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ABSTRACT			

This errata has been prepared to correct and supplement data included in the B revision of the CCD.

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ERRATA
TO
BRAYTON ISOTOPE POWER SYSTEM
PHASE I
(GROUND DEMONSTRATION SYSTEM)
CONFIGURATION CONTROL DOCUMENT (CCD)
75-311274B

Errata
Item No.

- 1 Page i: At the top of the page, as the first entry under the heading "TABLE OF CONTENTS," add:

"BIPS PROGRAM ABBREVIATIONS AND ACRONYMS iv"

- 2 On Abbreviations and Acronyms table (following Page iii) at the bottom of the page add:

75-311274B
Page iv

Under (H) on the same page, in the definition of HSA, change:

"HSS" to read "EHS"

- 3 On the second page of the Abbreviations and Acronyms table at the bottom of the page add:

75-311274B
Page v

Under (M) on the same page, as a last item, add:

"MW Molecular Weight"

75-311274B
Errata
Page 1

ERRATA (Contd)

Errata
Item No.

- 4 Page 3-3, Item (f): In the third line, add the word "AIRPHX" ahead of "Monthly"
- 5 Page 3-12, Table 3-1: In the first line under "Mini-BRU," change:
- "M = 83.8" to read "MW = 83.8"
- 6 Page 3-16, Paragraph 3.4.1.1: In the last sentence, add the word "AIRPHX" ahead of "Mini-BRU"
- 7 Page 3-19, first paragraph: In the last sentence, add the word "AIRPHX" ahead of "Mini-Brayton"
- Page 3-19, fourth paragraph: In the last sentence, add the word "AIRPHX" ahead of "Report"
- 8 Page 3-22, Table 3-4: In the third column heading, change:
- "Garrett" to read "AiResearch"
- 9 Page 3-26, Table 3-5: In the first line under "General," change:
- "83.8 M.W." to read "MW = 83.8"

ERRATA (Contd)

Errata
Item No.

- 10 Page 3-32, first paragraph: In the sixth line,
change:

"G" to read "g"

- 11 Page 3-38, Table 3-7: In the second item, change:

"(M.W.=83.8)" to read "(MW = 83.8)"

- 12 Page 3-47, Paragraph 3.4.3: In Item (c), change:

"24 W_t" to read "2400 W_t"

Page 3-47, Paragraph 3.4.3: In Item (d), change:

"(M.W. = 83.8)" to read "(MW = 83.8)"

- 13 Page 3-66, first paragraph: In the third line, change:

"whereever" to read "wherever"

- 14 Page 3-70, Paragraph 3.4.6.4: In the first sentence,
change:

"Mini-BRU" to read "GDS"

Page 3-70, Paragraph 3.4.6.4: In Item (c), add the
words "High local" ahead of "thermal"

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ERRATA (Contd)

Errata
Item No.

- 15 Page 3-72, fourth paragraph: In the equation, add brackets as follows:

$$\frac{Q}{A} = \frac{4.457 \times 10^{-13}}{N} \left[T_{HOT} 4.82702 - T_{COLD} 4.82703 \right]$$

- 16 Page 4-2, Table 4-1: In the first line under "Miscellaneous," change:

"Low" to read "Ion"

- 17 Page 4-3, Paragraph 4.2: In the third line, change:

"requirement" to read "requirements"

Page 4-3, Paragraph 4.3: In the first line, add the word "AIRPHX" ahead of "Engineering"

Page 4-3, Paragraph 4.3.1: In the eleventh line, change:

"perferably" to read "preferably"

- 18 Page 4-4, second paragraph: In the first line, add the words "AIRPHX Report" following the parenthesis and ahead of "76-311736)"

Page 4-4, second paragraph: In the sixth line, change:

"to 200°F" to read "at 200°F"

ERRATA (Contd)

Errata
Item No.

Page 44, third paragraph: In the fifth and sixth lines, delete the words "with outgassing rate virtually the same"

Page 4-4, fourth paragraph: In the fifth line, change:

"parts" to read "ports"

Page 4-4, fourth paragraph: In the seventh line, change:

"part" to read "port"

19 Page 4-7, Paragraph 4.3.2: In the first paragraph, fourth line, add the word "AIRPHX" ahead of "En-

Page 4-7, Paragraph 4.3.2: In the first paragraph, twelfth line, change:

".., is only a matter of hours."

to read

".., is only a few hours."

20 Appendix I: Replace the appendix with Appendix I, attached.

ERRATA (Contd)

Errata
Item No.

- 21 Appendix II, Page 1: In the second paragraph, lines three and five, change:

"MB-IBFS" to read "BIPS"

- 22 Appendix II, Page 3, Table II-2: Under the column heading "Contractor", change:

"AiPHX" to read "AIRPHX" (8 places)

"AiRLA" to read "AIRLA" (1 place)

- 23 Appendix II, Page 8, Figure II-5: Change the figure title to read:

"GENERAL ELECTRIC PHASE I PROGRAM SUPPORT SCHEDULE"

Appendix II, Page 8, Figure II-5: In Program Element (2), change:

"IBFS" to read "FS" (2 places)

- 24 Appendix II, Page 9, Figure II-6: Under Documents and Data block, change:

"G.A. Hofhine" to read "B.A. Hofhine"

Appendix II, Page 9, Figure II-6: Under Laboratory Engineering block, change:

"G. Beuhman" to read "V.P. Corcoran"

ERRATA (Contd)

Errata
Item No.

25 Appendix III, Table III-1: Under Document No.
QCGI No. 137:

- o Delete "(Rough Draft) "
- o Revise Publication Date to
November 19, 1975 (Revised)

Appendix III, Table III-1: Under Document No.
75-311274B:

- o Revise Publication Date to
March 15, 1976
- o Delete "(Proposed) "

26 Appendix III, Table III-1, second page: Under
Document No. 75-311665, change the first line of
the title to read:

"Preliminary Hazards Analysis for the"

This errata will be incorporated during the next CCD
revision/update.

H.W. Longee, Assistant Program
Manager - BIPS

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APPENDIX I

BRAYTON ISOTOPE POWER SYSTEM FLIGHT SYSTEM (BIPS FS)

1.0 INTRODUCTION

This CCD is for a GDS designed to be representative of a flight system utilizing the Mini-BRU, MBR, and HSA designed for application in a space power system. This appendix briefly describes the BIPS FS design, operating parameters used in performance parametric studies, and design-point operating conditions. A conceptual system layout (L3621582) is included in Appendix III, which is based on 4800 W_t total from two radioisotope heat sources. Conceptual BIPS FS estimated performance is shown in Figure I-1, and the energy balance in Figure I-2.

BIPS FS design is such that optional features can easily be incorporated into delivered units. One such feature is one-g bearings that may be desirable for low power-level applications, or high-g bearings required for operation during launch.

The Mini-BRU is designed as an "all purpose" machine, capable of operating over a wide spectrum of power levels (0.35 to 2.1 kw_e) and orbital environments (near earth, synchronous, and deep space), with little compromise in performance. An example of this flexibility is that the "all purpose" Mini-BRU designed for 2.1 kw_e output adds only a six percent weight penalty to the BIPS FS when integrated into a 0.4 kw_e system.

GDS features, not in the BIPS FS, include a turbine bypass valve for overspeed protection, and a valved fill system. The BIPS FS will have no valves with external stems that could result in working fluid (gas) leakage.

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390°R EFFECTIVE
SINK TEMP
 $\epsilon = 0.80$
 $\alpha = 0.08$

$T_1 = 525$
 $P_1 = 44.4$
 $W_1 = 0.2304$

NET OUTPUT 1.3 KW
NET EFFICIENCY 0.270

1338 WATTS
OUTPUT (GROSS)

FLOW SCHEMATIC AND ESTIMATED PERFORMANCE
FOR THE 4800 W_t ERDA BIPS FS
FIGURE I-1

ENERGY BALANCE - 4800 W_t

FIGURE I-2

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The GDS HRHX (radiator simulator) will be replaced by a space radiator for the BIPS FS. The ducting system will necessarily be different, but will have a similar pressure drop.

All references noted in the paragraphs that follow are presented on the last page of this appendix.

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2.0 BIPS FS OBJECTIVES AND DESIGN

The FS performance objectives are delineated on Table I-1. GDS design is based on these objectives except that an HRHX replaces the space radiator, and electrical resistance heat sources replaces radio-isotope heat sources. FS components and subcomponents are delineated in Table I-2.

The BIPS FS conceptual layout (L3621582) shows the Mini-BRU in the vertical position (same as GDS). This orientation was selected for two reasons:

- (a) For gyroscopic compatibility with a spin-stabilized spacecraft when mounted with the vehicle axis coincident with (or parallel to) the BIPS Mini-BRU axis.
- (b) Launch loads are usually greater in the vertical direction, and as presently designed, thrust bearings will withstand more load than journal bearings.

A horizontal orientation is equally feasible, but requires that some support structure and ducting be changed with the result that the MBR will be slightly lowered.

Because of potential future system requirements, some configuration changes may be required. These are:

- (a) Provision for Operation Through Launch - Since the BIPS FS is designed to operate in a space environment hard vacuum, a bell-jar approach must be taken to provide an inert gas atmosphere for refractory metals and Multi-Foil insulation protection. Bearings must also be checked for load adequacy (present journal and thrust bearing configurations are designed to accept 7 and 10 g acceleration loads, respectively).

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TABLE I-1

FS PERFORMANCE OBJECTIVES

- (1) The FS will be capable of power output from 500 to 2000 W_e , EOM, with minimum redesign and requalification.
- (2) 28 ± 2 percent vdc is the reference output voltage.

NOTE

A capability for higher ac voltage output may be advantageous if the output can be achieved directly from the generator.

- (3) The control system will be capable of modulating power to the spacecraft from 0 to 100-percent in 20 milliseconds response times. This will be accomplished by a parasitic load.
- (4) FS life time requirements is $L = 7$ years and mean mission duration (MMD) = 5 years.

$$\text{where MMD} = \int_0^L R dt$$

and R = probability of producing design power at time t

(Notwithstanding this requirement, AIRPHX has established a more stringent objective of $R = 0.95$ after 5 years operation)

Prelaunch, launch, and operational phase failure modes will be identified.

- (5) Based on a GFE heat source cost of \$1000 per W_t , the recurring cost goal for the FS at 1300 W_e will be less than \$5000 per W_e .
- (6) A FS weight goal, at 1300 W_e , is 450 pounds.
- (7) The FS will be capable of launch on the space shuttle.
- (8) Due to a potential explosive vapor environment, the on-pad temperature of exposed surfaces will be maintained below 380°F.
- (9) The system will be designed with an assumed sink temperature equal to, or greater than, that of a geo-synchronous orbit (19,323 nm). The system will be capable of stable operation with unbalanced solar input.
- (10) Thermal input to the spacecraft must be of an amount that will not cause the spacecraft to rise above 100°F.
- (11) The magnetic field at one meter is not yet defined.
- (12) The on-pad biological dose at one meter will be ≤ 0.20 REM per hour.
- (13) The FS will be resistant to natural and man-made radiations.
- (14) FS components will be inherently flexible in mounting to facilitate integration with the required spacecraft configuration.
- (15) On pad and in-orbit fueling capabilities should be provided.

TABLE I-2
BIPS-FS COMPONENTS

Mini-BRU

- o 1600°F turbine inlet temperature (working fluid is Xe-He, MW = 83.8)
- o Single shaft turbine, Rice alternator and compressor supported on foil bearings with compressor bleed cooling
- o Alternator cooled by compressor discharge
- o Refractory metal turbine plenum (Columbium C-103)

Recuperator

- o Hastelloy X construction with gold alloy braze
- o Fin/plate counterflow design

Radiator

- o Material [Be, aluminum alloy or Lockalloy (alloy of Al and Be)]
- o Cylindrical design, offset fin/tube geometry
- o Sink temperature, 390°R
- o Micrometeoroid survival, 0.99 (assumed)
- o Used as part of a low gage pressure vessel to contain an inert gas for protection of the C-103 and multifoil insulation from launch to orbit.

Heat Source

- o ERDA Multi-Hundred Watt (MHW) heat source, (advanced ERDA HS concepts will also be investigated)
- o Electrically heated heat source simulator (EHS) for FS checkout

Heat Source Assembly (HSA)

- o Columbium Alloy C-103 Heat Source Heat Exchanger (HSHX)
- o Auxiliary Cooling System - Helium short circuit of HSHX Multi-Foil insulation
- o Emergency Cooling System - Melting of HSHX Multi-Foil insulation (alternatives have been identified)

Insulation

- o High temperature Multi-Foil insulation
- o Eight percent heat loss from HSA (Goal)
- o Two percent heat loss from turbine and hot interconnecting ducting (Goal)

Controls

- o Motor start inverter
- o Parasitic load
- o Speed control
- o Voltage regulator
- o Power supply
- o Rectifier/filter

Piping and Structure

- o Ducting
- o Bellows
- o Support structure (Beryllium or aluminum alloy)
- o Radiator is used as part of the support structure

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- (b) Operation on a Spin-Stabilized Platform - Bearing load limits must not be exceeded [see (a) above]. If the Mini-BRU axis is transverse to the vehicle spin axis, the resulting coning angle must not exceed that allowed by mission requirements. For a spinning vehicle and Mini-BRU combination, the coning half-angle (ϕ) is defined by:

$$\phi = M_m / M_v$$

where:

M_m = Mini-BRU angular momentum (0.68 lb-ft rad sec)

M_v = Vehicle angular momentum, lb-ft-sec

ϕ = Vehicle coning angle, rad

Presuming that M_v is 500, the coning half-angle would be approximately 0.08 degrees.

- (c) Spacecraft Integration - Launch vehicle constraints, heat input to the space vehicle, and/or BIPS placement on the space vehicle may require that the assumed BIPS FS be reconfigured. As presently configured, the BIPS can be mounted on any flat surface, and be designed to limit heat input to the spacecraft. The BIPS power supply furnishes the most power at 120 vdc, but by adding other power conversion components, any desired voltage and frequency combination may be obtained.

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The BIPS FS schematic, Figure I-3, shows all components within the working fluid loop, and inter-connecting ducting. The duct numbers correlate with Table I-3 data. Note that the radiator and radiator ducting materials have not yet been selected. Approximate duct sizes, and lengths of ducts 7, 8, 12, 13, and 14 (Table I-3) are based on the conceptual design, shown on Drawing L3621582 and will vary with different radiator configurations.

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BIPS-FS DUCT SCHEMATIC

FIGURE I-3

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TABLE I-3

BIPS-FS DUCT SUMMARY

<u>Duct No.</u>	<u>Number of Joints</u>	<u>Material</u>	<u>Temperature °R</u>	<u>Pressure psia</u>	<u>OD Inch</u>	<u>Wall Inch</u>	<u>Duct Length</u>	<u>Number of Bellows</u>	<u>Bellows Length</u>
1	6	Hastelloy X	1760	66.9	2.50	0.035	43.3	3	3.00
2	3	Hastelloy X C-103	1760	66.9	1.60	0.035	10.0	1	2.00
3	2	Hastelloy X C-103	1760	66.9	1.60	0.035	6.0	1	2.00
4	1	C-103	2060	66.7	1.60	0.060	6.5	1	2.00
5	1	C-103	2060	66.7	1.60	0.060	6.5	1	2.00
6	9	C-103 Hastelloy X	1744	45.1	2.50	0.035	48.6	4	3.00
7	6	CRES/Be	721	44.9	2.50	0.035	37.0	3	3.00
8	9	Be/CRES	520	44.4	2.50	0.035	82.0	3	3.00
9	3	CRES	665	67.1	1.50	0.035	16.0	1	2.00
10	3	CRES	665	67.1	1.50	0.035	18.0	1	2.00
11	2	CRES	665	67.1	2.50	0.035	13.0	--	--
12	2/tube 32 tubes	TBD	721	44.8	TBD	TBD	2355	--	--
13	1	TBD	721	44.9	TBD	TBD	88.0	--	--
14	1	TBD	520	44.5	TBD	TBD	88.0	--	--
15	TBD	TBD

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3.0 PRELIMINARY SHOCK AND VIBRATION DESIGN CRITERIA

When considering structural dynamics, the BIPS consists of a cylindrical radiator within which four discrete masses are supported by means of interface structure consisting of beams and struts. The four discrete masses are; two heat source assemblies, recuperator, and Mini-BRU power package. As presently known, the BIPS will be mounted to the spacecraft, which will be mounted to the interim upper stage (IUS). The IUS will be mounted in a cradle or carrier in the space shuttle orbiter. This series of components comprises the orbiter payload. The Space Shuttle and IUS specifications (References 1 and 2, respectively) imply that the payload be cantilever-mounted, from the orbiter mount points when in the stowed configuration.

The principal source of structural vibration occurs during Space Shuttle powered ascent. Principal vibration levels the BIPS will experience depend on the payload dynamic response to orbiter vibration with the payload in the stowed configuration.

The principal source of shock occurs when using pyrotechnic devices on the IUS vehicle, such as that used for spacecraft separation. Principal shock levels the BIPS will experience depend on the payload dynamic response to pyrotechnic explosions, with the payload in the deployed configuration.

Shock and vibration levels at various interfaces, as estimated for conceptual design by the various referenced sources, are shown below.

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(a) Peak Random Vibration Levels

- o Shuttle Vehicle Payload Interface (Reference 1) - $0.1 \text{ g}^2/\text{Hz}$ (90 to 275 Hz) estimated response for an unloaded interface structure. Actual response should be lower due to mass of payload.
- o IUS-Spacecraft Interface (Reference 2) - $0.125 \text{ g}^2/\text{Hz}$ (100 to 1000 cps) recommended for conceptual design.
- o BIPS-Spacecraft Interface (Reference 3) - $0.1875 \text{ g}^2/\text{Hz}$ (900 to 1400 Hz) GE estimate based on LES 8/9 and Mariner J/S experience.

These vibration levels appear to represent a vibratory amplification through the payload. However, the levels are assumed to be estimates of the three reference sources that were determined independently. It will not be known whether the vibratory input to the payload will be amplified or attenuated until the total payload structure is defined and total payload dynamic analyses are conducted.

(b) Peak Shock Levels

- o IUS-Specification (Reference 2, Figure 6) - The shock response spectra gives a dynamic response of 115 g at the IUS-Spacecraft interface with a "Q" equal to ten for a 100 Hz system. Although

the BIPS response to shock at the IUS-Spacecraft interface is undefinable, it will be attenuated due to cantilever mounting and remoteness from the interface.

- o GE Specification Recommendations (Reference 3) -
50-g dynamic response for the Isotope Heat Source, and support structure, in the HSA housing and 25-g dynamic response for the overall BIPS structure, based on a shock response to a 775-g half sine pulse of 0.2 millisecond duration.

As noted above, actual shock and vibration levels the BIPS will experience depend on payload dynamic responses to the principal sources of excitation.

The Space Shuttle is well defined and the BIPS is conceptually defined. However, the spacecraft, IUS, and IUS support structure to the shuttle craft, are currently undefined except for the decision to utilize a solid rocket motor. It is anticipated that the solid rocket motor and structure will possess a high degree of stiffness. Because of many unknowns, no meaningful dynamic analyses can be made, at this time, for predicting BIPS, vibratory and shock responses. However, criteria does exist that system dynamics must satisfy to maintain BIPS responses within tolerable structural design limits. These are:

- (a) The cantilevered payload support structure must be designed to avoid coupling payload and Space Shuttle fundamental frequencies. To avoid this interaction the cantilevered payload fundamental frequencies should be at least two times greater than Space Shuttle fundamental frequencies. The shuttlecraft fundamental frequency range is estimated to be within 4 and 12 Hz. Therefore, the fundamental of the cantilevered payload should not be less than 24 Hz.

- (b) Support structures of BIPS discrete masses should be designed to avoid coupling the cantilevered payload fundamental frequencies with the rigid body fundamental frequencies of the BIPS masses. This means that BIPS components fundamental frequencies should be approximately 60 Hz.
- (c) Criteria (a) and (b) define cantilevered payload and BIPS components fundamental frequency limits. However, it is desirable to maintain the upper limits of natural frequencies no higher than necessary to satisfy (a) and (b), and to minimize BIPS components dynamic responses to shock and vibration. It is anticipated that the cascade of components, comprising the cantilevered payload, will respond to shock as a succession of simple systems, when each succeeding structure has a low mass relative to the next supporting structure.

3.1 Design Criteria

BIPS FS components (i.e., HSA, MBR, Mini-BRU) and mounting pads should be designed to a minimum limit loading of 50 g. BIPS interface structures (i.e., struts, beams, etc.) should be designed to a minimum limit loading of 25 g. The higher acceleration loading requirement provides increased structural integrity for BIPS components and mount pads. This is needed to compensate for the lower degree of mounting redundancy than the interface support structure (i.e., beams and struts). In the case of a statically determinate mounted component such as the MBR, failure of a single mount could result in separation of the component, whereas the interface structure is a many times redundant system capable of tolerating a number of member failures without total failure. The design criteria of providing sufficient stiffness to the BIPS interface structure, to maintain BIPS component

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natural frequencies above 60 cps, will inherently result in high strength. It is intended that this built-in strength will exceed 25 g. This limit loading should satisfy requirements for all other loadings such as pre-launch, launch, and operational environments, and in the case of an abort mission, crash landing requirements. This design criteria should be adequate for the BIPS preliminary design phase. After IUS and spacecraft definitions, dynamic analyses should be conducted on the orbiter cantilever-mounted payload, and the payload as deployed from the orbiter. The cantilevered payload and support design should minimize the BIPS dynamic response. Considerable latitude exists in designing the payload structure to minimize BIPS dynamic loading.

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4.0 ESTIMATED PERFORMANCE

The estimated FS Mini-BRU performance, for 1, 2, and 3 HSA (2400 W_t each), is shown on Table I-4. The data was generated assuming the systems were optimized at minimum weight by changing the MBR and radiator sizes. The GFE recuperator was used for the 3-capsule design only and the weight of hypothetical recuperators of 1- and 2-capsule designs was lowered, mainly by shortening lengths. Note that for the 1-capsule case, the optimum system weight was achieved with a radiator larger than for the 2-capsule case. The same performance could be achieved with some weight penalty by using a smaller radiator and larger recuperator. Users of this data are referred to the objectives stated in Table I-1.

Cycle sensitivity to performance parameters that could change because of build technique, aging, intent, or usage, has been evaluated. Table I-5 enumerates those performance variables with linear sensitivity factors. For sink temperatures and turbine inlet temperature non-linear effects, refer to Figures I-4 and I-5. The partial differentials of cycle efficiency, thus obtained, can be added to estimate the effects of small changes on any of the three system sizes studied.

Parameters for a two-capsule BIPS are shown in Table I-6. To use the sensitivity factors, refer to Table I-4 for the original value, and Table I-5 for sensitivity factor.

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To illustrate sensitivity factors usage, consider the compressor efficiency calculation. A new 0.747 efficiency is assumed, which is 0.01 less than the original, and defines the delta as -0.01. This is also the 0.55 sensitivity factor multiplier shown on Table I-5. The resulting -0.0055 cycle efficiency change is noted on Table I-6. In some cases, the independent variable is a delta to base number ratio (i.e., $\Delta P/P$) and the multiplier is the delta of this parameter. As an example of pressure drop effect, if the pressure ratio parameter changes from 0.972 to 0.975, the increase is 0.003 $\Delta P/P$. The multiplier is the same number and $(0.003) \times (-0.8)$ results in a -0.0024 cycle efficiency change. As an example of bearing loss effect, if kw changes from 0.137 to 0.145, the delta increase is 0.008, but the multiplier is $0.008/0.137$, which is 0.0584. The cycle efficiency change is then $(0.0584) \times (-0.031)$, equalling -0.0018. To obtain $\Delta \eta_{cy}$ for other than design sink temperature (Figure I-4), or turbine inlet design temperature (Figure I-5), refer to the respective figures.

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TABLE I-4
CYCLE DATA OPTIMIZED FOR MINIMUM WEIGHT

	<u>Capsule 1</u>	<u>Capsule 2</u>	<u>Capsule 3</u>
Compressor Efficiency	0.746	0.757	0.760
Turbine Efficiency	0.791	0.818	0.831
Alternator Efficiency	0.905	0.927	0.921
Lost Pressure Ratio Parameter	0.959	0.972	0.9755
Recuperator Effectiveness	0.970	0.975	0.9758
Bearing Loss (kw)	0.124	0.137	0.151
Windage (kw)	0.030	0.053	0.073
Turbine Inlet Temperature (°R)	2060.0	2060.0	2060.0
Compressor Inlet Temperature (°R)	440.0	500.0	520.0
Compressor Pressure Ratio	1.615	1.537	1.514
Turbine Pressure Ratio	1.549	1.493	1.477
Compressor Inlet Pressure (psia)	18.2	42.3	66.2
Radiator Area (ft ²)	112.0	110.6	134.2
Recuperator Length (inch)	15.7	20.4	24.0
Fractional Heat Loss*	0.13	0.13	0.13
Net Output Power (kw)	0.619	1.356	2.067
Net Cycle Efficiency	0.2578	0.2825	0.2872
Radiator Emissivity	0.83	0.83	0.83
Radiator Sink Temperature (°R)	390.0	390.0	390.0
Compressor Flow Rate (lb/sec)	0.1064	0.2262	0.3442
Turbine Flow Rate (lb/sec)	0.1043	0.2217	0.3347
Heater Inlet Pressure (psia)	29.11	64.60	99.74
Heater Inlet Temperature (°R)	1738.9	1758.4	1762.5

*Thermal Loss/Gross Heat Release

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TABLE I-5

BIPS FS CYCLE EFFICIENCY SENSITIVITY FACTORS*

Independant Variable			Sensitivity Factors			
			Multiplier	Number of 2400 W _t Capsules		
Name	Calculation Range	Symbol		1	2	3
Compressor Efficiency	0.761 to 0.701	η_c	$\Delta\eta_c$	0.55	0.55	0.55
Turbine Efficiency	0.832 to 0.772	η_t	$\Delta\eta_t$	0.55	0.55	0.55
Alternator Efficiency	-0.02 to -0.04	$\Delta\eta_A$	$\Delta\eta_A$	0.32	0.32	0.32
Compressor Inlet Temperature	-40°F to 40°F	ΔT_1	ΔT_1	-0.0006	-0.0006	-0.0006
Emissivity	0.83 to 0.74	ϵ	$\Delta\epsilon$	0.05	0.077	0.075
Pressure Drop	0.005 to 0.010	$\frac{\Delta P}{P}$	$\Delta\left(\frac{\Delta P}{P}\right)$	-0.8	-0.8	-1.0
Bearing Loss	0.50 to 1.00	$\frac{\Delta W_B}{W_B}$	$\Delta\left(\frac{\Delta W_B}{W_B}\right)$	-0.056	-0.031	-0.02
Recuperator Effectiveness	0.00 to -0.03	ΔE_1	ΔE_1	1.25	1.20	1.15
Heat Loss	0.00 to -0.04	ΔW_t	ΔW_t	-0.37	-0.30	-0.25

* $\Delta\eta_{cy} = (\text{Sensitivity Factor}) \times \text{Multiplier}$

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SINK TEMPERATURE EFFECTS
FIGURE I-4

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EFFECT OF TURBINE INLET TEMPERATURE
ON OVERALL PERFORMANCE

FIGURE I-5

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TABLE I-6
OFF-DESIGN PERFORMANCE

<u>Parameter</u>	<u>New Value</u>	<u>Delta</u>	<u>Multiplier</u>	<u>$\Delta\eta_{cy}$</u>
Compressor Efficiency	0.747	-0.01	-0.01	-0.0055
Turbine Efficiency	0.808	-0.01	-0.01	-0.0055
Alternator Efficiency	0.917	-0.01	-0.01	-0.0032
Compressor Inlet Temperature	510	10	10.0	-0.0060
Emissivity	0.80	-0.03	-0.03	-0.0023
Pressure Drop	0.975	0.003	0.003	-0.0024
Bearing Loss	0.145	0.008	0.0584	-0.0018
Recuperator Effectiveness	0.950	-0.025	-0.02	-0.0300
Heat Loss	0.160	0.03	0.03	-0.0090
Sink Temperature	420	+30	--	-0.0088
Turbine Inlet Temperature	2010	-50	--	<u>-0.0080</u>
			Total	-0.0825
				(or -8.25%)

In more practical cases, only a few performance variables would generally be considered at one time. Assuming that compressor efficiency, radiator emissivity, and bearing loss have new values as indicated in Table I-6, cycle efficiency would then be reduced 0.96 percent.

To bring the cycle efficiency back to the original value, the compressor inlet temperature sensitivity factor is used to determine the required increased temperature:

$$T_{1_{\text{new}}} = 500 + 0.0096/(-0.0006) = 484^{\circ}\text{R}$$

From Figure I-7, $(\Delta \text{ area})/(\Delta T_1) = -1.03$ and the required radiator area increase is therefore:

$$\Delta \text{ Area} = -16 \times (-1.03) = 16.48 \text{ ft}^2$$

for a total of 127.08 ft^2 , which represents a 14.5 percent increase.

This simplified approach to performance parameters effects on cycle efficiency, loses accuracy as parameters increase. Also, when the radiator size is changed, the performance of other components are changed slightly. Therefore, sensitivity factors, etc., should be used with caution.

To aid in assessing performance of a given system, with varying radioisotope quantities, off-design performance of the three systems is presented in Figure I-6. Since surface temperatures would be nearly constant, in each case it was assumed that the change in thermal loss would be insignificant.

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PERFORMANCE SPECTRUM OF 3 MINI-BRAYTON SYSTEMS

FIGURE I-6

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RADIATOR AREA EFFECTS

FIGURE I-7

5.0 LEAKAGE RATES

Estimated leakage rates of GDS components and joints are discussed in Section 3.3.5. 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	2.73×10^{-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}

Based on these rates the system total leakage rate is 1.387×10^{-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 21.87 standard cc total loss. This loss equates to only 0.0146 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 percentage after 5 years will be as high as the thermal input reduction resulting from

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radioisotope decay. This is the ideal and desired condition because the turbine inlet temperature and system efficiency 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 265 times greater than the assumed 1.387×10^{-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).

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LIST OF REFERENCES

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3. GE-BIPS-20-001. "Mission Environments for The Isotope Brayton Flight System (Preliminary), August 8, 1975", Memo No. BIPS-GDS-G0017, 10-22-75.

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BRAYTON ISOTOPE POWER SYSTEM
PHASE I
(GROUND DEMONSTRATION SYSTEM)
CONFIGURATION CONTROL
DOCUMENT (CCD)

75-311274B

March 15, 1976

Prepared by: Engineering Staff/BAH

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 Appendix II - 9 Pages
 Appendix III - 24 Pages

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BIPS PROGRAM

ABBREVIATIONS AND ACRONYMS

(A)		(F)	
ABS	Auxiliary Battery System	F	Fahrenheit Degrees
ACS	Auxiliary Cooling System (for HSA)	FBS	Flight Battery System Required for Start in Orbit
ACS	Attitude Control System	FIB	Fuel Impact Body
AEC	Atomic Energy Commission (now ERDA)	FM	Frequency Modulation
AEC PR	Atomic Energy Commission Procurement Regulation	FMA	Failure Mode Analysis
AIRPHX	AiResearch, Phoenix	FMEA	Failure Modes and Effects Analysis
AIRLA	AiResearch, Los Angeles	FMECA	Failure Modes, Effects and Criticality Analysis
AFSCF	Air Force Satellite Control Facility	FPR	Federal Procurement Regulation
AM	Amplitude Modulation	fps	Feet per Second
AOA	Abort-Once-Around	FS	Flight System
ASE	Airborne Support Equipment	FSA	Fuel Sphere Assembly
ARS	Atmospheric Revitalization Subsystem	FSAR	Final Safety Analysis Report
ATO	Abort-To-Orbit	FSE	Flight Support Equipment
ATCS	Active Thermal Control Subsystem	FUO	Follow-up Output
		FT	Feet, Foot
		FWW	Food, Water and Waste Management
(B)		(G)	
BCL	Battelle Columbus Laboratory	g	Acceleration Due to Gravity
BOM	Beginning of Mission	GDS	Ground Demonstration System - PCS + EHS-S
BIPS	Brayton Isotope Power System	GE	General Electric, Valley Forge
BRU	Brayton Rotating Unit	GET	Ground Elapsed Time
		GFE	Government Furnished Equipment
(C)		GMS	Gas Management System
C	Celsius (Centigrade) Degrees	GMT	Greenwich Mean Time
CCAFS	Cape Canaveral Air Force Station	GN2	Gaseous Nitrogen
CCD	Configuration Control Document	GN&C	Guidance, Navigation and Control
CCTV	Closed Circuit Television	GSE	Ground Support Equipment
CFM	Cubic Feet per Minute	GTC	Ground Test Console (a STE/GSE item)
c.g. or CG	Center of Gravity		
CO2	Carbon Dioxide	(H)	
CRT	Cathode Ray Tube	HS	Heat Source (Same as and replaced by IHS)
CSI	Control Servo Input	HSA	Heat Source Assembly (Does not include IHS or HSS. Does include HSHX, structure, insulation, ACS and ECS.)
(D)		HRHX	Heat Rejection Heat Exchanger (Radiator simulator for GDS)
DAS	Data Acquisition System	HSHX	Heat Source Heat Exchanger
db	Decibel	HSIS	Heat Source Insulation System
DC	Direct Current	HSS	Heat Source Simulator (Same as and replaced by EHS)
DCS	Demonstrator Cooling System		
Delta-V or ΔV	Velocity Change in Feet per Second	(I)	
DOD	Department of Defense	IBFS	Isotope Brayton Flight System
DOD STS	Department of Defense Space Transportation System	IBGDS	Isotope Brayton Ground Demonstration System (PCS + EHS-S)
(E)		IHE	Isotope Handling Equipment
EAI	Engineering Assembly Instructions	IHS	Isotope Heat Source
EAPB	Edwards Air Force Base	IMU	Inertial Measurement Unit
EPFS	Electrically Powered Flight System (PCS + EHS-D)	IUS	Interim Upper Stage
ECLS	Environmental Control and Life Support	IVA	Intra Vehicular Activity
ECS	Emergency Cooling System (for HSA)		
EHS-D	Electrical Heat Source - Dynamic	(J)	
EHS-S	Electrical Heat Source - Static	JPL	Jet Propulsion Laboratory (Pasadena, California)
ELS	Eastern Launch Site	JFC	Johnson Space Center (Houston)
EMS	Material Specification (AiResearch Term)		
EOM	End of Mission	(K)	
ESD	Electronic System Division (of Air Force Systems Command)	KB	Keyboard
ET	External Expendable Tank	Kbaud	Code Elements per second in 1,000's
EPS	Electrical Power System	Kbps	Bits per Second in 1,000's
ERDA	Energy Research and Development Administration (Formerly AEC)	KSC	Kennedy Space Center
EVA	Extravehicular Activity	KW _e	Kilowatts Electrical
		KW _t	Kilowatts Thermal

BIPS PROGRAM

ABBREVIATIONS AND ACRONYMS

(CONTD)

(L)

LASL Los Alamos Scientific Laboratory

LCC Launch Control Center

LES 8/9 Lincoln Experimental Satellite (No. 8 and 9)

LF Load Factor

LH2 Liquid Hydrogen

LiOH Lithium Hydroxide

LO2 Liquid Oxygen

LPS Launch Processing System

(M)

M Meters

MBR Mini-Brayton Recuperator

Mini-BRU 350 to 2100 Watts Electrical Brayton Rotating Unit

MCC Mission Control Center

MDM Multiplexer-Demultiplexer

MECO Main Engine Cut-Off

MHW Multi-Hundred Watt (AEC/GE IHS Technology)

MHZ Megahertz

MM Millimeters

MMD Mean Mission Duration

MOS Mission Operation System

MR Milliradians

MSS Mission Specialist Station

(N)

NA Not Applicable

NASA LeRC National Aeronautical and Space Administration Lewis Research Center

NRA Nuclear Research and Applications, Division of ERDA (formerly SNS)

(O)

OFB Orbiter Processing System

OHA Operational Hazard Analysis

ORNL Oak Ridge National Laboratory

OMS Orbital Maneuvering Subsystem

(P)

PCL Power Conversion Loop (Use of PCS preferred)

PCM Pulse Code Modulation

PCR Payload Changeout Room

PCS I Power Conversion System (HSA + BRU + MBR + Heat Sink + Controls + Piping and Structure)

PCS II Power Conversion Systems (HSA + BRU + MBR + Radiator + Controls + Piping and Structure)

PGHM Payload Ground Handling Mechanism

PHA Preliminary Hazard Analysis

PLC Parasitic Load Control System

P/L Payload

PLCC Payload Control Center

PLH Payload Handling

PLM Payload Management

POP Perpendicular to Orbit Plane

PSAR Preliminary Safety Analysis Report

PSC Power Supply Console (for RHS)

PSC Procurement Specification (Air Research Term)

PSE Peculiar Support Equipment

PSS Payload Specialist Station

PSSR Preliminary System Safety Review

(Q)

QA Quality Assurance

(R)

RCS Reaction Control System

RCS Radiator Cooling System

REM Roentgen Equivalent Man

RF Radio Frequency

RM Remote Manipulator

RMS Remote Manipulator System

RSS Root Sum Square

RTLS Return to Launch Site

RTG Radioisotope Thermoelectric Generator

RTS Remote Tracking Station

(S)

SAMSO Space and Missile System Organization

SNS Space Nuclear Systems (now NRA)

SMAB Solid Motor Assembly Buildup

SRB Solid Rocket Booster

SRM Solid Rocket Motor

SSP Space Shuttle Program

SSME Space Shuttle Main Engine

SSS Space Shuttle System

SSPP System Safety Program Plan

SSV Space Shuttle Vehicle

STDN/ TDRSS Space Tracking and Data Network/Tracking Data Relay Satellite System

STE Special Test Equipment

STS Space Transportation System

SURVSATCOM Air Force Survivable Communication Satellite (now AFSATCOM III)

(T)

TACB Temperature of Cabin

TBD To Be Defined

TDRS Tracking and Data Relay Satellite

TECO Thermo Electron Corporation

TES Teledyne Energy Systems (formerly Teledyne Isotopes)

TIT Turbine Inlet Temperature

TV Television

(U)

ULT Ultimate Loads

USAR Updated Safety Analysis Report

(V)

VAB Vehicle Assembly Building

VAFB Vandenberg Air Force Base

VDC Volts Direct Current

VHF Very High Frequency

VRE Voltage Regulator Exciter

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BRAYTON ISOTOPE POWER SYSTEM
PHASE I
(GROUND DEMONSTRATION SYSTEM)
CONFIGURATION CONTROL
DOCUMENT (CCD)

1.0 INTRODUCTION

This CCD was prepared by AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, under NASA Contract NAS3-18517 (NASA Mini-BRU Program). Revisions to this CCD are published, as system design progresses, under ERDA BIPS Contract E(04-3)-1123.

1.1 Purpose

This CCD defines the BIPS-GDS configuration. The GDS configuration is similar to a conceptual flight system design, referred to herein as the BIPS-FS, and which is discussed in Appendix I. The BIPS is being developed by ERDA as a 500 to 2000 W_e , 7-year life, space power system utilizing a closed Brayton cycle gas turbine engine to convert thermal energy (from an isotope heat source) to electrical energy at a net efficiency exceeding 25 percent.

This CCD relates to Phase I of an ERDA Program to qualify a dynamic system for launch in the early 1980's. Phase I is a 35-month effort to provide an FS conceptual design and GDS design, fabrication, and test. The baseline is a 7-year life, 450-pound, 4800 W_t , 1300 W_e system which will use two multihundred watt (MHW) isotope heat sources being developed by GE under ERDA contract AT (29-2)-2831. The baseline FS will also utilize components and technology being developed by NASA under Contracts NAS3-18517, NAS3-18029, and NAS3-18541 for the: Mini-Brayton rotating unit (AIRPHX); recuperator (AIRLA); and heat source assembly (GE); respectively.

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It is intended that the GDS simulate the FS as closely as possible. Testing includes detailed performance and 1000-hours endurance.

Information presented herein is intended to ensure proper integration of system components into a complete system. It is intended as a ready reference for all organizations such as ERDA, NASA, and industry contractors participating in BIPS development. This CCD provides the reader sufficient information and direction to obtain drawings and documents such that a system description can be obtained to any level desired. The CCD also serves as a working document, and index, to supporting detail documentation. Appendix III presents a listing of BIPS related documents and drawings.

1.2 Organization of Material

This document includes reference material, a related documents listing, and pertinent system and components design data. Also included is a preliminary BIPS-FS design description (Appendix I) and certain appropriate background information that may be useful to potential users (Appendix II). All drawings referenced in the text herein are included, in numerical order, in Appendix III.

As a working document, this CCD will be revised as necessary to maintain current descriptions of the components and system. After completing Phase I, the CCD will provide a GDS "as-built" description and record. When sufficient information is available, either new or changed, this CCD will be revised and updated to reflect these changes. Between these major revisions, Addenda and Errata will be issued to provide the most current information to all CCD holders.

Due to the current preliminary status of the GDS, some paragraphs herein are noted with a TBD (to be determined). When the status of TBDs become known or defined, this information will be included in Addenda and Errata, or updated editions of this CCD, as appropriate.

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2.0 CONFIGURATION CONTROL PROCEDURES

2.1 Scope

Configuration practices described herein will assure technical and administrative direction and surveillance to: (1) identify and document functional and physical characteristics of a configuration item; (2) control changes to these characteristics; and (3) record and report change processing and implementation status. Specifically, configuration management will accomplish the following:

- o Control and Documentation - Provide product configuration control and documentation through assemblies, subassemblies, and parts.
- o Interfacing - Assure interface compatibility with customer installation.
- o Change Control - Utilize established AIRPHX procedures for evaluation, coordination, and approval/disapproval of baseline equipment configuration changes.
- o Vendor Control - Impose and monitor configuration control disciplines on AIRPHX vendors.

AIRPHX intends to utilize present organization and management practices, as applicable, in performing the ERDA/BIPS GDS program, and all subsequent phases (i.e., BIPS-FS).

2.2 Specific AiResearch Configuration Control System

An original baseline configuration, as defined on AIRPHX drawings, will be established. Changes to existing drawings and/or new drawings will be integrated into the baseline, until a qualification baseline is established.

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2.2.1 Specifications

Equipment specifications applicable to the level of equipment to be procured will be prepared to define recommended technical requirements and acceptance criteria for the product. Specifications will conform to MIL-STD-490 format. Lists of Materials and Processing Specifications, in existence, or to be prepared, are included in Tables I and II of AIRPHX Report 76-311737 (Specification Requirements Summary for the BIPS).

2.2.2 Drawings

A complete set of engineering drawings will be prepared to define each procured item. Drawings will be prepared to the format defined in the AiResearch Drafting Room Manual, which satisfies MIL-STD-100A and MIL-D-1000 requirements.

2.2.3 Release Record

Drawings, related data, and associated changes, are released by Engineering Project in accordance with the AiResearch Drafting Room Manual and Operating Procedures.

2.2.4 Subcontractor

Major subcontractors will be required to comply with MIL-D-1000 and MIL-STD-100A requirements.

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3.0 SYSTEM DEFINITION

This CCD defines the GDS, but as previously stated, the GDS design represents typical flight hardware. Therefore, for information, the FS used as a model is described in Appendix I.

Basic Phase I objectives are to:

- (a) Conduct a two-phase flight system conceptual design, to establish typical flight system requirements, as the basis for GDS design.
 - (1) The first phase summarizes requirements known on October 1, 1975.
 - (2) A finalized conceptual design will be prepared in the last quarter of 1976.
- (b) Design, fabricate, and assemble the GDS and accomplish performance and endurance testing.
- (c) Conduct any long lead development necessary to effect first production FS delivery by April 30, 1981.

Testing will be conducted in an AIRPHX facility equipped to provide the clean room, assembly, and test support systems required to meet these basic objectives. The overall test system configuration is defined on Drawing 306960.

System testing will provide valuable data contributions that will assist in confirming the following design considerations:

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- o Component Performance
- o Synergistic Effects
- o System Performance
- o Control System Definition
- o Startup and Shutdown
- o Electrical Power Quality
- o Material Compatibility
- o Material Contamination
- o Thermal Gradients
- o Reactive Torques and Component Loading
- o Electromagnetic Fields
- o Insulation Effectivity and Structural Heat Loss
- o Configuration Flexibility
- o Preflight Checkout
- o Maintainability
- o Instrumentation/Test Equipment
- o Endurance Test Cost/Hr
- o FMECA Substantiation
- o System Confidence

3.1 System Objectives

It is intended that the GDS satisfy performance objectives and design criteria specified below.

3.1.1 Performance Objectives

GDS design objectives are, to the greatest extent possible, identical with FS performance objectives shown on Table I-1, Appendix I. Some noteworthy GDS differences are:

- (a) The MBR and HSA are designed to meet Requirement (4).
The radiator simulator (HRHX) is not.

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- (b) The heat rejection method will utilize a liquid-cooled heat exchanger to simulate the working-fluid side of a space radiator.
- (c) The weight goal, Requirement (6), will not be met since (1) the actual radiator will not be used, and (2) beryllium will not be used for the GDS support structure and HSA housing as contemplated for the FS.
- (d) An electrically heated simulated isotope heat source will be used, which limits output power to 1300 W_e . A slave heater has been proposed, which allows operation over the entire 500 to 2000 W_e range.
- (e) Controls will consist of breadboard circuits using military grade components.
- (f) 120 $\pm$ 2 percent vdc will be the reference output voltage after alternator output rectification. Refer to Monthly Progress Report 75-311457(02), Appendix B, "Output Voltage Study".

Several potential requirements may materialize at a later date. Examples of these are:

- (a) Provision for operation through launch
- (b) Provision for fueling on the pad or in orbit
- (c) Partial or complete power system spacecraft integration

System layout is based on objectives listed on Table I-1, Appendix I. Any new performance and configuration data resulting from Phase I efforts, will be incorporated in Appendix I.

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3.1.2 Design Criteria

System design criteria are defined in AIRPHX Report 76-311737, entitled, "BIPS/GDS System Design Specification".

3.2 Applicable Documents

Included in Appendix III are lists of applicable documents involving:

- (a) BIPS-FS related documents (i.e., study final reports, technical reports, development program plans, and drawings).
- (b) Incorporation of Government documents and specifications.

3.3 System Characteristics

Subparagraphs 3.3.1 through 3.3.6 present specific features and characteristics that are applicable to the GDS.

3.3.1 Thermodynamic Cycle

The closed-cycle gas turbine (Brayton cycle) theory of operation is similar to open cycles (Figure 3-1) used in turbojet and turbo-prop aircraft propulsion engines as well as many electrical, shaft, and compressor-air power generation systems. Closed cycle applications are suited for shaft power generation and electrical power generation with the generator integral to the turbocompressor shaft. The closed-cycle engine is generally recuperated, as shown in Figure 3-1, to obtain a high level of efficiency. The heat source may be any of several energy release systems such as fossil-fuel combustion, chemical reactants, solar, geothermal, and various forms of nuclear power.

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OPEN vs CLOSED CYCLE GAS TURBINE

FIGURE 3-1

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3.3.2 Reference Cycle

The reference cycle showing all state-point conditions is presented in Figure 3-2. The GDS reference design energy balance is shown in Figure 3-3.

Predicted GDS performance is based on predicted performance of the rotating unit, recuperator, and HSA, which will be GFE from NASA contracts, and on an assumed thermal loss of 20 percent rather than the 12 percent predicted for the BIPS-FS (refer to Appendix I). Higher GDS thermal loss was assumed because the instrumentation penetrations and insulation removability give heat losses not found in the BIPS-FS. System performance is shown for the same heat input and power output of the FS. Independent variables available to attain this performance are; coolant flow rate, coolant temperatures, and gas inventory.

3.3.3 Operating Environment

The environment of the GDS is as follows:

- o External Environment
 - o $<10^{-4}$ Torr for Multi-Foil insulation to be effective
 - o TBD to prevent excessive contamination of refractory material (allowable levels of O_2 , N_2 , CO , CO_2 , H_2 , and other contaminants to be determined).
- o Ambient Temperature
 - o Approximates the expected space radiator internal temperature

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GDS AT 4800W_t

FIGURE 3-2

ENERGY BALANCE

FIGURE 3-3

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- o Working Fluid - Xe/He mixture
 - o Molecular weight 83.8
 - o Trace amounts of other monatomic gases <2 percent
 - o Allowable contamination levels of O₂, N₂, CO, CO₂, H₂O, H₂, and other contaminants to be determined.

3.3.4 System Assembly

The integrated GDS is shown in the drawings listed below:

- (a) L3621580, GDS Assembly
- (b) L3621583 Sheets 2 and 3, GDS Installed in Test Facility
- (c) 306960, GDS Piping and Instrumentation Schematic

3.3.5 System Leakage Rates

NASA LeRC-developed components, used in the 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 33 joints that could lose working fluid to space vacuum, the total maximum leakage rate through joint welds is 3.3×10^{-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 2.73×10^{-8} .

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Preliminary maximum leakage rates for other components comprising the GDS are estimated as follows:

<u>Component</u>	<u>Rate (Standard CC He/Sec)</u>
HRHX	1×10^{-9}
Bellows/interconnecting ducting weld joints (each)	1×10^{-10}

3.3.6 Operational Transient Characteristics

System and specific components transient performance characteristics are defined below.

3.3.6.1 System Characteristics

System performance characteristics are defined in AIRPHX Report 75-311279A, relative to predicted; voltage, power, speed, pressure, temperatures, and working fluid flows for startup, load changes, and shutdown. Figures III-1, III-2, and III-3 included in Appendix III, are taken from the latest analysis report and represent start transients used for MBR and HSA transient analyses and test definitions.

3.3.6.2 MBR Characteristics

TBD and to be included in an updated edition of this CCD.

3.3.6.3 HSA Characteristics

TBD and to be included in an updated edition of this CCD.

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3.4 BIPS-GDS Components

An outline of GDS components is presented on Table 3-1. Component characteristics (i.e., operational limitations, design points, safety factor, acceptance testing parameters, and environmental hazards) will be defined during Phase I and included in future editions of this CCD. Component descriptions, presently defined related data, and related (referenced) detail design reports are presented in paragraphs 3.4.1 through 3.4.5 below. System sensitivity data, to evaluate the effects of variations in predicted component performance, is provided in Appendix III.

TABLE 3-1

BIPS-GDS COMPONENT OUTLINE

Mini-BRU

- o 1600°F turbine inlet temperature (working fluid is Xe-He, M = 83.8)
- o Single shaft turbine, Rice alternator, and compressor supported on foil bearings with compressor bleed cooling
- o Alternator cooled by compressor discharge, output voltage is for a 3-phase 120 vdc rectifier
- o Refractory metal turbine plenum (Columbium Alloy C-103)

Recuperator

- o Hastelloy X construction with gold alloy braze
- o Fin/plate counterflow design

Radiator Simulator (Heat Rejection Heat Exchanger-HRHX)

- o Inlet and outlet conditions equivalent to a space radiator with 390 degree equivalent sink temperature

Heat Source

- o Electrically heated heat source simulator (EHS)

Heat Source Assembly (HSA)

- o Columbium Alloy C-103 heat source heat exchanger (HSHX)
- o Auxiliary Cooling System - Helium short circuit of HSHX Multi-Foil insulation
- o Emergency Cooling System - Melting of HSHX Multi-Foil insulation (alternatives have been identified).

Insulation

- o High temperature Multi-Foil insulation
- o Twenty percent heat loss from HSA, turbine, and hot interconnecting ducting to allow for instrumentation penetration through the insulation, etc.

Controls

- o Motor start inverter
- o Parasitic load
- o Speed control
- o Voltage regulator
- o Power Supply
- o Rectifier/filter

Piping and Structure

- o Ducting
- o Bellows
- o Support structure

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3.4.1 Mini-Brayton Rotating Unit (Mini-BRU)

The Mini-BRU, shown on Figure 3-4, functions to convert Pu-238 radioisotope heat source thermal energy into electricity. The Mini-BRU is designed to produce from 0.35 to 2.1 kw electrical power for space satellite applications. Mini-BRU detail design is completed, with parts fabrication in process. First delivery is anticipated for late 1976.

The Mini-BRU consists of a radial-flow turbine, radial-flow compressor, and alternator. These components, which are mounted on a common shaft rotating nominally at 52,000 rpm and supported on gas lubricated hydrodynamic journal and thrust bearings, will produce up to 2.1 kw_e. The alternator is cooled by working fluid from the compressor discharge. The Mini-BRU includes a flight-type housing, and turbine and compressor inlet and exit ducting. Mounting pads are provided to permit installation in a space power system. Machined bosses or pads are provided for required instrumentation.

To facilitate alteration and major components replacement, the Mini-BRU is designed for ease of assembly and disassembly. Although specific operating characteristics are dependent on many variables, Mini-BRU components are designed to maintain high efficiency over the specified rated power output range. GDS performance data for 1.3 kw_e, 2-capsule heat source operation (1-capsule equates to 2.4 kw_t) are provided on Figure 3-2. However, Mini-BRU versatility is shown on Figure I-6, Appendix I, which relates to operating performance with 1, 2, and 3 heat source capsules.

Mini-BRU characteristics are as follows:

- (a) Type of rotating unit: single shaft
- (b) Cycle working gas: He-Xe, molecular weight 83.8

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Mini-BRU

Figure 3-4

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- (c) Rated power output range: (350 - 2146 W_e). The alternator is designed for a three phase full-wave 120 vdc rectifier load.
- (d) Turbine:
Type - radial flow
Optimized for 3-capsule configuration - Table I-4, Appendix I
- (e) Compressor:
Type - radial flow
Optimized for 3-capsule configuration - Table I-4, Appendix I
- (f) Alternator:
Type - stationary excitation coil, brushless, Rice type Lundell. Optimized for performance over the range of 1 to 3 heat source capsules
- (g) Overspeed capability - 62,400 rpm (120 percent of nominal 52,000 rpm design speed)
- (h) Environmental conditions: Exhibit "E", NASA RFP 3-456906-Q, except as noted in Item (i) below
- (i) Design operating life: 10 years at maximum rated power, and turbine inlet temperature, in space vacuum ($<10^{-4}$ Torr).
- (j) Final balance is consistent with objectives of minimum bearing deflections for 10-year design life.
- (k) Design provides the capability for 1000 startup-shutdown thermal cycles, minimum.

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- (1) Design to assure super alloy and refractory metal scrolls interchangeability with minimum rework.

Pertinent Mini-BRU component data and design features/ characteristics are presented below.

3.4.1.1 Compressor

The compressor is a 2.12 inch diameter radial outflow, backward curved impeller (see Figure 3-5) with vane diffuser and plenum. Compressor design efficiency (76 percent) is lower than larger designs. This is attributed to low specific speed, which results from the low physical speed (tip speed is 480 fps) required to optimize the entire system. Size effects appear in the form of clearance and tolerance losses. During the design phase, attention was given to increasing the exit absolute flow angle, which increases exit width and reduces the clearance loss. In an effort to achieve better performance, a tandem diffuser was incorporated. However, because of compressor deficiencies disclosed during testing, and limited development funding, this effort was stopped and a proven single-stage diffuser design was incorporated.

Table 3-2 iterates compressor design parameters from Mini-BRU Final Design Report, 75-311241.

3.4.1.2 Alternator

The selected alternator is a four-pole Rice machine designed for high efficiency when operated with a 3-phase, full-wave rectifier furnishing 120 vdc to a 350 to 2100-watt load. Preliminary studies for two, four, six and eight poles alternator designs indicated that a four-pole machine had the smallest, lightest rotor. Although total alternator weight was slightly less for six and eight poles designs, efficiencies of these machines were reduced by higher windage losses,

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MINI-BRU COMPRESSOR

FIGURE 3-5

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TABLE 3-2

MINI-BRU RADIAL COMPRESSOR DESIGN PARAMETERS
(SEE NOTE)

	<u>Impeller</u>	<u>Stage</u>
Gas	= Xe-He; MW = 83.8	η = 0.758
$W\sqrt{\theta/\delta}$	= 0.0753 lb/sec	P_{T3}/P_{T1} = 1.500
$N/\sqrt{\theta}$	= 51,153 rpm	$\Delta T/T_{OA}$ = 0.2313
η	= 0.876	
P_{T2}/P_{T1}	= 1.579	
$\Delta T/T_{EULER}$	= 0.2289	
Specific Speed	= 47.4 - Defined as $N_s = \frac{N\sqrt{Q_{AVG}}}{H_{ACT}^{3/4}}$	where N = RPM
Number of Blades:	= 13 full blades 13 splitters	$Q_{AVG} = (Q_1 Q_2)^{1/2}$, ft ³ /sec
Slip Factor	= 0.931	H_{ACT} = Head, Ft
T_{O1}	= 536°R	
P_{O1}	= 70.8 psia	
N_{PHYS}	= 52,000 rpm	
Diameter Tip	= 2.12 inch	
Inducer Hub Diam	= 0.509 inch	
Inducer Tip Diam	= 0.931 inch	

NOTE: Impeller efficiency, pressure ratio, and Euler work values calculated during preliminary design analyses.

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caused by larger diameter rotors. The four pole machine was further optimized by increasing field and stator core sizes to fully utilize available space in the alternator heat exchanger ID. Figure 3-6 depicts the alternator, and Table 3-3 provides design data. Additional detailed information is provided in the Mini-Brayton Alternator Final Design Report 75-311211.

Various materials used in alternator construction, such as resins, adhesives, and potting compounds, are listed in Table 3-4.

Behavior of these materials, under required operating temperatures and long life requirements, will be determined, as accurately as possible, to ensure desired reliability. The exact degree and nature of materials decomposition are not readily available, and in some instances do not exist. Tests to obtain outgassing rates and composition are planned for early 1976.

Alternator instrumentation is illustrated on Figure 3-7. Precise locating dimensions for thermocouples, and the flux search coil located in the stator assembly, are shown on Drawing 2045426, included in Report 75-311211.

3.4.1.3 Turbine

The Mini-BRU radially designed turbine impeller (see Figure 3-8A) has ten full blades, ten splitters, and an overall diameter of 2.858 inches. Considerable attention was given to the 52,000 rpm nominal design speed, and the 0.357 lb/sec maximum weight flow requirement. This turbine design is much smaller than any previous AiResearch design, thus, direct attention was given the various design details to assure a good performance level.

During a preliminary study, the turbine inlet configuration was a scroll. However, by using a scroll inlet, it was necessary that

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MINI-BRU ALTERNATOR ASSEMBLY

FIGURE 3-6

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TABLE 3-3

ALTERNATOR DESIGN SUMMARY

Type:	Four-Pole Rice Gas Cooled 3-Phase "Y" Connected 4 Parallel Shunt Field Coils
Design Rating:	2 KW _e , Rectifier Load 12.27 amps per phase 65.90 volts Line to Neutral* 1733 Hz
Materials:	Rotor - HP 9-4-20/INCO 713 LC Stack - AL 4750, 0.006 in. Laminations Frame and End Bells - SAE 1018 Field and Stator Windings - Copper
Geometry:	24 Slots 2 Parallel Circuits 5/6 Coil Pitch 2/3 Rotor Pole Pitch 1.51 in. Diam Rotor 0.020 Air Gap 0.72 in. Stack Width

*Intrinsic voltage behind X_{com} in rectified mode

TABLE 3-4

CONSTRUCTION MATERIAL USED IN MINI-BRU ALTERNATOR

<u>Application</u>	<u>Material</u> <u>Type</u>	<u>Garrett</u> <u>Identification</u>	<u>Manufacturer and</u> <u>Part No.</u>	<u>Temperature</u> <u>Data</u>	<u>Amount Used and</u> <u>Location Used</u>
Adhesive	One component RTV Silicone	105-097-9001 RS184C01 MIL-A-46106	GE Silicone Products Division, Waterford, New York - RTV 108	450°F maximum oper- ating temperature	Approximately 0.00017 lbs thermocouple bond 9 places field and stator
Adhesive	Nitrile-Phenolic	105-050-9001	Chemical Division Chrysler Corporation 5437 W. Jefferson Trenton, Michigan K-183 Cycle Weld	400°F operating temperature	0.0714 lbs lamination and damper ring bond
Adhesive	Epoxy one part	105-070-9001	Minnesota Mining and Manufacturing Company St. Paul, Minnesota Scotch Weld 2214	400°F maximum	Field to stator bond
Potting Compound	RTV silicone rubber	RS185E08 MIL-C-81306	Dow Corning Corpora- tion, Midland, Michigan, 96-069 Class 08	400°F maximum	0.1833 lbs field and stator encapsulation
Varnish	Solventless silicone resin		Dow Corning Corpora- tion, Midland, Michigan, R-4-3157	-85°F to 437°F	0.10361 lbs field wire coating
Tape	Polyimide film (Kapton)	722-022-9101	Connecticut Hard Rub- ber Company, New Haven Connecticut, Temp-R- Tape Kapton No. 850	400°F maximum	0.01005 lbs stator in- sulation
Tape	Nylon creped (Nomex Type 410)	722-015-9001 MIL-I-24204	Edgewater Paper Com- pany, Hoosick Falls, New York	428°F maximum	0.020 lb field bobbin corner insulation
Lacing Tape	Polyimide (Nomex) Microcrystalline Fungicide wax	MIL-T-43435 Type V Fin B Size 3	E.I. DuPont DeNemours and Company, Inc.	400°F operating temperature	Stator winding trace
Insulation Wire	Polytetrafluoro- Ethylene (PTFE)	S8936, S8937 MIL-W-168780		-130° to 482°F	0.0008 lb connecting wire insulation, stator and field
Insulation Sleeving	ML Polyimide Resin coated fiberglass	S9050 MIL-I-3190	Bentley-Harris Manu- facturing Company Conshohocken, Pennsylvania, Ben-Har 963C	482°F maximum	Stator wire insulation trace
Insulation Sleeving	Fluorinated Ethylene Propylene	S9051	Brand-Rex Company Box 498 Willimantic, Connecticut	275° - 400°F operating tem- perature	Field and stator assembly trace
Encapsu- lation	Epoxy Resin	219-116-9001	Emerson & Cuming, Inc., Dielectric Mtl. Div. Canton, Mass Stycast 2850 G.T.	400°F maximum	Stator end turn encapsu- lation

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- 1 - ROTOR GAS INLET TEMP
- 2 - ROTOR GAS EXIT TEMP
- 3 - END COIL TEMP
- 4 - END COIL TEMP
- 5 - END COIL TEMP
- 6 - FIELD BOBBIN TEMP
- 7 - FIELD BOBBIN TEMP
- 8 - MIDDLE STICK TEMP
- 9 - MIDDLE STICK TEMP

- 10 - SLOT BOTTOM TEMP
- 11 - STACK OD TEMP
- 12 - HX ID TEMP
- 13 - END BELL TEMP
- 14 - END BELL TEMP
- 15 - END BELL TEMP
- 16 - THRUST BEARING LEAKAGE GAS TEMP
- 17 - TURBINE END LEAKAGE GAS TEMP
- A, B, C - PRESSURE TAP\$
- I - SEARCH COIL

ALTERNATOR INSTRUMENTATION

FIGURE 3-7

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MINI-BRU TURBINE WHEEL

FIGURE 3-8A

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stators be designed to carry high stress loads. This resulted in thick blade sections and a relatively large trailing edge thickness. With a subsequent decision to go to a plenum configured turbine inlet, stator blade thicknesses were decreased because of lower stress loads.

Table 3-5 iterates turbine design parameters from AIRPHX Report 74-311068.

3.4.1.4 Cooling System

The Mini-BRU is self-cooled. Compressor discharge gas is used to cool the alternator and bearings. This is accomplished by directing two percent bleed flow through the bearing and alternator cavities, with the remaining flow (from the diffuser exit) directed through a 0.1 percent pressure drop heat exchanger surrounding the alternator stator and field coils. This is shown schematically in Figure 3-2. Predicted operating temperature for 1- and 3-capsule heat source operation are shown on Figures 3-8B through 3-12. These two conditions define component, and system, design extremes.

3.4.1.5 Gas Bearing System

The Mini-BRU utilizes "dry starting" (without hydrostatic jacking gas) hydrodynamic gas journal and thrust bearings capable of operating over the specified power range with minimum losses, particularly in the zero-"G" mode. Bearing load capacity permits operation in any attitude, within one-"G", with the bearing cavity pressure that exists when compressor inlet pressure is at 10 psia minimum. Thrust bearing load capacity is sufficient to continuously support, hydrodynamically, maximum anticipated cycle thrust loads in any Mini-BRU attitude, including loads that might occur during start-up and shutdown.

Journal and thrust bearings are capable of starting and stopping, under conditions previously specified, without external pressurization.

TABLE 3-5

DESIGN PARAMETERS FOR MINI-BRU RADIAL TURBINE

<u>General</u>	
Working fluid	Xe-He mixture, 83.8 M.W.
Inlet pressure	105 psia
Overall pressure ratio	1.47
Inlet temperature	2060°R
Design weight flow	0.3571 lb/sec
Rotating speed	52,000 rpm
Specific speed	44.7
Stage efficiency	82.8 percent
<u>Rotor</u>	
No. of blades	10 full blades 10 splitters
Inducer tip radius	1.429 inches
Exit shroud radius	0.842 inches
Exit hub radius	0.5 inches
$\beta_{2_SHROUD} = 69.6^\circ$	$\beta_{2_HUB} = 57.9^\circ$
<u>Inlet Stators</u>	
No. of blades	17
Inlet radius	1.876 inches
Exit radius	1.483 inches
$\beta_{IN} = 0^\circ$	$\beta_{OUT} = 78^\circ$

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STEADY-STATE TEMPERATURES 1
HIGH POWER LEVEL

FIGURE 3-8B

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ALL TEMPERATURES IN °F

STEADY-STATE TEMPERATURES I
LOW POWER LEVEL

FIGURE 3-10

FIGURE 3-11

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TEMPERATURES ARE SHOWN IN °F

**ALTERNATOR STATOR TEMPERATURES
AT HIGH-POWER OPERATION**

FIGURE 3-12

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To assure motor start capability, the bearings' total resisting breakaway torque is expected to be less than 60 percent of alternator motor-ing torque, at three times rated alternator output current. If high-g bearings (for operation through launch) are used, breakaway torque will increase approximately 25 percent. Breakaway torque is based on one-"G" loading on thrust and journal bearings. Torque data is presented in AIRPHX Mini-BRU Progress Report, 74-310631(16).

Gas bearing materials selection, and application of coatings, provide a minimum of 1000 start-stop cycles.

3.4.1.6 Instrumentation

Mini-BRU design incorporates the following instrumentation (see Drawing SKP32488):

- (a) Chromel-alumel thermocouples to measure critical static component and local gas temperatures within the Mini-BRU. Placement is shown on SKP32488.

Gas-sealed hermetic through bulkhead-type receptacles are used for thermocouple connections. Friction contact sleeves similar to those in mating external sockets are used on thermocouple leads. All thermocouples are electrically insulated from alternator windings.

- (b) Three magnetic pickup shaft-speed sensors.
- (c) Static pressure measurement line with filters to sense pressure in each rotor and bearing cavity pressure zone shown on SKP32488.
- (d) A coil of one full pole pitch is installed in the stator for magnetic flux measurements.

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3.4.1.7 Physical Data

Mini-BRU physical dimensions and configuration are presented on the following AIRPHX drawings and parts list:

- o Engine Layout L3621255
- o Engine Assembly 240610-1
- o Parts List PL 240610-1
- o Engine Installation 240611-1

Drawing 3604385 and Table 3-6 show materials to be used for Mini-BRU component parts.

3.4.1.7.1 Weight Analysis

Mini-BRU assembly weight was determined by calculating and estimating component part weights. The weight breakdown is presented on Parts List PL 240610-1. Total weight, including the refractory plenum, is estimated at 36.1 pounds.

3.4.1.7.2 Interface Data - Static

Appropriate Mini-BRU static interface data is defined below:

- (a) Flange Loading - Turbine and compressor maximum allowable flange loads are calculated to be:

<u>Flange</u>	<u>Moment (in.-lb)</u>	<u>Shear (lb)</u>	<u>Axial Load (lb)</u>
Turbine Exhaust	400	300	300
Turbine Inlet	360	825	375
Compressor Inlet	500	400	450
Compressor Exhaust	TBD	TBD	TBD

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TABLE 3-6

MINI-BRU MATERIALS

ITEM NO.	DESCRIPTION	MATERIALS	FUNCTION	BASIS FOR SELECTION
1	IMPELLER, COMP.	CRES 410	GAS COMPRESSION	GOOD STRENGTH GOOD THERMAL CONDUCTIVITY
2	TIE BOLT	INCO 718	RETAIN ROTOR ASSY	GOOD COMBINATION OF STRENGTH AND FATIGUE PROPERTIES
3	NUT, TIE BOLT	4340 STEEL	RETAIN ROTOR ASSY	GOOD STRENGTH
4	WASHER, TIE BOLT	CRES 347	LOCKS ITEM 3	PAST EXPERIENCE
5	ROTOR, THRUST BRG.	6260 STEEL	THRUST SUPPORT	STRENGTH & HIGH HARDNESS
6	WHEEL, TURBINE	INCO 713LC OR ASTROLOY	ENERGY EXTRACTION	PAST EXPERIENCE - HIGH TEMP. STRENGTH & FABRICABILITY
7	ROTOR, ALTERNATOR	HP9-4-20, 713LC	INTERRUPT FLUX FIELD	PAST EXPERIENCE WITH TAC
8	HEAT SHUNT	COPPER	CONDUCT HEAT FROM THRUST ROT. TO COMP. IMP.	HIGH THERMAL CONDUCTIVITY
9	FOIL BRG, JOURNAL	INCO X-750	RADIAL SHAFT SUPPORT	PAST EXPERIENCE
10	FOIL BRG, THRUST	INCO X-750	AXIAL SHAFT SUPPORT	PAST EXPERIENCE
11	SPRING, FOIL BRG.	INCO X-750	FOIL LEAF SUPPORT	PAST EXPERIENCE
12	SLEEVE, FOIL BRG. COMP.	4340 STEEL	RETAIN FOIL LEAFS	THERMAL EXPANSION COMPATIBILITY
13	SLEEVE, FOIL BRG. COMP.	4340 STEEL	RETAIN FOIL LEAFS	THERMAL EXPANSION COMPATIBILITY
14	RET. FOIL JOURNAL	CRES 300	RETAIN FOIL LEAFS	GOOD FABRICABILITY LOW COST
15	PLATE, THRUST BRG.	17-4PH STAINLESS	THRUST BRG SUPPORT	HIGH STRENGTH - GOOD FATIGUE COMPATIBLE THERMAL EXPERIENCE
16	SHIM, THRUST BRG.	CRES 300	CONTROL THRUST BEARING CLEARANCE	CORROSION RESISTANCE, LOW COST
17	SPACER, THRUST BRG.	17-4PH STAINLESS	SPACE THRUST PLATES	THERMAL EXPANSION COMPATIBILITY
18	SHIM, COMP.	CRES 300	CONTROL COMPRESSOR CLEARANCE	CORROSION RESISTANCE, LOW COST
19	SFAL COMP. BACK SHROUD	CRES 347	CONTROL GAS CIRCULATION ON BACKSIDE OF ROTOR	CORROSION RESISTANCE, GOOD FABRICABILITY
20	INLET, COMP.	CRES 347	CHANNEL GAS FLOW	CORROSION RESISTANCE, GOOD FABRICABILITY
21	DIFFUSER COMP.	CRES 17-4PH	INCREASE P _s	CORROSION RESISTANCE, GOOD FABRICABILITY, HIGH STRENGTH
22	END BELL, COMP.	1018 STEEL	CHANNEL MAGNETIC FLUX	GOOD MAGNETIC PROPERTIES GOOD THERMAL CONDUCTIVITY
23	END BELL, TURB.	1018 STEEL	CHANNEL MAGNETIC FLUX	GOOD MAGNETIC PROPERTIES GOOD THERMAL CONDUCTIVITY
24	HSG. ALTERNATOR	1018 STEEL, CRES 347	CHANNEL MAGNETIC FLUX	GOOD MAGNETIC PROPERTIES GOOD THERMAL CONDUCTIVITY
25	TURB. BACK SHROUD	WASPALLOY	CONTROL GAS CIRCULATION ON BACKSIDE OF ROTOR	HIGH TEMPERATURE CAPABILITY
26	PLENUM, TURB.	Cb-103	CHANNEL TURBINE GAS	HIGH TEMPERATURE STRENGTH & CREEP LIFE
27	FIELD COIL BOBBINS	Al 2024	CONTAIN FIELD WINDINGS	GOOD THERMAL CONDUCTIVITY NONMAGNETIC
28	SHIM, TURB.	CRES 300	CONTROL TURBINE CLEARANCE	CORROSION RESISTANCE, LOW COST
29	RING, HERMETIC SEAL	CRES 347	GAS SEAL TO ATMOSPHERE	CORROSION RESISTANCE, GOOD WELDABILITY
30	RING, HERMETIC SEAL	CRES 347	GAS SEAL TO ATMOSPHERE	CORROSION RESISTANCE, GOOD WELDABILITY
31	SHIM ALT. ADJ.	CRES 300	CONTROL ALT POSITION	CORROSION RESISTANCE, LOW COST
32	COVER -2 ALT LEADS -1	CRES 347	PROTECT ALT TERMINALS	CORROSION RESISTANCE, LOW COST
33	ORIFICE, BLEED FLOW	CRES 347	METER TURBINE BEARING COOLING GAS FLOW	CORROSION RESISTANCE, LOW COST
34	STACK LAMINATIONS	AL4750 STEEL	CHANNEL MAGNETIC FLUX	GOOD MAGNETIC PERMEABILITY
35	COATING, FOIL BRGS.	OBD-26 OR TEFLON-S	REDUCE FRICTION DURING STARTUP	HIGH TEMPERATURE CAPABILITY, LOW FRICTION, DURABILITY

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- (b) Center of Gravity - Estimated at 5.75 inches from the compressor inlet flange, and 0.02 inch from the center-line in the direction of the alternator terminals.
- (c) Orientation - Any attitude.
- (d) Mounting - An 8-bolt hole patterned, large OD flange, at the compressor-end, which may be adapted to a variety of mounting arrangements (see Drawing 240611-1).

3.4.1.7.3 Interface Data - Dynamics

Appropriate Mini-BRU dynamic interface data is defined below:

- (a) Rotating group polar moment of inertia (I_p): Calculated to be 0.00149 in.-lb-sec².
- (b) Rotating group diametral moment of inertia (I_d): Calculated to be 0.0359 in.-lb-sec².
- (c) Bearing span: Center of journal to center of journal = 3.63 inch.
- (d) Unit rotating speed: 52,000 rpm
- (e) Critical speeds:
 - o First rigid body critical = 10,560 rpm
 - o Second rigid body critical = 17,129 rpm
 - o Third bending critical = 127,000 rpm

3.4.1.8 Electrical Data

Location of electrical connections is shown on Installation Drawing 240611-1. Electrical connector types are TBD.

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3.4.1.8.1 External Magnetic Field

Magnetic field intensity, external to the Mini-BRU and generated by the Rice alternator, will be determined during GDS testing.

3.4.1.9 Radiation Tolerance

Alternator materials and system electronics radiation tolerances will be determined and appropriate shielding provided, if necessary.

3.4.1.10 Handling and Storage

Mini-BRU handling and storage procedures are defined as follows:

- (a) At all times, protect the Mini-BRU from moisture during handling and storage. Specific procedures are TBD, although vacuum packing with desiccant is under consideration.
- (b) Maintain Mini-BRU temperature, during storage, below 200°F.
- (c) Keep all refractory alloy parts in a vacuum, or inert environment, if exposed to temperatures above 400°F.
- (d) Special handling procedures are TBD for Multi-Foil insulation protection.

3.4.1.11 Cleaning

Cleaning procedures are TBD.

3.4.1.12 Nuclear

Nuclear characteristics are TBD.

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3.4.2 Mini-Brayton Recuperator (MBR)

The MBR functions to transfer turbine discharge working fluid thermal energy to the compressor discharge working fluid. This thermal energy recovery increases cycle efficiency by reducing required heat source output for a given power level.

MBR design requirements, for the reference 2.08 kw_e system, are presented on Table 3-7. Heat transfer performance is based on no heat loss to the surroundings. MBR detail design is complete, with parts fabrication in process. First delivery is anticipated for late 1976.

3.4.2.1 Physical Data

MBR design is shown on Figure 3-13, Table 3-8, and Drawing 190930. Envelope dimensions are 32.1 inches by 16.3 inches by 9.4 inches. Internal construction, illustrated in Figure 3-14, is typical of that used on counterflow heat exchangers. Heat transfer takes place predominately in the rectangular counterflow section where high-performance rectangular offset fins are used. Triangular end sections are used to distribute and collect gas flow to, and from, the counterflow section. End sections incorporate plain rectangular fins to uniformly distribute gas flow, with minimum pressure drop. In the core pure counterflow section, fins in the hot and cold passages are 20R-0.10-1/8-0.004 (20 fins per inch, rectangular, 0.10 inch high, 1/8 inch offset, and 0.004-inch thick). In transition sections, plain rectangular fins (16 fins per inch) are utilized. Additional core features are shown in Figure 3-15.

3.4.2.1.1 Materials

The MBR is fabricated entirely from Hastelloy X. The core assembly is brazed, using gold-base braze alloys applied in foil form.

TABLE 3-7

MBR DESIGN REQUIREMENTS

Item	Requirement
System net power output, kw_e	2.08 (ref 3 heat source capsule design)
Working fluid	Xe-He (M.W. = 83.8)
Hot side (low pressure)	
Flow rate, lb/sec	0.357
Inlet temperature, °R	1792
Inlet pressure, psia	71.7
Cold Side (high pressure)	
Flow rate, lb/sec	0.350
Inlet temperature, °R	685
Inlet pressure, psia	106.2
Effectiveness (cold side)	0.975
Pressure drop, total of both sides, percent	0.70
Operating life, years	10
Number of startup/shutdown cycles	1000
<p>NOTE</p> <p>Refer to Appendix I, Figure I-1 for corresponding cycle data.</p>

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MINI-BRU RECUPERATOR

FIGURE 3-13

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MBR CORE DETAIL

FIGURE 3-14

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MBR CORE DESIGN

FIGURE 3-15

TABLE 3-8

MINI BRAYTON RECUPERATOR (MBR) MATERIALS

ITEM NO.	PART	MATERIAL	FUNCTION	BASIS FOR SELECTION
1	FINS	HASTELLOY-X WITH GOLD BASE BRAZE	HEAT TRANSFER; STRUCTURAL MEMBERS.	YIELD STRENGTH, CREEP STRENGTH, RESISTANCE TO LOW CYCLE FATIGUE AT ELEVATED TEMPERATURES (1330°F)
2	TUBE PLATES		CONTAINMENT OF WORKING FLUID; SURFACE FOR HEAT INTERCHANGE.	
3	HEADER BARS		CONTAINMENT OF WORKING FLUID; PREVENTS EXCESSIVE FIN DEFORMATION DURING BRAZING.	
4	SPLITTERS		GAS FLOWPATH; BULKHEADS BETWEEN HIGH AND LOW PRESSURE FLOW.	
5	SIDE PLATES		CONTAINMENT OF WORKING FLUID; ATTACHMENT POINT FOR PAN ASSEMBLIES.	
6	SEAL PLATES		SECONDARY CONTAINMENT OF WORKING FLUID IN EVENT OF HEADER BAR-TO-PLATE JOINT DEFECT.	
7	SIDE FLANGES		STRUCTURAL COMPONENT FOR ATTACHING PAN ASSEMBLIES TO SIDES OF CORE ASSEMBLY.	
8	PAN ASSEMBLIES		CONTAINMENT OF WORKING FLUID; CONTROLS FLOWPATH INTO AND OUT OF CORE PLATE-FIN MATRIX.	
9	MOUNT ASSEMBLIES		FOR ATTACHING RECUPERATOR TO POWER SYSTEM SUPPORT NETWORK.

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3.4.2.1.2 Structural Design Criteria

MBR design criteria are summarized as follows:

- (a) Design Operating Life - 100,000 hr (approximately 10 years) at 1330°F maximum operating temperature.
- (b) Cyclic Life - 1000 operating cycles without failure for contractual transients. Revised transient start-up conditions, which form the basis for new analysis and development testing, are shown in Plots A and B in Appendix III. Additional transient performance details are included in AIRPHX Report 75-311279, dated May 19, 1975.
- (c) Short-Time Pressure Containment - At operating conditions and 2.5 times the working pressure. Room-temperature proof pressure testing will be accomplished to verify these pressure capabilities.

NOTE

High-pressure-side pressure must be greater than low-pressure-side pressure, with a maximum allowable pressure differential of 85 psi across the manifold splitter plate.

- (d) Inertial and Vibratory Loads - Conditions are as specified in Contract NAS3-18029, Exhibit E. Design allowable stress for inertial loads is determined from short-term material properties using the following equation:

$$\sigma_{all} = (f_{tu})/2.5$$

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Where: σ_{all} = Allowable stress

f_{tu} = material ultimate tensile stress

Allowable indicated elastic stress, due to bending loads, is established at 1.5 times the allowable value computed using the above equation.

3.4.2.2 Detail Design Data

A list of drawings with an estimated weight breakdown of components comprising the MBR is presented in Table 3-9. Additional design data is presented below:

- (a) Estimated Weight - 132 lb (could be reduced to 106 lb for 1300 W_e system)
- (b) Center of Gravity - TBD
- (c) Dimensions - Refer to Outline Drawing 190930.

3.4.2.3 Installation Data

Specific installation items include the following:

- (a) Mounting Provisions - Designed for mounting at four locations, with allowable mount loads and thermal growth provisions as defined on Drawing 190930.
- (b) Interface Connections - Flange location and style, position tolerance, and allowable interface loads are defined on Drawing 190930.

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TABLE 3-9

LIST OF DRAWINGS AND WEIGHT BREAKDOWN
OF MINI-BRAYTON RECUPERATOR
P/N 190930-1-1

AiResearch Drawing Number	Description	Estimated Weight
190930	Recuperator outline	--
190931	Recuperator assembly	132.5
189614	Core assembly	115.42
189627	Pan assembly	3.42
189936	Pan assembly	3.48
189629	Identification plate	0.10
189809	Flow direction plate	--
197-505-9004	Protective cap	--
189615	Tube plate	36.30
189616	Side plate	4.16
189622	Channel header	0.03
189623	Header bar	1.90
189677	Header bar	1.98
189617	Offset fin	20.09
189618	Turning fin	0.52
189619	Turning fin	1.51
189624	Pan splitter	0.93
189625	Pan splitter	3.60
189626	Side flange	3.64
189628	Mount	1.29

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- (c) Duct Arrangement - Working fluid flow through the MBR must be as shown on Drawing 190930. Flow direction arrows are permanently attached to each of the four ducts.
- (d) Contamination - The recuperator assembly is cleaned in accordance with AIRPHX Specification C-38, using tri-chlorotrifluoroethane followed by a nitrogen purge to achieve Class II, Level III cleanliness.
- (e) Allowable Pressure Differential - Test operations shall be conducted to assure that a maximum pressure differential of 85 psi, across the high- and low-pressure sides of the recuperator, at operating temperatures is not exceeded.

3.4.2.4 Environmental Conditions

The MBR is designed to withstand environmental conditions listed in Contract NAS3-18029, Exhibit E, without malfunction or performance degradation.

3.4.2.5 Maximum Allowable Leakage

After completing all manufacturing operations, the MBR is subjected to a proof-pressure test and is leak tested using a helium mass spectrometer. MBR leakage is required to be less than 10^{-7} standard cc He/sec, to surroundings, and less than 10^{-7} standard cc/sec between streams.

3.4.2.6 Nuclear

Nuclear characteristics are TBD.

3.4.3 Heat Source Assembly (HSA)

The HSA functions to receive radiated heat, from a heat source, and impart this heat into the working fluid. This heat impartation is accomplished by forced convection, utilizing a Heat Source Heat Exchanger (HSHX). While the FS heat source will be radioisotopic, it is intended that the GDS heat source be an electrical resistance heater.

The HSA, which does not include a heat source, is designed to accommodate the ERDA Multi-Hundred Watt (MHW) isotope heat source, as described in NASA CR 121223 (Volumes I and II), and is capable of transferring 2400 W_t to the power conversion system working fluid. The HSA is also designed to accommodate the GDS Electrical Heat Source (EHS).

Specific design parameters are:

- (a) Design Life - 7 years
- (b) Thermal Cycles - Capability to sustain 100 startup-shutdowns
- (c) Power Source - Capability of operating with 24 W_t MHW heat source of electric heat source simulator for ground test demonstration
- (d) Working Fluid - Xe-He (M.W. = 83.8)
- (e) Weight Goal - 90 lb
- (f) Environmental - Capability to operate in a space vacuum and meet conditions specified in Exhibit C of NAS3-18541 and as TBD

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- (g) State Points - Inlet temperature 1307°F
Outlet temperature 1600°F
Flow 0.12 lb/sec

The HSA includes the following items:

- (a) HSHX
- (b) A Multi-Foil insulation blanket
- (c) An outer housing with mounting points and instrumentation leads
- (d) Auxiliary Cooling System (ACS)
- (e) Emergency Cooling System (ECS)

The HSA is defined on Drawing SK No. MB-30-4-75-1. Figure 3-16 is an exploded view of the HSA, showing component parts, and Table 3-10 provides a materials list.

3.4.3.1 Auxiliary Cooling System (ACS)

ACS design must encompass the following temperature limitations:

- (a) Maximum temperature of exposed surfaces: 380°F - assumes forced cooling (ground support furnished) on exposed surfaces, or cooling and inert gas flow in the ACS.
- (b) Maximum temperature of refractory alloys exposed to air: 400°F

EXPLODED VIEW REFERENCE BASELINE HSA

HSA REFERENCE DESIGN

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FIGURE 3-16

TABLE 3-10

HEAT SOURCE ASSEMBLY (HSA) MATERIALS

Item No.	Part	Material	Function	Basis For Selection
1	Insulation Blanket (HSIS)	Zirconia coated multi-foil. (Cylindrical sect.) inner layer 0.005 in. C-103: 59 outer layers. 0.0005 in. Ni; End caps, inner layer 0.005 in. C-103: 59 outer layers, 0.0005 in. C-103	Minimize heat loss; conductive path during auxiliary cooling periods; emergency heat removal-cylindrical section only (Ni layers melt at 2650°F).	Superior insulating properties
2	Insulation Blanket Support Structure	Cb-103	Provide support to HSIS during launch.	High temperature strength and compatibility with HSA
3	HSHX Mounting Supports ("L" Brackets)	Cb-103	Supports HSHX; permits radial and longitudinal expansion.	Compatible w/HSHX
4	Heat Source End Supports	Graphite (Tentative)	Provide large surface area to distribute heat source preload.	MHW/RTG program experience
5	Heat Source Mounting Brackets	Cb-103	Structural support for HSHX.	Compatible w/HSHX
6	End Enclosures (Spiders)	Titanium	HS support; compensates for thermal expansion and contraction between HS and outer case.	MHW/RTG program experience
7	Preload Fitting	INCO X 750	Preloads end enclosures under compressive load.	MHW/RTG program experience
8	Heat Source Heat Exchgr (HSHX)	C-103	Transfer of heat from heat source to power conversion system via working fluid.	High temperature strength and creep life; excellent formability.
9	Inlet-Outlet Headers	C-103	Provides egress and ingress of working fluid, out of and into the HSHX.	High temperature strength and creep life.
10	Be External Support Housing w/End Domes	Beryllium (FS) Stainless Steel (GDS)	Houses heat source, HSHX, and support assembly (Items 4-7 above); transmits launch loads.	MHW/RTG program experience.

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To accomplish this, HSA design includes a Multi-Foil insulation system that will function as an effective insulation in a space hard vacuum environment. Auxiliary HSA cooling is required immediately after isotope heat source loading, if the BIPS remains idle for more than a short (TBD) period of time. The ACS utilizes a method of filling the HSA outer surface. This results in a radial temperature gradient reduction, across the HSA, such that fuel sphere assemblies within the heat source are at acceptable temperatures. The HSA retains this inert gas by the sealed housing. (The GDS HSA will utilize a stainless steel housing in lieu of the more expensive FS HSA beryllium housing.) Conversely, this sealed design prevents air from entering the refractory and graphitic parts of the HSA. To ensure that HSA exterior surfaces are maintained below 380°F on the launch pad, forced convection cooling over the surface may be necessary. Tests conducted on the MHW-RTG indicate that temperatures below this limitation can be provided with moderate nitrogen gas flow rates. An alternate approach for maintaining exterior surfaces below 380°F would be to use a cooled, flowing, inert gas in the ACS.

Operation with the space shuttle may require a revision in ACS utilization. A preliminary evaluation indicates that, during pre-launch operation, cooling gas must be circulated through the HSA housing to reject prelaunch generated heat, and to subcool the system prior to launch. Detailed temperature profile analyses, for normal and abnormal operating conditions, will be accomplished during the second phase of Task 2.

Gas venting from the HSA is effected by ground command, which fires a squib to rupture a vent disc. Eliminating this gas from the HSA allows the Multi-Foil insulation system to again perform as an effective insulation.

Advantages of this design approach are:

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- (a) High reliability is provided by the helium filled, and sealed, HSA and by using cooling gas flow (on-pad).
- (b) Low weight due to minimum additional (vent system) hardware
- (c) Minimal heat leaks by eliminating insulation penetrations (i.e., piping connections)
- (d) Low development risk since no new technologies are involved
- (e) Capability of being ground tested

3.4.3.2 Emergency Cooling System (ECS)

The emergency cooling concept is based on a HSA insulation system, with a relatively low melting point, to assure melting during an emergency situation. Analysis, performed by GE, indicate that a loss in insulation effectiveness allows safe temperatures to be maintained within the heat source.

In determining feasibility of a melting insulation system, transient and steady-state temperature response analyses were performed. In addition, accomplishing a scheduled, full-scale, melt down test is expected to provide evidence that the ECS functions as intended.

The melting insulation ECS design concept offers:

- (a) High reliability (to be determined)
- (b) Low weight
- (c) High thermal efficiency
- (d) Low development risk
- (e) Low development and unit cost
- (f) Unlimited operating duration

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The ECS must maintain the heat source (HS) at a safe temperature in the event of power conversion system failure (maximum HS surface temperature is estimated at 3000°F). During ECS activation, the HS outer surface maximum temperature shall not exceed 2700°F for more than 15 minutes.

3.4.3.3 SHX

SHX design parameters include:

- (a) Material - Columbium (niobium) alloy C-103
- (b) Maximum Pressure Drop - 0.22 psi at flow rate of 0.126 lb/sec and pressure of 35.3 psia
- (c) Maximum Leak Rate - 1×10^{-9} standard cc/sec of helium
- (d) Maximum Design Life Creep Rate - 2-percent (radial direction) and 1-percent (axial direction) at design temperature, plus 50°F, with 15-percent safety margin.

The SHX is defined on GE Drawing 707E839.

3.4.3.4 Development Status

Under the current NASA Contract (NAS3-18029), detail design is completed with fabrication in progress. First delivered hardware is expected in late 1976.

3.4.3.5 Interface Data

Interface data is TBD.

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3.4.4 Heat Rejection Heat Exchanger (HRHX)

A vacuum tank with refrigerated walls and proper emissivity and absorbance would be needed to properly simulate the effective space radiant temperature (217°K or 390°R is the temperature used for all performance estimates herein) for the space radiator. To simplify system and test facilities designs, a liquid to gas HRHX, that simulates space radiator effects, will be designed and fabricated for GDS testing. The HRHX is depicted on Figure 3-17.

It is intended that HRHX design simulate a radiant cooler, as nearly as possible. This includes heat exchanger effectiveness, pressure drop, and dynamic responses to transients. The design must also have structural integrity compatible with system reliability and safety objectives.

3.4.4.1 Steady-State Performance

Basic HRHX performance meets the engine defined steady-state performance criteria. Drawing L3621587 represents the required HRHX envelope, for integration with the system. It has been determined that this envelope is compatible with cooler requirements.

3.4.4.2 Dynamic Simulation

It is important to achieve reasonable dynamic similarity between the HRHX and FS radiator designs to assess overall effects on system performance. Since the cooler time constant is expected to be long, relative to major system dynamics, an exact dynamics match should not be required. However, a comparative evaluation will be made, using the digital computer Dynamic Simulation Model, in the event that heat exchanger characteristics are significantly different.

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HEAT REJECTION HEAT EXCHANGER
BIPS-GDS

FIGURE 3-17

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3.4.4.3 Structural Analysis

To ensure system integrity, HRHX stress and vibration analyses will be made. Since this is a simple, non-flight configuration, only the analyses that assure safety and reliability will be performed.

3.4.4.4 Structural Integrity

Proof pressure testing will be conducted to obtain pressure drop data and structural integrity confidence. Testing pressure and temperature will be specified as a result of a stress analysis.

3.4.4.5 Performance Verification

A heat transfer performance test will be conducted, after the HRHX is assembled into the GDS, using air on the working fluid side of the heat exchanger. The cooling side temperature control loop will be operating during this test to verify heat exchanger operation, as a system.

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3.4.5 Controls

The GDS control system is designed to perform the following major functions:

- o Engine starting
- o Engine shutdown
- o Load-following capability
- o Component protection

GDS controls will be designed to implement control functions that are expected in the FS. Controls will employ "breadboard" electronic circuit hardware. During GDS design and development, consideration will continually be given to ultimately miniaturize controls hardware for the FS.

A major design requirement is to provide the flexibilities to modify design, alter individual circuits, and adjust set points and gains. This permits exploration of a variety of control modes, and maximum accumulation of engineering data during the development phase.

3.4.5.1 Development Status

A control system developed by AIRPHX for the NASA "B" Engine (a 15 kw_e closed Brayton cycle) has been tested for over 32,500 hours. A follow-on system was breadboarded by NASA-Lewis Research Center, which also conducted initial functional tests and derived system performance characteristics.

This system is currently being evaluated for use on the GDS. The design provides considerable latitude for improving functional characteristics and reliability, through redesign and adding redundant components.

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An AIRPHX designed alternate control scheme is also being evaluated. Although similar in philosophy, this scheme differs considerably from the NASA control in circuit implementation. However, the alternate control scheme does provide a basis for trade-off.

3.4.5.2 Reliability

Control system reliability requirements are TBD.

3.4.5.3 Physical Data

Control system physical data are TBD.

3.4.5.4 Description of Operation

Controls and instrumentation required for GDS ground testing are shown on Figure 3-18 and schematically on Drawing 306960. This schematic shows the basic engine loop and nomenclature used to define various state points around the loop, along with major required laboratory connections.

The electrical heat source is supplied electrical power, from the facility, to provide heat to the closed Brayton cycle loop. Power to the electrical heater will be constant to simulate isotope heat source input. The laboratory setup contains an argon supply, and vacuum system, to allow the heat source to be pressurized and conduct heat to ambient, or to be evacuated. This greatly reduces conduction to ambient, and allows heat to enter the Brayton loop.

The basic loop contains a turbine bypass shutoff valve (SV-1) and a pressure relief valve (PRV-1) in the control loop for development testing protection. (To enhance reliability and avoid inadvertent system shutdowns, SV-1 will consist of two normally open valves,

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BLOCK DIAGRAM
BASIC IBFS CONTROL SYSTEM

FIGURE 3-18

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in series.) The bypass is used to accept flow directly from the compressor to turbine discharge, thus bypassing the turbine and reducing engine power. Although the compressor continues to require energy for gas flow compression in bypassing the turbine, the rotating group power and speed are both reduced. This bypass applies to fault and overspeed protection only, since normal speed control is provided by the electrical parasitic load, which is a function of speed, T_6 , and user load. PRV-1 is a safety feature to prevent overpressuring the entire loop and damaging ducting and heat exchangers.

Check valve (CV-1), in the compressor discharge, prevents reverse flow during startup. The possibility of removing CV-1 will be investigated during engine testing.

The HRHX (radiator simulator) will be supplied with liquid coolant. HRHX inlet, and outlet, gas stream temperatures will be monitored and an automatic control will adjust cooling flow to control the outlet temperature.

The test loop will not be as well sealed as the flight configuration, because the test loop contains extensive instrumentation and more potential leak paths. For this reason, in addition to the initial charge, a He-Xe tank is connected to the loop for charging during operation. A pressure regulator is used to control inlet pressure into the Brayton closed loop, and will replenish leakage as required, to maintain constant pressure.

As stated above, the turbine bypass valve is a fault and overspeed device used only for system protection. The bypass is actuated by faults, which could be damaging to the engine, including:

- o Engine overspeed
- o Overtemperature of compressor inlet, turbine inlet, bearings, or alternator

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o Underpressure of bearings

In addition to the automatic shutdown feature, an alarm is initiated when dc voltage is too high, or too low, or when compressor discharge pressure is too low (requiring make-up gas), or when the engine is motored for too long a period during the start cycle.

Start is initiated by momentarily depressing a start switch. This applies power, from the batteries through the inverter, to the alternator, which motors the compressor and turbine. The electric heaters will be separately controlled and at operating temperature, it is only necessary to create flow through the heater by driving the compressor to sufficient speed. Heated gas then enters the turbine and a net positive torque can be achieved as heat to the turbine increases.

Since thermal stress is a major consideration, it may be desirable to limit the heat exchangers temperature rise rate. The temperature rise rate can be reduced if the flow rate is lower. It is anticipated that the rate of temperature rise can be limited by the rate of speed rise. Therefore, the speed control set-point may be programmed to be ramped with time or as a function of recuperator discharge temperature. This will control the speed change rate, and subsequently, the temperature rise rate. It is desirable to achieve self-sustaining speed before this scheduling occurs, to minimize battery power required for the start cycle.

Engine shutdown is accomplished by a signal to the speed control that reduces the speed set point. An overload that drives the engine below self-sustaining speed will be produced by the alternator. The engine should then roll down rapidly, and the heater pressurized with argon, or helium, to short circuit the insulation and allow thermal energy dissipation.

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The flight monitoring system will be included in the GDS to a limited degree. It is anticipated that transducers selected for flight, and some associated electronics, will be included in the test. This test provides an opportunity to study installation and to log endurance time on proposed flight monitoring equipment.

3.4.5.5 Drawings and Parts List

Control system drawings and parts list are TBD.

3.4.5.6 Interface Data

The following interface data applies to the control system:

- (a) Electrical Power Output - See Section 3.1, item (f) and Table I-1, Appendix I.
- (b) Electrical Connectors - TBD.
- (c) Electrical Power Input for EHS - Provided by Power Supply Console, which requires 120 ± 5 percent vac (60 ± 3 Hz) facility power.

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3.4.6 Ancillaries

Data on the following ancillary components will be documented, pending further design definition.

3.4.6.1 Bi-Metallic Joints

Materials of various components in the GDS require that two types of bi-metallic joints be developed. Materials in the ducting sections between the MBR and HSHX inlet(s), and MBR and Mini-BRU turbine exhaust require Hastelloy "X" to Columbium Alloy C-103 joints. The space radiator will require an aluminum alloy and/or beryllium alloy to stainless steel ducting joint. This joint will be made by brazing in accordance with commercially available procedures.

The high temperature Hastelloy X to Columbium Alloy C-103 joint is being developed at NASA, with two configurations under study. One configuration provides a joint by direct brazing, using a nickel-base alloy. The second method involves a transition joint made from blended powder metal (80 percent W, 14 percent Ni, 6 percent Fe at the Columbium Alloy C-103 end, and 30 percent W, 49 percent Ni, 21 percent Fe at the Hastelloy X end). The joint will be brazed to the Columbium Alloy C-103 ducting. Brazing and TIG welding are being evaluated for joining to the Hastelloy X.

A test program to evaluate mechanical integrity (after joint aging and cycling), and metallurgical stability (of joint combinations) will be performed prior to final joint configuration testing.

3.4.6.2 Ducting

To optimize the GDS ducting system and facilitate interface design of all system components, four basic requirements were considered. These are:

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- (a) Orientation of components relative to one another
- (b) Orientation of Mini-BRU during launch
- (c) Minimize flange loading due to ducting pressure and thermal growth
- (d) Thermal loss and pressure drop

The approach developed to meet these basic requirements is shown on Drawing L3621580. Short lengths of straight ducting were utilized, wherever possible, to minimize flange loading, especially in the turbine plenum area where temperatures and stresses are highest. By reducing the number of bends, pressure drop is minimized, and, short duct lengths minimize thermal loss. Multiple bellows links are used to absorb the large relative thermal growths of components.

Three duct diameters were used; 1.50, 1.60, and 2.50 OD. Wall thicknesses remain TBD. Fusion welding will be used in joining the system.

Figure 3-19 presents a duct size summary, listing requirements for each duct in the system. Included in this summary are the required size and number of each bellows in the system, plus the number and locations of all duct weld joints. Figure 3-20 is a working fluid system schematic that represents the ducting in Figure 3-19. It should be noted that two joints per bellows (connecting bellows convolutions to the weld cuffs) are not shown on Figure 3-20.

Sheet 3 of Drawing L3621580 shows locations and configurations of the Columbium Alloy C-103 welds to be made. Sheet 4 of Drawing L3621583 shows all GDS joints.

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GDS DUCT SIZING SUMMARY

Duct No.	No. of Joints	Material	Temp °R	Press Psia	O.D. in.	Wall in.	Duct* Length	No. of Bellows	Bellows Length
1	6	Hast-X	1757	57.7	2.50	0.035	46.3	3	3.00
2	3	Hast-X	1757	57.7	1.60	0.035	10.0	1	2.00
3	2	Hast-X	1757	57.7	1.60	0.035	6.0	1	2.00
4	1	C103	2060	57.6	1.60	0.050	6.5	1	3.35
5	1	C103	2060	57.6	1.60	0.050	6.5	1	3.35
6	9	Hast-X	1778	37.7	2.50	0.035	48.6	4	3.00
7	10	Cres	672	37.6	2.50	0.035	86.0	2	3.00
8	11	Cres	480	37.0	2.50	0.035	67.0	3	3.00
9	3	Cres	628	57.8	1.50	0.035	16.0	1	2.00
10	3	Cres	628	57.8	1.50	0.035	18.0	1	2.00
11	3	Cres	628	57.8	2.50	0.035	13.00	-	-
12	5	Cres	672	57.8 max	0.75	0.025	TBD	-	-
13	2	Cres	480	37.0	TBD	TBD	TBD	-	-

*Includes bellows length

FIGURE 3-19

75-311274B

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GDS WORKING FLUID SYSTEM
FIGURE 3-20

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Drawing SKP32749 shows the HSA assembly sequence, tentatively agreed upon by GE and AIRPHX. As shown, AIRPHX will supply stub end ducts for inlet and outlet ports to the HSHX.

The inlet stub end duct will consist of a Bi-metallic joint section of Columbium Alloy C-103 to Hastelloy X with a Hastelloy X bellows and cuff. The outlet stub end duct will comprise Columbium Alloy C-103 duct, and bellows, with a plenum interface weld flange.

3.4.6.3 Structure

Drawing L3621586 represents the GDS support structure, without the radiator. The structure comprises three sections as follows:

- (a) Upper support structure that supports the HSA
- (b) Lower support structure that supports the Mini-BRU and MBR
- (c) Interim struts that tie the upper structure to the lower structure and radiator.

Tubular construction is used to minimize weight, while maintaining a high degree of stiffness and strength. The GDS structure basic material is aluminum with mount interfaces and fasteners made of stainless steel or titanium.

Basic GDS design criteria, as currently defined by applied mechanics, is a lowest natural frequency of 60 Hz with all mounts and mount interfaces designed for 50 g limit loading. All struts and beams are designed for 25 g limit loading.

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3.4.6.4 Insulation System

Mini-BRU operating temperatures, relatively low output power, and high cost and weight of the radioisotopic heat source, require a low loss insulation system. The system tentatively selected for the GDS (and FS) consists primarily of a multiple layer metal foil insulation. Penetrations in hot areas must be kept to a minimum to limit the effects of these thermal short circuits. A detailed discussion of Thermo Electronics Multi-Foil insulation, and associated fabrication problems, is contained in Mini-BRU Progress Report, 74-310631(13). Total GDS losses, because extensive instrumentation is required, may be as high as $980 W_t$. The FS design goal is $600 - 650 W_t$.

Multi-Foil denotes a thermal insulation system developed by Thermo Electron Corporation in which thin metal foils are spaced in a vacuum by oxide particles. Examples of cylindrical and planar Multi-Foil constructions are shown in Figure 3-21. Oxide particles are selected on the basis of low thermal conductivity and foil compatibility, depending on application temperatures. The oxide particles are optimized relative to size, and real density, to minimize thermal transport. The multiple foils are effective thermal radiation shields, and the vacuum environment eliminates gas conduction heat transport. Oxide particles provide a high thermal impedance to conduction by:

- (a) Selecting oxides with low thermal conductivity
- (b) High thermal interface resistance between foils and particles
- (c) Thermal resistance of the thin foil

Multi-Foil has demonstrated low heat losses perpendicular to the foils. However, extreme care must be taken when designing and fabricating Multi-Foil assemblies, to minimize heat losses at the joints. Typically, joint heat loss is comparable to that directly through the foil.

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PLANAR AND CYLINDRICAL MULTI-FOIL INSULATION

FIGURE 3-21

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Three types of Multi-Foil will be evaluated for the GDS (and FS).

- o Conventional "cylindrical-planar" Multi-Foil
- o "Wrapped" Multi-Foil
- o "Electroformed" Multi-Foil

Thermo Electron has supplied AIRPHX with Multi-Foil heat transfer data generated in 1968-69 for the AEC. AIRPHX has reduced this data into the form of effective emissivity.

The effective emissivity derived from 61 TECO data points agrees well with published hemispherical total emittance data for "sand-blasted" nickel. Study of other published data suggests that the surface finish of "as received" nickel foil cannot be considered a polished surface, as assumed to date. An RMS surface finish of 0.01 microns (0.4 micro inches) is considered a polished surface. The nickel foil material, as tested, was close to a factor of 40 times this roughness. In light of this information, and effects of zirconia coating, correlation with the sandblasted surface data appears logical.

Current heat flux estimates are made using the semi-empirical equation below:

$$\frac{Q}{A} = \frac{4.457 \times 10^{-13}}{N} T_{HOT}^{4.82703} - T_{COLD}^{4.82703}$$

where:

$$\frac{Q}{A} = \text{Unit Heat Flux [BTU/hr-ft}^2\text{]}$$

$$T_{HOT} = \text{Hot Face or Foil Temperature [}^{\circ}\text{R]}$$

$$T_{COLD} = \text{Cold Face or Foil Temperature [}^{\circ}\text{R]}$$

$$N = \text{Number of Radiation Gaps Between } T_{HOT} \text{ and } T_{COLD} \text{ [Dimensionless]}$$

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3.4.7 GDS Tests

GDS tests and evaluation will consist of performance and endurance testing.

Performance tests will consist of performance mapping, and a series of start up and shutdown tests. The GDS will be instrumented for measurements to be taken at all key thermodynamic cycle state points, and at selected metal and insulation system temperatures.

The endurance test (following performance) will consist of operating the GDS for 1000 hours, with the following basic objectives:

- (a) Substantiate the FMECA
- (b) Determine life-limiting components
- (c) Determine the potential system lifetime
- (d) Detect basic design deficiencies that may exist in the original configuration, including synergistic effects
- (e) Detect test facility design discrepancies that could prevent economical long duration tests
- (f) Determine precise costs for testing (\$/hr for endurance testing).

The 1000-hours endurance test may be expected to accomplish the following:

- (a) Contribute in substantiating the FMECA (Objective a)

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- (b) May disclose system or component weakness not previously discovered in component tests or performance mapping (Objective d)
- (c) Demonstrate GDS ability to operate in a given test facility for 1000 hours (objective e)
- (d) Provide an accurate determination of test costs per hour (Objective f), which is important to follow on program planning
- (e) Provide a reasonable confidence level that test facilities and procedures will permit trouble-free GDS running over longer periods, if desired.

It is to be noted that the performance tests will also contribute to satisfying the same objectives. A listing of formal procedures, specifications, and tests, planned for the GDS is provided in AIRPHX Report 76-311737, entitled, "Specification Requirements Summary for the BIPS GDS".

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4.0 FACILITY

This section summarizes GDS vacuum system and test facility design objectives and requirements. GDS piping and instrumentation, associated controls, power to the HSAs, vacuum system, etc., are shown on Drawing 306960. The test facility will provide:

- (a) Energy and fluid requirements for GDS operation instrumentation, and vacuum facility.
- (b) A clean room for GDS assembly and instrumentation.
- (c) A vacuum chamber and pumping system for GDS space environment simulation.
- (d) Control panel, information readouts, recording equipment, and automatic failure shutdowns and alarms, as required.
- (e) Working fluid gas management system.
- (f) Vacuum chamber gas management system.

The following sections address the subjects of energy, clean room, and vacuum system requirements.

4.1 Facility Energies Requirements

A preliminary tabulation summarizing required energies to support the GDS test facility, has been compiled and is presented in Table 4-1.

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TABLE 4-1

ERDA BIPS ENERGY REQUIREMENTS

<u>Item</u>	<u>Elec. Req't (KW)</u>	<u>Tower Water (GPM)</u>	<u>Percent Usage</u>
<u>Vacuum System</u>			
WFMS Pump (15 scfm)	1		10
Ti Pump	~1	~1	100
Hi Vac Pump			
TM (ea.)	1.5	0.25	10
16 Oil	10	1.5	10
Fore Pump (100 cfm)	4	1	10
(Roots) (500 cfm)	3	(1)	10
Ti Pump Cavity Pump	1		5
Total	21.5	5	
<u>Loop Support</u>			
Waste Heat H.X. Refrig Loop (1.5 Ton)	7	2	100
HSA Power In	5		100
GE HSA GMS Service Cart	1		100
HSA Controls	1		100
Total	14	2	
<u>Miscellaneous</u>			
Low Gages (2)	0.2		100
Thermocouple Gages (2)	0.2		100
RGA (2)	1		100
Solenoid Valves (ea)	0.01		100
Engine Controls	0.1		100
Instrumentation	0.5		100
D.A.S.			
Sanborn (ea)	1		100
Tape Recorder (ea)	1		100
High Speed Digital	0.5		100
Vac Dry Box			
Pump System	5	3	1
Weld	5	3	
<u>Grand Total</u>	50	10

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4.2 Clean Room Requirements

As of the publication date of this CCD edition, clean room requirements have not been totally defined. However, the need for a clean room stems from stringent requirement that GDS components be as free from contaminants as possible. Possible contaminants include base material, oxidizer, H_2O , O_2 , N_2 , CO , CO_2 , dust, lint, oil and grease. The clean room will provide a highly controlled environment, and all personnel entering will be required to wear ultra-clean clothing. The completed GDS assembly will be bagged in a clean, dry atmosphere before delivery to the test area. However, specific clean room requirements are TBD.

4.3 Vacuum System Requirements

Vacuum system requirements are addressed in detail in Engineering Report 76-311736, which includes a study of a reference system. This section of the CCD presents a summary of this study and the vacuum system requirements.

4.3.1 Vacuum Chamber

The present 8600-liter reference vacuum chamber is large enough to house the GDS except that the HRHX will be mounted external to the chamber, regardless of chamber size, since it is desired that HRHX coolant flow not penetrate the chamber. This precludes any external GDS contamination from leaked coolant. The existing AIRPHX vacuum chamber would require considerable rework to: (1) install a double polymer gasket at the chamber mating flange (83 inch diameter) with intervening groove for evacuation with a roughing pump; (2) add new flanges for GDS operation parameter sensing, controls, power, HRHX piping, ion pressure gages, and various vacuum pumping system inlets; (3) remove the painted interior, preferably by glass bead blasting; and (4) thoroughly clean and degrease. A possible drawback is that

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the existing chamber is a mild steel chamber. Mild steel is subject to oxidation and H_2O retention to a greater extent than stainless steel. A smooth, unpainted, cleaned surface is required to lessen tank outgassing.

According to results of a system study (76-311736), which assumed an effective pumping speed of 2230 liters/sec pumping capacity and a vacuum chamber the same size as the present chamber (8600 liters), the present 8600-liter, mild-steel chamber if reworked as indicated above would be evacuated to 10^{-6} Torr in 35 hours. This time reduces to 22 hours if baked to $200^{\circ}F$ (Figure 4-1). Higher temperatures were not considered due to temperature limits of seals, gaskets, sensor lines, and other instrumentation, as well as a more stringent insulation requirement. Chamber cleaning and degreasing would be required each time the chamber was evacuated to ensure a reasonable pumpdown time. An aluminum chamber would have essentially the same outgassing, pumpdown characteristics, and cleaning requirements as a mild steel chamber. Plating a mild steel chamber does not significantly affect these characteristics.

By contrast, a cleaned and degreased stainless-steel chamber exhibits a significantly lower outgassing rate, and if a stainless-steel chamber is not cleaned, it exhibits outgassing characteristics similar to aluminum and mild-steel chambers. For an ultimate pressure of 10^{-6} Torr, a cleaned stainless-steel chamber with outgassing rate virtually the same, whether baked or not, gives a 22-hour pumpdown time for the reference system.

Currently known vacuum chamber penetration requirements are presented on Table 4-2. The table is arranged by usage and, in general, penetration locations will be on the chamber non-movable end. Possible exceptions to this are the ion pressure gages, which must be located at some distance from other power sources. Some parts may accommodate more than one usage (i.e., the inert gas backfill, number 5, could be in the same part as electrical power, instrumentation, etc.).

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ESTIMATED PERFORMANCE
BIPS GDS VACUUM TEST FACILITY

FIGURE 4-1

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TABLE 4-2

ANTICIPATED CHAMBER PENETRATIONS

<u>Item No.</u>	<u>Quantity</u>	<u>Port Diameter</u>	<u>Remarks</u>
1	1 or 2	12 in. to 16 in.	High vacuum pumps
2	1	12 in.	Sustaining pump
3	3	TBD	Ion gages
4	1	TBD	Residual gas analyzer
5	1	TBD	Inert gas backfill
6	1	TBD	Electrical power leads
7	1	TBD	Instrumentation
8	2	TBD	HRHX working fluid ducts
9	1	TBD	Sustaining roughing pump

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4.3.2 Pumping Requirements

Vacuum facility pumping requirements can be satisfied by a high vacuum pump of 1000 liters/sec. Under conditions of outgassing, which continues for several days after the ultimate pressure is reached, chamber pressure is proportionally inverse to the pump capacity. Engineering Report 76-311736 reported that the desired ultimate pressure of 10^{-6} Torr could be reached in approximately 22 hours, using a stainless steel chamber and an effective pumping speed of 2230 liters/sec. If this capacity were reduced to 1000 liters/sec, the pressure would be 2.23×10^{-6} Torr after 22 hours of pumping. Due to the steep negative pressure versus time curve (Figure 4-1) slope, additional pumping time required to bring the pressure to 10^{-6} Torr, for the assumed 1000 liter/sec pump, is only a matter of hours.

The type of pump to be used is still TBD, since all pumps have peculiar advantages and disadvantages. Requirements and candidate pump criteria that must be considered are:

- (a) Pump life and reliability
- (b) Need for isolation valves of adequate time response and sealing ability in case of pump failure and/or lubricant backstreaming into the chamber.
- (c) Need of some types of pumps to be furnished with a continuous supply of liquid nitrogen.
- (d) Liquid (refrigerant or water) cooling of some pumps may be required.
- (e) Isolation from the chamber may be required for pump rejuvenation while a vacuum is held in the chamber (i.e., a titanium sublimation pump ball or an absorption pump exchange).

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- (f) Size the roughing pump so that it may also be placed downstream of a mechanical or fluid entrainment pump to be used as a forepump.
- (g) Adequate shutdown and alarm sequencing is to be provided to preclude any detrimental effects on the GDS.
- (h) Startup, control, shutdown, power failure shutdowns, and subsequent restarts must all be as automatic and as fail-safe as possible.

APPENDIX I

BRAYTON ISOTOPE POWER SYSTEM FLIGHT SYSTEM (BIPS FS)

1.0 INTRODUCTION

This CCD is for a GDS designed to be representative of a flight system utilizing the Mini-BRU, MBR, and HSA designed for application in a space power system. This appendix briefly describes the BIPS FS design, operating parameters used in performance parametric studies, and design-point operating conditions. A conceptual system layout (L3621582) is included in Appendix III, which is based on 4800 W_t total from two radioisotope heat sources. Conceptual BIPS FS estimated performance is shown in Figure I-1, and the energy balance in Figure I-2.

BIPS FS design is such that optional features can easily be incorporated into delivered units. One such feature is one-g bearings that may be desirable for low power-level applications, or high-g bearings required for operation during launch.

The Mini-BRU is designed as an "all purpose" machine, capable of operating over a wide spectrum of power levels (0.35 to 2.1 kw_e) and orbital environments (near earth, synchronous, and deep space), with little compromise in performance. An example of this flexibility is that the "all purpose" Mini-BRU designed for 2.1 kw_e output adds only a six percent weight penalty to the BIPS FS when integrated into a 0.4 kw_e system.

GDS features, not in the BIPS FS, include a turbine bypass valve for overspeed protection, and a valved fill system. The BIPS FS will have no valves with external stems that could result in working fluid (gas) leakage.

390°R EFFECTIVE
SINK TEMP
 $\epsilon = 0.80$
 $\alpha = 0.08$

$T_1 = 525$
 $P_1 = 44.4$
 $W_1 = 0.2304$

1338 WATTS
OUTPUT (GROSS)

NET OUTPUT 1.3 KW
NET EFFICIENCY 0.270

FLOW SCHEMATIC AND ESTIMATED PERFORMANCE
FOR THE 4800 W_t ERDA BIPS FS
FIGURE I-1

ENERGY BALANCE - 4800 W_t

FIGURE I-2

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The GDS HRHX (radiator simulator) will be replaced by a space radiator for the BIPS FS. The ducting system will necessarily be different, but will have a similar pressure drop.

2.0 BIPS FS OBJECTIVES AND DESIGN

The FS performance objectives are delineated on Table I-1. GDS design is based on these objectives except that an HRHX replaces the space radiator, and electrical resistance heat sources replaces radio-isotope heat sources. FS components and subcomponents are delineated in Table I-2.

The BIPS FS conceptual layout (L3621582) shows the Mini-BRU in the vertical position (same as GDS). This orientation was selected for two reasons:

- (a) For gyroscopic compatibility with a spin-stabilized spacecraft when mounted with the vehicle axis coincident with (or parallel to) the BIPS Mini-BRU axis.
- (b) Launch loads are usually greater in the vertical direction, and as presently designed, thrust bearings will withstand more load than journal bearings.

A horizontal orientation is equally feasible, but requires that some support structure and ducting be changed with the result that the MBR will be slightly lowered.

Because of potential future system requirements, some configuration changes may be required. These are:

- (a) Provision for Operation Through Launch - Since the BIPS FS is designed to operate in a space environment hard vacuum, a bell-jar approach must be taken to provide an inert gas atmosphere for refractory metals and Multi-Foil insulation protection. Bearings must also be checked for load adequacy (present journal and thrust bearing configurations are designed to accept 7 and 10 g acceleration loads, respectively).

TABLE I-1

FS PERFORMANCE OBJECTIVES

- (1) The FS will be capable of power output from 500 to 2000 W_e , EOM, with minimum redesign and requalification.
- (2) 28 ± 2 percent vdc is the reference output voltage.

NOTE

A capability for higher ac voltage output may be advantageous if the output can be achieved directly from the generator.

- (3) The control system will be capable of modulating power to the spacecraft from 0 to 100-percent in 20 milliseconds response times. This will be accomplished by a parasitic load.
- (4) FS life time requirements is $L = 7$ years and mean mission duration (MMD) = 5 years.

$$\text{where MMD} = \int_0^L R dt$$

and R = probability of producing design power at time t

(Notwithstanding this requirement, AIRPHX has established a more stringent objective of $R = 0.95$ after 5 years operation)

Prelaunch, launch, and operational phase failure modes will be identified.

- (5) Based on a GFE heat source cost of \$1000 per W_t , the recurring cost goal for the FS at 1300 W_e will be less than \$5000 per W_e .
- (6) A FS weight goal, at 1300 W_e , is 450 pounds.
- (7) The FS will be capable of launch on the space shuttle.
- (8) Due to a potential explosive vapor environment, the on-pad temperature of exposed surfaces will be maintained below 380°F.
- (9) The system will be designed with an assumed sink temperature equal to, or greater than, that of a geo-synchronous orbit (19,323 nm). The system will be capable of stable operation with unbalanced solar input.
- (10) Thermal input to the spacecraft must be of an amount that will not cause the spacecraft to rise above 100°F.
- (11) The magnetic field at one meter is not yet defined.
- (12) The on-pad biological dose at one meter will be ≤ 0.20 REM per hour.
- (13) The FS will be resistant to natural and man-made radiations.
- (14) FS components will be inherently flexible in mounting to facilitate integration with the required spacecraft configuration.
- (15) On pad and in-orbit fueling capabilities should be provided.

TABLE I-2
BIPS-FS COMPONENTS

Mini-BRU

- o 1600°F turbine inlet temperature (working fluid is Xe-He, M = 83.8)
- o Single shaft turbine, Rice alternator and compressor supported on foil bearings with compressor bleed cooling
- o Alternator cooled by compressor discharge
- o Refractory metal turbine plenum (Columbium C-103)

Recuperator

- o Hastelloy X construction with gold alloy braze
- o Fin/plate counterflow design

Radiator

- o Material [Be, aluminum alloy or Lockalloy (alloy of Al and Be)]
- o Cylindrical design, offset fin/tube geometry
- o Sink temperature, 390°R
- o Micrometeoroid survival, 0.99 (assumed)
- o Used as part of a low gage pressure vessel to contain an inert gas for protection of the C-103 and multifoil insulation from launch to orbit.

Heat Source

- o ERDA Multi-Hundred Watt (MHW) heat source, (advanced ERDA HS concepts will also be investigated)
- o Electrically heated heat source simulator (EHS) for FS checkout

Heat Source Assembly (HSA)

- o Columbium Alloy C-103 Heat Source Heat Exchanger (HSHX)
- o Auxiliary Cooling System - Helium short circuit of HSHX Multi-Foil insulation
- o Emergency Cooling System - Melting of HSHX Multi-Foil insulation (alternatives have been identified)

Insulation

- o High temperature Multi-Foil insulation
- o Eight percent heat loss from HSA (Goal)
- o Two percent heat loss from turbine and hot interconnecting ducting (Goal)

Controls

- o Motor start inverter
- o Parasitic load
- o Speed control
- o Voltage regulator
- o Power supply
- o Rectifier/filter

Piping and Structure

- o Ducting
- o Bellows
- o Support structure (Beryllium or aluminum alloy)
- o Radiator is used as part of the support structure

- (b) Operation on a Spin-Stabilized Platform - Bearing load limits must not be exceeded [see (a) above]. If the Mini-BRU axis is transverse to the vehicle spin axis, the resulting coning angle must not exceed that allowed by mission requirements. For a spinning vehicle and Mini-BRU combination, the coning half-angle (ϕ) is defined by:

$$\phi = M_m / M_v$$

where:

M_m = Mini-BRU angular momentum (0.68 lb-ft rad sec)

M_v = Vehicle polar moment of inertia, lb-ft sec²

ϕ = Vehicle coning angle, rad

Presuming that M_v is 500, the coning half-angle would be approximately 0.08 degrees.

- (c) Spacecraft Integration - Launch vehicle constraints, heat input to the space vehicle, and/or BIPS placement on the space vehicle may require that the assumed BIPS FS be reconfigured. As presently configured, the BIPS can be mounted on any flat surface, and be designed to limit heat input to the spacecraft. The BIPS power supply furnishes the most power at 120 vdc, but by adding other power conversion components, any desired voltage and frequency combination may be obtained.

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The BIPS FS schematic, Figure I-3, shows all components within the working fluid loop, and inter-connecting ducting. The duct numbers correlate with Table I-3 data. Note that the radiator and radiator ducting materials have not yet been selected. Approximate duct sizes, and lengths of ducts 7, 8, 12, 13, and 14 (Table I-3) are based on the conceptual design, shown on Drawing L3621582 and will vary with different radiator configurations.

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Appendix I
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BIPS-FS DUCT SCHEMATIC

FIGURE I-3

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TABLE I-3

BIPS-FS DUCT SUMMARY

<u>Duct No.</u>	<u>Number of Joints</u>	<u>Material</u>	<u>Temperature °R</u>	<u>Pressure psia</u>	<u>OD Inch</u>	<u>Wall Inch</u>	<u>Duct Length</u>	<u>Number of Bellows</u>	<u>Bellows Length</u>
1	6	Hastelloy X	1757	57.7	2.50	0.035	43.3	3	3.00
2	3	Hastelloy X C-103	1757	57.7	1.60	0.035	10.0	1	2.00
3	2	Hastelloy X C-103	1757	57.7	1.60	0.035	6.0	1	2.00
4	1	C-103	2060	57.6	1.60	0.060	6.5	1	2.00
5	1	C-103	2060	57.6	1.60	0.060	6.5	1	2.00
6	9	C-103 Hastelloy X	1778	37.7	2.50	0.035	48.6	4	3.00
7	6	CRES/Be	672	37.6	2.50	0.035	37.0	3	3.00
8	9	Be/CRES	480	37.0	2.50	0.035	82.0	3	3.00
9	3	CRES	628	57.8	1.50	0.035	16.0	1	2.00
10	3	CRES	628	57.8	1.50	0.035	18.0	1	2.00
11	2	CRES	628	57.8	2.50	0.035	13.0	--	--
12	2/tube 32 tubes	TBD	TBD	37.6	TBD	TBD	2355	--	--
13	1	TBD	672	37.6	TBD	TBD	88.0	--	--
14	1	TBD	480	37.6	TBD	TBD	88.0	--	--
15	TBD	TBD

3.0 PRELIMINARY SHOCK AND VIBRATION DESIGN CRITERIA

When considering structural dynamics, the BIPS consists of a cylindrical radiator within which four discrete masses are supported by means of interface structure consisting of beams and struts. The four discrete masses are; two heat source assemblies, recuperator, and Mini-BRU power package. As presently known, the BIPS will be mounted to the spacecraft, which will be mounted to the interim upper stage (IUS). The IUS will be mounted in a cradle or carrier in the space shuttle orbiter. This series of components comprises the orbiter payload. The Space Shuttle and IUS specifications (References 1 and 2, respectively) imply that the payload be cantilever-mounted, from the orbiter mount points when in the stowed configuration.

The principal source of structural vibration occurs during Space Shuttle powered ascent. Principal vibration levels the BIPS will experience depend on the payload dynamic response to orbiter vibration with the payload in the stowed configuration.

The principal source of shock occurs when using pyrotechnic devices on the IUS vehicle, such as that used for spacecraft separation. Principal shock levels the BIPS will experience depend on the payload dynamic response to pyrotechnic explosions, with the payload in the deployed configuration.

Shock and vibration levels at various interfaces, as estimated for conceptual design by the various referenced sources, are shown below.

(1) and (2) Refer to List of References.

(a) Peak Random Vibration Levels

- o Shuttle Vehicle Payload Interface (Reference 1) - $0.1 \text{ g}^2/\text{Hz}$ (90 to 275 Hz) estimated response for an unloaded interface structure. Actual response should be lower due to mass of payload.
- o IUS-Spacecraft Interface (Reference 2) - $0.125 \text{ g}^2/\text{Hz}$ (100 to 1000 cps) recommended for conceptual design.
- o BIPS-Spacecraft Interface (Reference 3) - $0.1875 \text{ g}^2/\text{Hz}$ (900 to 1400 Hz) GE estimate based on LES 8/9 and Mariner J/S experience.

These vibration levels appear to represent a vibratory amplification through the payload. However, the levels are assumed to be estimates of the three reference sources that were determined independently. It will not be known whether the vibratory input to the payload will be amplified or attenuated until the total payload structure is defined and total payload dynamic analyses are conducted.

(b) Peak Shock Levels

- o IUS-Specification (Reference 2, Figure 6) - The stock response spectra gives a dynamic response of 115 g at the IUS-Spacecraft interface with a "Q" equal to ten for a 100 cps system. Although

(3) Refer to List of References.

the BIPS response to shock at the IUS-Spacecraft interface is undefinable, it will be attenuated due to cantilever mounting and remoteness from the interface.

- o GE Specification Recommendations (Reference 3) -
50-g dynamic response for the Isotope Heat Source, and support structure, in the HSA housing and 25-g dynamic response for the overall BIPS structure, based on a shock response to a 775-g half sine pulse of 0.2 millisecond duration.

As noted above, actual shock and vibration levels the BIPS will experience depend on payload dynamic responses to the principal sources of excitation.

The Space Shuttle is well defined and the BIPS is conceptually defined. However, the spacecraft, IUS, and IUS support structure to the shuttle craft, are currently undefined except for the decision to utilize a solid rocket motor. It is anticipated that the solid rocket motor and structure will possess a high degree of stiffness. Because of many unknowns, no meaningful dynamic analyses can be made, at this time, for predicting BIPS, vibratory and shock responses. However, criteria does exist that system dynamics must satisfy to maintain BIPS responses within tolerable structural design limits. These are:

- (a) The cantilevered payload support structure must be designed to avoid coupling payload and Space Shuttle fundamental frequencies. To avoid this interaction the cantilevered payload fundamental frequencies should be at least two times greater than Space Shuttle fundamental frequencies. The shuttlecraft fundamental frequency range is estimated to be within 4 and 12 Hz. Therefore, the fundamental of the cantilevered payload should not be less than 24 Hz.

- (b) Support structures of BIPS discrete masses should be designed to avoid coupling the cantilevered payload fundamental frequencies with the rigid body fundamental frequencies of the BIPS masses. This means that BIPS components fundamental frequencies should be approximately 60 Hz.
- (c) Criteria (a) and (b) define cantilevered payload and BIPS components fundamental frequency limits. However, it is desirable to maintain the upper limits of natural frequencies no higher than necessary to satisfy (a) and (b), and to minimize BIPS components dynamic responses to shock and vibration. It is anticipated that the cascade of components, comprising the cantilevered payload, will respond to shock as a succession of simple systems, when each succeeding structure has a low mass relative to the next supporting structure.

3.1 Design Criteria

BIPS FS components (i.e., HSA, MBR, Mini-BRU) and mounting pads should be designed to a minimum limit loading of 50 g. BIPS interface structures (i.e., struts, beams, etc.) should be designed to a minimum limit loading of 25 g. The higher acceleration loading requirement provides increased structural integrity for BIPS components and mount pads. This is needed to compensate for the lower degree of mounting redundancy than the interface support structure (i.e., beams and struts). In the case of a statically determinate mounted component such as the MBR, failure of a single mount could result in separation of the component, whereas the interface structure is a many times redundant system capable of tolerating a number of member failures without catastrophic results. The design criteria of providing sufficient stiffness to the BIPS interface structure, to maintain BIPS component

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natural frequencies above 60 cps, will inherently result in high strength. It is anticipated that this built-in strength will exceed 25 g. This limit loading should satisfy requirements for all other loadings such as pre-launch, launch, and operational environments, and in the case of an abort mission, crash landing requirements. This design criteria should be adequate for the BIPS preliminary design phase. After IUS and spacecraft definitions, dynamic analyses should be conducted on; the orbiter cantilever-mounted payload, and the payload as deployed from the orbiter. The cantilevered payload and support design should minimize the BIPS dynamic response. Considerable latitude exists in designing the payload structure to minimize BIPS dynamic loading.

4.0 ESTIMATED PERFORMANCE

The estimated FS Mini-BRU performance, for 1, 2, and 3 HSA (2400 W_t each), is shown on Table I-4. The data was generated assuming the systems were optimized at minimum weight by changing the MBR and radiator sizes. The GFE recuperator was used for the 3-capsule design only and the weight of hypothetical recuperators of 1- and 2-capsule designs was lowered, mainly by shortening lengths. Note that for the 1-capsule case, the optimum system weight was achieved with a radiator larger than for the 2-capsule case. The same performance could be achieved with some weight penalty by using a smaller radiator and larger recuperator. Users of this data are referred to the objectives stated in Table I-1.

Table I-5 delineates those performance variables with linear sensitivity factors. For sink temperatures, and turbine inlet temperature, non-linear effects refer to Figures I-4 and I-5. Performance variables are those parameters that may change due to build technique, aging, intent, or usage. The partial differentials of cycle efficiency, thus obtained, can be added to estimate the effects of small changes on any of the three system sizes studied.

To illustrate the use of sensitivity factors, consider the parameter changes to a two-capsule BIPS shown in Table I-6, (refer to Table I-4 for the original value and to Table I-5 for the sensitivity factor).

Off-design performance of these three systems is given in Figure I-6, to aid in assessing performance of a given system after the radioisotopes have degraded. In each case, since surface temperatures would be nearly constant, it was assumed that the change in thermal loss would be insignificant.

TABLE I-4
CYCLE DATA OPTIMIZED FOR MINIMUM WEIGHT

	<u>Capsule 1</u>	<u>Capsule 2</u>	<u>Capsule 3</u>
Compressor Efficiency	0.746	0.757	0.760
Turbine Efficiency	0.791	0.818	0.831
Alternator Efficiency	0.905	0.927	0.921
Lost Pressure Ratio Parameter	0.959	0.972	0.9755
Recuperator Effectiveness	0.970	0.975	0.9758
Bearing Loss (kw)	0.124	0.137	0.151
Windage (kw)	0.030	0.053	0.073
Turbine Inlet Temperature (°R)	2060.0	2060.0	2060.0
Compressor Inlet Temperature (°R)	440.0	500.0	520.0
Compressor Pressure Ratio	1.615	1.537	1.514
Turbine Pressure Ratio	1.549	1.493	1.477
Compressor Inlet Pressure (psia)	18.2	42.3	66.2
Radiator Area (ft ²)	112.0	110.6	134.2
Recuperator Length (inch)	15.7	20.4	24.0
Percent Heat Loss	13.0	13.0	13.0
Net Output Power (kw)	0.619	1.356	2.067
Net Cycle Efficiency	0.2578	0.2825	0.2872
Radiator Emissivity	0.83	0.83	0.83
Radiator Sink Temperature (°R)	390.0	390.0	390.0
Compressor Flow Rate (lb/sec)	0.1064	0.2262	0.3442
Turbine Flow Rate (lb/sec)	0.1043	0.2217	0.3347
Heater Inlet Pressure (psia)	29.11	64.60	99.74
Heater Inlet Temperature (°R)	1738.9	1758.4	1762.5

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TABLE I-5

BIPS FS CYCLE EFFICIENCY SENSITIVITY FACTORS*

Independant Variable			Sensitivity Factors			
			Multiplier	Number of 2400 W _t Capsules		
Name	Calculation Range	Symbol		1	2	3
Compressor Efficiency	0.761 to 0.701	η_c	η_c	0.55	0.55	0.55
Turbine Efficiency	0.832 to 0.772	η_t	η_t	0.55	0.55	0.55
Alternator Efficiency	-0.02 to -0.04	η_A	$\Delta\eta_A$	0.32	0.32	0.32
Compressor Inlet Temperature	-40°F to 40°F	ΔT_1	ΔT_1	-0.0006	-0.0006	-0.0006
Emissivity	0.83 to 0.74	ϵ	$\Delta\epsilon$	0.05	0.077	0.075
Pressure Drop	0.005 to 0.010	$\frac{\Delta P}{P}$	$\Delta\left(\frac{\Delta P}{P}\right)$	-0.8	-0.8	-1.0
Bearing Loss	0.50 to 1.00	$\frac{\Delta W_t}{W_t}$	$\Delta\left(\frac{\Delta W_t}{W_t}\right)$	-0.056	-0.031	-0.02
Recuperator Effectiveness	0.00 to -0.03	ΔE_1	ΔE_1	1.25	1.20	1.15
Heat Loss	0.00 to -0.04	$\frac{\Delta W_t}{W_t}$	$\Delta\left(\frac{\Delta W_t}{W_t}\right)$	-0.37	-0.30	-0.25

* $\Delta\eta_{cy} = (\text{Sensitivity Factor}) \times \text{Multiplier}$

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SINK TEMPERATURE EFFECTS

FIGURE I-4

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EFFECT OF TURBINE INLET TEMPERATURE
ON OVERALL PERFORMANCE

FIGURE I-5

TABLE I-6
OFF-DESIGN PERFORMANCE

<u>Parameter</u>	<u>New Value</u>	<u>Delta</u>	<u>Multiplier</u>	<u>$\Delta\eta_{cy}$</u>
Compressor Efficiency	0.747	-0.01	-0.01	-0.0055
Turbine Efficiency	0.808	-0.01	-0.01	-0.0055
Alternator Efficiency	0.917	-0.01	-0.01	-0.0032
Compressor Inlet Temperature	510	10	10.0	-0.0060
Emissivity	0.08	-0.03	-0.03	-0.0023
Pressure Drop	0.975	0.03	0.003	-0.0024
Bearing Loss	0.145	0.008	0.0584	-0.0018
Recuperator Effectiveness	0.950	-0.025	-0.02	-0.0240
Heat Loss	16.0	+3.0	0.23	-0.0690
Sink Temperature	420	+30	--	-0.0088
Turbine Inlet Temperature	2010	-50	--	<u>-0.008</u>
			Total	-0.1365
				(or -13.65%)

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PERFORMANCE SPECTRUM OF 3 MINI-BRAYTON SYSTEMS

FIGURE I-6

In more practical cases, only a few performance variables would generally be considered at one time. Assuming that compressor efficiency, radiator emissivity, and bearing loss have new values as indicated in Table I-6, cycle efficiency would then be reduced 0.96 percent.

To bring the cycle efficiency back to the original value, the compressor inlet temperature sensitivity factor is used to determine the required increased temperature:

$$T_{1 \text{ new}} = 500 + 0.0096/(-0.0006) = 484^{\circ}\text{R from Figure I-7, } (\Delta \text{ area})/$$

$(\Delta T_1) = -1.03$ and the required radiator area increase is therefore:

$\Delta \text{ Area} = -16 \times (-1.03) = 16.48 \text{ ft}^2$, for a total of 127.08 ft^2 , which represents a 14.5 percent increase.

This simplified approach to performance parameters effects on cycle efficiency, loses accuracy as parameters increase. Also, when the radiator size is changed, the performance of other components are changed slightly. Therefore, sensitivity factors, etc., should be used with caution.

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RADIATOR AREA EFFECTS

FIGURE I-7

5.0 LEAKAGE RATES

Estimated leakage rates of GDS components and joints are discussed in Section 3.3.5. 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	2.74×10^{-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}

Based on these rates the system total leakage rate is 1.387×10^{-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 21.87 standard cc total loss. This loss equates to only 0.0146 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 percentage after 5 years will be as high as the thermal input reduction resulting from

radioisotope decay. This is the ideal and desired condition because the turbine inlet temperature and system efficiency 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 265 times greater than the assumed 1.387×10^{-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).

LIST OF REFERENCES

1. JCS 07700 Volume XIV Revision D, "Space Shuttle System Payload Accommodations."
2. SS-ST5-100 Volume 3 Code Identification 07868 "Interim Upper Stage System Segment Basic Requirements for January 76."
3. GE-BIPS-20-001. "Mission Environments for The Isotope Brayton Flight System (Preliminary), August 8, 1975", Memo No. BIPS-GDS-G0017, 10-22-75.

APPENDIX II

BACKGROUND INFORMATION

Since the early 1960's, NASA has funded closed Brayton cycle development work for the purpose of achieving "technology readiness" by 1980. This effort has culminated in the operation of a 2-16 kw_e closed Brayton cycle engine for over 20,000 hours at NASA LeRC. This endurance test, which is continuing, has convincingly demonstrated the inherent reliability of this power generation equipment. A list of documents concerning BIPS component development is presented in Appendix III, and documents that are a part of the Statement of Work by reference are included in Table II-1.

Development contracts with NASA have been in existence since mid-1974 for the Brayton rotating unit and recuperator. (Table II-2 presents a list of contracts related to the MB-IBFS.) Design and testing of a GDS comprising these GFE components, will be accomplished during Phase I of the MB-IBFS development program. Advanced component development will also be conducted in Phase I.

The long-term scheduling of Phase I (Figure II-1) and of Phases II and III (Figure II-2) are included in this appendix. The individual component program schedules are:

- o Figure II-3 - Mini-BRU (Brayton Rotating Unit)
- o Figure II-4 - Mini-Brayton Recuperator (MBR)
- o Figure II-5 - Heat Source Assembly (HSA)

The BIPS functional engineering organization chart is presented on Figure II-6.

TABLE II-1

INCORPORATION OF GOVERNMENT DOCUMENTS AND SPECIFICATIONS

The following documents referenced in the Statement of Work are hereby incorporated by references and made a part hereof:

MIL-G-21480A	Generators and Regulators, Air Cooled, A-C, Aircraft General Specification for
MIL-STD-810B	Environmental Test Methods
MIL-STD-202C	Test Methods for Electronic and Electrical Component Parts
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
NASA SP-78	The Meteoroid Environment and Its Effect on Materials and Equipment
NASA TMX-53957	Space Environment Criteria Guidelines for Use in Space Vehicle Development
NASA CR-1870	Design and Fabrication of the Brayton Rotating Unit

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TABLE II-2

CONTRACTS RELATING TO THE MB-IBFS

Customer	Contractor	Date	Contract Number and/or Program	Value
NASA/NAA MCD-Douglas	AiRPHX	1964 1971	Space Station/Base Power System Studies	203,000
NASA-Houston	AiRPHX	1963 1971	Design-Construct-Test 3 KW _e Demonstrator Engine	169,000
NASA/LeRC	AiRPHX	1966 1972	Design-Construct-Test 10 KW _e Single-Spool Engine	6,154,000
NASA/LeRC	AiRPHX	1970 1972	Design-Construct-Test 100 KW _e Turbo-Alternator-Compressor for Reactor Heat Source	3,000,000
NASA/AEC/ USAF/GE	AiRPHX	1972 1974	Study 0.5 - 2.0 KW _e Mini-Brayton System for Satellites	130,000
AEC/WECO	AiRPHX	1972	3 KW _e Demonstrator CBC with Co60 Heat Source	100,000
AECL	AiRPHX	1973	Study of a 30 KW _e Underwater Power System	25,000
NASA/LeRC	AiRLA	1974	NAS3-18029 Mini-BRU Recuperator	267,265
NASA/LeRC	AiRPHX	1974	NAS3-18517 Mini-BRU Turboalternator	1,771,967
NASA/LeRC	GE/VF		NAS3-18541 Isotope Heat Source Assembly	990,500

BRAYTON ISOTOPE POWER SYSTEM (BIPS)

PHASE I

PROGRAM SCHEDULE AND MILESTONES

D - DEDICATED
E - EXPECTED
R - REQUIRED

FIGURE II-1

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FIGURE II-2

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MINI-BRU PROGRAM SCHEDULE

FIGURE II-3

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

75-311274B
Appendix II
Page 7

NASA APPROVED SCHEDULE
CONTRACTOR'S WORKING SCHEDULE

NASA APPROVED
SCHEDULE DATE MARCH 25, 1974

S-89650-P

MBR PROGRAM SCHEDULE
FIGURE II-4

FIGURE II-5

HEAT SOURCE ASSEMBLY (HSA) PROGRAM SCHEDULE

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

FIGURE II-6

TABLE III-1
BIPS RELATED DOCUMENTS

Document No.	Company or Agency	Title	Publication Date
SNS-RFP-75-1-CAO	ERDA-SNS	Request for Proposal, Ground Demonstration Test of a 1.3 KW Isotope Power Conversion System Leading Toward Development of an Isotope Space Power System for the 0.5 to 2 KW Power Engine	November 4, 1974
QC-048, Rev. 4	AIRPHX	AiResearch Manufacturing Company of Arizona General Quality Program Plan	October 1, 1974
QCGI No. 137 (Rough Draft)	AIRPHX	Quality Control Program Supplement for ERDA-Brayton Isotope Power System (BIPS)	September 30, 1975
74-310631	AIRPHX	Progress Reports of Design and Fabrication of Compressor-Alternator-Turbine for the Mini-Brayton Rotating Unit (Mini-BRU) Contract NAS3-18517	May 1974 - (Initial Issue)
74-310831	AIRPHX	System Studies of Closed-Cycle Gas Turbine Engines Utilizing the Mini-Brayton Rotating Unit (Mini-BRU)	August 10, 1974
74-311015-1, -2	AIRPHX	Isotope Brayton Ground Demonstration Testing and Flight Qualification Technical Proposal, Volumes 1 and 2	December 9, 1974
75-311221	AIRPHX	System Safety Program Plan for the Isotope Brayton Ground Demonstration System (Phase I)	September 30, 1975
75-311267	AIRPHX	Final Design Report Analysis and Design to the Mini-Brayton Rotating Unit (Mini-BRU)	December 15, 1975
75-311274B	AIRPHX	Brayton Isotope Power System Configuration Control Document (CCD)	March 1976 (Proposed)
75-311279A	AIRPHX	Transient Analysis Isotope Brayton Flight System	May 1976 (Proposed)
75-311360	AIRPHX	Reliability Program Plan for the Isotope Brayton Ground Demonstration System (Phase I)	September 30, 1975
75-311375A	AIRPHX	Statement of Work for General Electric as Major Subcontractor for the Design, Fabrication, and Test of the Ground Demonstration System Brayton Isotope Power System	December 9, 1975

TABLE III-1 (CONTD)

Document No.	Company or Agency	Title	Publication Date
75-311376B	AIRPHX	Program Plan for the Brayton Isotope Power System Phase I Design, Fabrication, and Test Brayton Isotope Power System	October 22, 1975
75-311446	AIRPHX	Statement of Work - Application of Multi-Foil Insulation to the Isotope Brayton Ground Demonstration System and Conceptual Design of Super Insulation for the IBFS	August 14, 1975
75-311457	AIRPHX	Monthly Technical Progress Reports Brayton Isotope Power System (BIPS) Phase I Design, Fabricate, and Test of the Ground Demonstration System	August 1975 (Initial Issue)
75-311472A	AIRPHX	Statement of Work to AiResearch, Los Angeles for the Isotope Brayton Ground Demonstration System (IBGDS) and Isotope Brayton Flight System (IBFS)	February 11, 1976
76-311499A	AIRPHX	Statement of Work to Thermo Electron Corporation for Application of Multi-Foil Insulation to the Brayton Isotope Power System and Conceptual Design of Super Insulation for the Flight System	December 15, 1975
75-311574	AIRPHX	Brayton Isotope Power System (BIPS) Phase I Integrated Program Plan (IPP)	November 20, 1975
75-311591	AIRPHX	Electronic Analog Simulation of ERDA BIPS Using "Bang-Bang" Speed and Voltage Regulation	October 23, 1975
75-311629	AIRPHX	Preliminary Hazard Analysis for the Isotope Brayton Flight System	November 30, 1975
75-311665	AIRPHX	Preliminary Failure Modes, Effects, Brayton Isotope Ground Demonstration System (Including Vacuum Test Chamber)	November 30, 1975
76-311709	AIRPHX	Preliminary Failure Modes, Effects, and Criticality Analysis (FMECA) Brayton Isotope Power System Flight System	January 12, 1976
76-311737	AIRPHX	Specification Requirements Summary for the Brayton Isotope Power System (BIPS) Ground Demonstration System (GDS)	February 10, 1976
76-311742	AIRPHX	BIPS-GDS System Design Specification	
76-311770	AIRPHX	ERDA-BIPS Program Update - February 19, 1976	February 16, 1976
74-10188	AIRLA	Recuperator Progress Reports (Monthly)	
GEMS-4117	GE-ESP	Mini-BRU Economic RTG Study	January 1974
	GE	HSA Progress Reports (Monthly)	
TBD	AIRPHX	Preliminary System Safety Review Report	TBD

FIGURE III-1

TID-27252 #040100836

RUN 212

ALL COMPONENTS AT COLD START TEMPERATURE - T6-1660 DEG R

FIGURE III-2

TID-27252 #040100-836

RUN 212
RIPS COLD START
ALL COMPONENTS AT COLD START TEMPERATURE - T6:1660 DEG R

TID-27252 #040100830

REVISIONS			
NO.	DESCRIPTION	DATE	APPROVED
1	ISSUED	10-15-75	
2	REVISED	10-15-75	

TID-27252
#0401.00836

SECTION A-A

ALLOWABLE MOUNT LOADS

LOCATION	DESIGN LOAD - LBS	MINIMUM DESIGN LOAD - LBS
HP INLET	1500	1500
LP INLET	1500	1500
HP OUTLET	1500	1500
LP OUTLET	1500	1500

ALLOWABLE DUCT LOADS

LOCATION	FORCE - LBS	MOMENT IN - LB
HP INLET	240	240
LP INLET	240	240
HP OUTLET	240	240
LP OUTLET	240	240

THIS UNIT IS DESIGNED TO WITHSTAND THE FOLLOWING PROOF PRESSURES:
 1. HIGH PRESSURE SIDE 250 PSIG @ 70°F
 2. LOW PRESSURE SIDE 175 PSIG @ 70°F
 3. HIGH PRESSURE SIDE MUST ALWAYS BE AT HIGHER PRESSURE THAN LOW SIDE WITH A MIN. GP OF 5 PSI
 4. ALL OPENINGS ARE PROVIDED WITH SHIPPING CLOSURES. REMOVE ONLY AT INSTALLATION PURPOSES ONLY
 5. ALL DIMENSIONS ARE FOR INSTALLATION PURPOSES ONLY

190930-1-1 190930-1-1

PART NUMBER	ASSY NUMBER	CALC WEIGHT	REMARKS
190930-1-1	190930-1-1		

190930-1-1 190930-1-1

RECUPERATOR OUTLINE

190930-1-1 190930-1-1

190930 57

8

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1

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REVISIONS

ZONE LTR

DESCRIPTION

DATE

APPROVED

REDUCED PRINT

- ● THERMOCOUPLES - SIMULATOR
- THERMOCOUPLES - ENGINE
- ▲ STATIC PRESSURE - ENGINE
- FLUX COIL

CAUTION: THIS DRAWING SHOWS PROPOSED CONFIGURATION & DOES NOT NECESSARILY REPRESENT EXACT DESIGN DETAIL OR SCALE

QUANTITY REQD	FIND NO	PART NO. OR IDENTIFYING NO.	SYM	NOMENCLATURE OR DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	ZONE
PARTS LIST							
CONTRACT NO.				AIRSEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA			
DWG TITLE				SCHEMATIC INTERNAL INSTRUMENTATION CCP32-1			
REQD NEXT ASSY USED ON				SIZE CODE IDENT NO. DWG NO.			
HEAT TREATMENT PROCESS				D 99193 5KP32488			
HARDNESS AND SPEC NAME AND SPEC				SCALE 1/1 WT SHEET 1 OF 1			

5KP32488

UNCLASSIFIED

A

3

REVISIONS		DATE	APPROVED
NO.	DESCRIPTION		
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79	REVISED TO SHOW MANUFACTURING CHANGES		
80	REVISED TO SHOW MANUFACTURING CHANGES		

SEE SEPARATE PARTS LIST

- ITEM 50 USED FOR COLD SPIN TEST ONLY. REMOVE 50 PRIOR TO INSTALLING 30 & 45. SEE 3600380 FOR INSTALLATION SCHEMATIC.
- MANUFACTURED BY ELECTRO PRODUCTS LABORATORIES INC. CHICAGO, ILL.
- APPLY A 3000 LB TIE BOLT LOAD TO OBTAIN A .013-.015 STRETCH OF FIND NO. 3.
- WELD PER AIRESEARCH WBS 5018
- 1. SHALL CONFORM TO AIRESEARCH SC6000 INTERPRETATION OF DRAWINGS

QUANTITY REQD	FIND NO	PART NO OR IDENTIFYING NO	SYM	NOMENCLATURE OR DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	ZONE
PARTS LIST							
MINI BRU				SIGNATURES	DATE	PARTS LIST	
CPS2-1				BY	10-23-76	AIRESEARCH MANUFACTURING COMPANY OF ARIZONA	
				CHK	11-12-76	A DIVISION OF THE AIRPAC CORPORATION	
				DATE		PHOENIX, ARIZONA	
FINAL				TYPE		ENGINE ASSEMBLY,	
NEXT ASSY				USED ON		MINI BRAYTON ROTATING	
HEAT TREATMENT				PROCESS		UNIT, TURBOALTERNATOR	
WELDING AND SPC				NAME AND SPC		240610	
				REVISION ACTIVITY DATE		E 99193	
				REVISION ACTIVITY DATE		240610	
				SCALE 2/1	WT	1 SHEET - OF -	

WORK SHEET ONLY

PARTS LIST PL 240610-1

REV
LYR

CONTRACT NO.

LIST TITLE

DATE

11/26/74

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

ENGINE ASSY
MINI-BRAYTON
ROTATING UNIT
TURBOALTERNATOR

REV
AUTH
NO.

CODE IDENT NO. 99193 APPROVAL ORIGINAL ISSUE

SHEET 1 OF 3

FIND NO.	SHT P.O.	DWG ZONE	PART NO. OR IDENTIFYING NO.	SYM	NOMENCLATURE OR DESCRIPTION	EST WEIGHT	QTY REQD
1	1	B5	240610-1		ENGINE ASSY		X
2	1		240611		INSTALLATION DWG.		X
3	1	D8	3604331-1		TIE BOLT	0.17	1
4	1	D8	3604332-1		NUT, TIE BOLT	0.03	1
5	1	D8	3604333-1		NASHER, LOCKING		1
6	1	F3	3604335-1		WHEEL, TURBINE	0.65	1
7	1	B6	3604336-1		ROTOR, ALTERNATOR	1.11	1
8	1	F7	3604337-1		HEAT SHUNT	0.07	1
9	1	G3	3604338-1		FOIL BRG, JOURNAL	0.05	6
9	1	G7	"		" " "	0.05	6
10	1	G6	3604339-1		FOIL BRG, THRUST	0.05	1
11	1	G5	3604339-2		" " "	0.05	1
12	1	G6	3604340-1		SPRING, FOIL BRG	0.03	1
13	1	G5	3604340-2		" " "		1
14	1	B6	3604341-1		RETAINER, BRG	0.18	1
15	1	F5	3604342-1		" "	0.24	1
16	1	B6	3604343-1		" "	0.10	1
17	1	G3	3604343-2		" "	0.10	1
18	1	G6	3604344-1		PLATE, THRUST BRG	0.28	1
19	1	G5	3604344-2		" " "	0.28	1
20	1	H4	3604345-1		SHIM		AR
20	1	H6	"		"		"
21	1	H4	3604345-2		"	0.04	"
21	1	H6	"		"		"
22	1	H4	3604345-3		"		"
22	1	H6	"		"		"
23	1	G6	3604346-1		SPACER, THRUST BRG	0.32	1
24	1	C8	3604347-1		SHIM		AR
25	1	C8	3604347-2		"	0.10	"
26	1	C8	3604347-3		"		"
27	1	C8	3604347-4		"		"
28	1	C8	3604348-1		SEAL, BACK SHROUD	0.09	1
29	1	E8	3604349-1		INLET COMPRESSOR	0.26	1

WORK SHEET ONLY

PARTS LIST

PL 240010-1

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LTR

DATE

REV
AUTH
NO.

SHEET 2

CONTRACT NO.

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

CODE IDENT NO.
99193

APPROVAL

ORIGINAL ISSUE

LIST TITLE

ENGINE ASSY
MINI-BRAYTON
ROTATING UNIT
TURBOALTERNATOR

FIND NO.	SHT NO.	DWG ZONE	PART NO. OR IDENTIFYING NO.	SYM	NOMENCLATURE OR DESCRIPTION	EST WEIGHT	QTY REQD
30	1	C8	3604350-1		DIFFUSER	2.10	1
31	1	B6	3604351-1		END BELL, COMP.	1.10	1
32	1	B5	3604352-1		" TURB.	1.23	1
33	1	F3	3604354-1		BACK SHROUD, TURB.	0.39	1
34	1	C3	3604355-1		PLENUM, TURB.	3.97	1
35	1	B5	3604357-1		SPACER, ALTERNATOR	0.07	1
36	1	G3	3604358-1		SHIM	0.02	AR
37	1	G3	3604358-2		"		"
38	1	G3	3604358-3		"		"
39	1	G3	3604358-4		"		"
40	1	B4	3604359-1		SHIM	0.17	AR
41	1	B4	3604359-2		"		"
42	1	B4	3604359-3		"		"
43	1	B4	3604359-4		"		"
44	1	G7	3604360-1		RING, HERMETIC SEAL	0.28	1
45	1	B5	3604361-1		" " "	0.40	1
46	1	D8	3604362-1		SET, IMPELLER & ROTOR	0.48	1
47	1	G7	3604363-1		SHIM (0.32) (0.16)	-	AR
48	1	G7	3604363-2		"		"
49	1	G7	3604363-3		"		"
50	1	B7	3604376-1		ALTERNATOR ASSY	17.66	1
51	1	B5	3604378-1		ORIFICE	-	2
					Alternator Hsg	9.80	
					FIELD	3.79	
					STATOR	0.60	
					STACK	1.47	
					BAL. OF ALT. ASSY	2.00	
56	1	B4	58990-158		PACKING	-	1
56	1	B7	" "		"	-	1
57	1	G6	59017B6P1		NAMEPLATE	-	1
58	1	B4	S 9431-3		NUT		18
60	1	B6	626-001-9095	1	SNAP RING	-	1
60	1	C3	" "	1	" "		1

WORK SHEET ONLY

PARTS LIST

PL 240610-1

REV
LTR

DATE

REV
AUTH
NO.

SHEET 3

LIST TITLE
ENGINE ASSY,
MINI-BRAYTON
ROTATING UNIT,
TURBOALTERNATOR

CONTRACT NO.

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

CODE IDENT NO.
99193

APPROVAL

ORIGINAL ISSUE

FIND NO.	SHT NO.	DWG ZONE	PART NO. OR IDENTIFYING NO.	SYM	NOMENCLATURE OR DESCRIPTION	EST. WEIGHT	QTY REQD
63	1	B4	MS9489-06		BOLT	0.18	18
64	1	C8	MS9499-14		SCREW		4
65	1	C3	MS9504-05		SCREW	0.16	4
65	1	C4	"		"		6
65	1	C8	"		"		6
66	1	C8	MS9565-06		BOLT	0.18	18
67	1	G6	MS20470ADR-3		RIVET		2
70	1	B7	MS20995C52		LOCKWIRE		4
70	1	C3					"
70	1	C3					"
70	1	C4					"
70	1	C7					"
70	1	C7					"
70	1	C8					"
71	1	B7	MS24676-2		SCREW		4
71	1	C3	"		"	0.10	4
72	1	F8	MS35650-304		NUT		3
			INSULATION			1.00	
			MISC. HDWIE			2.30	
77	1	C8	NAS620-8		WASHER		4
80	1	F3	50-0	2	SPEED SENSOR	0.06	3
					TOTAL	36.1	LBS.
			1. VENDOR ITEM, SEE CONTROL DWG				
			2. MFG BY ELECTRO PRODUCTS				
			LABORATORIES, INC., CHICAGO ILL.				
			C.G. LOCATED 5.75 INCHES FROM FORWARD FLANGE

WIRING DIAGRAM

SECTION A-A

SECTION B-B

SECTION C-C

DEVELOPMENT SYSTEM PROTECTION & ALARMS

G.D.S. CONTROLS

FACILITY EQUIPMENT

REVISIONS	DATE	APPROVED
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TID-27252
040100836

DATA ACQUISITION

TREND RECORDER	DIGITAL DATA	ALARM SYSTEM
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
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9	9	9
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LEGEND

- PRIMARY LOOP
1 COMPRESSOR INLET
2 COMPRESSOR DISCHARGE
3 ALTERNATOR IN DISCHARGE - DUCT "A"
4 ALTERNATOR IN DISCHARGE - DUCT "B"
5 RECUPERATOR N.P. INLET
6 RECUPERATOR N.P. DISCHARGE
7 RECUPERATOR N.P. FLOW DIVIDER
8 RECUPERATOR N.P. FLOW DIVIDER
9 RECUPERATOR N.P. FLOW DIVIDER
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- DC ELECTRICAL SYSTEM
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NOMENCLATURE

FIRST LETTER	SECOND LETTER	THIRD LETTER
A	ALARM	
B	BUS	
C	CONTROL	
D	DISCHARGE	
E	ELAPSED	
F	FLOW	
G	GAGE	
H	HAND	
I	INDICATOR	
J	JAN	
K	CONTROLLER	
L	LEVEL	
M	MOTOR	
N	NEUTRAL	
P	PRESSURE	
Q	TEMP	
R	RELIEF	
S	SOLENOID	
T	TEMP	
U	TEMP	
V	VOLTAGE	
W	WATER	
X	EXHAUST	
Y	YIELD	
Z	ZONE	

- LINE SYMBOLS
1 SAMPLING LINES
2 INLET LOOP LINES
3 ELECTRICAL LINES
4 PRIMARY GAS LOOP LINES
5 AUXILIARY GAS LOOP LINES

- 1 HIGH PRESSURE GAS VALVE, REGULATOR AND GAGE.
2 BI-METALLIC JOINT
3 MATERIAL SAMPLE
4 INSTRUMENT
5 TRANSDUCER
6 DEVELOPMENT, TEST ONLY
7 DUCT MATERIAL, O.D., WALL THICKNESS & LENGTH
8 ORIFICE
9 DUCT WELD JOINT

VACUUM TANK

HSA ACS GAS MANAGEMENT SYSTEM

FACILITY COOLANT SYSTEM

WORKING FLUID MANAGEMENT SYSTEM

PRELIMINARY
REV A 3-12-76

306960 - 1

REVISIONS	DATE	APPROVED
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PRELIMINARY
BIPS GDS PIPING &
INSTRUMENTATION DIAGRAM
306960
J 99193
SCALE
SHEET 1 OF 1

[illegible]

TID-27252
 #040100836

TID-27252
#040100836

ELECTED PRODUCTS			
Q2	SPEED SENSOR	3000	3
Q1	TURBINE, REVERSE		2
Q3	ALUT	HYPER-24	3
Q4	SCREEN	HYPER-24	3
Q5	BOLT	HYPER-24	10
Q6		HYPER-24	10
Q7	ALUT	HYPER-24	10
Q8	SCREEN	HYPER-24	10
Q9	O-RING	HYPER-24	2
Q10	SLIP BUSH	HYPER-24	2
Q11	UNDER TIE	HYPER-24	2
Q12	COVER BUSH	HYPER-24	2
Q13	COVER BUSH	HYPER-24	2
Q14	COVER BUSH	HYPER-24	2
Q15	COVER BUSH	HYPER-24	2
Q16	COVER BUSH	HYPER-24	2
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Q98	COVER BUSH	HYPER-24	2
Q99	COVER BUSH	HYPER-24	2
Q100	COVER BUSH	HYPER-24	2

2-L 3621255

[illegible]

7-100-6-11-8

[illegible]

PROPRIETARY NOTICE THIS LAYOUT DRAWING SHOWING A POWER START SYSTEM POWER BY THE GARDEN CORPORATION AND IS SUBJECT TO A CONFIDENTIALITY AGREEMENT MADE FOR USE EXCLUSIVELY GRANTED IN WRITING ALL RIGHTS ARE RESERVED BY THE GARDEN CORPORATION THIS DRAWING SHALL BE RETURNED WITHIN THE WEEK END OF THE WEEK END CLIMB		DATED 10-22-73 APPROVED [Signature] [Signature] [Signature]	LAYOUT NAME POWER CONVERSION SYSTEM SCALE 1/4 SHEET CCPS 2-1	L3621580 SHEET
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TOP VIEW
DOME REMOVED

REVISIONS			
REV	DATE	DESCRIPTION	APPROVED

PROPRIETARY NOTICE THIS LAYOUT DRAWING IS THE PROPERTY OF THE GARRETT CORPORATION. IT IS NOT TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM, WITHOUT THE WRITTEN PERMISSION OF THE GARRETT CORPORATION.			
DRAWN BY 1-6-76 CHECKED BY 1-6-76 APPROVED BY 1-6-76 DATE 1-6-76	TITLE CONCEPTUAL BIPS-FS	SHEET 1 OF 1	PART NO. L3621582

REVISIONS		DATE	APPROVED
1	INITIALS		
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TID-27252
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REVISIONS		DATE	APPROVED
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TOP VIEW

L 3621583 (2)

REVISIONS		DATE	APPROVED
NO.	DESCRIPTION

REVISIONS			
NO.	DATE	DESCRIPTION	BY

TID-27252
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DESIGNATION		LAYOUT	
1/2	1/2	1/2	1/2
SUPPORT		STRUCTURE	
L3621586		L3621586

SK 173 30-4-15-1
 T ID-27252
 # 040100836

SECTION S-2 (rotated 30°)
 TYPICAL INLET-OUTLET PORT

14.09
 357.65 mm

DOME SHOWN CUT
 ALONG VERTICAL E

AFT END

SECTION A-A

14.09
 357.65 mm

DOME SHOWN CUT
 ALONG VERTICAL E

FORWARDED END

VALVE C-C

MINI-BRAYTON HEAT SOURCE ASSEMBLY (HSA)
 SK# 173 30-4-75-1