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LOOP CONTAINMENT
(JOINT INTEGRITY) ASSESSMENT
BRAYTON ISOTOPE POWER SYSTEM
FLIGHT SYSTEM

76-311791

June 1, 1976

MASTER

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

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ATTACHMENTS: Drawing 3604385 (Fig. 3-2) after page 10

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LOOP CONTAINMENT
(JOINT INTEGRITY) ASSESSMENT
BRAYTON ISOTOPE POWER SYSTEM

1.0 INTRODUCTION

The Brayton Isotope Power System (BIPS) contains a large number of joints. Since the failure of a joint would result in loss of the working fluid and consequential failure of the BIPS, the integrity of the joints is of paramount importance. In 1974, General Electric, under contract to the Jet Propulsion Laboratory (JPL), assessed the loop reliability of the "JPL Brayton System ". This was a closed Brayton cycle power system which was under study by JPL. While similar in concept to the ERDA BIPS, now under development by AiResearch, the JPL Brayton system used only one Heat Source Assembly. The General Electric study* assessed the systems loop reliability to be 0.9974 at 5 years (or 0.9988 if double containment weld joints were used where possible to do so).

The purpose of this present effort is to assess the reliability of the ERDA BIPS loop containment (joint integrity). The conceptual Flight System as presently configured is depicted in Figure 1-1. A brief description of the Flight System follows.

*"Mini-Brayton Outer Planets Class of Mission Study - Loss of Coolant Assessment," Final Report by R. Killen, G.E. Valley Forge Space Center, 15 January 1975.

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BRAYTON ISOTOPE POWER SYSTEM

FIGURE 1-1

2.0 BIPS-FS CONCEPTUAL CONFIGURATION

The BIPS-FS is being developed by the ERDA as a 500 to 2000 W_e , 7 year life space power system. The system utilizes a closed Brayton cycle to convert thermal energy emanating from an isotope heat source to electrical energy at a net efficiency exceeding 25 percent. The working fluid is a mixture of helium and xenon having a molecular weight of 83.8. The baseline design utilizes two of the multihundred-watt isotope heat sources (MHW/IHS) developed by General Electric Space Division. The heart of the system is a turbine-compressor-alternator rotating machine, the Mini-BRU (for Miniature Brayton Rotating Unit). The Mini-BRU is being developed by the AiResearch Manufacturing Company of Arizona (AIRPHX), a Division of The Garrett Corporation. The major components which will comprise the BIPS-FS are briefly described in the following paragraphs. For additional information, the reader is referred to the BIPS Configuration Control Document (CCD), AIRPHX 75-311274B, dated March 15, 1976, which is revised periodically.

The major components of the BIPS-FS consist of the following:

2.1 Mini-BRU

This machine contains a radial-flow turbine, a radial-flow compressor, and a radial-gap alternator. These components are mounted on a common shaft which rotates at 52,000 rpm and is supported on gas lubricated hydrodynamic journal and thrust bearings. The alternator is cooled by the compressor discharge; the foil bearings are cooled with compressor bleed cooling. The complete Mini-BRU assembly includes a flight-type housing, turbine and compressor inlet and exit ducting, and an output terminal block. Mounting pads are provided to permit the unit to be installed in the BIPS-FS. Power output is 1300 W_e with input of 4800 W_t (two MHW heat sources).

2.2 Heat Source Assembly (HSA)

The purpose of the HSA is to receive heat by radiation from the Isotope Heat Source and transfer it to the working fluid by forced convection within the Heat Source Heat Exchanger (HSHX). In addition to the HSHX, the HSA consists of a multifoil insulation blanket, an outer housing with mounting points and instrumentation leads, an auxiliary cooling system, and an emergency cooling system.

2.3 Mini-Brayton Recuperator (MBR)

The purpose of the MBR is to transfer thermal energy from the working fluid coming from the Mini-BRU turbine discharge to the compressor discharge working fluid prior to its return to the Heat Source Heat Exchanger of the HSA. This recovery of thermal energy serves to increase cycle efficiency by reducing the required heat source output for a given power level. The MBR is a counterflow heat exchanger fabricated entirely from Hastelloy X. The core assembly is brazed using a gold braze alloy applied in foil form.

2.4 Space Radiator

The purpose of the radiator is to reject the waste heat of the Brayton cycle and thereby maintain the compressor inlet temperature at a low level. A number of possible radiator configurations has been studied. The present concept is of cylindrical tube fin design (32 tubes, 2 headers) which will enclose the remainder of the BIPS components (except for cylinder ends), thereby contributing to the protection of other components from micrometeoroid impact. Either aluminum, beryllium, or Lockalloy will be selected as the radiator material.

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2.5 Ducts and Bellows

The Mini-BRU, MBR, HSA, and radiator will be connected by means of a system of ducts and bellows. Multiple bellows will be required to absorb the relatively large thermal growths of the major components of the BIPS-FS. Ducts and bellows will be fabricated from Columbium (C-103 alloy), from stainless steel, and from Hastelloy X. Certain sections will require bimetallic joints or transition sections (C-103 to Hastelloy X; Hastelloy X to Aluminum or Beryllium).

2.6 Insulation System

The high operating temperatures of the BIPS, the relatively low output power, and the high cost and weight of the radioisotope require the use of a low loss insulation system in order to increase cycle efficiency and keep overall weight and cost within limits. Multiple layers of thin metallic foil (zirconia coated nickel and zirconia coated Columbium) have tentatively been selected to shroud the Mini-BRU, MBR, and the hot ducts and bellows of the BIPS-FS.

2.7 Controls

The BIPS Control System provides for engine starting, load-following (control of output), system component protection, and engine shutdown. The present baseline design provides considerable latitude for improvements in reliability and functional characteristics through redesign and the addition of redundant components.

2.8 Isotope Heat Source (IHS)

The Isotope Heat Source as developed for and utilized in the MHW-RTG (currently in space orbit supplying power to the Lincoln Experimental Satellites 8 and 9) is an integral part of the BIPS-FS as presently conceived. Each HSA contains one IHS supplying 2400 W_t.

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3.0 JOINT INTEGRITY ASSESSMENT

In the following sections, the weld joints of the BIPS will be cataloged, failure rates assigned, and an overall loop containment reliability determined.

Experience has shown that welds are inherently reliable if properly designed and fabricated. Inspections are capable of detecting faulty welds. Once determined to be sound, a weld will normally remain sound.

Table 3-1 is a summary of the weld failure rates used in this assessment. It is based on aerospace weld experience and quality control procedures. These rates are identical to those used in the earlier G.E. assessment, previously referenced.

Table 3-1
WELD FAILURE RATES*

Weld Type	Temperatures	$\lambda \left(\frac{\text{Failures}}{\text{HR}} \right)$
Butt	>600°F	1×10^{-9}
	<600°F	1×10^{-10}
Seam	>600°F	2×10^{-9}
	<600°F	2×10^{-10}

The majority of the welds in the system are butt type welds. However, in the Mini-BRU the weld joints are predominantly fusion welds (electron beam or TIG). Butt weld failure rates were used in assessing fusion weld integrity. In the base of resistance brazes, seam weld failure rates were used as a close approximation. Little failure rate data is presently available on bimetallic joints such as the Columbium C-103 to Hastelloy X transitions which will exist

*From "Space Station-Reactor Power System Design Document,"
Vol. II, Appendix G, Contract NAS8 25140.

McDonnell Douglas Astronautics Company-West, MDC G0750, Dec. 1970.

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between the Mini-BRU and the MBR as well as between the MBR and the HSA. However, an extensive development and testing effort currently being conducted by the Oak Ridge National Laboratory, Battelle Columbus Laboratory, and NASA Lewis-Research Center is expected to provide confidence in the ability to fabricate reliable bimetallic joints and/or transition sleeves for joining of the dissimilar metals. Therefore, the failure rates of Table 3-1 have been used for the six bimetallic joints in the BIPS Flight System.

All joints are inspectable which adds to the confidence placed in the integrity of the welds.

3.1 BIPS-FS Duct Summary

Figure 3-1 is a schematic of the BIPS closed loop. Duct welds and bimetallic joints are indicated. Table 3-2 provides a summary of the physical characteristics of the ducts and bellows. Table 3-3 provides a summary of the joints in the interconnecting ducts and bellows and includes the total failure rate ($\eta\lambda$) for each section. (Duct numbers in Tables 3-2 and 3-3 are keyed to Figure 3-1.)

3.2 Mini-BRU Joint Summary

Figure 3-2 depicts the joints in the Mini-BRU which could conceivably leak working fluid. Table 3-4 provides a summary of these joints and their estimated failure rates.

3.3 HSA Joint Summary

Figure 3-3 depicts the weld joints in the HSHX which could conceivably leak working fluid. Table 3-5 provides a summary of these joints and their estimated failure rates.

BIPS-FS DUCT SCHEMATIC

FIGURE 3-1

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TABLE 3-2
BIPS-FS DUCT SUMMARY

<u>Duct No.</u>	<u>Number of Joints</u>	<u>Material</u>	<u>Temperature °F</u>	<u>Pressure psia</u>	<u>OD Inch</u>	<u>Wall Inch</u>	<u>Duct Length Inch</u>	<u>Number of Bellows*</u>	<u>Bellows Length</u>
1	6	Hastelloy X	1300	66.9	2.50	0.035	43.3	3	3.00
2	3	Hastelloy X C-103	1300	66.9	1.60	0.035	10.0	1	2.00
3	2	Hastelloy X C-103	1300	66.9	1.60	0.035	6.0	1	2.00
4	1	C-103	1600	66.7	1.60	0.060	6.5	1	2.00
5	1	C-103	1600	66.7	1.60	0.060	6.5	1	2.00
6	9	C-103 Hastelloy X	1334	45.1	2.50	0.035	48.6	4	3.00
7	6	CRES/Be	261	44.9	2.50	0.035	37.0	3	3.00
8	9	Be/CRES	60	44.4	2.50	0.035	82.0	3	3.00
9	3	CRES	205	67.1	1.50	0.035	16.0	1	2.00
10	3	CRES	205	67.1	1.50	0.035	18.0	1	2.00
11	2	CRES	205	67.1	2.50	0.035	13.0	--	--
12	2/tube 32 tubes	TBD	261	44.8	~0.4	TBD	2355	--	--
13	1	TBD	261	44.9	~1.5	TBD	88.0	--	--
14	1	TBD	60	44.5	~1.5	TBD	88.0	--	--

*Each bellows requires two welds (not included in second column)

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TABLE 3-3

DUCTING/BELLOWS WELDS SUMMARY

<u>Duct No.</u>	<u>Connects</u>	<u>Temp*</u>	<u>No. of** Joints</u>	<u>Total Weld Length-Inches</u>	<u>$n\lambda$ Total Failure Rate</u>
1-3	MBR to HSA (Includes 5 Bellows)	HI	21	139.49	21×10^{-9}
4-5	HSA to MINI-BRU Turb. Inlets (Includes 2 Bellows)	HI	6	30.16	6×10^{-9}
6	Turbine Exit to MBR (Includes 4 Bellows)	HI	17	133.52	17×10^{-9}
7	MBR to Radiator (Includes 3 Bellows)	LO	12	94.25	1.2×10^{-9}
8	Radiator to Compressor Inlet (Includes 3 Bellows)	LO	15	117.81	1.5×10^{-9}
9-11	Compressor Exits to MBR (Includes 2 Bellows)	LO	12	62.83	1.2×10^{-9}
TOTALS			83	578.06	47.9×10^{-9}

*HI indicates $>600^{\circ}\text{F}$, LO indicates $<600^{\circ}\text{F}$

**All joints are butt welds

○ — $< 600^{\circ}F$
 ⊙ — $> 600^{\circ}F$

QUANTITY REQD		PROD NO.	PART NO. OR IDENTIFYING NO.	SYM	MANUFACTURE OR DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	DATE
← PART NUMBER				PARTS LIST				
RPS-1 MINI BRU				SIGNATURES BY <u>FA</u> DATE <u>7-75</u> FOR _____ TITLE _____ DESIG _____ UNIT _____ DRAWN _____ CHECKED _____ INSP _____ RECD _____ DATE _____ REVISION ACTIVITY _____ REVISION ACTIVITY _____				
REQD NEXT ASSY USED ON WHAT TREATMENT PROCESS DIMENSIONS AND SPEC NAME AND SIZE				DRAWING MANUFACTURING COMPANY OF AMERICA A DIVISION OF THE DANNY CORPORATION P.O. BOX 1000 BRAYTON, ALABAMA MINI BRAYTON ROTATING UNIT MATERIALS SIZE 1/4 E 99193 3604385 SCALE 2/1 WT SHEET -- OF --

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TABLE 3-4

MINI-BRU WELD JOINT SUMMARY

Joint No.	Location	Dia. Inches	Temp*	No. of** Joints	Material	Total Weld Length-Inches	n ₁ Total Failure Rate (x 10 ⁻⁹)
1	Inlet to Diffuser	1.65	LO	1	CRES 17-4	5.18	0.1
2	Speed Pickup	0.060	LO	3 (Braze)	CRES 17-4 to 1018 Steel	0.57	0.6
3	Bolt Flange Seal Ring	4.95	LO	1	CRES 347	15.55	0.1
4	Bolt Flange Seal Ring	6.6	LO	1	CRES 347	20.73	0.1
5	Housing, Compr. Discharge	6.0	LO	1	CRES 347	18.85	0.1
6	Hermetic Connectors	0.95	LO	12	CRES 347	35.81	1.2
7	Housing, Compr. Discharge	6.0	LO	1	CRES 347	18.85	0.1
8	Compressor Disch. Flange	1.5	LO	2	CRES 347	9.42	0.2
9	Compressor Disch. Flange	2.25	LO	2	CRES 347	14.14	0.2
10	Housing, Compr. Discharge	6.0	LO	1	CRES 347	18.85	0.1
11	Turbine Plenum	3.4	HI	1	Cb C-103	10.68	1.0
12	Turbine Plenum BI-MET	5.4	LO	1 (Braze)	Cb C-103 to CRES 347	16.96	0.2
13	Turbine Plenum	4.0	HI	1	Cb C-103	12.57	1.0
14	Turbine Plenum	2.0	HI	1	Cb C-103	6.28	1.0
15	Turbine Plenum	3.0	HI	1	Cb C-103	9.42	1.0
16	Turbine Inlet Flange	1.5	HI	2	Cb C-103	9.42	2.0
17	Turbine Plenum	1.75	HI	1	Cb C-103	5.50	1.0
18	Turbine Plenum	4.75	HI	1	Cb C-103	14.92	1.0
19	Turbine Plenum	4.35	HI	1	Cb C-103	13.67	1.0
20	Turbine Plenum	5.4	LO	1	Cb C-103	16.96	0.1
21	Turbine Plenum	3.35	HI	1	Cb C-103	10.52	1.0
22	Bolt Flange Seal Ring	6.60	LO	1	CRES 347	20.73	0.1
23	Bolt Flange	6.60	LO	1	CRES 347	20.73	0.1
24	Bolt Flange Seal Ring	2.80 Long	LO	1	CRES 347	2.80	0.1
TOTALS				40		329.11	13.4 x 10 ⁻⁹

*HI indicates >600°F; LO indicates <600°F

**All joints are fusion welds except where otherwise indicated.

HSA (HSHX) JOINTS

FIGURE 3-3

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TABLE 3-5

HSA (HSHX) WELD JOINTS SUMMARY

<u>Joint No.</u>	<u>Location</u>	<u>Dia. Inches</u>	<u>Temp*</u>	<u>No. of** Joints</u>	<u>Material</u>	<u>Total Weld Length-Inches</u>	<u>Total Failure Rate (x 10⁻⁹)</u>
1	Inlet and Out-let	1.6	HI	2	Cb C-103	10.05	2.0
2	Port to Header	~1.6	HI	2	Cb C-103	10.05	2.0
3	Header Split Line	7.8	HI	2	Cb C-103	49.01	2.0
4	Heat Exchanger to Header	9.0	HI	2	Cb C-103	56.55	2.0
5	Heat Exchanger to Header	9.625	HI	2	Cb C-103	60.48	2.0
6	Header Split Line	11.0	HI	2	Cb C-103	69.12	2.0
7	Heat Exchanger Split Line	13.54 Long	HI	2	Cb C-103	27.08	2.0
TOTALS				14		282.34	14 x 10 ⁻⁹

*HI indicates >600°F

**All joints are fusion welds

3.4 MBR Joint Summary

Figure 3-4 depicts the weld joints in the MBR which could conceivably leak working fluid to the vacuum of space. (Leakage of other joints would result in cross flow leakage, possibly affecting system performance, but would not result in loss of working fluid). Table 3-6 provides a summary of the joints of Figure 3-4.

3.5 Radiator Joint Summary

Radiator design is not yet completed. The present concept is a cylindrical tube fin design. The 2 headers will be approximately 1.5 inch diameter with 32 finned tubes of approximately 0.4 inch diameter. It is included schematically in Figure 3-1. Table 3-7 provides a summary of weld joints based upon this tentative design.

3.6 BIPS Joint Summary

Table 3-8 provides an overall summary of the complete BIPS Flight System. It accounts for every weld in the entire system which could conceivably leak working fluid. The total failure rate of 110.1×10^{-9} weld failures per hour equates to a reliability of 0.9952 at 5 years.

Increased confidence in the systems ability to retain the working fluid can also be gained from a review of the maximum allowable leakage rates of the components. This is discussed in the following section.

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MBR JOINTS

FIGURE 3-4

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TABLE 3-6

MBR WELD JOINT SUMMARY

<u>Joint No.</u>	<u>Location</u>	<u>Length Inches</u>	<u>Temp*</u>	<u>No. of** Joints</u>	<u>Material</u>	<u>Total Weld Length-Inches</u>	^{nλ} <u>Total Failure Rate (x 10⁻⁹)</u>
1	Side Plate	21.0	HI	4	Hastelloy X	84.0	4.0
2	Splitter and Pan Cold End	24.5	LO	2	Hastelloy X	49.0	0.2
3	Splitter and Pan Hot End	22.25	HI	2	Hastelloy X	44.5	2.0
4	Side Flange Braze Palniro 7 AMS 4786	11	HI	4	Hastelloy X	44	8.0
TOTALS				12		221.5	14.2 x 10 ⁻⁹

*HI indicates >600°F; LO indicates <600°F

**All joints are butt welds except where otherwise indicated.

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TABLE 3-7
RADIATOR WELD JOINT SUMMARY

<u>Joint No.</u>	<u>Location</u>	<u>Dia. Inches</u>	<u>Temp*</u>	<u>No. of** Joints</u>	<u>Material</u>	<u>Total Weld Length-Inches</u>	^{nλ} <u>Total Failure Rate (x 10⁻⁹)</u>
12	Tubes to Headers	~0.4	LO	64	Be, Al, or Lockalloy	80.42	6.4
13	Inlet Header Closure	~1.5	LO	1	Be, Al, or Lockalloy	4.71	0.1
14	Outlet Header Closure	~1.5	LO	1	Be, Al, or Lockalloy	4.71	0.1
TOTALS				66		89.84	6.6 x 10 ⁻⁹

* LO indicates <600°F

** All joints are butt welds

TABLE 3-8

BIPS - FLIGHT SYSTEM WELD JOINT SUMMARY
(2 Capsules - 1300 W_e Output)

<u>Reference</u>	<u>Sub System</u>	<u>No. of Joints</u>	<u>Total Weld Length-Inches</u>	<u>Failure Rate nλ</u>
Table 3-3	Interconnecting Ducting/Bellows	83	578.06	47.9 x 10 ⁻⁹
Table 3-4	Mini-BRU	40	329.11	13.4 x 10 ⁻⁹
Table 3-5	*HSA (HSHX) (2)	28	564.68	28.0 x 10 ⁻⁹
Table 3-6	MBR	12	211.5	14.2 x 10 ⁻⁹
Table 3-7	Radiator	<u>66</u>	<u>89.84</u>	<u>6.6 x 10⁻⁹</u>
	TOTALS	229	1783.19	110.1 x 10 ⁻⁹

*Note - Two HSAs required.

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4.0 ALLOWABLE LEAKAGE RATES

Nasa LeRC-developed components, used in the BIPS Ground Demonstration System (GDS), have specific maximum contractual leakage rates as follows:

<u>Component</u>	<u>Rate (Standard CC He/Sec)</u>
Mini-BRU, each joint	1×10^{-10}
MBR	1×10^{-7}
HSA	1×10^{-9}

Since the Mini-BRU has 40 joints that could loose working fluid to space vacuum, the total maximum leakage rate through joint welds is 4.0×10^{-9} . In addition, the Mini-BRU contains 12 hermetic connectors used for feed through of electrical and monitoring leads. Each connector may leak at the rate of 2×10^{-9} resulting in a total leakage rate through the connectors of 2.4×10^{-8} . This, added to the joint leakage, results in a Mini-BRU total maximum leakage rate of 2.80×10^{-8} . FS hardware can be expected to meet or exceed existing estimates of leak tightness. However, assuming that all FS components and joints leak at the maximum rates estimated for GDS components, the total loss rate is calculated as:

<u>Component</u>	<u>Rate (Standard CC He/Sec)</u>
Mini-BRU	2.80×10^{-8}
MBR	1×10^{-7}
2 HSA at 1×10^{-9}	2×10^{-9}
Space Radiator	1×10^{-9}
Duct Welds (46)	4.6×10^{-9}
Bellows (19 with 2 welds each)	3.8×10^{-9}

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Based on these rates, the system total leakage rate is 1.394×10^{-7} standard cc He/sec. Since the allowable MBR leakage rate is 72 percent of the total, it may prove feasible to allow only a 1×10^{-9} standard cc/sec of He leakage rate in the FS MBR.

A constant maximum leakage rate for five years will result in 21.98 standard cc total loss. This loss equates to only 0.0145 percent of inventory, since the FS contains 1.16 pounds (150,079 standard cc) of Xe/He (MW = 83.8) gas at standard conditions. The resultant effects of this loss are negligible.

It is recognized that leakage rates do not normally remain constant, but rather, tend to grow with time. However, this is not considered a problem because the FS can tolerate leakage rates exceeding two orders of magnitude greater than the above noted maximum rate.

For example, assume the total working fluid loss after 5 years will be as high percentagewise as the thermal input reduction resulting from radioisotope decay. (Although technically impractical to achieve, this would represent an ideal condition because the turbine inlet temperature and system efficiency would remain constant.)

It is estimated that thermal input will degrade to 96.13 percent after 5 years. An equivalent reduction in working fluid is $0.0387 \times 150,079$ cc, which equates to 5808 standard cc. This computes to a constant system loss of 3.68×10^{-5} standard cc He/sec, which is 264 times greater than the assumed 1.394×10^{-7} maximum rate. From this, it is obvious that the FS can tolerate an average maximum leakage rate exceeding 3×10^{-5} standard cc He/sec.

The FS control system will compensate for thermal input and working fluid decreases. This is accomplished by altering engine speed to maintain a constant turbine inlet temperature (T_6).