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The FFTF LMFBR is intended to have a near zero release of radioactive gases during normal reactor operation with 1% failed fuel. This report presents calculations which provide an approximation of these cover gas leakages. Data from ongoing static and dynamic seal leak tests at AI are utilized. Leakage through both elastomeric and metallic seals in all sub-assemblies and penetrations comprising the reactor cover gas containment during reactor operation system are included.

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I. INTRODUCTION

The FFTF LMFBF is intended to have a near zero release of radioactive gases during normal reactor operation with 1% failed fuel. This report presents calculations which provide an approximation of these cover gas leakages. Data from ongoing static and dynamic seal leak tests at AI are utilized. Leakage through both elastomeric and metallic seals in all subassemblies and penetrations comprising the reactor cover gas containment system are included. Specifically not included, are units of service and support equipment; CLEM, Interim Decay Storage, Conditioning Stations, CLIRA and OTA Grapple Adapter, etc. Also not included are the cover gas purification system and buffer gas systems.

Total leakage is divided into argon, xenon, krypton and hydrogen (substituted for neon) which are the species of radioactive gases in the FFTF reactor cover gas system.

These calculations were made as a part of the Cover Gas Seals program of AEC Task 11 - FFTF/LMFBF Seal Test Program.

II. OBJECTIVES

These calculations were made to obtain a preliminary estimate of the total cover gas leakage through elastomeric and past metallic seals during normal reactor operation, and includes all seals in both the reactor head and head penetration assemblies. Identified are the leak rate conductances of all individual seals, plus the effective seal conductances of the series and parallel combinations of these seals which comprise the actual leakage paths.

A. System Description

Only those seals used for the containment of the reactor cover gas are considered. Seals such as those used to isolate the sodium heat transfer system are not included in these calculations. Table I lists the major assembly drawings and their respective change letters/numbers in effect at the time of this calculation.

TABLE I
FFTF DRAWING STATUS FOR LEAK RATE CALCULATION

	<u>Sub-assembly</u>	<u>Drawing No.</u>	<u>Change</u>	<u>Date</u>
1.	IVHM Assembly	H 4-28674	0	7-72
2.	Arm Support/RRP Assy. (FFTF-IVHM)	H 4-28667	0	
3.	Plug Assy - Orientation Orientation System (FFTF- (IVHM)	H 4-28669	2	8-71
3.1	Toe Adjust Drive Assy Orientation System(FFTF- IVHM)	H 4-28668	2	-
4.	Chain Hoist System Rising Stem IVHM	H 4-28676	4	1-73
5.	Fuel Transfer Port Assy	H 4-22927	D2	1-73
6.0	Instrument Tree Upper Section Elevation & Drive Mechanism	H 4-23112	2	6-73
6.1	Instrument Tree Bellows Installation	H 4-23117	2	6-73
6.2	Instrument Tree Sealing Mast & Flange	H 4-23122	2	6-73
7.	Fuels Open Test Assy	H 4-21940	0	7-73
8.	Control Rod Drive Mechanism Assy	H 4-20631	D	11-73
9.	Temperature & Liquid Level Port Plug Detail Assembly	H 4-23535	0	7-73
10.	Closed Loop in Reactor Assy Flanged Joint Assy	H 4-20733	6	4-73
11.	Proximity Test Plug Assy	H 4-23481	0	1-74
12.	Low Level Flux Monitor Thimble Assy	H 4-22263	4	4-73

Table I (cont'd)

	<u>Sub-assembly</u>	<u>Drawing No.</u>	<u>Change</u>	<u>Date</u>
13.	Closure Head Assy Sectional Elevation	H 4-25260	3	10-73
13.1	Installation Interface Control Dwg-Reactor Refueling Plug to Reactor Vessel Head	H 4-28612	6	3-73
14.	Gas System Assy Installation	H 4-28652	1	11-72

B. Assumptions and Limitations

When the tabulation and calculations were started some data were not available. Also, some generalizations were made to expedite calculations. In all cases, these generalizations were in the conservative (greater leakage) direction. Refinements can be made, if a more accurate compilation is found necessary.

The following basic assumptions were used in the leakage calculations. The specific items on which the assumptions are applicable, are repeated throughout the report.

1. The effect of seal housing and shaft finishes is ignored. Seal leakage data accumulated at the time leakage calculations were started, indicated that, in the practical range of metal surface finishes specified on the drawings, no differences in leak rates, in the range of data accuracies, was apparent. (Ref 1)

2. Seal compressions are grouped as follows:

<u>Calculated Compression</u>	<u>Assumed Compression</u>
30% and greater	30%
10 to 30%	10%
< 10%	As calculated

2. (Cont'd)

The use of the lower compression in the calculations give a higher or more conservative leakage value.

3. Seal temperatures, as provided by ARD and listed in Column 5 of the App. I worksheet, are rounded off to the next higher value of 90, 110, 130F etc., when determining the permeation of the seal material. Since the permeability of elastomers increases with temperature, the use of the higher temperature gives a higher or more conservative leakage value.

4. Several types of elastomer seal leakage could be considered in calculations of this type, that is, permeation-type leakage, motion-type leakage, and leakage by physical breaching of the seal from a tear, excessive wear, etc. Only permeation-type leakage and motion-type leakage have been considered. Both rotary and reciprocating leak rates were assumed to be five times greater than static seal leak rates when these calculations were started. This value is high based upon current data. A factor of one for rotary seals and slightly more than one for reciprocating seals would be more realistic.

5. When metal seal leak rates did not appear on the drawings, the following rates, provided by ARD, were used:

<u>Seal</u>	<u>Leak Rate</u>
O-Ring	1×10^{-7} (Std cc He)/(sec, mean circumferential inch, atm)
Cone type (Aeroquip)	2.6×10^{-6} (Std cc He)/(sec, circumferential inch of sealing edge, atm)
Compression (Swagelok)	1×10^{-9} (Std cc of He)/sec, 1/4 inch shaft dia, atm)

6. The permeation of Neon (one of the cover gas constituents of interest) through the elastomer seals could not be measured since Neon has an ionization potential similar to Helium which is used as the carrier gas in the Trace Gas Analyzer. The analyzer cannot differentiate between the two gases because of this similarity. Hydrogen was substituted for Neon in the calculations, since H₂ leakage and permeation data were available from the on-going seal permeation test program. Interpretation of calculated hydrogen leakage relative to the allowable Neon leakage is discussed in Section V.

III. METHODS

A. Leak Path Systems

The elastomeric seals are installed in pairs, and in some sub-assemblies, a number of seals are used to effect cover gas containment. In keeping with the overall conservative approach used in these calculations, all cavities between seals were assumed sufficiently small, so that no allowance was made for partial pressure buildup or nuclide holdup time. These seal systems are then treated as analogies of capacitance free electrical systems to determine single valued seal conductances.

From the ohms expression $i = E/R$ or $i = EC$ the analogy for the leakage calculation becomes $L = \Delta P \ell L_i$ in which L is the leak rate in std cc/sec, ΔP = partial pressure in atmospheres of gas, i , ℓ is the seal length in inches and L_i is seal permeation leakage for the gas, i , in cc/(sec, inch, atmos) for a specified seal, compression, temperature and service. The product of ℓL_i is the conductance term C , in the electrical expression and also leakage.

For a leak path system with seals in series the equivalent seal conductance is:

$$C_{EQ} = \frac{1}{\ell L_i}_{EQ} = \frac{1}{\ell L_i}_1 + \frac{1}{\ell L_i}_2 + \frac{1}{\ell L_i}_3 + \dots,$$

for seals in parallel:

$$C_{EQ} = (\ell L_i)_{EQ} = (\ell L_i)_1 + (\ell L_i)_2 + (\ell L_i)_3 + \dots,$$

so that for the following system,

$$C_{EQ} = (\ell L_i)_{EQ} = \frac{1}{\frac{1}{(\ell L_i)_1} + \frac{1}{(\ell L_i)_2 + (\ell L_i)_3 + (\ell L_i)_4} + \frac{1}{(\ell L_i)_5}}$$

Calculations for individual seal conductances are described in the following sections for elastomeric and metallic seals.

1. Elastomeric Seal Leak Conductance

Following the calculation of the elastomeric seal compressions from assembly and detail drawings, the conductance of each seal for krypton gas, lL_{Kr} , was determined using the AI data for L_{Kr} . The operating conditions for this calculation, in addition to compression, were the permeating gas, elastomeric compound, temperature and type of service, (static or dynamic). AI data used at this point is plotted for partial pressures of 1 atmosphere as a convenience. Calculations in the tables of Appendix I are also in terms of 1 atmosphere pressure drop. Correction to the appropriate cover gas partial pressures are made in Table II. (Actual partial pressures in AI tests were approximately .012 atmospheres for H_2 , Kr and Xe and .238 for Ar. References 2 and 3). Conductances for the seal with Ar, Xe and H_2 gases were determined using the krypton-to-gas permeation ratios of Figures I-2, I-3, and I-4.

2. Metallic Seal Leak Conductance

Metallic seal leak rates were sufficiently small so that in the one case where a metallic seal appeared in series with elastomeric seals, the metal seal was considered controlling, and no effort was made to calculate a single equivalent seal system conductance which combined the elastomer and metallic seal. Leak rates for metal seals were usually determined from leak test requirements as specified on most of the FFTF subassembly drawings. These leakages, generally in terms of standard cc/(sec, atm) helium, were converted to the equivalent argon cover gas leakage at the operating temperatures and a ΔP of 0.47 psid. This conversion was based on the assumption of laminar, rather than molecular flow model and provided slightly higher leak rates in the temperature range of interest. The helium-to-argon leak rate conversion appears in Figure I-5.

When helium leakages did not appear on the drawings, the values provided by ARD were used for the metal O-ring, cone (Aeroquip) and compression type seals. These are listed as Item 5 under Assumptions, Section II-B.

All metal seal leakages are shown in Table II at a pressure of one atmosphere for convenience in summing with the elastomeric permeations which were also at one atmosphere. The cover gas partial pressures could then be applied at one time to the total leakage for each assembly.

B. Calculation of Cover Gas Nuclide Leakage

Permeation leakages for each cover gas nuclide are initially calculated for the elastomeric seals by assuming a partial pressure drop across the seal of one atmosphere. Total leakages for each reactor unit are then corrected to the actual leak rate by multiplying by the correct partial pressure, for each nuclide, expressed in atmospheres.

TABLE II
FFTF COVER GAS LEAK RATIO

	Seals per Unit		Units per FFTF	Total FFTF Elastomer Seal Leak Rate in $\left[\frac{\text{STPcc}}{\text{Sec}}\right]$ in Partial P = 1 Atmos				Total FFTF Metal Seal Leak Rate Argon in $\frac{\text{cc}}{\text{sec}}$ STP ⁽²⁾ At $\Delta P = 0.47$ PSID	Leakage $\left[\frac{\text{STPcc}}{\text{Sec}}\right]$ At Partial P Noted				
	Elast.	Metal		Kr	H ₂	Xe	Ar		Kr 0.467-7	H ₂ 0.0025-7	Xe 2.54-7	Ar 0.086-10	
1. IVHM Assembly	2	0	3	10.2-6 ⁽³⁾	40.8-6 ⁽³⁾	11.9-6 ⁽³⁾	6.9-6 ⁽³⁾		0.476-13 ⁽³⁾	0.102-13 ⁽³⁾	30.2-13 ⁽³⁾	0.59-16 ⁽³⁾	
2. IVHM Arm Support	63	0	3	537.3	1600.0	840.0	430.0		250.9	4.00	2133.6	36.9	
3. IVHM Orientation System	14	0	3	11.9	41.9	14.1	7.98		5.6	0.11	35.8	0.7	
4. IVHM Chain Hoist	30	0	3	20.0	88.7	16.2	23.4		9.4	0.22	41.1	2.01	
5. Fuel Transfer Port	4	0	3	0.36	0.84	0.36	0.09		0.17	0.002	0.91	0.008	
6. Instrument Tree	20		3	78.6	362.1	94.2	69.0	0.163-6 ⁽³⁾	36.7 0.1	0.90 0.0004	239.2 0.414	5.9 0.01	
7. Fuels Open Test Assembly	4		3 ⁽¹⁾	1044.0	1983.0	1146.0	375.0		487.0	4.96	2910.8	32.3	
8. Control Rod Drive Mech. Assembly	0	4	18					0.141 37.8	0.1 17.7	0.0003 0.09	0.36 96.0	0.01 3.25	
9. Temp & Liquid Level Port Plug & Instrumentation	0	4	3					0.133	0.06	0.0003	0.34	0.011	
10. Closed Loop In-Reactor Assembly	0	1	3 ⁽¹⁾					0.063	0.03	0.0002	0.16	0.005	
11. Proximity Test Plug	0	2	3 ⁽¹⁾						0.002	0.00001	0.01	0.0004	
12. Low Level Flux Monitor	0	1	3					0.117	0.05	0.0003	0.30	0.01	
13. Closure Head Assembly	0	2	1					97.6	45.5	0.24	248.0	8.4	
									853.8 or 8.5-11	10.38 or 1.0-12	5753.2 or 5.8-10	84.3 or 8.4-15	
									Allowable FFTF leakage per Table 1 of Reference 5	6.0-11	Ne = 8.4-14	9.6-10	2.4-4

NOTE: (1) The OTA, CLIRA and Proximity Test Plug Ports total 9.
(2) STP is 1 atmos pressure and 0°C.
(3) 10.2-6 means 10.2×10^{-6} .

Metallic seal leakage is calculated by converting allowable helium leak rates, as they appeared in the drawings or as provided by ARD, to an equivalent argon gas leak rate at a pressure drop of 0.47 psid. A laminar (vs molecular) flow correlation was assumed for this conversion. The leak rate of each cover gas nuclide is then taken in the same proportion as the partial pressures, again expressed in atmospheres. Arithmetically then, the elastomeric and metallic seal leakage totals from the individual unit worksheet totals of Appendix I can be handled in the same manner, which is done in Table II. Viz:

- (1) For elastomeric seals;

Final gas nuclide leakage = (Leakage for each nuclide at one atm ΔP) x (Partial pressure in atm.)

- (2) For metallic seals;

Final gas nuclide leakage = (Argon leakage in STDcc/sec) x (Partial pressure in atm)

The above approach, that of separating elastomeric and metallic seal leakages, can be used because with one exception, the two kinds of seals do not appear in the same leakage system. In the one exception, a silicone and metallic seal are in series and it was considered reasonable to ignore the leakage through the silicone because it was felt the metal seal would be leak controlling. In the event it was considered appropriate to more closely calculate the leakage through a mixed seal system, the helium leakages for the metallic seals would be converted to Kr, H₂, Ar and Xe equivalents so a conductance could be calculated which could be combined with those calculated for the elastomeric seals.

C. Effect of a Common Buffer Gas Manifold on a Seal System Conductance

Most assemblies with primary and backup seals (seals in series) include a common buffer gas manifold between seals. (A current exception is the dual metal O-Ring system on the Temperature and Liquid Level Port Plug, H 4-23535, and the possible deletion of the buffer system on the Closure Head Assembly, H 4-25260, per the recommendations of Ref. 4). If the conductances of both seals in each series comprising a seal system is the same or close to the same, the overall system conductance is changed very little by the addition of a common buffer gas manifold. Figure 1 illustrates the conclusion. In the FFTF most pairs of seals are the same material, the same temperature and may have only a small difference in their length. Therefore, the effect of the common buffer manifold on the total seal system conductance will be negligible. The term "manifold" is used here to denote a tubing or porting system free of conductance; without valves, seals or other leakage paths.

a) WITHOUT COMMON BUFFER MANIFOLD

$$\begin{aligned}
 C_{EQ} &= \frac{1}{\frac{1}{A} + \frac{1}{A}} + \frac{1}{\frac{1}{C} + \frac{1}{C}} + \frac{1}{\frac{1}{E} + \frac{1}{E}} \\
 &= \frac{1}{\frac{2}{A}} + \frac{1}{\frac{2}{C}} + \frac{1}{\frac{2}{E}} \\
 &= \frac{A+C+E}{2} \text{ CC/SEC}
 \end{aligned}$$

b) WITH COMMON BUFFER MANIFOLD

$$\begin{aligned}
 C_{EQ} &= \frac{1}{\frac{1}{A+C+E}} + \frac{1}{\frac{1}{A+C+E}} \\
 &= \frac{1}{\frac{2}{A+C+E}} \\
 &= \frac{A+C+E}{2} \text{ CC/SEC}
 \end{aligned}$$

NOTE: See Section III, Methods, for explanation of C_{EQ}

Figure 1. Effect of Common Buffer Manifold on Seal System Conductance

Of significance, however, is that whatever probability of leakage is assumed for any one seal downstream of the manifold, is now the probability of leakage for that entire seal system. That is, the sealing integrity of the system downstream of the manifold node is no better than the seal most likely to leak.

D. Effect of a High Conductance Buffer System on
IVHM Leakage

The leakages summarized in Table II are for the individual FFTF subassemblies and their closure head inner face seals only. These values do not include leakage from any of the inflatable seal pressurization or buffer gas systems. The primary reason for this exclusion is that no leakage test data is available for the three-way ball valve which is used extensively in the IVHM. Because the IVHM has a more extensive system than any of the subassemblies considered in this survey, its omission would render leakage rates for the other systems meaningless. In the event calculations for this system are needed, tests on a large number of valves to determine a statistically significant leak rate, and drawings from ARD describing these pressurization and buffer systems would be required.

An estimate of the effect of a high conductance buffer system on the IVHM can be made if we assume a leak rate for each ball valve of 1×10^{-4} std cc/(sec atm) argon for a total of 49 valves. The effect on the overall seal conductances for the IVHM is seen to be pronounced, as shown in Figure 2. The seal conductance values used in the calculation are roughly the same as the IVHM system but are rounded off to simplify the calculation.

IV. RESULTS

The calculated leak rates for the FFTF/LMFBR appear in Table II, and are compared with the allowable leak rates from Ref. 5. The partial pressures (in atmospheres) used for these calculations, are listed at the head of the columns for each nuclide. The equilibrium concentrations in Ci/meter³, partial pressures (in cm hg) for the nuclide specie and formula for the calculation of the partial pressures, are shown in Table III. The total number of seals and seal lengths for the system appear in Table IV.

The outstanding leakages in the system occur through a set of EPR seals, operating at 167° F in the Arm Support subassembly of the IVHM, and through a set of silicone seals operating at 300° F in the Materials Open test assembly.

The large silicone shaped seal on the Arm Support system, and the inflatable seals on the Arm Support System and Instrument Tree are a part of a seal system consisting of other seals in series, during normal reactor operation. As a result, actual leakage through these seals is low, in spite of their individually high conductances.

SEAL SYSTEM CONDUCTANCE:
DOWNSTREAM OF MANIFOLD
UPSTREAM OF MANIFOLD

COMMON MANIFOLD
BUFFER LINE & CONDUCTANCE

a) SYSTEM CONDUCTANCE WITHOUT MANIFOLD

$$C_{EQ} = \frac{1}{\frac{1}{400 \times 10^{-6}} + \frac{1}{400 \times 10^{-6}}}$$

$$= \underline{\underline{200. \times 10^{-6} \text{ cc/SEC}}}$$

b) SYSTEM CONDUCTANCE WITH MANIFOLD CONDUCTANCE

$$C_{EQ} = \frac{1}{\frac{1}{400. \times 10^{-6}} + \frac{1}{400. \times 10^{-6} + 4900. \times 10^{-6}}}$$

$$= \underline{\underline{371.9 \times 10^{-6} \text{ cc/SEC}}}$$

NOTE: See Section III, Methods, for explanation of C_{EQ} .

Figure 2. Effect of IVHM Buffer Gas System on Seal System Conductance

TABLE III
COVER GAS NUCLIDE PARTIAL PRESSURES
(COVER GAS SOURCES: 1% FAILED FUEL WITH 2 SCFM PURGE)

Mean temp = 1000°F
 $\Delta P = .47$ psid

NUCLIDE	LIFE	EQUILIBRIUM CONCENTRATION IN COVER GAS, Ci/m ³	PARTIAL ⁽³⁾ PRESSURE cm Hg
Kr 83m	114 mo	50.7	1.58-7 ⁽¹⁾
Kr 85	10.3 yr	3.-3	4.71-7
Kr 85m	4.4 hr	115.	8.41-7
(2) Kr 87	76 mo	301.	6.34-7
(2) Kr 88	2.8 hr	302.	1.41-6
Ar 40	None		78.42
Ar 41	1.83 hr	.216	6.53-10
Ne 23	38 sec.	1111.	1.93-8
Xe 131 m	12. dy	.005	2.40-9
Xe 133	5.27 dy	45.6	9.61-6
Xe 133m	2.26 dy	2.91	2.67-7
(2) Xe 135	9.2 hr	618.	9.47-6

(1) 1.58-7 means 1.58×10^{-7}

(2) Principal sources

(3)
$$\text{Partial Pressure} = \frac{\text{Ci/m}^3 \times 3.7 \times 10^{10} \text{ dis/Ci} \times t^{1/2} / .6932 \times \text{Total Pressure}}{\frac{.6023 \times 10^{24} \text{ at/mol}}{.0224 \text{ m}^3/\text{mol}} \times \frac{273.16}{810.938}}$$

Above information received from ARD in March 1974, Ref.9.

TABLE IV
FFTF SUB-ASSEMBLY SEAL LENGTHS AND COUNT

FFTF Sub-Assembly	Units Per FFTF	Seal Length Per FFTF (Inches)				Cover Gas Seals Per FFTF
		O-Ring	Metal Core	Metal O-Ring	Other	
IVHM Assy	3	729				6
IVHM Arm Support	3	2754			T Seal=153	189
IVHM Orientation Sys.	3	756			Shaped=711	54
IVHM Chain Hoist	3	1641			Inflat =1353	90
Fuel Transfer Port	3	384				78
Instrument Tree	3	2247		744	Inflat=957	
Fuels Open Test Assy	3 ⁽¹⁾	204	231			15
Control Rod Drive Mech.	18		1980			72
Temp & Liq Level Port Plug & Instrumentation	3			234		12
Closed Loop In-Reactor Assy	3 ⁽¹⁾		120			3
Proximity Test Plug	3 ⁽¹⁾		231			6
Low Level Flux Monitor	3		213			3
Closure Head Assy	1			1744		2
		<u>8715</u>	<u>2775</u>	<u>2722</u>	<u>3174</u>	<u>530</u>

Note: (1) The OTA, CLIRA, and
Proximity Test Plug ports total 9.

Total seal length = 1449 feet

V. DISCUSSION

Referring to Table II, Page 10, the calculated leak rates for the Argon and Xenon radioactive isotopes are seen to be less than the allowable leak rates, whereas the calculated leak rate for Krypton is larger by a factor of 1.4. However, if only the longer-lived Krypton isotopes are considered (Kr 83m, 85 and 87) as contributing significant radiation levels, the leak rate reduces to about 3×10^{-11} or about one-half the allowable.

The calculated leak rate for Hydrogen is larger than the allowable leak rate for Neon (see Assumptions and Limitations, Item 6, Page 7 for explanation of substitution) by a factor of 12. However, limited data show hydrogen to have twice the permeation rate of neon (through silicone rubber at 0°C) which, together with a half-life of 38 seconds for the neon 23 isotope infers a significantly lower actual leakage for this gas. As mentioned previously, no attempt was made to calculate the effect of holdup times on the overall leakage.

As discussed in II-B, the higher, more conservative leakage values were used in all cases in the leakage calculations. It is, therefore, reasonable to conclude that the total leakage of radioactive gaseous species is not greater than the allowable leakages.

No attempt was made in this report to evaluate the effect of physical breaching of a seal and the resultant action of the buffer gas system. Only permeation or motion-related leakage through elastomers, or molecular leakage past metal seals, was considered.

Experimental testing of elastomeric seals in the LMFBR Seal Technology program has demonstrated that, basically, only permeation type leakage occurs for these seals, even dynamic seals, during tests simulating a normal lifetime of motion, if the seals are properly installed with the correct compression, finish, and lubrication.*

*For Reciprocating or Rotary seals, a 10% compression and an 8 RMS finish is recommended.

VI. REFERENCES

1. TI-707-810-013, "Cover Gas Seal Development: Recommendations for Seal Types, Seal Materials and Seal Gland Sizes and Finishes for Use in the FFTF," F. Welch, 12-13-73
2. DTP-707-810-005, "Cover Gas Seal Development: Static Testing of Elastomeric Seals for the FFTF-I: O-Ring Seals"
3. DTP-707-810-002, "Cover Gas Seal Development: Dynamic Testing of Elastomeric Seals for FFTF-I: The Reciprocating Seal Test."
4. ARD Memo FRP 1405, "Main Head Seal Leak Rate" A. J. Court, 6-29-73
5. ARD Memo FD 545, "WDTRS 1.25 Head Penetrations Seal Tests (Revision 1) Contract AT(45-1)-2171 Task 1," C. Roderick
6. TI-707-810-005, "FFTF Cover Gas Seals: Review and Categorization of the FFTF Elastomeric and Metallic Seals," F. Welch 6-8-72
7. TR-707-810-002, "Test Report (Development)-IVHM Primary Seal Test," F. W. Poucher, 7-2-73
8. TR-707-810-001, "Permeability and Solubility of Gases for FFTF/LMFBR Cover Gas Seal Materials," A. J. Darnell, 3-29-73
9. Telefax communication, Court to Asquith, March 7, 1974.

APPENDIX I

FFTF COVER GAS SEAL LEAKAGE CALCULATION WORKSHEETS

I. EXPLANATION OF COLUMNS & CALCULATIONS

A. Temperature (Col. 5)

Seal temperatures are as estimated in Sept. '72, and reported in Ref. 6. An informal note reporting temperature and material updates for the Arm Support System, in the area of the dip seal and inflatable seal, were received in January of '74.

B. Seal Compression (Col. 8)

Calculated as a nominal ring cross-section in a nominal groove. Groove and seal tolerance stackups produce a compression tolerance of +2, -4%. No allowance was made for the effect of O-ring stretch or compression, which was calculated to be less than 1%. No compression is calculated for metal seals.

C. Seal Length (Col. 9)

1. For inflatable seals, O-rings and quad-rings; the circumference of the mean diameter.
2. For metal cone seals; the sum of the sealing circumferences of the ID and OD.
3. For compression seals (e.g. Swagelok); the circumference of the shaft being sealed.

D. Leakage Path (Col. 9.1)

Leakage is depicted flowing from the cover gas on the left, through various seals, to the head compartment on the right.

E. Krypton Unit Leak Rate (Col. 10)

This value is read from one of Figures I-1.1 through I-1.6, for the elastomer listed in Column 2 and for the following installation/operating parameters:

1. Compression of 10% or 30%, whichever is the value lower than that shown in Column 8. That is, 30% compression was used for calculated compressions of 30% and greater; 10% compression was used for calculated compressions between 10% and 30%. Compressions of less than 10% were used as calculated.

2. The next higher temperature of 90, 110, 130 -- 250, 270, 290°F etc., above the temperature listed in Column 5.
3. Static or dynamic service. The unit leak rate for static seals is read directly from the curves of Figure I-1. The leak rate for dynamic seals is estimated to be five times greater than static seal leakages, based on test data available at the time these calculations were started.

- F. Leak Rate for Seal Series/Parallel Leakage System, lL_i , for Elastomeric and Metallic Seals (Col. 12) and (Col. 18).

The values in these columns are the conductances for the series/parallel leakage systems depicted in Col. 9.1 using the procedure described in Section III, Methods. The equivalent single conductance value calculated for each seal leakage system is listed in the row of the seal furthest upstream in the leakage path. The leakage gas for the elastomeric seals (Col. 12) is krypton and for the metallic seals, (Col. 18) argon.

- G. Leak Rate for Seal Series/Parallel Leakage System L_{H_2}, L_{Xe}, L_{Ar} (Cols. 13, 14, & 15)

These values are the equivalent H_2 , Xe, and Ar conductances for the same series/parallel seal systems identified in Col. 12. The conductance for each of these gases is determined by multiplying the system conductance leaking krypton, (Col. 12) by the permeation ratios:

$$\bar{P}_{H_2} / \bar{P}_{Kr}, \bar{P}_{Xe} / \bar{P}_{Kr} \text{ or } \bar{P}_{Ar} / \bar{P}_{Kr} ,$$

selected from Figure I-2, I-3, or I-4.

- H. Helium Unit Leak Rate, Q_{He} , per Inch of Seal at 68°F (Col. 16)

Read from drawings or as provided by ARD.

- I. Laminar Leakage Correction Factor, Helium to Argon Cover Gas (Col. 19)

Figure I-5 provides the factor for converting helium leakage measured at 68°F and a ΔP of 1.0 atmosphere (as specified on the drawings) to the corresponding argon leakage at the normal operating temperature and a ΔP of 0.47 psid. This factor includes the temperature correction so that the final leakage, Col. 20, is at 32°F and 1 atmosphere.

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FIGURE I-1.1: KRYPTON PERMEATION, L_{Kr} , VS TEMPERATURE FOR PARKER SEAL BUNA N (N741)

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FIGURE I-1.2: KRYPTON PERMEATION, L_{kr} , VS TEMPERATURE
FOR MINN RUBBER BUNA N (366 Y)

PREPARED BY: *W.D. 11873*

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STATIC LEAKAGE, $L_{Kr} = \text{STD cc/sec/linear inch of seal./Atmos } \Delta P$

FIGURE I-1.3: KRYPTON PERMEATION, L_{Kr} , VS TEMPERATURE FOR PARKER SILICONE (S684)

PREPARED BY: *W. D. H.*

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STATIC LEAKAGE, $L_{Kr} = \text{STD cc/sec / linear inch of seal / Atmos } \Delta P$

FIGURE I-1.4: KRYPTON PERMEATION, L_{Kr} , VS TEMPERATURE
FOR MINN RUBBER SILICONE (71417)

FIGURE I-1.5: KRYPTON PERMEATION, L_{Kr} , VS TEMPERATURE FOR PARKER SEAL EPR (E692)

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FIGURE I-1.6: KRYPTON PERMEATION, L_{Kr} , VS TEMPERATURE FOR GREENE TWEED URETHANE (379)

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FIGURE I-2: ARGON TO KRYPTON PERMEATION RATIO VS TEMPERATURE FOR VARIOUS ELASTOMERS

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FIGURE I-3: XENON TO KRYPTON PERMEATION RATIO VS TEMPERATURE FOR VARIOUS ELASTOMERS

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FIGURE I-4: HYDROGEN TO KRYPTON PERMEATION RATIO VS TEMPERATURE FOR VARIOUS ELASTOMERS

FIGURE I-4: HYDROGEN TO KRYPTON PERMEATION RATIO VS TEMPERATURE FOR VARIOUS ELASTOMERS

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(ASSUMING LAMINAR FLOW)

$$\dot{Q}_{AR} = \left[\frac{492}{460+T} \right] \left[\frac{(P_1^2 - P_2^2)}{\eta} \right]_{Ar} \left[\frac{\eta}{(P_1^2 - P_2^2)} \right]_{He} \dot{Q}_{He}$$

η = ABS VISCOSITY
 $\dot{Q}$ = LEAK RATE

FIGURE I-5: ARGON COVER GAS TO HELIUM TEST GAS LEAK RATE RATIO VS COVER GAS TEMP

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FIGURE I-6: PERMEATION VS TEMP FOR K_r THROUGH
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APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

-1 IVHM Assembly Dwg. No. H4-28674

APPENDIX I-F TTF COVER GAS LEAKAGE WORKSHEET																						
-1 IVHM Assembly Dwg. No. H4-28674														Elastomeric Seals								
Seal Number	Seal Type ^(a)	Seal Callout ^(b)			Application ^(c)	Service ^(d)	Temperature (*F)	Seal Location (On assembly dwg unless Otherwise noted) Dwg Sht No./Zone	Seal Dimensions (in.)			Seal Compression (%)	Seal Length (in.)	9.1 Leakage Path Cover Gas Head Compartment Seal(s)	10 Krypton Permeation, L _{Kr} per Seal Corrected to 32°F Figure 1. (cc/sec in. atm)	11 Krypton Leak Rate /L _{Kr} per Seal (cc/sec atm) ⑨ x ⑩	Leak Rate for Seal Series / Parallel Leakage System (cc/sec atm)				Seal Number	Remarks
		Vendor	Part No.	Material					ID	OD	CS						12 /L _{Kr}	13 /L _{H₂}	14 /L _{Xe}	15 /L _{Ar}		
1	Gask-O-Seal	PS	N681200223	Buna N741	P	SF	100	3/21 A	Irreg			30	121.		5.6-8	6.8-6	3.4-6	13.6-6	3.95-6	2.3-6	1	
2	Gask-O-Seal				B	SF	100					30	122.		5.6-8	6.8-6	In seal 1 system				2	
Total number of seals per unit = 2														Total length per unit: O rings = 243.								

-3 IVHM Orientation System Dwg. H4-28669

1	0	PS	2-331	Buna N741	P	D Ro	100	2/20F	2.225		0.210	21.	7.65		9.7-8	74.2-8	1.35-6	3.4-6	1.57-6	0.92-6	1	
2	0	PS	2-331	Buna N741	B	D Ro	100	2/20F	2.225		0.210	21.	7.65		9.7-8	74.2-8	In seal 1 system				2	
3	0	PS	2-323	Buna N741	P	D Ro	100	2/21B	1.287		0.210	10.	4.703		5.6-8	26.4-8	In seal 1 system				3	
4	0	PS	2-323	Buna N741	B	D Ro	100	2/21B	1.287		0.210	10.	4.703		5.6-8	26.4-8	In seal 1 system				4	
5	0	PS	2-348	Buna N741	P	SG	100	H4-28668 1/4 C	4.350		0.210	29.	14.326		5.6-8	80.2-8	0.4-6	1.6-6	0.5-6	0.3-6	5	These seals on Toe Adjust H4-28674. Two required in Orientation System.
6	0	PS	2-348	Buna N741	B	SG	100		4.350		0.210	29.	14.326		5.6-8	80.2-8	In seal 1 system				6	
7	Not assigned																				7	
8	0	PS	2-331	Buna N741	P	D Ro	100	H4-28668 1/4 E	2.225		0.210	21.	7.650		9.7-8	74.2-8	0.37-6	1.5-6	0.44-6	0.2-6	8	
9	0	PS	2-331	Buna N741	B	D Ro	100		2.225		0.210	21.	7.650		9.7-8	74.2-8	In seal 8 system				9	
10	0	PS	2-451	Buna N741	P	SG	100	2/20B	10.975		0.275	40.	35.343		5.6-8	2.0-6	1.0-6	4.0-6	1.16-6	0.68-6	10	
11	0	PS	2-451	Buna N741	B	SG	100	2/20B	10.975		0.275	40.	35.343		5.6-8	2.0-6	In seal 11 system				11	
12	0	PS	2-448	Buna N741	P	SG	100	2/21B	9.475		0.275	40.	30.631		5.6-8	1.7-6	In seal 1 system				12	
13	0	PS	2-448	Buna N741	B	SG	100	2/21B	9.475		0.275	40.	30.631		5.6-8	1.7-6	In seal 1 system				13	
14	thru 16 un-assigned																				14	
17	0	PS	2-114	Buna N741	P	SF	100	3/16E	0.612		0.103	50.	2.246		5.6-8	12.5-8	.09-6	.36-6	0.10-6	0.06-6	15	
18	0	PS	2-128	Buna N741	B	SF	100	3/16E	1.487		0.103	50.	4.995		5.6-8	28.0-8	In seal 15 system				16	
Total number of seals per unit = 18														Total length per unit: O rings = 252.			3.98-6	13.96-6	4.71-6	2.66-6	(Includes 2 Toe Adjust Drives)	

Footnotes:

- (a) I = Inflatable; O = O-ring; Q = Quad ring; MC = Metal cone; MO = Metal O-ring
 (b) GT = Greene Tweed; M = Marmon; MR = Minn Rubber; PS = Parker Seal
 (c) P = Primary; B = Backup
 (d) S = Static; F = Face; G = Gland or piston; D = Dynamic; Re = Recip; Ro = Rotary
 (e) Value/material shown is assumed, due to incomplete information. Entry is based on best estimate relative similar usage elsewhere in the system or is selected for greater leakage.
 (f) All leak rates are given in powers of 10. Example: 4.9-6 means 4.9×10^{-6} .

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

-1 IVHM Assembly

-3 IVHM Orientation System

-2 IVHM Arm Support Dwg. H4-28667

-2 IVHM Arm Support Dwg. H4-28667

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Seal Number	1	Seal Type (a)	2		3	4	5	6	7			8	9	9.1	10-15					Seal Number	Remarks					
			Seal Callout (b)						Application (c)	Service (d)	Temperature (°F)				Seal Location (On assembly dwg unless otherwise noted) Dwg Sht No./Zone	Seal Dimensions (in.)			Seal Compression (%)			Seal Length (in.)	Leakage Path	10	11	12
			Vendor	Part No.	Material				ID	OD	CS				Cover Gas	Head Compartment	Krypton Permeation, L _{Kr} per Seal, Corrected to 32°F Figure 1. X ((cc/sec in. atm)	Krypton Leak Rate (L _{Kr} per Seal) (cc/sec atm)	L _{Kr}	Leak Rate for Seal Series/ Parallel Leakage System (cc/sec atm)	L _{H2}	L _{Xe}	L _{Ar}			
1		O	PS	N681200548-11	EPR	P	SF	167	3/19D	76.844		0.210	38	242.1	→	To Seal 32	0.96-6	232.4-6	118.-6	278.6-6	214.8-6	100.7-6			1	
2		O	PS	N681200548-10	EPR	B	SF	167	3/19D		78.718	0.210	38	246.6	→		0.96-6	236.7-6	In Seal 1 System					2		
3		O	GT	N681200548-02	Urethane	P	SF	100	3/20D	76.844		0.210	38	242.1	→		3.5-8	8.5-6	In Seal 10.5 System					3		
4		O	GT	N681200548-01	Urethane	B	SF	100	3/20D		78.718	0.210	38	246.6	→		3.5-8	8.5-6						4		
5		O	GT	N681200548-04	Urethane	P	SF	100	3/21D	76.812		0.210	38	242.0	→		3.5-8	8.5-6						5		
6		O	GT	N681200548-03	Urethane	B	SF	100	3/21D		78.718	0.210	38	246.6	→		3.5-8	8.6-6						6		
7		O	GT	N681200548-06	Urethane	P	SF	100	3/21E	68.200		0.210	30	214.9	→		3.5-8	7.5-6						7		
8		O	GT	N681200548-05	Urethane	B	SF	100	3/21D		71.050	0.210	30	222.6	→		3.5-8	7.8-6						8		
9		I	B. F. Goodrich	3C1322-1	Nylon Reinforced Hycar 139PC12	P	D Ro	90	3/21D	---	---	---	--	221.9	→		0.25-6 (Appendix II-1)	55.5-6						9		
10		I		3C1322-2		B	D Ro	90	3/21D	---	---	---	--	229.7	→			47.4-6	In Seal 10.5 System					10		
10.5	Shaped Ring	Arrow-head Products	PS	N681200253	Silicone	P	SF	200	3/20D	---	---	---	--	237.3	→		82.-6 (Appendix II-2)	19653.-6	38.-6	174.1-6	55.2-6	33.1-6			10.5	
11	O	PS		N681200548-09	Buna N 741	P	SF	90	2/12F	18.265		0.210	46	58.0	→		3.6-8	2.1-6	1.1-6	4.4-6	0.72-6	1.3-6			11	
12	O	PS		N681200548-08	Buna N 741	B	SF	90	2/12F		20.545	0.210	46	65.2	→		3.6-8	2.3-6	In Seal 11 System					12		
13.1	Gask-O-Seal Pair	PS		N681200224	Buna N 741	P	SF	90	2/11E				63	96.9	→ To Seal 36		3.9-8	3.8-6	1.9-6	7.6-6	2.2-6	1.0-6			13.1	
13.2	Gask-O-Seal Pair	PS		N681200224	Buna N 741	B	SF	90	2/11E				63	99.0	→		3.9-8	3.9-6	In Seal 13.1 System					13.2		
14 through 16 not assigned.																										
17	O	MR		Q4114	Buna N 366V	P	DG	90	4/18E	0.612		0.103	9.22	2.25	→		6.-8	0.1-6	0.1-6	0.6-6	0.2-6	0.1-6			17	
18	O	MR		Q4114	Buna N 366V	B	DG	90	4/18E	0.612		0.103	9.22	2.25	→		6.-8	0.1-6	In Seal 17 System					18		
19	O	PS		2-119	Buna N 741	P	SF	90	4/18E	0.924		0.103	36	3.23	→		3.9-8	0.1-6	0.1-6	0.3-6	0.1-6	0.1-6			19	
20	O	PS		2-132	Buna N 741	B	SF	90	4/18E	1.737		0.103	36	5.78	→		→	0.2-6	In Seal 19 System					20		
21	not assigned																									
22																										
23	O	PS		2-331	Buna N 741	P	SF	90	4/16C	2.22		0.210	46	7.65	→		3.9-8	0.3-6	0.2-6	0.7-6	0.1-6	0.2-6			23	
24	O	PS		2-344	Buna N 741	B	SF	90	4/16C	3.85		0.210	46	12.76	→		3.9-8	0.5-6	In Seal 23 System					24		
25	O	PS		2-337	Buna N 741	P	SF	90	4/13C	2.975		0.210	46	10.00	→		3.9-8	0.4-6	0.2-6	0.9-6	0.15-6	0.23-6			25	
25.5	O	PS		2-337	Buna N 741	P	SF	90	4/13C	2.975		0.210	46	10.00	→		3.9-8	0.4-6	0.2-6	0.9-6	0.15-6	0.23-6			25.5	
26	O	PS		2-350	Buna N 741	B	SF	90	4/13C	4.600		0.210	46	15.11	→		3.9-8	0.4-6	In Seal 25 System					26		
26.5	O	PS		2-350	Buna N 741	B	SF	90	4/13C	4.600		0.210	46	15.11	→		3.9-8	0.4-6	In Seal 25.5 System					26.5		
27	Tee Seal	PS		TR 031	Buna N 741	P	DG	90	4/12C			0.062	10 (a)	8.437	→		3.0-8	0.2-6	0.1-6	0.34-6	0.05-6	0.1-6			27	
27.5	Tee Seal	PS		TR 031	Buna N 741	P	DG	90							→		3.0-8	0.2-6	0.1-6	0.34-6	0.05-6	0.1-6			27.5	
28	Tee Seal	PS		TR 031	Buna N 741	B	DG	90							→		→	→	In Seal 27 System					28		
28.5	Tee Seal	PS		TR 031	Buna N 741	B	DG	90							→		→	→	In Seal 27.5 System					28.5		
29	Tee Seal	PS		TR 031	Buna N 741	B	DG	90							→		→	→	In Seal 27 System					29		
29.5	Tee Seal	PS		TR 031	Buna N 741	B	DG	90							→		→	→	In Seal 27.5 System					29.5		
30	O	PS		2-114	Buna N 741	P	SF	175	1/25E	0.612		0.103	46	2.246	→		1.7-7	0.38-6	0.3-6	1.0-6	0.32-6	0.12-6			30	
30.5	O	PS		2-114	Buna N 741	P	SF	175							→		1.7-7	0.38-6	0.3-6	1.0-6	0.32-6	0.12-6			30.5	
31	O	PS		2-128	Buna N 741	B	SF	175		1.487				4.995	→		1.7-7	0.85-6	In Seal 30 System					31		
31.5	O	PS		2-128	Buna N 741	B	SF	175							→		1.7-7	0.85-6	In Seal 30.5 System					31.5		

Footnotes:

- (a) I = Inflatable; O = O-ring; Q = Quad ring; MC = Metal cone; MO = Metal O-ring
 (b) GT = Greene Tweed; M = Marmon; MR = Minn Rubber; PS = Parker Seal
 (c) P = Primary; B = Backup
 (d) S = Static; F = Face; G = Gland or piston; D = Dynamic; Re = Recip; Ro = Rotary
 (e) Value/material shown is assumed, due to incomplete information. Entry is based on best estimate relative similar usage elsewhere in the system or is selected for greater leakage.
 (f) All leak rates are given in powers of 10. Example: 4.9-6 means 4.9×10^{-6}

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

-2 IVHM Arm Support Dwg. H4-28667

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-2 IVHM Arm Support Dwg. H4-28667																				Elastomeric Seals										Page 33/34
Seal Number	1	Seal Type (a)	2			3	4	5	6	7			8	9	9.1	10	11	12			13			14	15	Seal Number	Remarks			
			Seal Callout (b)	Application (c)	Service (d)					Temperature (°F)	Seal Location (On assembly dwg unless otherwise noted) Dwg Sht No./Zone	Seal Dimensions (in.)						Seal Compression (%)	Seal Length (in.)	Leakage Path Cover Gas Head Compartment Seal(s)	Krypton Permeation, L_{Kr} per Seal, Corrected to 32°F Figure 1. X (cc/sec in. atm)	Krypton Leak Rate L_{Kr} per Seal (cc/sec atm) (9×10^{-6})	L_{Kr}					L_{H_2}	L_{Xe}	L_{Ar}
1		O	PS	N681200548-11	EPR	P	SF	167	3/19D	76.844		0.210	38	242.1		0.96-6	232.4-6	118.-6	278.6-6	214.8-6	100.7-6			1						
2		O	PS	N681200548-10	EPR	B	SF	167	3/19D		78.718	0.210	38	246.6		0.96-6	236.7-6	In Seal 1 System					2							
3		O	GT	N681200548-02	Urethane	P	SF	100	3/20D	76.844		0.210	38	242.1		3.5-8	8.5-6	In Seal 10.5 System					3							
4		O	GT	N681200548-01	Urethane	B	SF	100	3/20D		78.718	0.210	38	246.6		3.5-8	8.5-6						4							
5		O	GT	N681200548-04	Urethane	P	SF	100	3/21D	76.812		0.210	38	242.0		3.5-8	8.5-6						5							
6		O	GT	N681200548-03	Urethane	B	SF	100	3/21D		78.718	0.210	38	246.6		3.5-8	8.6-6						6							
7		O	GT	N681200548-06	Urethane	P	SF	100	3/21E	68.200		0.210	30	214.9		3.5-8	7.5-6						7							
8		O	GT	N681200548-05	Urethane	B	SF	100	3/21D		71.050	0.210	30	222.6		3.5-8	7.8-6						8							
9		I	B.F. Goodrich	3C1322-1	Nylon Reinforced Hycar 139PC12	P	D Ro	90	3/21D	---	---	---	--	221.9		0.25-6 (Appendix II-1)	55.5-6						9							
10		I		3C1322-2		B	D Ro	90	3/21D	---	---	---	--	229.7			47.4-6	In Seal 10.5 System					10							
10.5	Shaped Ring	Arrow-head Products	PS	N681200253	Silicone	P	SF	200	3/20D	---	---	---	--	237.3		82.-6 (Appendix II-2)	19653.-6	38.-6	174.1-6	55.2-6	33.1-6		10.5							
11		O	PS	N681200548-09	Buna N 741	P	SF	90	2/12F	18.265		0.210	46	58.0		3.6-8	2.1-6	1.1-6	4.4-6	0.72-6	1.3-6		11							
12		O	PS	N681200548-08	Buna N 741	B	SF	90	2/12F		20.545	0.210	46	65.2		3.6-8	2.3-6	In Seal 11 System					12							
13.1	Gask-O-Seal Pair	PS	PS	N681200224	Buna N 741	P	SF	90	2/11E				63	96.9		3.9-8	3.8-6	1.9-6	7.6-6	2.2-6	1.0-6		13.1							
13.2	Gask-O-Seal Pair	PS	PS	N681200224	Buna N 741	B	SF	90	2/11E				63	99.0		3.9-8	3.9-6	In Seal 13.1 System					13.2							
14 through 16 not assigned																														
17		O	MR	Q4114	Buna N 366V	P	DG	90	4/18E	0.612		0.103	9.22	2.25		6.-8	0.1-6	0.1-6	0.6-6	0.2-6	0.1-6		17							
18		O	MR	Q4114	Buna N 366V	B	DG	90	4/18E	0.612		0.103	9.22	2.25		6.-8		In Seal 17 System					18							
19		O	PS	2-119	Buna N 741	P	SF	98	4/18E	0.924		0.103	36	3.23		3.9-8	0.1-6	0.1-6	0.3-6	0.1-6	0.1-6		19							
20		O	PS	2-132	Buna N 741	B	SF	90	4/18E	1.737		0.103	36	5.78			0.2-6	In Seal 19 System					20							
21	not assigned																													
22																														
23		O	PG	2-331	Buna N 741	P	SF	90	4/16C	2.22		0.210	46	7.65		3.9-8	0.3-6	0.2-6	0.7-6	0.1-6	0.2-6		23							
24		O	PS	2-344	Buna N 741	B	SF	90	4/16C	3.85		0.210	46	12.76		3.9-8	0.5-6	In Seal 23 System					24							
25		O	PS	2-337	Buna N 741	P	SF	90	4/13C	2.975		0.210	46	10.00		3.9-8	0.4-6	0.3-6	0.9-6	0.15-6	0.24-6		25							
25.5		O	PS	2-337	Buna N 741	P	SF	90	4/13C	2.975		0.210	46	10.00		3.9-8	0.4-6	0.2-6	0.9-6	0.15-6	0.22-6		25.5							
26		O	PS	2-350	Buna N 741	B	SF	90	4/13C	4.600		0.210	46	15.11		3.9-8	0.4-6	In Seal 25 System					26							
26.5		O	PS	2-350	Buna N 741	B	SF	90	4/13C	4.600		0.210	46	15.11		3.9-8	0.4-6	In Seal 25.5 System					26.5							
27	Tee Seal	PS	PS	TR 031	Buna N 741	P	DG	90	4/12C			0.062	10 (a)	8.437		3.0-8	0.2-6	0.1-6	0.34-6	0.05-6	0.1-6		27							
27.5	Tee Seal	PS	PS	TR 031	Buna N 741	P	DG	90								3.0-8	0.2-6	0.1-6	0.34-6	0.05-6	0.1-6		27.5							
28	Tee Seal	PS	PS	TR 031	Buna N 741	B	DG	90										In Seal 27 System					28							
28.5	Tee Seal	PS	PS	TR 031	Buna N 741	B	DG	90										In Seal 27.5 System					28.5							
29	Tee Seal	PS	PS	TR 031	Buna N 741	B	DG	90										In Seal 27 System					29							
29.5	Tee Seal	PS	PS	TR 031	Buna N 741	B	DG	90										In Seal 27.5 System					29.5							
30		O	PS	2-114	Buna N 741	P	SF	175	1/25E	0.612		0.103	46	2.246		1.7-7	0.38-6	0.3-6	1.0-6	0.32-6	0.12-6		30							
30.5		O	PS	2-114	Buna N 741	P	SF	175								1.7-7	0.38-6	0.3-6	1.0-6	0.32-6	0.12-6		30.5							
31		O	PS	2-128	Buna N 741	B	SF	175		1.487				4.995		1.7-7	0.85-6	In Seal 30 System					31							
31.5		O	PS	2-128	Buna N 741	B	SF	175								1.7-7	0.85-6	In Seal 30.5 System					31.5							

Footnotes:

- (a) I = Inflatable; O = O-ring; Q = Quad ring; MC = Metal cone; MO = Metal O-ring
 (b) GT = Greene Tweed; M = Marmon; MR = Minn Rubber; PS = Parker Seal
 (c) P = Primary; B = Backup
 (d) S = Static; F = Face; G = Gland or piston; D = Dynamic; Re = Recip; Ro = Rotary
 (e) Value/material shown is assumed, due to incomplete information. Entry is based on best estimate relative similar usage elsewhere in the system or is selected for greater leakage.
 (f) All leak rates are given in powers of 10. Example: 4.9-6 means 4.9×10^{-6}

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

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-4 IVHM Chain Hoist Dwg. No. H4-28676

-4 IVHM Chain Hoist Dwg. No. H4-28676																						
Seal Number	1 Seal Type ^(a)	2 Seal Callout ^(b)			3 Application ^(c)	4 Service ^(d)	5 Temperature (°F)	6 Seal Location (On assembly dwg unless otherwise noted) Dwg Sht No./Zone	7 Seal Dimensions (in.)			8 Seal Compression (%)	9 Seal Length (in.)	9.1 Leakage Path Cover Gas Head Compartment	10 Krypton Permeation, L _{Kr} , per Seal, Corrected to 32°F Figure 1, X (cc/sec in. atm)	Elastomeric Seals					Seal Number	Remarks
		Vendor	Part No.	Material					11 Krypton Leak Rate, L _{Kr} , per seal (cc/sec atm)	12 L _{Kr}	13 Leak Rate for Seal Series/ Parallel Leakage System (cc/sec atm)					15 L _{Ar}						
											14 L _{Xe}						15 L _{Ar}	16 L _{Ar}				
1	Gas-O-Seal	PS		Buna N741	P	SF	90	2/22D				30	119.06		3.9-8	4.64-6	2.36-6	9.44-6	1.6-6	2.8-6	1	
2	Gas-O-Seal	PS		Buna N741	B	SF	90	2/22D				30	123.77		3.9-8	4.83-6	-	-	-	-	2	
3	Q	MR	Q4214	Buna N366Y	P	D Ro	90	2/21R	0.984		0.139	8.	3.53		6.0-8	0.21-6	0.11-6	0.60-6	0.1-6	0.13-6	3	
4	Q	MR	Q4214	Buna N366Y	B	D Ro	90	2/21B	0.984		0.139	8.	3.53		6.0-8	0.21-6	-	-	-	-	4	
5	O	PS	2-231	Buna N741	P	SF	90	2/22B	2.609		0.139	45.	8.63		3.9-8	0.34-6	0.20-6	0.80-6	0.1-6	0.2-6	5	
6	O	PS	2-242	Buna N731	B	SF	90	2/22B	3.984		0.139	45.	12.95		3.9-8	0.51-6	-	-	-	-	6	
7	Q	MR	Q4333	Buna N366Y	P	D Re	90	2/23D	2.475		0.210	6.	8.43		3.0-7	2.53-6	1.26-6	6.93-6	1.6-6	1.5-6	7	
8	Q	MR	Q4333	Buna N366Y	B	D Re	90	2/28D	2.475		0.210	6.	8.43		3.0-7	2.53-6	-	-	-	-	8	
9	O	PS	2-252	Buna N741	P	SG	90	2/24C	5.234		0.139	20	16.88		3.9-8	0.66-6	0.33-6	1.32-6	0.2-6	0.4-6	9	
10	O	PS	2-252	Buna N741	B	SG	90	2/24C	5.234		0.139	20.	16.88		3.9-8	0.66-6	-	-	-	-	10	
11	Q	MR	Q4330	Buna N366Y	P	D Ro	90	2/30B	2.100		0.210	7.	7.25		6.0-8	0.44-6	0.22-6	1.21-6	0.3-6	0.3-6	11	
12	Q	MR	Q4330	Buna N366Y	B	D Ro	90	2/30B	2.100		0.210	7.	7.25		6.0-8	0.44-6	-	-	-	-	12	
13	O	PS	2-254	Buna N741	P	SF	90	2/29B	5.484		0.139	45.	17.66		3.9-8	0.69-6	0.38-6	1.52-6	0.2-6	0.4-6	13	
14	O	PS	2-262	Buna N741	B	SF	90	2/29B	6.984		0.139	45.	22.3		3.9-8	0.87-6	-	-	-	-	14	
15	Q	MR	Q4330	Buna N366Y	P	D Ro	90	2/30B	2.100		0.210	7.	7.25		6.0-8	0.44-6	0.22-6	1.21-6	0.3-6	0.3-6	15	
16	Q	MR	Q4330	Buna N366Y	B	D Ro	90	2/30B	2.100		0.210	7.	7.25		6.0-8	0.44-6	-	-	-	-	16	
17	O	PS	2-254	Buna N741	P	SF	90	2/30B	5.484		0.139	45.	17.66		3.9-8	0.69-6	0.38-6	1.52-6	0.2-6	0.4-6	17	
18	O	PS	2-262	Buna N741	B	SF	90	2/30B	6.984		0.139	45.	28.38		3.9-8	0.87-6	-	-	-	-	18	
19	O	PS	2-228	Buna N741	P	SG	~90	2/32D	2.234		0.139	20.	7.46		3.9-8	0.30-6	0.15-6	0.60-6	0.1-6	0.2-6	19	
20	O	PS	2-228	Buna N741	B	SG	~90	2/32D	2.234		0.139	20.	7.46		3.9-8	0.30-6	-	-	-	-	20	
21	O	PS	2-229	Buna N741	P	SF	~90	2/26D	2.359		0.139	47.	7.85		3.9-8	0.31-6	0.19-6	0.76-6	0.1-6	0.2-6	21	
22	O	PS	2-240	Buna N741	B	SF	~90	2/26D	3.734		0.139	47.	12.71		3.0-8	0.47-6	-	-	-	-	22	
23	O	PS	2-128	Buna N741	P	SF	~90	1/6D	1.487		0.103	50.	5.00		3.9-8	0.19-6	0.06-6	0.24-6	0.04-6	0.07-6	23	
24	O	PS	2-114	Buna N741	B	SF	~90	1/6D	0.612		0.103	50.	2.24		3.9-8	0.09-6	-	-	-	-	24	
25	O	PS	2-230	Buna N741	P	SF	~90	1/9A	2.484		0.139	45.	8.24		3.9-8	0.32-6	0.20-6	0.80-6	0.1-6	0.2-6	25	
26	O	PS	2-242	Buna N741	B	SF	~90	1/9A	3.984		0.139	45.	12.95		3.9-8	0.51-6	-	-	-	-	26	
27	Q	MR	Q4330	Buna N366Y	P	D Ro	~90	1/12A	2.100		0.210	7.	7.26		6.0-8	0.44-6	0.22-6	0.10-6	0.3-6	0.3-6	27	
28	Q	MR	Q4330	Buna N66Y	B	D Ro	~90	1/12A	2.100		0.210	7.	7.26		6.0-8	0.44-6	-	-	-	-	28	
29	O	PS	2-254	Buna N741	P	SF	~90	1/12A	5.484		0.139	45.	17.66		3.9-6	0.69-6	0.38-6	1.52-6	0.2-6	0.4-6	29	
30	O	PS	2-262	Buna N741	B	SF	~90	1/12A	6.984		0.139	45.	22.38		3.9-6	0.87-6	-	-	-	-	30	

Total number of seals per unit = 30

Total length per unit: O rings = 547

Footnotes:

- (a) I = Inflatable; O = O-rings; Q = Quad ring; MC = Metal cone; MO = Metal O-ring
(b) GT = Greene Tweed; M = Marmon; MR = Minn Rubber; PS = Parker Seal
(c) P = Primary; B = Backup
(d) S = Static; F = Face; G = Gland or piston; D = Dynamic; Re = Recip; Ro = Rotary
(e) Value/material shown is assumed, due to incomplete information. Entry is based on best estimate relative similar usage elsewhere in the system or is selected for greater leakage.
(f) All leak rates are given in powers of 10. Example: 4.9-6 means 4.9×10^{-6} .

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

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-5 Fuel Transfer Port

Dwg. H4-22927

Elastomeric Seals

Metallic Seals

Seal Number	1	2		3	4	5	6	7			8	9	9.1		10	11	12	13	14	15	16	17	18	19	20	Seal Number	Remarks			
	Seal Type (a)	Seal Callout (b)		Application (c)	Service (d)	Temperature (°F)	Seal Location (On assembly dwg unless otherwise noted) Dwg Sht No./Zone	Seal Dimensions (in.)			Seal Compression (%)	Seal Length (in.)	Leakage Path Cover Gas Head Compartment ↙ ↘ Seal(s)		Krypton Permeation, L Kr, per Seal, Corrected to 32°F Figure 1.X (cc/sec in. atm)	Krypton Leak Rate /L Kr per Seal (cc/sec atm) 9 x 10 (cc/sec atm)	IL Kr	Leak Rate for Seal Series/ Parallel Leakage System (cc/sec atm)			He Unit Leak Rate, QHe, per Inch of Seal 68°F (cc/sec in. atm)	He Leak Rate per Seal at 68°F 9 x 16 or per dwg (cc/sec atm)	Leak Rate for Seal Series/ Parallel Leakage System 68°F (cc/sec atm)	Leakage Ratio Ar(STP)32°F to He(STP)68°F Figure 5	Argon Cover Gas Leakage 32°F, 1 atm 18 x 19 (cc/sec atm)					
																		ID	OD	CS								IL H2	IL Xe	IL Ar
1	O	PS	2-276	Sil S684	P	SF	400	1/7B	10.984		0.139	20	39.94		1.5-4	0.52-6	← In seal 2 system →									1				
2	O	PS	2-278	Sil S684	B	SF	400	1/7B	11.984		0.139	20	38.09		1.5-4	0.57-6	0.12-6 0.28-6 0.12-6 0.03-6									2				
3	O	PS	2-171	Sil S684	P	SF	400	1/7B	7.987		0.139	20	25.55		1.5-4	0.38-6	← In seal 2 system →									3				
4	O	PS	2-176	Sil S684	B	SF	400	1/7B	9.237		0.139	20	29.06		1.5-4	0.44-6	← In seal 2 system →									4				
Total Number of seals per unit = 4									Total length per unit: O-rings=128																					

-6 Instrument Tree Upper Section Dwg. H 4-23112

1	I	B. F. Goodrich	4C1425-1	Silicone 91-14A	P	SG	150	1/13B	dm=23.72		Not applicable	74.5	161.3-6(App II -3) 12107.-6	In seal 17, 19 system								1	
2	I		4C1425-1		B	SG	150	1/13B	dm=23.72		Not applicable	74.5	161.3-6 12107.-6	In seal 17, 19 system								2	
3	I		4C1425-2		P	DG	100	1/17B	dm=18.094		Not applicable	56.8	120.4-6 (App II-3) 6839.-6	In seal 3 system								3	
4	I		4C1425-2		B	DG	100	1/17B	dm=18.094		Not applicable	56.8	120.4-6 6839.-6	In seal 3 system								4	
5	I		4C1425-2		B	DG	100	1/17B	24.84	0.275	Not applicable	56.8	120.4-6 6839.-6	In seal 3 system								5	
6	O	PS		Buna N 741 (e)	P	SG	100	1/17B	24.84	0.275	Not applicable	80.19	9.6-8 7.7-6 3.8-6 15.2-6 4.4-6 2.6-6	In seal 6 system								6	
7	O	PS		Buna N 741	B	S. Comp	100	1/17B	dm=0.5		30	80.19	9.6-8 7.7-6	In seal 6 system								7	
8	O	PS		Buna N 741	P		100	3/7C	dm=0.5		30	1.75	6.6-8 10.36-8 0.10-6 0.4-6 0.12-6 0.07-6	In seal 6 system								8	Inflatable seal pressurization fittings (5 ples)
9	O	PS		Buna N 741	P		100	3/6C	dm=0.5		30	1.75	6.6-8 10.36-8 0.10-6 0.4-6 0.12-6 0.07-6	In seal 6 system								9	Buffer line fittings (4 places)
12	O	MR		Sil 71417	B	SG	300 est	1/11B	dm=0.5	0.275	Not applicable	73.34	48.-6 3520.-6	In seal 17, 19 system								12	
13	O	PS		Buna N 741		SF	100 est	1/18B	18.000	0.139	19	56.99	11.-8 6.3-6	In seal 3 system								13	
14	O	PS		Buna N 741		SF	100 est	1/18B	18.750	0.139	19	59.34	11.-8 6.3-6	In seal 3 system								14	
15	O	PS		Buna N 741	D	SF	100 est	1/20B		0.275	10	55.17	11.-8 6.1-6	In seal 3 system								15	
16	O	PS		Buna N 741	B	SF	110 est	1/20B				55.17	11.-8 6.1-6	In seal 3 system								16	

-6 Instrument Tree Bellows Installation Dwg. H4-23117

17	O	MR		Buna N 366Y	P	SG	100	1/10C	22.99	0.139	36	72.65	6.6-8 4.8-6 6.2-6 30.1-6 8.2-6 9.7-6	In seal 17, 19 system								17	
18	O	MR		Buna N 366Y	B	SG	100	1/10C	22.99	0.139	36	72.65	6.6-8 4.8-6	In seal 17, 19 system								18	
19	O	MR		Buna N 366Y	P	SF	100	1/8A	21.22	0.103	19	66.99	11.0-8 7.4-6	In seal 17, 19 system								19	
20	O	MR		Buna N 366Y	B	SF	100	1/8A	21.22	0.103	19	69.78	11.0-8 7.4-6	In seal 17, 19 system								20	

-6 Instrument Tree Sealing Mast and Flange Dwg. H4-23122

21	M.O. Spl Slope	Bennett Hopkins	711108	321 SST	P	SF	300	2/14C	Irregular		0.375	218.91					1.-7 21.9-6	In seal 22 system				21	
22	M.O.		H4-23122 Item	304 SST	P	SF	300	1/21A	dm=1.34			4.22					1.-7 0.42-6	In seal 22 system	0.021	0.054-6		22	
23	M.O.				P	SF	300	1/21A				4.22					1.-7 0.42-6	In seal 22 system				23	
24	M.O.				P	SF	300	1/21A				4.22					1.-7 0.42-6	In seal 22 system				24	
25	M.O.				P	SF	300	1/21A				4.22					1.-7 0.42-6	In seal 22 system				25	
26	M.O.				P	SF	300	1/21A				4.22					1.-7 0.42-6	In seal 22 system				26	
27	M.O.				P	SF	300	1/21A				4.22					1.-7 0.42-6	In seal 22 system				27	
28	M.O.				P	SF	300	1/21A				4.22					1.-7 0.42-6	In seal 22 system				28	

Total number of seals per unit = 26

Total length per unit:
O-rings = 749
Metal cone = 248
Inflatable = 319

26.2-6 108.7-6 31.4-6 23.0-6

0.054-6

Footnotes:

- (a) I = Inflatable; O = O-ring; Q = Quad ring; MC = Metal cone; MO = Metal O-ring
 (b) GT = Greene Tweed; M = Marmon; MR = Minn Rubber; PS = Parker Seal
 (c) P = Primary; B = Backup
 (d) S = Static; F = Face; G = Gland or piston; D = Dynamic; Re = Recip; Ro = Rotary
 (e) Value/material shown is assumed, due to incomplete information. Entry is based on best estimate relative similar usage elsewhere in the system or is selected for greater leakage.
 (f) All leak rates are given in powers of 10. Example: 4.9×10^{-6}

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

-5 Fuel Transfer Port

-6 Instrument Tree Upper Section

-6 Instrument Tree Bellows Installation

-6 Instrument Tree Sealing Mast and Flange

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

-7 Fuels Open Test Assy. Dwg. No. H4-21490

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Page 37																																										
Seal Number	1	2	3	4	5	6	7	8	9	9.1	Elastomeric Seals					Metallic Seals					Seal Number	Remarks																				
											Seal Type (a)	Seal Callout (b)	Application (c)	Service (d)	Temperature (°F)	Seal Location (On assembly dwg unless otherwise noted) Dwg Sht No./Zone	Seal Dimensions (in.)			Seal Compression (%)			Seal Length (in.)	Leakage Path	Krypton Permeation L _{Kr} per Seal, Corrected to 32°F Figure 1, X (cc/sec in. atm)	Krypton Leak Rate IL _{Kr} per Seal (9 x 10) (cc/sec atm)	Leak Rate for Parallel Leakage System (cc/sec atm)	15	16	17	18	19	20									
																	ID	OD	CS															IL _{Kr}	IL _{H₂}	IL _{Xe}	IL _{Ar}	He Unit Leak Rate, Q _{He} per Inch of Seal 68°F (cc/sec in. atm)	He Leak Rate per Seal at 68°F (9 x 16) or per dwg (cc/sec atm)	Leak Rate for Seal Series/ Parallel Leakage System 68°F (cc/sec atm)	Leakage Ratio Ar(STP)32°F to He(STP)68°F Figure 5	Argon Cover Gas Leakage 32°F, 1 atm (18 x 19) (cc/sec atm)
1	0	PS	2-343	Silicone S604-70	P	SG	300	1/30B	3.72		0.210	40	12.42		35. -6	435. -6	348. -6	661. -6	382. -6	125. -6						1																
2	0	PS	2-343	Silicone S604-70	B	SG	300	1/30B	3.72		0.210	40	12.42		35. -6	435. -6	In seal 1 system									2																
3	0	PS	2-438	Silicone S604-70	B	SG	300	1/31B	6.22		0.275	18	21.44		61. -6	1307. -6	In seal 6 system									3																
4	0	PS	2-438	Silicone S604-70	B	SG	300	1/31B	6.22		0.275	18	21.44		61. -6	1307. -6	In seal 6 system									4																
5	MC	M	NK 100496 -0600 SC	316 SST	P	S	400	1/21C	6.008	6.703			39.93								0.26-7	1.04-6	1.04-6	0.026	0.027-6	5																
6	MC	M		316 SST	P	S	400	1/24C	≈6.60	7.050			37.30								0.26-7	0.97-6	0.97-6	0.021	0.020-6	6																

Total number
of seals per
unit = 5Total length
per unit
O-rings = 68
Metal cone = 77

348. -6 661. -6 382. -6 125. -6

0.047-6

-8 Control Rod Drive Mech. Dwg. H4-20631

1	MC	Royal Indust.	128F153-1	Assume 321 SST	P	S	300	128J003	1/5B	1.938	2.250		—	13.16								1.0-7	0.5-7	0.026	0.013-7	1	
4	MC	(Marman)	128F102-1	321 SST	P	S	150		1/14B	6.686	7.064		—	43.20								1.0-7	In seal 1 system	-	-	4	Leak rate from Royal Indust Dwg 128F102-1
2	MC		128F093-501	321 SST	B	S	300		1/18B	2.080	2.375		—	14.00								1.0-7	1.0-7	0.026	0.026-7	2	Leak rate from Royal Indust Dwg 128F093-501
3	MC		128F138-1	321 SST	P	S	400	128J003	1/13B	6.052	6.448		—	39.27								1.0-4	1.0-4	0.021	0.021-4	3	Leak rate from Royal Indust Dwg 128F138-1

Total number of
seals per unit = 4Total length per
unit:
Metal cone = 110.

2.1-6

-9 Temp. & Liquid Level Port Plug & Instrumentation Dwg. H4-23535

1	MO	United Airc Products	U-7412- 1050-SX-M	304 SST	P	S	300	1/25B	Dm ≈10.50			-	32.5								1.0-7	32.5-7	17.0-7	0.026	0.044-6	1	
2	MO		U-7412- 1150-SX-M	304 SST	B	S	300	1/25B	Dm ≈11.50			-	35.6								1.0-7	35.6-7	In seal 1 system	-	-	2	
3	Swagelok type	Pitt Valve & Fitting	RDT 200R Q73176-1		P	S	400	1/28C	0.188			-										6.0-9	6.0-9	0.021	0.126-9	3	Calculated from 1.0-9 $\frac{\text{cc(STP)}}{\text{sec}}$ He (g) for 1/4 dia shaft
4	Swagelok type		RDT 200R Q73176-2		P	S	400	1/27C	1.50			-										0.75-9	0.75-9	0.021	0.016-9	4	

Total number of
seals per unit = 4Total length per
unit:
Metal O-ring = 78

0.044-6

Footnotes:

- (a) I = Inflatable; O = O-ring; Q = Quad ring; MC = Metal cone; MO = Metal O-ring
 (b) GT = Greene Tweed; M = Marmon; MR = Minn Rubber; PS = Parker Seal
 (c) P = Primary; B = Backup
 (d) S = Static; F = Face; G = Gland or piston; D = Dynamic; Re = Recip; Ro = Rotary
 (e) Value/material shown is assumed, due to incomplete information. Entry is based on best estimate relative similar usage elsewhere in the system or is selected for greater leakage.
 (f) All leak rates are given in powers of 10. Example: 4.9-6 means 4.9×10^{-6}

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

-7 Fuels Open Test Assy.

-8 Control Rod Drive Mech.

-9 Temp. & Liquid Level Port Plug & Instrumentation

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

Seal Number	1 Seal Type (a)	2 Seal Callout (b)			3 Application (c)	4 Service (d)	5 Temperature (°F)	6 Seal Location (On assembly dwg unless otherwise noted) Dwg Sht No./Zone	7 Seal Dimensions (in.)			8 Seal Compression (%)	9 Seal Length (in.)	9.1 Leakage Path		16 He Unit Leak Rate, Q _{He} , per Inch of Seal 68°F (cc/sec in. atm)	17 He Leak Rate per Seal at 68°F (cc/sec atm)	Metallic Seals		19 Leakage Ratio Ar(STP)32°F to He(STP)68°F Figure 5	20 Argon Cover Gas Leakage 32°F, 1 atm (cc/sec atm)	Seal Number	Remarks
		Vendor	Part No.	Material					ID	OD	CS			Cover Gas	Head Compartment			18 Leak Rate for Seal Series/Parallel Leakage System 68°F (cc/sec atm)	20 Argon Cover Gas Leakage 32°F, 1 atm (cc/sec atm)				
-10 Closed Loop In-Reactor Assembly, Dwg. H4-20733																							
1	MC	Pitt Valve & Fitting	NK100496-0600SC80	AISI 316	P	S	400	H4-21883 1/3E	6.008			-	40.00			1.0-7 (g)	1.0-7	0.021	0.0021-6	1			
Total number of seals per unit = 1									Total length per unit: Metal cone = 40. 0.0021-6														
-11 Proximity Test Plug, Dwg. H4-23481																							
1	MC	M	H4-21883 IT 8	Assume 321 SST	P	S	400	1/19B	~6.00	~6.72		-	40.00			1.0-7(Dwg)	1.0-7	0.021	0.021-7	1			
2	MC	M	H4-21883 IT 7	Assume 321 SST	P	S	400	1/20B	~5.48	~6.16		-	36.00			1.0-7(Dwg)	1.0-7	0.021	0.021-7	2			
Total number of seals per unit = 2									Total length per unit: Metal cone = 77. 0.042-7														
-12 Low Level Flux Monitor, Dwg. H4-22263																							
1	MC	M	55666-300JJ	ASME SA240	P	S	400	1/25A	10.88	11.62		-	70.69			0.26-7	1.84-6	1.84-6	0.021	0.039-6	1		
Total number of seals per unit = 1									Total length per unit: Metal cone = 71. 0.039-6														
-13 Closure Head Assembly, Dwg. H4-25260																							
1	MO		H4-25151-01	Inconel 600	P	S	400	1/12A	~276.	0.625		-	~867.		1.1-7 Ar for 2 seals in series Appendix II-4	97.6-6 Ar	97.6-6 AR	-	97.6-6	1	Column 20 from 1.7.10 ⁻¹¹ scfm Ar at 400°F inch psid		
2	MO		H4-25151-02	Inconel 600	P	S	400	1/10A	~279.	0.625		-	~877.				In seal 1 system		97.6-6	2			
Total number of seals per unit = 2									Total length per unit: Metal O-ring = 1744. 97.6-6														

Footnotes:
(a) I = Inflatable; O = O-ring; Q = Quad ring; MC = Metal cone; MO = Metal O-ring
(b) GT = Greene Tweed; M = Marmon; MR = Minn Rubber; PS = Parker Seal
(c) P = Primary; B = Backup
(d) S = Static; F = Face; G = Gland or piston; D = Dynamic; Re = Recip; Ro = Rotary
(e) Value/material shown is assumed, due to incomplete information. Entry is based on best estimate relative similar usage elsewhere in the system or is selected for greater leakage.
(f) All leak rates are given in powers of 10. Example: 4.9-6 means 4.9 x 10⁻⁶.
(g) As provided by ARD

APPENDIX I-FFTF COVER GAS LEAKAGE WORKSHEET

- 10 Closed Loop In-Reactor Assembly
-11 Proximity Test Plug
-12 Low Level Flux Monitor
-13 Closure Head Assembly

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APPENDIX II. MISCELLANEOUS CALCULATIONS
 -1: L_{Kr} FOR IVHM INFLATABLE SEAL

$$L_{Kr} = \bar{P} \times \frac{h}{t} \times 2.54 \frac{\text{cm}}{\text{inch}} \times 76. \frac{\text{cm hg}}{\text{atm}}$$

$$= 193. \bar{P} \frac{h}{t}$$

$$\frac{h}{t} = 2.4 \text{ FROM CURRENT TESTS}$$

$$\bar{P} = 5.5 \times 10^{-10} \frac{\text{cc (STP) cm}}{\text{sec, inch}^2 \text{ cm hg}} \text{ AT } 90^\circ\text{F}$$

$$= 193. \times 5.5 \times 10^{-10} \times 2.4$$

(Fig I-6)

$$\underline{\underline{L_{Kr} = .25 \times 10^{-6} \frac{\text{cc (STP) Kr}}{\text{sec, inch, atm}}}}$$

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APPENDIX II MISCELLANEOUS CALCULATIONS
 -2: L_{Kr} FOR IVHM SHAPED PRIMARY
 (SILICONE) SEAL

$$\dot{Q}_{Ar} = L_{Ar} \ell \Delta P$$

$$L_{Ar} = \frac{\dot{Q}_{Ar}}{\ell \Delta P}$$

$$\begin{aligned}
 &= \frac{.0015 \text{ cc(STP)} / (\text{Sec Psid}) \text{ AT } 300^{\circ}\text{F}}{237.1 \ln(1/14.7) \text{ Atm}} \quad (\text{REF 7.}) \\
 &= 9.3 \times 10^{-5} \frac{\text{cc(STP)}}{\ln \text{ Atm}} \text{ AT } 300^{\circ}\text{F} \quad \left(\begin{array}{l} \text{CALC TABLE} \\ \text{II-2, SEAL 10.5} \end{array} \right)
 \end{aligned}$$

$$L_{Kr} \text{ AT } 200^{\circ}\text{F} = \frac{L_{Ar}}{(\bar{P}_{Ar} / \bar{P}_{Kr}) (\text{TEMP CORRECTION})}$$

$$\text{TEMP CORR} = \frac{L_{Kr} \text{ AT } 300^{\circ}\text{F}}{L_{Kr} \text{ AT } 200^{\circ}\text{F}}$$

$$= 1.57 \quad (\text{FIG. I-1.3})$$

$$\bar{P}_{Ar} / \bar{P}_{Kr} = .72 \text{ FOR AVG SILICONE} \quad (\text{FIG. I 2})$$

$$= \frac{9.3 \times 10^{-5}}{.72 \times 1.57}$$

$$L_{Kr} \text{ AT } 200^{\circ}\text{F} = \underline{\underline{82.0 \times 10^{-6} \frac{\text{cc(STP)}}{\ln \text{ ATM}}}} \quad \longleftarrow$$

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APPENDIX II MISCELLANEOUS CALCULATIONS
 -3: L_{Kr} FOR INSTRUMENT TREE
 INFLATABLE SEAL

$$L_{Kr} = \bar{P} \times \frac{h}{t} \times 2.54 \frac{\text{cm}}{\text{hg}} \times 76. \frac{\text{cm hg}}{\text{atm}}$$

$$= 193. \bar{P} \frac{h}{t}$$

$$\frac{h}{t} = \frac{.90}{2 \times .07}$$

$$= 6.43$$

B.F. GOODRICH
 TYPE C SEAL

$$\bar{P} = 1.3 \times 10^{-7} \frac{\text{cc (STP) cm}}{\text{sec, in}^3, \text{cm hg}} \quad \text{AT } 150^\circ\text{F}$$

(TABLE
 III, REF
 1)

$$\bar{P} = 9.7 \times 10^{-8}$$

AT 100°F

$$= 193. \times 1.3 \times 10^{-7} \times 6.43$$

$$= 161.3 \times 10^{-6} \frac{\text{cc}}{\text{sec, in, atm}} \quad \text{AT } 150^\circ\text{F} \quad \leftarrow$$

†

$$= 193. \times 9.7 \times 10^{-8} \times 6.43$$

$$= 120.4 \times 10^{-6} \frac{\text{cc}}{\text{sec, in atm}} \quad \text{AT } 100^\circ\text{F} \quad \leftarrow$$

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APPENDIX II MISCELLANEOUS CALCULATIONS

-4: METAL SEAL LEAK RATE PER HWIS
1504 TO CC/(SEC IN. ATM) Ar

$$Q = 1.7 \times 10^{-11} \frac{Ft^3}{Min, In, Psi} \text{ Ar @ } 68^\circ F \left(\frac{1728(16.4)cc}{Ft^3} \times \right.$$

$$\left. \frac{Min}{60 Sec} \times \frac{14.7 Psi}{Atm} \times \frac{492^\circ K}{522^\circ K} \right)$$

$$= \underline{\underline{1.1 \times 10^{-7} \frac{cc}{Sec, In, ATM} \text{ Ar @ } 32^\circ F}} \longleftarrow$$