased from 100 lbs to 140 lbs. The method of applying the load to the seal is identical to that used for the upper grafoil. The load in this case was applied by the Adjusting Screw, Item 9, of Drawing 101E031 (refer to Figure 3-15).

Figure 4-15 shows the pre-test condition of a lower grafoil seal and Figures 4-16 and 4-17 show the post-test condition of the tested seals. These seals were easier to remove from the test fixture than the upper grafoil seals and resulted in minimal damage to the seal.

Section 4.2, Test Results, presents a listing of the data for this seal. The data include the effects of ten (10) thermal cycles, sixty (60) cycles of axial sliding of the liner tube, and sixty (60) cycles of perpendicular bending of the liner tube.

Figure 4-18 shows the effect of compressive loads on leak rate for seal E2, ambient conditions; Figure 4-19 shows the effect of liner tube sliding of .125 inch axially on leak rate; and Figure 4-20 shows the effects on the leak rate caused by .050 inch of perpendicular bending of the liner tube 3.5 inches below the seal.

The maximum observed leakage rate for this design at 140 lbs compressive load was 4.96×10^{-5} lbs/sec at 148°R and 300 psi ΔP for seal number E5 at the end of 10 thermal cycles.

Figure 4-15. Lower Grafoil Seal E, Pre-Test Condition

Figure 4-16. Lower Grafoil Seal E, Post-Test Condition

DATE 7/21/70

Sub. Tested Lower Grafoil 2-1
 Seals E-6, E-7, E-8, & E-9
 INFORMATION CATEGORY, unclassified

Figure 4-17. Lower Grafoil Seals E-6, E-7, E-8, and E-9,
 Post-Test Condition

Figure 4-18. H_2 Leakage Rate Vs. Seal Pressure Differential as a Function of Compressive Load (Lower Grafoil Seal E)

Figure 4-19. H₂ Leakage Rate Vs. Seal Pressure Differential as a Function of Axial Sliding of Liner Tube (Lower Grafoil Seal E)

Figure 4-20. H₂ Leakage Rate Vs. Seal Pressure Differential as a Function of Perpendicular Liner Tube Bending (Lower Grafoil Seal E)

4.2 TEST RESULTS

The following is a summary of tests performed, and a listing of tests for which data were obtained. DRM 51388 contains all of the measured data.

4.2.1 Top "O"-Ring Seal Leak Test Data

The following seals and torque loadings produced leakage rates which could be measured under the imposed test conditions outlined in the Operating Test Directive.

<u>Seal Number</u>	<u>Torque (in-lbs)</u>	<u>Temperature Conditions</u>
A2	415	LN ₂
A2	415	Ambient (Post LN ₂)
A2	465	Ambient
A2	465	LN ₂
A2	465	Ambient (Post LN ₂)
A4	340	LN ₂

The following seals and torque loadings produced no observable leakage under similar conditions as above seals.

<u>Seal Number</u>	<u>Torque (in-lbs)</u>	<u>Temperature Conditions</u>
A1	435	Ambient
LN ₂
		Ambient (Post LN ₂)
	485	Ambient
		LN ₂
		Ambient (Post LN ₂)
	415	Ambient

<u>Seal Number</u>	<u>Torque (in-lbs)</u>	<u>Temperature Conditions</u>
A3 ↓	375	Ambient LN ₂
		Ambient (Post LN ₂)
↓	425	Ambient LN ₂
		Ambient (Post LN ₂)
A4 ↓	255 (.5X)*	Ambient LN ₂
		Ambient (Post LN ₂)
↓	325 (.75X)	Ambient LN ₂
		Ambient (Post LN ₂)
↓	340	Ambient LN ₂
		Ambient (Post LN ₂)
↓	10 Cycles	Ambient LN ₂
		Ambient (Post LN ₂)
↓		Ambient LN ₂
		Ambient (Post LN ₂)
A5 ↓	335 (.5X)	Ambient LN ₂
		Ambient (Post LN ₂)
↓	360 (.75X)	Ambient LN ₂
		Ambient (Post LN ₂)
↓	415	Ambient LN ₂
		Ambient (Post LN ₂)
↓	10 Cycles	Ambient LN ₂
		Ambient (Post LN ₂)
↓		Ambient LN ₂
		Ambient (Post LN ₂)

*X = Manufacturer's Recommended Compression

4.2.2 Metal-To-Metal Seal Leak Test Data

The following seals and torque loadings produced leakage rates which could be measured under the imposed test conditions outlined in the Operating Test Directive.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
F1	75	Ambient
↓	100	Ambient
↓	150	Ambient
F2	100	Ambient
↓	150	Ambient
↓	200	Ambient
F3	100	Ambient
↓	150	Ambient
↓	200	Ambient
F4	250	LN ₂
↓	↓	Ambient
F5	250	Ambient
↓	↓	LN ₂
↓	↓	Ambient (Post LN ₂)
↓	↓	Ambient
↓	↓	LN ₂
↓	↓	Ambient (Post LN ₂)
↓	↓	Ambient
↓	↓	LN ₂
↓	↓	Ambient (Post LN ₂)

10 Cycles

The following seals and torque loadings produced no observable leakage under similar conditions as above seals.

4.2.2 Metal-To-Metal Seal Leak Test Data (Cont'd.)

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
F1	200	Ambient
↓	250	Ambient
↓	↓	LN ₂
		Ambient (Post LN ₂)
F2	250	Ambient
↓	↓	LN ₂
		Ambient (Post LN ₂)
F3	250	Ambient
↓	↓	LN ₂
		Ambient (Post LN ₂)
F4	250	Ambient
↓	↓	Ambient (Post LN ₂)
		Ambient
		10 Cycle { Ambient
		Ambient (Post LN ₂)
		Ambient

The following seal tests were aborted because of excessive (over-ranging of measuring device) seal leakage.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
F1	50	Ambient
F3	50	Ambient

4. 2. 3 Bottom "O"-Ring Seal Leak Test Data

The following seals and torque loadings produced leakage rates which could be measured under the imposed test conditions outlined in the Operating Test Directive.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
C1	515	LN ₂
C2	565	LN ₂
C3	565	Ambient
C4	182	Ambient
C4	545	LN ₂
C4	545	LN ₂ (10 Cycles)
C5	555	LN ₂ (60 Cycles)

The following seals and torque loadings produced no observable leakage under similar conditions as above seals.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
C1	365	Ambient
C1	365	Ambient (Post LN ₂)
C1	565	Ambient
C1	565	Ambient (Post LN ₂)
C2	565	Ambient
C2	565	Ambient (Post LN ₂)
C3	565	Ambient
C4	310 (. 5X)	Ambient
C4	330 (. 75X)	Ambient
C4	345 (X)	Ambient
C4	545	Ambient
C4	545	Ambient (Post LN ₂)

4.2.3 Bottom "O"-Ring Seal Leak Test Data (Cont'd.)

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
C4	545	Ambient Tests of 10 Cycles
C5	285 (.5X)	Ambient
C5	317 (.75X)	Ambient
C5	355	Ambient
C5	555	Ambient
C5	555	Ambient Tests of 60 Cycles

The following seal tests were aborted because of excessive (over-ranging of measuring device) seal leakage.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
C1	365	LN ₂
C3	365	LN ₂

4.2.4 Middle "O"-Ring Seal Leak Tests

The following seals and torque loadings produced leakage rates which could be measured under the imposed test conditions outlined in the Operating Test Directive.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
B1	385	LN ₂
B1	435	LN ₂
B2	400	LN ₂
B2	450	LN ₂
B3	400	LN ₂
B3	450	LN ₂
B4	460	LN ₂
B4	460	10 Cycles } LN ₂
B4	460	LN ₂
B5	468	LN ₂
B5	468	10 Cycles } LN ₂
B5	468	LN ₂

The following seals and torque loadings produced no observable leakage under similar conditions as above seals.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
B1 ↓ ↓ ↓ ↓ ↓ ↓	185	Ambient
	185	Ambient (Post LN ₂)
	385	Ambient
	385	Ambient (Post LN ₂)
	435	Ambient
	435	Ambient (Post LN ₂)

4.2.4 Middle "O"-Ring Seal Leak Tests (Cont'd.)

Seal Number	Torque (in-lb.)	Temperature Conditions
B2 ↓	200	Ambient
	350	Ambient
	350	Ambient (Post LN ₂)
	400	Ambient
	400	Ambient (Post LN ₂)
	450	Ambient
	450	Ambient (Post LN ₂)
B3 ↓	200	Ambient
	200	Ambient (Post LN ₂)
	350	Ambient
	350	Ambient (Post LN ₂)
	400	Ambient
	400	Ambient (Post LN ₂)
	450	Ambient
	450	Ambient (Post LN ₂)
B4 ↓	187	Ambient
	193	Ambient
	210	Ambient
	410	Ambient
	460	Ambient
	10 Cycle ↓	Ambient (Post LN ₂)
		Ambient
		Ambient (Post LN ₂)
		Ambient
		Ambient (Post LN ₂)

4.2.4 Middle "O"-Ring Seal Leak Tests (Cont'd.)

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
B5 ↓	165	Ambient
	200	Ambient
	218	Ambient
	418	Ambient
	468	Ambient
	↓	Ambient
		Ambient (Post LN ₂)
		Ambient
		Ambient (Post LN ₂)
		Ambient
		Ambient (Post LN ₂)

10 Cycle

The following seal tests were aborted because of excessive (over-ranging of measuring device) seal leakage.

<u>Seal Number</u>	<u>Torque (in-lb.)</u>	<u>Temperature Conditions</u>
B1	185	LN ₂
B2	350	LN ₂
B3	200	LN ₂
B3	350	LN ₂
B4	410	LN ₂
B5	418	LN ₂

4.2.5 Upper Grafoil Seal Leak Test Data

Every seal tested at each axial compressive load produced a leakage rate which could be measured.

Data for the following seals, axial loads, and temperature conditions were obtained as outlined in Operating Test Directive.

<u>Seal Number</u>	<u>(1) Compressive Load (lbs.)</u>	<u>Temperature Conditions</u>
D1 ↓	10 ↓ 100	Ambient ↓ LN ₂ Ambient (Post LN ₂)
D2 ↓	10 ↓ 100	Ambient ↓ LN ₂ Ambient (Post LN ₂)
D3 ↓	10 ↓ 100	Ambient ↓ LN ₂ Ambient (Post LN ₂)
D4 & D5 ↓	100 ↓	Ambient LN ₂ Ambient (Post LN ₂) Ambient 10 Cycles LN ₂ Ambient (Post LN ₂) Ambient LN ₂ Ambient (Post LN ₂)

(1) Compressive load increments are 10 lbs. Several intermediate loads were eliminated when trends were becoming evident.

4.2.6 Lower Grafoil Seal Leak Test Data

Every seal tested at each axial compressive load produced a leakage which could be measured.

The same type of tests were done as on the Upper Grafoil series, but with some significant differences. The maximum compressive load was increased to 140 lbs. , the thermal cycle temperature range included a soak at 550°F level for one (1) hour, and the seal I. D. sealing surface (liner tube) was subjected to 60 cycles of stroking and bending.

The following data were obtained from the Lower Grafoil Seal Test Series.

<u>Seal Number</u>	<u>Compressive Load (lbs.)</u>	<u>Temperature Conditions</u>
E1 ↓	30 ↓ 100	Ambient ↓
E2 ↓	30 ↓ 140	Ambient ↓
E3 ↓	30 ↓ 90	Ambient ↓
E3 A ↓	90 ↓ 140	Ambient ↓

4.2.6 Lower Grafoil Seal Leak Test Data (Cont'd.)

<u>Seal Number</u>	<u>Compressive Load (lbs.)</u>	<u>Temperature Conditions</u>
E4 & E5 ↓	140 ↓	Ambient LN ₂ Ambient (Post LN ₂) 10 Cycles { Ambient LN ₂ Ambient (Post LN ₂) Ambient LN ₂ Ambient (Post LN ₂)
E6 & E7 ↓	140 - 0 Strokes ↓ 20 Strokes ↓ 40 Strokes ↓ 60 Strokes	Ambient ↓ ↓ ↓ ↓
E8 & E9 ↓	140 - 0 Bends ↓ 20 Bends ↓ 40 Bends ↓ 60 Bends	Ambient ↓ ↓ ↓ ↓

4.2.7 Discussion of Data

Extracted from the scope of test document, page 3, are the parameters to be reported in tabular form:

- 4.2.7.1 Seal High-Side Pressure = PSIA
- 4.2.7.2 Seal Low-Side Pressure = PSIA
- 4.2.7.3 Seal Pressure Differential = PSID
- 4.2.7.4 Gas Temperature at Seal Location = °R
- 4.2.7.5 Gas Density Upstream of Seal = lbs/in³
- 4.2.7.6 Product of Gas Density X Seal Pressure Differential = lbs²/in⁵
- 4.2.7.7 Seal Leak Rate = lbs/sec
- 4.2.7.8 Seating and Spring Compressive Load or Torque (lbs or in-lbs)
- 4.2.7.9 Effects of Sliding and Bending Liner Tube
- 4.2.7.10 Dimensional Check of Hardware Used in Test Configuration

Paragraph 4.2.7.6 was not requested in the scope of test document, but is presented in tabular form in lieu of rectilinear plots of this parameter versus seal leak rate. Paragraph 4.2.7.2 can be obtained by subtracting seal pressure differential from seal high-side pressure.

Quality control inspection reports on hardware are available in TFFL files for reference if desired.

Seal leak rate versus applied seal ΔP for the compressive loads used is presented in graphical form for the purpose of showing trends.

The data for these seal leak tests as presented in Section 4.2.1 were obtained in the following manner.

Seal upstream pressure, P_1 , is the sum of a gage reading and barometric pressure. Seal upstream gas temperature, T_1 , is obtained by means of a copper/constantan thermocouple and converted to degrees Rankine. Seal upstream density is obtained from the parahydrogen tables

of TME-1478 by entering with upstream pressure and temperature. Seal pressure differential is obtained directly as a gage reading. The seal leakage rate in lb/sec. is obtained as a reading in SCCM from a Hastings Mass Flowmeter. A true reading in SCCM is obtained from a calibration curve, and the true SCCM reading is converted to lb/sec. H_2 . Occurring in the title heading of the tabulated data for use as a cross-reference is the serial number of the mass flowmeter used in reducing the leakage data (example, HFM-24). This would enable a check to be made of the data that are presented for uncertainty, range and resolution of the meter. It may be noticed that several leakage rates for low ΔP 's for HFM-30 indicate a negative reading. This is a result of the 6 degree polynomial curve fit and indicates that the meter reading is very close to zero. Under the very best of conditions readings close to the zero point have a large uncertainty attached to them, so it is recommended that these data points receive little attention in analyzing the seals performance.

5.0 ANALYSIS

A series of leakage tests were performed on the O-ring seals and the grafoil seals located in the cold end cluster assembly hardware. A post test evaluation was performed on each seal to determine its sealing capability for various loadings. The seal leak rates were compared to the specification requirement to determine the acceptability of the seal designs for R-1 application.

5.1 ANALYTICAL MODEL

The various seals tested which exhibited measurable leakage were categorized according to location, seating load or torque, and temperature conditions. The seal locations are shown in Figure 5-1. The flow parameter $\rho \Delta p / \mu$, where ρ is the fluid density evaluated at the bulk fluid temperature, Δp is the pressure drop across the seal, and μ is the fluid viscosity evaluated at bulk fluid temperature, was calculated for each test point. The flow parameter was derived from the laminar flow relationship:

$$W \left(\frac{L}{A} \right) = K \left(\frac{p \Delta p}{\mu R T} \right)^n = K \left(\frac{\rho \Delta p}{\mu} \right)^n \quad (1)$$

where,

W = flow rate - lb_m/sec

L = flow length - in

A = flow area - in^2

p = upstream pressure - psia

Δp = pressure drop - psi

μ = viscosity - $\text{lb}_m/\text{in-sec}$

R = gas constant - $\text{ft-lb}_f / \text{lb}_m \text{-}^\circ \text{R}$

T = temperature - $^\circ \text{R}$

ρ = density - $\text{lb}_m / \text{in}^3$

K = constant

n = slope on log paper

In order to extrapolate to R-1 reactor conditions, the test data were plotted on log paper for the flow parameter, $\rho \Delta p / \mu$, versus the leak rate W . Theoretically, for laminar flow, a linear relationship should result for this type of plot. In all cases, a linear curve was fit to data.

Figure 5-1: Cluster Attachment Seal Leakage Test, 58DT-151-4, Location of Seals

The R-1 reactor thermal/hydraulic environment in the vicinity of the seal location, Figure 5-2, was used to calculate the flow parameter, $\rho\Delta p/\mu$, for the reactor. The bulk fluid temperature in the vicinity of the seal location and the average fluid pressures were used to evaluate the flow parameter, $\rho\Delta p/\mu$. An additional calculation was performed using the support plate material temperatures in the vicinity of the seals shown on Fig. 5-2 evaluate the fluid properties in the flow parameter expression. The calculation indicated that using the bulk fluid temperatures and average fluid pressures a more conservative calculation resulted and, therefore, was used in this evaluation. The R-1 reactor flow parameter was then used in conjunction with the experimental relationships to obtain a leak rate expected for the R-1 reactor. An inventory of leak for each seal configuration with measurable leakage was made and then assessed to determine if the specification requirement was exceeded.

5.2 COMPARISON OF PREDICTIONS AND RESULTS

Table 5-1 is a summary sheet of the seal configurations tested, the test torques or seating loads, the test temperature, the calculated flow parameter $\rho\Delta p/\mu$ for the R-1 reactor conditions, and the calculated leak rates for the R-1 based on the test results. The test results for the seals with measurable leakage are presented in Figures 5-3 through 5-13. For a complete listing all tests both with measurable and non-measurable leakage, refer to Section 4.1, Test Results.

The measured results for the top O-ring seal are presented in Figure 5-3. The results correlate well for a linear relationship. Figure 5-4 presents the measured results for the middle O-ring seal and again linear relationships were obtained. However, an interesting trend was noted on several of the middle O-ring seals. As the imposed pressure drop across the seal was increased, the leak rate decreased. This is due to the self-energizing feature of this type of O-ring seal, where the sealing capability is dependent upon the direction in which the Δp was imposed.

The performance of the bottom O-ring seal shown on Figure 5-5 was similar to the top O-ring seal with the exception that a higher leak rate was observed on several of the configurations. A metal to metal seal was tested which in the R-1 reactor core periphery will be used instead of the top O-ring. This seal for reactor application had considerably higher leak rates, ($>10^{-3}$ lb/sec), than any of the other O-ring seals, particularly at the low torque levels. The leakage performance of this seal is illustrated in Figure 5-6. For almost all the O-ring seal tests there was a noticeable decrease in leak rate with an increase in torque.

A series of tests were performed on the upper and lower grafoil seals to determine their leakage characteristics and to investigate the effects of cyclic operation, effects of sliding on

Figure 5-2. Plenum Pressures in Cluster Attachment Region for the R-1 Reactor Core, Nominal Conditions
Ref: State Point Information for Composite Core Dated July '1, 1970

TABLE 5-1

SUMMARY SHEET OF SEAL PERFORMANCE FOR SEALS WITH MEASURABLE¹ LEAKAGE

Seal Number		Test Torque - in-lb	Test Temperature - °R	$\rho \Delta p / \mu$ Calculated for R-1		Measured Leakage for Calculated R-1 $\rho \Delta p / \mu$	
				SOL - lb/sec-in ⁴	EOL - lb/sec-in ⁴	SOL - lb/sec	EOL - lb/sec
Top O-Ring	A2	465	140	40.4×10^7	42.7×10^7	1.08×10^{-6}	1.13×10^{-6}
	A2	465	515	"	"	8.4×10^{-7}	8.6×10^{-7}
	A2	415	140	"	"	6.6×10^{-7}	6.9×10^{-7}
	A2	415	515	"	"	1.2×10^{-6}	1.22×10^{-6}
Metal to Metal	F1	75	530	40.4×10^7	42.7×10^7	$>10^{-3}$	$>10^{-3}$
	F1	100	530	"	"	"	"
	F2	100	547	"	"	"	"
	F2	150	520	"	"	"	"
	F3	100	547	"	"	"	"
	F4	250	140, 525	"	"	1.40×10^{-6}	1.45×10^{-6}
	F5	250	140, 524	"	"	1.55×10^{-6}	1.60×10^{-6}
Middle O-Ring	B1	385	147	0.615×10^7	2.94×10^7	No Data Available	3.0×10^{-5}
	B2	450	147	"	"	"	1.05×10^{-7}
	B2	400	147	"	"	"	3.2×10^{-5}
	B1	435	147	"	"	"	7.3×10^{-5}
Bottom O-Ring	C1	515	147	41.7×10^7	39.5×10^7	1.1×10^{-5}	9.0×10^{-6}
	C2	565	147	"	"	2.4×10^{-7}	1.80×10^{-7}
	C3	565	542	"	"	1.6×10^{-6}	1.52×10^{-6}
	C4	182	521	"	"	$>10^{-3}$	$>10^{-3}$
		<u>Seating Load - lbs</u>					
Upper Grafoil	D1	100	493	0.615×10^7	2.94×10^7	No Data Available	1.29×10^{-7}
	D2	100	496	"	"	"	1.5×10^{-6}
	D3	100	506	"	"	"	3.6×10^{-7}
	D1	10	493	"	"	"	2.45×10^{-6}
	D2	10	502	"	"	"	2.05×10^{-5}
	D3	10	502	"	"	"	1.10×10^{-5}
	D1	100	141	"	"	"	2.8×10^{-6}
	D2	100	144	"	"	"	2.8×10^{-6}
	D3	100	145	"	"	"	2.7×10^{-5}
Lower Grafoil	E1	100	536	8.5×10^7	11.1×10^7	6.5×10^{-6}	9.0×10^{-6}
	E2	140	547	"	"	6.5×10^{-7}	8.5×10^{-7}
	E3	140	543	"	"	2.5×10^{-6}	3.5×10^{-6}
	E1	40	535	"	"	7.5×10^{-5}	9.6×10^{-5}
	E2	40	539	"	"	6.0×10^{-5}	7.5×10^{-5}
	E3	40	535	"	"	3.3×10^{-4}	4.2×10^{-4}

¹ Refer to Section 4.1, Test Results for Listing of Seals Without Measurable Leakage.

Figure 5-3 Cluster Attachment Seal Leakage Test
Top O-Ring Seal "A"

Figure 5-4 Cluster Attachment Seal Leakage Test
Middle O-Ring Seal "B"

Figure 5-5 Cluster Attachment Seal Leakage Test
Bottom O-Ring Seal "C"

Figure 5-6 Cluster Attachment Seal Leakage Test
Metal to Metal Seal "F"

Figure 5-7 Cluster Attachment Seal Leakage Test
Upper Grafoil Seal, Ambient Test

Figure 5-8 Cluster Attachment Seal Leakage Test
Upper Grafoil Seal, Cryogenic Test

Figure 5-9 Cluster Attachment Seal Leakage Test
Upper Grafoil Seal, Ambient Test, Seating Load 10 lbs.

Figure 5-10 . Cluster Attachment Seal Leakage Test
Lower Grafoil Seal, Ambient Test, Seating Load 40 lbs.

Figure 5-11 Cluster Attachment Seal Leakage Test
Lower Grafoil Seal, Ambient Test, Seating Load 100 lbs. and 140 lbs.

Figure 5-12 Cluster Attachment Seal Leakage Test
Effect of Sliding on Lower Grafoil Seal Performance

Figure 5-13 Cluster Attachment Seal Leakage Test
Effect of Bending on Lower Grafoil Seal Performance

the sealing surface, and the effects of bending on the seal leakage. For purposes of illustration, both the minimum and maximum seating loads were selected. Figures 5-7, 5-8, and 5-9 present the upper grafoil seal leakage characteristics for both ambient and cryogenic conditions. An increase in leak rate is exhibited for the ambient test at the minimum seating load of 10 lbs. Of interest is the discontinuity of the linear relationship between the ambient and cryogenic leak rates for the 100 lb. seating load runs. The noticeable shift in the measured data is not attributed to fluid property changes but due to a physical change in the sealing surface geometry.

Figures 5-10 and 5-11 present the lower grafoil seal leakage characteristics. Linear relationships are shown for both seating loads with a noticeable increase in leak rate for the seal configuration with a seating load of 30 lbs.

The lower and upper grafoil seals were subjected to cyclic tests for a total of 10 thermal cycles. A thermal cycle was sequenced to subject the seal configuration to ambient, liquid nitrogen, and ambient temperatures with leak tests at the termination of each event in the cycle. The middle O-ring and the bottom O-ring were also subjected to 10 cycles. One bottom O-ring was tested for 60 cycles. Table 5-2 is a summary of the cyclic tests and indicates a definite increase in leak rate at the end of each cyclic test with the exception of three tests: middle O-ring B5, bottom O-ring C4, and metal to metal F5, which resulted in a decrease in leakage.

The lower grafoil seal test fixture had the added feature of determining the effects of tube sliding and bending on leakage rate. The tube was moved 0.125 inches axially with respect to the seal and deflected 0.05 inches perpendicular to the tube centerline at a location approximately 3.5 inches below the seal.

The effects of tube sliding are illustrated on Figure 5-12. Designated on this Figure are the leak rates prior to sliding the tube and after 60 strokes of tube sliding. In general, the two seals tested exhibited a small increase in leak rate after being subjected to 60 strokes of sliding.

The effects of tube bending are illustrated on Figure 5-13. The leakage performance of both tested seals did not deteriorate greatly after the tube liner was bent 60 times.

5.3 POST TEST COMPARISON

The Cluster Attachment Seal Leakage Tests were conducted to characterize the leakage performance of various seal designs and to obtain engineering data to evaluate seal designs for the R-1 reactor application. In such a case, there is no post test comparison with pretest predictions.

TABLE 5-2
THERMAL CYCLIC PERFORMANCE OF SEALS

Seal Location	Seal No.	⁽¹⁾ No. Cycles	⁽²⁾ Temp. Conditions	Press- psia	Δp - psi	Torque - in-lb	Seating Load- lbs	Leak Rate Cycle 1-lb/sec	Leak Rate End of Test-lb/sec
Middle O-Ring	B4	10	Cryogenic	1014	300	460	—	1.03×10^{-6}	1.99×10^{-5}
Middle O-Ring	B5	10	Cryogenic	1014	300	468	—	2.09×10^{-6}	1.43×10^{-6}
Bottom O-Ring	C4	10	Cryogenic	1014	600	545	—	4.19×10^{-6}	7.58×10^{-7}
Bottom O-Ring	C5	60	Cryogenic	1014	600	555	—	2.93×10^{-6}	6.57×10^{-5}
Metal to Metal	F5	10	Cryogenic	1014	600	250	—	2.62×10^{-6}	9.53×10^{-7}
Metal to Metal	F5	10	Ambient	1014	600	250	—	2.29×10^{-7}	3.36×10^{-7}
Upper Grafoil	D4	10	Ambient	1214	300	—	100	2.82×10^{-7}	2.66×10^{-6}
Upper Grafoil	D5	10	Ambient	1217	300	—	100	2.70×10^{-7}	3.24×10^{-7}
Lower Grafoil	E4	10	Ambient	1014	300	—	140	7.38×10^{-6}	1.76×10^{-5}
Lower Grafoil	E5	10	Ambient	1014	300	—	140	4.48×10^{-6}	6.24×10^{-6}

⁽¹⁾ A Thermal Cycle Consists of Ambient, LN_2 , and Ambient Temperatures.

⁽²⁾ Temperature Conditions are for the Measurement at the End of Test. Cryogenic Conditions Indicate No Measurable Leakage for the Ambient Leak Check.

6.0 CONCLUSIONS

All seals tested are capable of meeting the sealing requirements as stated in items b, c, d, and e of Paragraph 3.3.1.3.2 of the Cluster Hardware Specification EC-677558. However, care must be taken in the design arrangement utilizing the seals so that the thermal motions that normally occur within the arrangement during reactor operation do not unseat the bottom "O"-ring seal (see Paragraph 6.3 below) (for location of seals see Figure 5-1).

Seating forces and torques used at reactor assembly must be controlled in order to assure that adequate sealing is obtained. Seating forces and/or torque values were determined for each type of seal and are listed in Table 6-1.

The lower grafoil seal (Seal E) is capable of meeting the sealing requirement conditions. This seal can accommodate the expected support plate bow and core thermal growth as verified by the sliding and bending cycle tests.

A discussion of test results and specification requirements follows.

Table 6-2 shows the comparison between allowable and the maximum measured leakage rate values for each type of seal tested. The allowable values were taken from the Cluster Hardware ECC Specification, EC-677558, Paragraph 3.3.1.3.2. The measured values were extrapolated from the test data for reactor conditions at start-of-life (SOL) and end-of-life (EOL). In all cases where assembly conditions were similar to the conditions planned for reactor use, the measured leakage values were well below the allowable limits. In fact, 74% of the test runs on the metal "O"-ring seals, and 43% of runs on the metal-to-metal seals resulted in leakage rates too small to measure ($< 6 \times 10^{-8}$ lbs/sec).

During reactor operation, the lower grafoil seals are subjected to slight bending due to support plate thermal shrinkage, nonparallelism between the support plate and the core forward face curvatures and core lateral shift. The combined effect of these phenomena is expected to be less than the effect of offsetting the liner tube .050 approximately 3.5 inches below the seal. Seals E-8 and E-9 were leak tested while the simulated liner tube

TABLE 6-1

TENTATIVE SEATING FORCE OR TORQUE RECOMMENDED FOR REACTOR ASSEMBLY

<u>Seal Description</u>	<u>Test Seating Force or Torque Range</u>	<u>Tentative Seating Force (Lbs) or Torque (In-Lbs) Recommended for Reactor Assembly</u>
Seal A (Top "O" Ring) (Closure Nut Seal)	340 - 465 In-Lbs	525 ± 50 In-Lbs
Seal B (Middle "O" Ring) (Cluster Nut Seal)	385 - 450 In-Lbs	$*625 \pm 50$ In-Lbs
Seal C (Bottom "O" Ring) (Stem Holder Seal)	515 - 565 In-Lbs	$*625 \pm 10$ In-Lbs
Seal D (Upper Grafoil)	10 - 100 Lbs	100 ± 10 Lbs
Seal E (Lower Grafoil) (Liner Tube Seal)	30 - 140 Lbs	140 ± 10 Lbs
Seal F (Metal-to-Metal) (Closure Nut Seal at Periphery of Support Plate)	75 - 250 In-Lbs	300 ± 50 In-Lbs

*This torque on the cluster nut is required for seating Seal C and applies load to both Seals B & C.

TABLE 6-2
COMPARISON MATRIX BETWEEN MEASURED AND ALLOWABLE SEAL LEAKAGE

Allowable leakage from Spec. No. EC-677558, Para. 3.3.1.3.2 operating periods with the NSS operating at rated conditions, the combined leakage from equipment covered by this Spec for all clusters shall be limited to:

periods with the NSS operating at rated conditions, the combined leakage from equipment covered by this Spec for all clusters shall be limited to:			Seals in This Category		Max. Measured Leakage Per Seal Corrected to R-1 Conditions, Lbs/Sec		Total Max. NSS Measured Leakage, Lbs/Sec	
			Description	No. in NSS	From Table 5-1			
					SOL	EOL	SOL	EOL
b.	From the seals at the support stem inlet (plenum) to support plate forward face, lbs/sec - 0.2	Seal A (Top "O" Ring)	247		1.02×10^{-6}	1.22×10^{-6}	.00029	.00030
		Seal F (Metal-to-Metal)	102	(1)	1.55×10^{-6}	(1) 1.60×10^{-6}	.00016	.00016
		TOTAL SEALS A & F	349				.00043	.00044
c.	From the seals between the support stem bypass flow plenum in the support plate and the core inlet plenum, lbs/sec - 0.2	Seal C (Bottom "O" Ring)	349		1.1×10^{-5}	9.0×10^{-6}	.0038	.0031
d.	From the seals between the support stem inlet plenum and the support stem discharge plenum, lbs/sec - 0.2	Seal B (Middle "O" Ring)	349	(5)	$< 2 \times 10^{-5}$	7.3×10^{-5}	$< .0070$	.0254
		Seal D (Upper Grafoil)	349	(2) (4)	$< 6 \times 10^{-7}$	(2) 2.7×10^{-5}	$< .0002$	.0094
		TOTAL SEALS B & D	698				$< .0072$	.0348
e.	From the seals between the support stem discharge plenum and the core inlet plenum, lbs/sec - 0.2	Seal E (Lower Grafoil)	349	(3)	2.5×10^{-6}	(3) 3.5×10^{-6}	.00067	.00122
		After 60 Cycles of Sliding		(6)	3×10^{-6}	(6) 2×10^{-5}	.0010	.0080
		After 60 Cycles of Bending		(7)	2.6×10^{-6}	(7) 4.6×10^{-6}	.0009	.0016

CODE:

- 1) At 250 in-lbs torque
- 2) At 100 lbs seating force
- 3) At 140 lbs seating force
- 4) This value extrapolated from Figure 5-7.
- 5) This value extrapolated from Figure 5-4.
- 6) These values extrapolated from Figure 5-12.
- 7) These values extrapolated from Figure 5-13.

was deflected .050 inch perpendicular to its centerline for 60 cycles. Table 6-2 shows that the leakage after the test was much less than the allowable limit.

The lower grafoil seal is also subjected to a sliding motion of the liner tube inside of the seal during reactor operation. This sliding motion is expected to be approximately 1/8 inch axially for 60 cycles during 10 hours of reactor operation. Seals E-6 and E-7 were leak tested while the simulated liner tube was moved 0.125 inch axially with respect to the seals. Table 6-2 shows that the leakage rate after 60 cycles is still less than the allowable.

Table 6-1 lists the optimum seating forces and/or torque values recommended for each type of seal for reactor assembly. These values were determined from the measured values by selecting a value higher than the maximum required in the tests.

APPENDIX A
LIST OF SEALS TESTED

<u>Drawing 939J698A Item Number</u>	<u>Seal Identification For Test</u>	<u>Manufacturer's or Part Number</u>
57	A	U-2105-01313-SEA
56	B	U-2210-0100-SOA
55	C	U-2210-0125-SEA
43	D	800C659 H01 & 800C660 H01
38	E	800C661 H01 & 800C662 H01

TITLE Cluster Attachment Seal Leakage Test	
	DOCUMENT NO. WANL-TME-2732	DATE 15 Sept. 1970
ABSTRACT Three types of seals are used in the attachment of the cluster hardware to the support plate in order to contain the SSCA hydrogen flow. These O-rings, grafoil seals, and metal-to-metal seals were tested under varied laboratory conditions. Data obtained was extrapolated to R-1 reactor conditions and compared with the Cluster Hardware Specification No. EC-677558 requirements for leakage. Each seal, when assembled to conditions similar to proposed reactor assembly conditions, was found to be capable of meeting the sealing requirements.		
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