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BRAYTON ISOTOPE POWER SYSTEM CONFIGURATION CONTROL DOCUMENT (CCD)

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AC03-76 SF01123

PREPARED FOR THE ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION

CONTRACT NO. E (04-3)-1123

SEPTEMBER 25, 1975

75-311274A

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

75-311274A

September 23, 1975

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Prepared by Engineering Staff

Initial Issue
Approved by

C.L. Kevan, Supervisor
Documentation and Data Management

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H.W. Longee, Asst. Program Manager
BIPS

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ISOTOPE-BRAYTON ACRONYMS AND ABBREVIATIONS

ABS	Auxiliary Battery System
ACS	Auxiliary Cooling System (for HSA)
AEC	Atomic Energy Commission (now ERDA)
AEC PR	Atomic Energy Commission Procurement Regulation
AIRPHX	AiResearch, Phoenix
AIRLA	AiResearch, Los Angeles
BIPS	Brayton Isotope Power System
BOM	Beginning of Mission
BRU	Brayton Rotating Unit
DAS	Data Acquisition System
DCS	Demonstrator Cooling System
DOD	Department of Defense
EPFS	Electrically Powered Flight System (PCS + EHS - D)
ECS	Emergency Cooling System (for HSA)
EHS - D	Electrical Heat Source - Dynamic
EHS - S	Electrical Heat Source - Static (same as HSS and GEHS)
EOM	End of Mission
ERDA	Energy Research and Development Administration (successor to AEC)
ESD	Electronics Systems Division (of Air Force Systems Command)
FIB	Fuel Impact Body
FMA	Failure Mode Analysis
FBS	Flight Battery System Required for Start in Orbit
FMEA	Failure Modes and Effects Analysis
FPR	Federal Procurement Regulation
FS	Flight System
FSA	Fuel Sphere Assembly
FSAR	Final Safety Analysis Report
FSE	Flight Support Equipment Required to Protect Hot Refractory Parts in Earth's Atmosphere
GDEHS	Graphite Dynamic Electric Heat Source (GE term for EHS-D)
GDS	Ground Demonstration System - PCS + EHS-S

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ISOTOPE-BRAYTON ACRONYMS AND ABBREVIATIONS (Contd)

GE	General Electric, Valley Forge
GEHS	Graphite Electric Heat Source (GE term for EHS-S)
GFE	Government Furnished Equipment
GMS	Gas Management System
GSE	Ground Support Equipment
GTC	Ground Test Console
HS	Heat Source (same as and replaced by EHS)
HSA	Heat Source Assembly (does <u>not</u> include IHS or EHS. Does include HSHX, structure, insulation, ACS and ECS.)
HSHX	Heat Source Heat Exchanger
HSIS	Heat Source Insulation System
HSS	Heat Source Simulator (same as and replaced by EHS)
IBFS	Isotope Brayton Flight System
IHE	Isotope Handling Equipment
IHS	Isotope Heat Source (Isotope and Reentry Protection)
JPL	Jet Propulsion Laboratory, Pasadena, Ca.
LASL	Los Alamos Scientific Laboratory
LES 8/9	Lincoln Experimental Satellite (No. 8 and No. 9)
MBR	Mini-Brayton Recuperator
MB-ERTG	400 Watt Mini-Brayton-Economic Radioisotope Thermodynamic Generator Design (refer also to IBFS)
MHW	Multi-Hundred Watt (AEC/GE IHS Technology)
MMD	Mean Mission Duration
NA	Not Applicable
NASA LeRC	National Aeronautical and Space Administration Lewis Research Center
OHA	Operational Hazard Analysis
ORNL	Oak Ridge National Laboratory
PCL	Power Conversion Loop (use of PCS preferred)

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ISOTOPE-BRAYTON ACRONYMS AND ABBREVIATIONS (Contd)

PCS II	Power Conversion System (HSA + BRU + Radiator + Controls + Piping and Structure)
PHA	Preliminary Hazard Analysis
PCL	Parasitic Load Control System
PSAR	Preliminary Safety Analysis Report
PSC	Power Supply Console (for EHS)
QA	Quality Assurance
RCS	Radiator Cooling System
RTG	Radioisotope Thermodynamic Generator (obsolete, replaced by MB-ERTG)
SAMSO	Space and Missile Systems Organization (of Air Force Systems Command)
SNS	Space Nuclear Systems (Division of AEC)
SSPP	System Safety Program Plan
STE	Test Equipment
SURVSATCOM	Air Force Survivable Communication Satellite
TBD	To Be Defined
TES	Teledyne Energy Systems (Formerly TI, Teledyne Isotopes)
TIT	Turbine Inlet Temperature
USAR	Updated Safety Analysis Report
VRE	Voltage Regulator Exciter

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MINI-BRU ISOTOPE BRAYTON
SYSTEM CONFIGURATION CONTROL
DOCUMENT (CCD)

1.0 INTRODUCTION

The initial draft of this CCD was prepared by the AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, under NASA Contract NAS3-18517 (the NASA Mini-BRU Program). This revision, and subsequent revisions, published as the system design progresses, is under ERDA direction.

1.1 Purpose

This document defines the Brayton Isotope Power System (BIPS) Ground Demonstration System (GDS) configuration. The GDS is configured to be similar to a conceptual flight system design referred to herein as the BIPS Flight System (FS) and discussed in Appendix I.

The Brayton Isotope Power System is being developed by the ERDA as a 500 to 2000 W_e , 7 year life 3.5 W_e per pound space power system. The system was a closed Brayton dynamic system to convert energy from an isotope heat source at a net efficiency exceeding 25 percent. This CCD is for the first phase of the ERDA program to have a qualified system ready for launch by June 30, 1981. Phase I is a 36 month effort to provide a conceptual design of the flight system and design, fabricate and test a ground demonstration system. The baseline system is predicated on using two of the multihundred-watt isotope heat sources being developed for the ERDA by GE under contract AT (29-2)-2831. The Ground Demonstration System will simulate, as closely as possible, the Brayton Isotope Power Flight System and will utilize components and technology being developed by the 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. The Ground Demonstration System includes a performance test and a 1000-hour endurance test.

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TABLE 1-1
DOCUMENTS RELATING TO THE BIPS

Document No.	Company or Agency	Title	Publication Date
74-310831	AiRPHX	System Studies of Closed-Cycle Gas Turbine Engines Utilizing the Mini-Brayton Rotating Unit (Mini-BRU)	August 10, 1974
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 (first issue)
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
74-311015-1, -2	AiRPHX	Isotope Brayton Ground Demonstration Testing and Flight Qualification	December 9, 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 General Instruction	TBD
75-311221	AiRPHX	System Safety Program Plan	July 25, 1975
TBD	AiRPHX	Preliminary System Review Report	TBD
75-311360	AiRPHX	Reliability Program Plan	July 25, 1975
GEMS-417	GE-ESP	Mini-Brayton Economic RTG Study	January 1974
75-311267	AiRPHX	Mini-BRU Design Final Report	May 1975
74-10188	AiRLA	Recuperator Progress Reports	Monthly
	GE	HSA Progress Reports	Monthly
TBD	AiRPHX	FMECA	TBD
75-311279	AiRPHX	Transient Analysis	May 19, 1975
75-311274-1	AiRPHX	Configuration Control Document (CCD)	
SC-6016	AiRPHX	Engineering Change Control Procedure for AiResearch Vendors

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Information presented in this CCD is to be used to ensure proper integration of system components into the system as a whole. It is to be a ready reference for all organizations such as ERDA, NASA, and industry contractors participating in the development of the closed Brayton space power system. It should be understood that the CCD provides the reader sufficient information and direction to obtain drawings and documents such that a system description can be obtained to whatever level is desired; the CCD serves as a working document and an index to the supporting detail documentation. A compendium of documents relating to the BIPS may be found in Table 1-1.

1.2 Organization of Material

This document includes reference material, a list of related documents, and pertinent design data for the system and components. Also included is a description of the preliminary BIPS Flight System (Appendix I) and certain appropriate background information that might be of interest to potential users (Appendix II).

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

2.0 CONFIGURATION CONTROL PROCEDURE

2.1 Scope

Configuration management organization and practices described in this document 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 control and documentation of the product configuration through assemblies, subassemblies, and parts.
- o Interfacing - Assure compatibility of all interfaces with the customer installation.
- o Change Control - Utilize established contractor procedures for evaluation, coordination, and approval/disapproval of changes to the equipment configuration baseline.
- o Vendor Control - Impose and monitor configuration control disciplines of AiResearch vendors.

It is the intent of AiResearch to utilize present organization and management practices as applicable in the performance of the ERDA/BIPS GDS program and all subsequent phases (e.g. BIPS-FS).

2.2 Specific AiResearch Configuration Control System

An original configuration baseline, as defined on AiResearch drawings, will be established. Changes to existing drawings and/or

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new drawings will be integrated into the baseline up to establishment of a qualification baseline.

2.3 Marking and Configuration Identification

2.3.1 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 for preparation, interpretation, change, and revision. Future editions of this CCD will include a list of Materials and Processing Specifications related to this program.

2.3.2 Drawings

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

2.3.3 Release Record

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

2.4 Subcontractor

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

3.0 SYSTEM CONFIGURATION

This CCD is expressly intended for the GDS. It has been previously stated that the GDS is designed to represent typical flight hardware. The BIPS Flight System used as a model is described in Appendix I.

The basic GDS objectives are to:

- (a) Conduct a two-phase flight system conceptual design to establish typical flight system requirements as the basis for the GDS design:
 - (1) The first phase will summarize requirements known as of 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 long lead development required to effect delivery of the first production flight system by June 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 is intended to provide the following design configuration:

NI.
T1
T5
T6
T9
T12A
T12B
P1
P2
V30
V40

ACQUISITION	
TREND RECORDER	DIGITAL DATA
N1	N1
T1	N40
T5	T1
T6	T2
T11	T5
T12A	T6
T12B	T9
T13	T10
P1	T11A,B,C
P2	T12A,B,C
KV30	T13A,B,C
KV40	T16
KV31	T15
V48	T16

STATE POINTS

RELIEF VALVE

CHECK VALVE

SOLENOID OPERATED GATE VALVE

MANUALLY OPERATED GATE VALVE

QUANTITY REQD	UNIT NO	PART NO OR IDENTIFYING NO	SYM	DESCRIPTION OR DISCUSSION	CODE	MATERIAL AND SPECIFICATION	ZONE
PART NUMBER			PARTS LIST				
SIGNATURES			DATES		MINIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BRASSBOARD CORPORATION PHOENIX, ARIZONA		
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HEAT TREATMENT			DRG FILE DRG NO DRG REV DRG DATE DRG BY DRG CHK DRG APPR				
HANDLER AND SPEC			DRG FILE DRG NO DRG REV DRG DATE DRG BY DRG CHK DRG APPR				
REVISION ACTIVITY SHEET			DRG FILE DRG NO DRG REV DRG DATE DRG BY DRG CHK DRG APPR				
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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 Maintainability
- o Ground Support Test Equipment
- o Endurance Test Cost/hr
- o FMEA Substantiation
- o System Confidence Level

3.1 System Requirements

GDS system design requirements are, to the greatest extent possible, identical to requirements of the FS shown in Table 3-1. Several important differences are:

- (a) While the BRU, recuperator, and HSA are designed to meet Requirement (4), the radiator simulator is not.
- (b) The heat rejection method will utilize a simulated space radiator, the heat sink being a refrigerated liquid.
- (c) The weight goal, Requirement (6), will not be met.

TABLE 3-1

SYSTEM REQUIREMENTS

- (1) The BIPS-FS will be capable of power output from 500 to 2000 W_e (EOM) with a minimum of redesign and requalification.
- (2) Twenty-eight (28) vdc output ± 2 percent is the reference output voltage. The alternator is designed for use with a 3-phase 120 vdc rectifier load.
- (3) The control system will be capable of modulating power to the spacecraft from 0 to 100-percent power in a response time in the order of milliseconds. This will be accomplished by a parasitic load.
- (4) The MB-IBFS will have a MMD in excess of five years when:

Lifetime requirements are less than seven years

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

where R is the probability of producing design power at time t. Notwithstanding this requirement, AIRPHX has established, as an objective, the more stringent goal of $R = 0.95$ at the end of five years operation.

Failure modes in the prelaunch, launch, and operational phases will be identified.

- (5) Based on a cost of \$1000 per W_e for the GFE heat source, the recurring cost goal for the MB-IBFS at 1300 W_e will be less than \$5000 per W_e .
- (6) A weight goal for the MB-IBFS at 1300 W_e will be less than or equal to 3.5 W_e per pound.
- (7) The MB-IBFS will be capable of launch on Titan IIIC, or space shuttle.
- (8) On-pad temperature of exposed surfaces, based on explosive vapor environment, will be maintained below 380°F.
- (9) The system will be designed with the sink temperature of geo-synchronous orbit (19,323 mm). The system will be capable of stable operation with maximum solar radiation.
- (10) Thermal input to the spacecraft will be controlled. The radiator can be mounted with the cold end either next to or away from the spacecraft without affecting system performance.
- (11) The magnetic field at one meter will be determined by spacecraft requirements. Techniques are available to ensure the goal is met.
- (12) The on-pad biological dose at one meter will be ≤ 0.20 REM per hour.
- (13) The power system will be resistant to natural and man-made radiation.
- (14) The components of the MB-IBFS will be inherently flexible in their mounting; this will facilitate integration with the spacecraft in whatever configuration is required.
- (15) On pad and in-orbit fueling capability will be provided.

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- (d) An electrically heated simulated isotope heat source will be used.
- (e) Controls will comprise breadboard circuits using military grade components.
- (f) 120 vdc ± 2 percent will be the reference output voltage (reference Monthly Progress Report 75-311457(02), Appendix B, "Output Voltage Study").

There are several potential requirements that may materialize at a later date, but do not apply to the current GDS. Examples of these are:

- (a) Provision for operation through launch
- (b) Operation on a spin stabilized platform
- (c) Partial or complete power system spacecraft integration

The layout of the system is based on the requirements of Table 3-1. As the impact of new performance and configuration data is determined from the Phase I effort, they will be reported as updates of Appendix I.

3.2 Applicable Documents

Included in Appendix III are lists of applicable document involving:

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

3.3 System Configuration

3.3.1 Thermodynamic Cycle

The closed-cycle gas turbine (Brayton cycle) theory of operation is similar to that of the open cycle (Figure 3-1) used in turbojet and turboprop aircraft propulsion engines as well as many electrical, shaft, and compressor-air power generation systems. Closed cycle application is suited for shaft power generation and ideally so for electrical power generation with the generator integral to the turbo-compressor 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 any of the various forms of nuclear power.

3.3.2 Reference Cycle

The reference cycle showing all of the 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 thermal loss for the GDS 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 the coolant flow rate, coolant temperatures, and gas inventory.

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GAS TURBINE

OPEN BRAYTON CYCLE
HIGH POWER DENSITY
COMPACT
SIMPLE

GAS TURBINE

RECUPERATED OPEN BRAYTON CYCLE
REDUCED HEAT INPUT
COOL EXHAUST
LOW OPTIMUM PRESSURE RATIO
HIGH AERODYNAMIC EFFICIENCY
HIGH CYCLE EFFICIENCY AT RATED POWER

GAS TURBINE

RECUPERATED CLOSED BRAYTON CYCLE
INDEPENDENT COMBUSTION & AERODYNAMIC LOOPS
SELECTION OF HEAT SOURCES
SELECTION OF WORKING FLUIDS
GAS BEARINGS - NO RUBBING SEALS
LOW POLLUTION
QUIET
EXCELLENT OFF DESIGN PERFORMANCE

OPEN vs CLOSED CYCLE GAS TURBINE

FIGURE 3-1

GDS AT 4800W_t

FIGURE 3-2

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ENERGY BALANCE

FIGURE 3-3

13

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Design: <i>Elm</i> Date: <i>8-28-75</i>	Drawn: <i>Elm</i> Date: <i>8-28-75</i>	POWER CONVERSION SYSTEM		
Project: <i>CCPS-1</i>		Drawing No: <i>L3621581</i>		Sheet: <i>1</i>

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3.3.3 Operating Environment

The environment of the GDS is to be as follows:

- o External Environment - Simulation of space ($<10^{-4}$ Torr)
- o Ambient Temperature - Simulation of internal space radiator ($<240^{\circ}\text{F}$)
- 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 O_2 , N_2 , CO , CO_2 , H_2 and other contaminants to be determined.

3.3.4 System Assembly

The integrated GDS is shown in the drawings listed below:

- (a) L3621581, GDS Assembly
- (b) TBD, GDS Installed in Test Facility
- (c) 306960, GDS Plumbing and Instrumentation Diagram

3.3.5 BIPS GDS Components

Since not all GDS components appear in the drawings listed in Paragraph 3.3.4, an outline of the system components is presented on Table 3-2. Descriptions of these components may be found in Section 3.4, Component Data.

TABLE 3-2

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 (Niobium)

Recuperator

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

Radiator Simulator

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

Heat Source

- o Electrically heated heat source simulator (EHS)

Heat Source Heat Exchanger (HSHX)

- o Niobium construction
- o Cylindrical geometry, annular, finned flow passages

Insulation

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

Auxiliary Cooling System

- o Helium Short Circuit

Emergency Cooling System

- o Melting insulation (alternates have been identified)

Controls

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

Piping and Structure

- o Ducting
- o Support structure

It is recognized that component characteristics such as operational limitations, design points, safety factors, acceptance testing parameters and environmental hazards will be defined during Phase I of this program and will be included in future editions of this CCD.

3.4 Component Data

The following paragraphs provide additional component information and reference related detail design reports.

3.4.1 Mini-Brayton Rotating Unit (Mini-BRU)

3.4.1.1 Function

The function of the Mini-BRU is to convert thermal energy contained in a radio isotope (Pu_{238}) heat source into electricity. The Mini-BRU is designed to produce from 0.5 to 2.0 kw of electrical power for space satellite applications.

3.4.1.2 Design Characteristics

3.4.1.2.1 General

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

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The Mini-BRU is designed for ease of assembly and disassembly such that alteration and replacement of major components is facilitated. Components are designed to maintain high efficiency over the entire specified rated power output range. Table 3-3 defines the nominal operating conditions for 1/2, 1, 2 and 3 heat source capsule operation in a flight system.

The Mini-BRU characteristics are as follows:

- (a) Type of rotating unit: single shaft
- (b) Cycle working gas: He-Xe, molecular weight 83.8
- (c) Mini-BRU rated power output range: (300 - 2146 W_e).
The alternator is designed for a three phase full-wave 120 vdc rectifier load.
- (d) Turbine:
Type - radial flow
Optimized for Case IV - Table 3-3
- (e) Compressor:
Type - radial flow
Optimized for Case IV - Table 3-3
- (f) Alternator:
Type - stationary excitation coil, brushless, Rice type Lundell. Optimized for performance over the range of 1/2 to 3 heat source capsules
- (g) Overspeed capability - 120 percent of 52,000 rpm
(nominal design speed)
- (h) Environmental conditions: Exhibit "E" RFP No. 3-456906-Q, except as noted in Item (i) below.

TABLE 3-3

NOMINAL REFERENCE OPERATING CONDITIONS

The following defines expected performance of the Mini-BRU at its nominal reference operating conditions.

	CASE			
	I	II	III	IV
Alternator output power, kw	0.350	0.676	1.484	2.146
Gross cycle efficiency, percent*	0.226	0.282	0.309	0.298
Compressor efficiency, percent	0.750	0.753	0.758	0.76
Turbine efficiency, percent	0.780	0.798	0.820	0.832
Alternator efficiency, percent	0.86	0.907	0.927	0.920
Lost pressure ratio parameter, B	0.950	0.964	0.975	0.980
Recuperator effectiveness, E_r	0.980	0.983	0.980	0.975
Compressor inlet temperature, °R	458	470	503.4	536.4
Compressor discharge temperature, °R	589.0	604.4	632.7	663.5
Compressor inlet pressure, psia	12.8	21.5	44.6	71.0
Compressor discharge pressure, psia	20.5	33.8	68.3	106.2
Compressor pressure ratio	1.60	1.572	1.532	1.495
Bearing loss, kw	0.120	0.125	0.144	0.153
Windage loss, kw	0.020	0.032	0.059	0.087
Compressor flow rate, lb/sec	0.072	0.120	0.239	0.361
Turbine inlet temperature, °R	2060	2060	2060	2060
CRU speed, rpm	52000	52000	52000	52000

$$\text{*Gross Cycle Efficiency} = \frac{\text{Gross Output at Alternator Terminals}}{\text{Total Heat Available}}$$

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- (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 a minimum of 1000 startup-shutdown thermal cycles.
- (l) The unit is designed such that super alloy and refractory metal scrolls are interchangeable with a minimum of rework.

3.4.1.2.2 Mini-BRU Design Specifications

The following specifications were employed in the Mini-BRU design in addition to the general design requirements discussed in the preceding paragraphs.

Compressor

The compressor is a 2.12 in. diameter radial outflow, backward curved type incorporating a tandem vane diffuser and a plenum. The design efficiency of the compressor (76 percent) is lower than larger designs. This is attributed to low specific results from a low physical speed (tip speed is 480 fps) which was required to optimize the entire system. Size effects appear in the form of clearance and tolerance losses. Special attention was given in the design phase to increase the exit absolute flow angle, thus increasing the exit width and reducing the clearance loss. To achieve better performance a tandem diffuser was incorporated.

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The following design parameters for the Mini-BRU Radial Compressor were taken from Report 75-311241 (Mini-BRU Final Design).

MINI-BRU RADIAL COMPRESSOR DESIGN PARAMETERS

	<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 $N_s = \frac{N\sqrt{Q_{AVG}}}{H_{ACT}^{3/4}}$	
No. of Blades:	13 full blades 13 splitters	where N = RPM
Slip Factor	= 0.931	$Q_{AVG} = (Q_1 Q_2)^{1/2}$, ft ³ /sec
T_{O1}	= 536°R	H_{ACT} = Head, ft
P_{O1}	= 70.8 psia	
N_{PHYS}	= 52,000 rpm	
Diameter Tip	= 2.12 inch	
Inducer Hub Dia.	= 0.509 inch	
Inducer Tip Dia.	= 0.931 inch	

The values of impeller efficiency, impeller pressure ratio, and Euler work were calculated during the preliminary design analysis.

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-pole 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, efficiency of these machines was reduced by higher windage losses caused by larger diameter rotors. The four-pole machine was further optimized by increasing the size of the field and stator core to fully utilize the available space in the alternator heat exchanger ID. Figure 3-4 is a photograph of the alternator and Table 3-4 provides design data. Detailed information is provided in the Mini-Brayton Alternator Final Design Report 75-311211.

The various materials used in the construction of the Mini-BRU alternator such as resins, adhesives and potting compounds are listed in Table 3-5.

The behavior of these materials under the temperature and long life requirements they will be subjected to in operation must be determined as accurately as possible to insure desired reliability. The exact degree and nature of decomposition for all the materials are not readily available and in some instances, do not exist. Tests to obtain outgassing rates and composition are planned for late 1975.

Instrumentation for the alternator is illustrated on Figure 3-5. Precise locating dimensions for the thermocouples and the flux search coil located in the stator assembly are shown on Drawing 2045426, included in report 75-311211.

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MINI-BRU ALTERNATOR ASSEMBLY

FIGURE 3-4

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TABLE 3-4

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

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TABLE 3-5

CONSTRUCTION MATERIAL USED IN MINI-BRU ALTERNATOR

Application	Material Type	Garrett Identification	Manufacturer and Part No.	Temperature Data	Amount Used and Location Used
Adhesive	One component RTV Silicone	105-097-9001 RS184C01 MIL-A-46106	GE Silicone Products Division, Waterford, New York - RTV 108	450°F maximum operating 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 Corporation, Midland, Michigan, 96-069 Class 08	400°F maximum	0.1833 lbs field and stator encapsulation
Varnish	Solventless silicone resin		Dow Corning Corporation, 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 Rubber Company, New Haven Connecticut, Temp-R-Tape Kapton No. 850	400°F maximum	0.01005 lbs stator insulation
Tape	Nylon creped (Nomex Type 410)	722-015-9001 MIL-I-24204	Edgewater Paper Company, 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	Polytetrafluoroethylene (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 Manufacturing Company Conshohocken, Pennsylvania, Ben-Har 963C	482°F maximum	Stator wire insulation trace

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TABLE 3-5 (Contd)

Application	Material Type	Garrett Identification	Manufacturer and Part No.	Temperature Data	Amount Used and Location Used
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	10 - SLOT BOTTOM TEMP
2 - ROTOR GAS EXIT TEMP	11 - STACK OD TEMP
3 - END COIL TEMP	12 - HX ID TEMP
4 - END COIL TEMP	13 - END BELL TEMP
5 - END COIL TEMP	14 - END BELL TEMP
6 - FIELD BOBBIN TEMP	15 - END BELL TEMP
7 - FIELD BOBBIN TEMP	16 - THRUST BEARING LEAKAGE GAS TEMP
8 - MIDDLE STICK TEMP	17 - TURBINE END LEAKAGE GAS TEMP
9 - MIDDLE STICK TEMP	A, B, C - PRESSURE TAPS
	I - SEARCH COIL

ALTERNATOR INSTRUMENTATION

FIGURE 3-5

Turbine

The Mini-BRU turbine is a radial design with ten full blades, ten splitters, and an overall diameter of 2.858 inches. Considerable attention was given to the nominal design speed, 52,000 rpm and the maximum weight flow requirement of 0.357 lb/sec. This turbine design is much smaller than any previous AiResearch design, thus considerable attention was given to various design details to assure a reasonable level of performance for the turbine stage.

When a preliminary study was first conducted the inlet configuration for the turbine was a scroll. However, with the use of scroll inlet, the stators were designed to carry a high stress load, thereby requiring thick blade sections and relatively large trailing edge thickness. With a subsequent decision to go to a plenum configuration for the turbine inlet, stator blade thicknesses could be reduced because of lower stress loads.

The design parameters for the Mini-BRU Radial Turbine from Report 74-311068 may be found on Table 3-6.

TABLE 3-6

DESIGN PARAMETERS FOR MINI-BRU RADIAL TURBINE

General

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

Rotor

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
$\beta_{2\text{SHROUD}} = 69.6^\circ$	$\beta_{2\text{HUB}} = 57.9^\circ$

Inlet Stators

No. of blades	17
Inlet radius	1.876 inches
Exit radius	1.483 inches
$\beta_{\text{IN}} = 0^\circ$	$\beta_{\text{OUT}} = 78^\circ$

Cooling System

The Mini-BRU is self-cooled. Compressor discharge gas is used to cool the alternator and bearings. This is accomplished by a two percent bleed flow through the bearing and alternator cavities with the remainder of the flow (from the diffuser exit) directed through a 0.1 percent pressure drop heat exchanger that surrounds the alternator stator and field coils. This is shown schematically in Figure 3-2.

Gas Bearing System

The Mini-BRU employs "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 the unit to be operated in any attitude in one-"G" with the bearing cavity pressure that exists when compressor inlet pressure is at a minimum of 10 psia. Thrust bearing load capacity is sufficient to continuously support, hydrodynamically, the maximum anticipated cycle thrust loads in any attitude of the Mini-BRU, including those loads that might occur during start-up and shutdown.

Journal and thrust bearings have the capability of starting and stopping under conditions previously specified without the aid of external pressurization. To assure motor start capability, the total resisting breakaway torque of the bearings is expected to be less than 60 percent of alternator motoring torque at three times rated alternator output current. If high-g bearings (for operation through launch) are used, the breakaway torque will increase approximately 25 percent. Breakaway torque is based on one-"G" loadings on both thrust and journal bearings. Torque data may be found in AIRPHX Progress Report for the Mini-BRU, Report 74-310631(16).

Selection of gas bearing materials and application of coatings provides a minimum of 1000 start-stop cycles.

Instrumentation

Each Mini-BRU has the following instrumentation incorporated into the design (see Drawing SKP32488):

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

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

- (b) Three magnetic pickup shaft-speed sensors are provided.
- (c) Static pressure measurement line with filters are provided to sense pressure in each of the rotor and bearing cavity pressure zones shown on Drawing SKP32488.
- (d) A coil of one full pole pitch is installed in the stator to make magnetic flux measurements.
- (e) Predicted operating temperatures are shown in Figures 3-6 through 3-10 (all temperatures are in °F).

8 7 6 5 4 3 2 1

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REVISIONS		DATE	APPROVED
ZONE	LTR

- 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.				GARRETT			
DFT 10-10-74				AIRESEARCH MANUFACTURING COMPANY OF ARIZONA			
DWG TITLE				A DIVISION OF THE GARRETT CORPORATION			
SCHEMATIC				PHOENIX, ARIZONA			
INTERNAL INSTRUMENTATION							
CCPS 2-1							
REQD NEXT ASSY USED ON				SIZE CODE IDENT NO. DWG NO.			
HEAT TREATMENT PROCESS				D 99193 SKP32488			
HARDNESS AND SPEC NAME AND SPEC				SCALE 1/1 WT SHEET -- OF --			
DESIGN ACTIVITY APVD							
OTHER ACTIVITY APVD							

8 7 6 5 4 3 2 1

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STEADY-STATE TEMPERATURES 1 HIGH POWER LEVEL

FIGURE 3-6

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STEADY-STATE TEMPERATURES 2 HIGH POWER LEVEL

FIGURE 3-7

ALL TEMPERATURES IN °F

Technical drawing of a mechanical assembly, likely a turbine or engine component, showing various parts and temperature callouts. The drawing includes a central vertical shaft with multiple bearings and seals. A large, curved component on the left is labeled with '0'. The right side shows a complex arrangement of pipes and structural elements. Numerous temperature points are indicated by numbers, such as 120, 125, 130, 150, 160, 196, 230, 255, 261, 271, 280, 296, 315, 333, 350, 363, 375, 380, 385, 390, 395, 400, 405, 410, 415, 420, 425, 430, 435, 440, 445, 450, 455, 460, 465, 470, 475, 480, 485, 490, 495, 500, 505, 510, 515, 520, 525, 530, 535, 540, 545, 550, 555, 560, 565, 570, 575, 580, 585, 590, 595, 600, 605, 610, 615, 620, 625, 630, 635, 640, 645, 650, 655, 660, 665, 670, 675, 680, 685, 690, 695, 700, 705, 710, 715, 720, 725, 730, 735, 740, 745, 750, 755, 760, 765, 770, 775, 780, 785, 790, 795, 800, 805, 810, 815, 820, 825, 830, 835, 840, 845, 850, 855, 860, 865, 870, 875, 880, 885, 890, 895, 900, 905, 910, 915, 920, 925, 930, 935, 940, 945, 950, 955, 960, 965, 970, 975, 980, 985, 990, 995. The drawing is labeled with 'A35584' in the bottom right corner.

FIGURE 3-8

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FIGURE 3-9

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TEMPERATURES ARE SHOWN IN °F

ALTERNATOR STATOR TEMPERATURES
AT HIGH-POWER OPERATION

FIGURE 3-10

Leakage Rates

The contractual maximum leakage rates are as follows:

Mini-BRU joints, each: 1×10^{-10} standard cc/sec
Recuperator: 1×10^{-7} standard cc/sec
HSA: 1×10^{-9} standard cc/sec

Assuming a maximum of 50 joints in the system, the maximum total equals 1.06×10^{-7} standard cc/sec leakage. This amounts to 16.71 cc over a five year period and represents a maximum loss of 0.011 percent.

3.4.1.3 Development Status

Mini-BRU detail design has been completed and parts fabrication is in process. Delivery of the first unit is anticipated in mid 1976.

3.4.1.4 Physical Data

3.4.1.4.1 Configuration

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

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

3.4.1.4.2 Materials

Drawing 3604385 and Table 3-7 show materials to be used for Mini-BRU component parts.

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TABLE 3-7

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. TURB.	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	SEAL 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 Ps	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

75-311274A

REVISIONS			
NO.	DATE	BY	APP.
1	7-2-58		

REVISIONS			
NO.	DATE	BY	APP.
1	7-2-58		

OSTI #040101934 / DDE/SF/01123--T60

ELECTRO PRODUCTS			
1	WHEEL, GEAR	3000	3
2	WHEEL, GEAR	3000	3
3	WHEEL, GEAR	3000	3
4	WHEEL, GEAR	3000	3
5	WHEEL, GEAR	3000	3
6	WHEEL, GEAR	3000	3
7	WHEEL, GEAR	3000	3
8	WHEEL, GEAR	3000	3
9	WHEEL, GEAR	3000	3
10	WHEEL, GEAR	3000	3
11	WHEEL, GEAR	3000	3
12	WHEEL, GEAR	3000	3
13	WHEEL, GEAR	3000	3
14	WHEEL, GEAR	3000	3
15	WHEEL, GEAR	3000	3
16	WHEEL, GEAR	3000	3
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22	WHEEL, GEAR	3000	3
23	WHEEL, GEAR	3000	3
24	WHEEL, GEAR	3000	3
25	WHEEL, GEAR	3000	3
26	WHEEL, GEAR	3000	3
27	WHEEL, GEAR	3000	3
28	WHEEL, GEAR	3000	3
29	WHEEL, GEAR	3000	3
30	WHEEL, GEAR	3000	3
31	WHEEL, GEAR	3000	3
32	WHEEL, GEAR	3000	3
33	WHEEL, GEAR	3000	3
34	WHEEL, GEAR	3000	3
35	WHEEL, GEAR	3000	3
36	WHEEL, GEAR	3000	3
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39	WHEEL, GEAR	3000	3
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41	WHEEL, GEAR	3000	3
42	WHEEL, GEAR	3000	3
43	WHEEL, GEAR	3000	3
44	WHEEL, GEAR	3000	3
45	WHEEL, GEAR	3000	3
46	WHEEL, GEAR	3000	3
47	WHEEL, GEAR	3000	3
48	WHEEL, GEAR	3000	3
49	WHEEL, GEAR	3000	3
50	WHEEL, GEAR	3000	3
51	WHEEL, GEAR	3000	3
52	WHEEL, GEAR	3000	3
53	WHEEL, GEAR	3000	3
54	WHEEL, GEAR	3000	3
55	WHEEL, GEAR	3000	3
56	WHEEL, GEAR	3000	3
57	WHEEL, GEAR	3000	3
58	WHEEL, GEAR	3000	3
59	WHEEL, GEAR	3000	3
60	WHEEL, GEAR	3000	3
61	WHEEL, GEAR	3000	3
62	WHEEL, GEAR	3000	3
63	WHEEL, GEAR	3000	3
64	WHEEL, GEAR	3000	3
65	WHEEL, GEAR	3000	3
66	WHEEL, GEAR	3000	3
67	WHEEL, GEAR	3000	3
68	WHEEL, GEAR	3000	3
69	WHEEL, GEAR	3000	3
70	WHEEL, GEAR	3000	3
71	WHEEL, GEAR	3000	3
72	WHEEL, GEAR	3000	3
73	WHEEL, GEAR	3000	3
74	WHEEL, GEAR	3000	3
75	WHEEL, GEAR	3000	3
76	WHEEL, GEAR	3000	3
77	WHEEL, GEAR	3000	3
78	WHEEL, GEAR	3000	3
79	WHEEL, GEAR	3000	3
80	WHEEL, GEAR	3000	3
81	WHEEL, GEAR	3000	3
82	WHEEL, GEAR	3000	3
83	WHEEL, GEAR	3000	3
84	WHEEL, GEAR	3000	3
85	WHEEL, GEAR	3000	3
86	WHEEL, GEAR	3000	3
87	WHEEL, GEAR	3000	3
88	WHEEL, GEAR	3000	3
89	WHEEL, GEAR	3000	3
90	WHEEL, GEAR	3000	3
91	WHEEL, GEAR	3000	3
92	WHEEL, GEAR	3000	3
93	WHEEL, GEAR	3000	3
94	WHEEL, GEAR	3000	3
95	WHEEL, GEAR	3000	3
96	WHEEL, GEAR	3000	3
97	WHEEL, GEAR	3000	3
98	WHEEL, GEAR	3000	3
99	WHEEL, GEAR	3000	3
100	WHEEL, GEAR	3000	3

REVISIONS		LAYOUT	
1	21	21	21
2	21	21	21
3	21	21	21
4	21	21	21
5	21	21	21
6	21	21	21
7	21	21	21
8	21	21	21
9	21	21	21
10	21	21	21
11	21	21	21
12	21	21	21
13	21	21	21
14	21	21	21

OSTI # 040101924 / DOE / SF / 01133 - T60

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WORK SHEET ONLY					PARTS LIST	PL 240610-1	REV LTR
CONTRACT NO.					LIST TITLE		DATE
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA <small>A DIVISION OF THE GARRETT CORPORATION</small> <small>PHOENIX, ARIZONA</small>					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	BS	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	F3	3604342-1		" "	0.24	1
16	1	B6	3604343-1		" "	0.10	1
17	1	C3	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	REV LTR	
CONTRACT NO.				LIST TITLE		DATE
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA <small>A DIVISION OF THE DARRETT CORPORATION</small> <small>PHOENIX, ARIZONA</small>				ENGINE ASSY MINI-BRAYTON ROTATING UNIT TURBOALTERNATOR		REV AUTH NO.	
CODE	IDENT NO.	APPROVAL	ORIGINAL ISSUE	SHEET 2			
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
CONTRACT NO.				LIST TITLE			DATE
AIRSEARCH MANUFACTURING COMPANY OF ARIZONA <small>A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA</small>				ENGINE ASSY, MINI-BRAYTON ROTATING UNIT, TURBOALTERNATOR			REV AUTH NO.
CODE IDENT NO.		APPROVAL		ORIGINAL ISSUE		SHEET 3	
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	0.16	4
65	1	C3	MS9564-05		SCREW		4
65	1	C4	"		"		6
65	1	C8	"		"		6
66	1	C8	MS9565-06		BOLT	0.18	18
67	1	G6	MS20470AD3-3		RIVET		2
70	1	B7	MS2099SC32		LOCKWIRE		AR
70	1	C3	"		"		
70	1	C3	"		"		
70	1	C4	"		"		
70	1	C7	"		"		
70	1	C7	"		"		
70	1	C8	"		"		
71	1	B7	MS24676-2		SCREW	0.10	4
71	1	C3	"		"		4
72	1	F8	MS35650-304		NUT		3
			INSULATION			1.00	
			MISC. HDWE			2.30	
77	1	C3	NAS620-8		WASHER		4
80	1	F8	3080	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

3.4.1.4.3 Weight Analysis

Weight of the Mini-BRU assembly was determined by calculating and estimating weight of the component parts. The weight breakdown is presented on Parts List PL 240610-1.

Total weight, including refractory plenum, was estimated to be 36.1 lb.

3.4.1.5 Interface Data3.4.1.5.1 MechanicalStatic

- (a) Flange Loading: To be determined (TBD)
- (b) Center of Gravity: Estimated to be 5.75 in. from the compressor inlet flange and 0.02 in. from the centerline in the direction of the alternator terminals.
- (c) Orientation: Any attitude.
- (d) Mounting: Large OD flange at compressor-end of the machine. Flange has 8-bolt hole pattern and may be adapted to a variety of mounting arrangements (see Drawing 240611-1).

Dynamic

- (a) Rotating group polar moment of inertia: $I_p = 0.00149 \text{ in.-lb-sec}^2$

WIRING DIAGRAM

SECTION A-A

SECTION B-B

SECTION C-C

38 B

- (b) Rotating group diametral moment of inertia: $I_d = 0.0359 \text{ in.-lb-sec}^2$
- (c) Bearing span: Center of journal to center of journal = 3.63 in.
- (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

3.4.1.5.2 Thermal

Surface Temperature

TBD

Heat Loss

TBD

3.4.1.5.3 Electrical

Electrical Connections

Location of electrical connections are shown on Installation Drawing 240611-1.

Electrical connector types: TBD

External Magnetic Field

Intensity of the magnetic field external to the Mini-BRU, generated by the Rice alternator, will be determined during GDS testing.

3.4.1.5.4 Environmental, Handling, and CleaningEnvironmental

Radiation tolerance of alternator materials and system electronics will be determined and appropriate shielding provided, if necessary.

Handling

- (a) The unit should, at all times, be protected from moisture during handling and storage. Specific procedures are to be determined; vacuum packing with desiccant is under consideration.
- (b) Unit temperature during storage shall not exceed 200°F.
- (c) All refractory alloy parts must be kept in a vacuum or inert environment if exposed to temperatures above 400°F.
- (d) Special handling procedures will be determined for protection of the Multi-Foil insulation.

Cleaning

TBD

3.4.1.5.5 Nuclear

TBD

3.4.2 Mini-Brayton Recuperator (MBR)3.4.2.1 Function

The function of the Mini-BRU recuperator is to transfer thermal energy from the turbine discharge working fluid to the compressor discharge working fluid. This recovery of thermal energy serves to increase cycle efficiency by reducing required heat source output for a given power level.

3.4.2.2 Design Requirements

MBR design requirements for the reference 2.08 kw_e system are presented on Table 3-8. Heat transfer performance is based on no heat loss to the surroundings.

3.4.2.3 Development Status

MBR detail design has been completed and parts fabrication is in process. Delivery of the first unit is anticipated early in 1976.

3.4.2.4 Physical Data3.4.2.4.1 Configuration

The MBR design is shown on Figure 3-11, Table 3-9, and Drawing 190930. Recuperator envelope dimensions are 32.1 in. by 16.3 in. by 9.4 in. It is of all-brazed and welded construction and is fabricated entirely of Hastelloy X. Internal construction, illustrated in Figure 3-12, is typical of that used on counterflow heat exchangers. Heat

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TABLE 3-8
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

NOTE

Refer to Appendix I, Figure I-1 for corresponding cycle data.

MBR PRELIMINARY DESIGN

FIGURE 3-11

TABLE 3-9

MINI BRAYTON RECUPERATOR (MBR) MATERIALS

ITEM NO.	PART	MATERIAL	FUNCTION	BASIS FOR SELECTION
1	FINS	HASTALLOY-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.

MBR CORE DETAIL
FIGURE 3-12

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. Plain rectangular fins are used in the end sections to uniformly distribute gas flow with minimum pressure drop. In the pure counterflow section of the core, fins in both the hot and cold passages are 20R-0.10-1/8-0.004 (20 fins per inch, rectangular, 0.10 in. high, 1/8 in. offset, and 0.004-in. thick). In the transition sections, plain rectangular fins at 16 fins per inch are employed. Additional core features are shown in Figure 3-13.

3.4.2.4.2 Materials

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

3.4.2.4.3 Structural Design Criteria

Criteria used in the MBR design are summarized as follows:

- (a) Operating Life - Design life - 100,000 hr (approximately 10 years) at 1330°F maximum operating temperature
- (b) Cyclic Life - 1000 operating cycles without failure for contractual transients (Transient startup conditions, which are the basis for new analysis, are shown in Figures 3-14 and 3-15. Additional details of FS transient performance are included in AiResearch Report 75-311279, dated May 19, 1975.)
- (c) Short-Time Pressure Containment - Proof pressure is 1.5 times working pressure and burst pressure at 25 times working pressure at operating conditions. The following room-temperature proof pressure test is specified to verify unit integrity.

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MBR CORE DESIGN

FIGURE 3-13

RUN 101
MINI BRU COLD START - ALL COMPONENTS AT 450 DEG R - HEATER AT 2060 DEG R

50B

OSTI #64010124/DSE/570123--T60

FIGURE 3-15

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High pressure side 260 psig at 70°F
Low pressure side 175 psig at 70°F

NOTE: High-pressure-side pressure must be greater than low-pressure-side pressure with a maximum allowable pressure differential of 91 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:

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

Where: σ_{all} = allowable stress

f_{tu} = material ultimate tensile stress

Allowable indicated elastic stress due to bending loads is taken to be 1.5 times the allowable value computed using the above equation.

3.4.2.4.4 Detail Design

A list of drawings and the estimated weight that defines the MBR are presented in Table 3-9.

3.4.2.4.5 Physical Data

MBR physical data is as follows:

- o Estimated weight: 132 lb (could be reduced to 106 lb for 1300 W_e system)

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PHOENIX, ARIZONA

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

- o Center of gravity: TBD
- o Dimensions: Refer to Outline Drawing 190930

3.4.2.4.6 Installation Data

Specific items of installation include the following:

- (a) Mounting Provisions - Designed to be mounted 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.
- (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 AiResearch Specification C-38 using trichlorotrifluoroethane followed by a nitrogen purge to achieve Class II, Level III cleanliness.
- (e) Allowable Pressure Differential - Test operations shall be conducted to prevent exceeding a maximum pressure differential of 81 psi across the high- and low-pressure sides of the recuperator at operating temperatures.

3.4.2.4.7 Environmental Conditions

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

3.4.2.4.8 Maximum Allowable Leakage

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

3.4.2.5 Nuclear

TBD

3.4.3 Heat Source Assembly (HSA)

3.4.3.1 Definition

The HSA includes the following items:

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

NOTE

The HSA does not include a heat source. Two types of heat sources can be used with the HSA: (1) IHS - Isotope Heat Source, and (2) EHS - Electrical Heat Source.

SECTION A-A

LOCATION	DESIGN LOAD - LB'S			TENSILE STRENGTH FROM INSITUATES		
	X-AXIS	Y-AXIS	Z-AXIS	X-AXIS	Y-AXIS	Z-AXIS
INSITUATE 1	1500	1500	1500	0	0	0
INSITUATE 2	1100	1500	1500	0	+110	0
INSITUATE 3	1300	1500	1500	0	0	+045
INSITUATE 4	1500	1500	1500	0	+110	0.055

LOCATION	FORCE - LBS			MOMENT IN.-LB		
	Y-Axis	Z-Axis	X-Axis	Y-Axis	Z-Axis	X-Axis
H.P. JET	240	240	240	1450	1450	1450
L.P. JET	240	240	240	1125	1125	1125
H.P. INLET	240	240	240	1450	1450	1450
L.P. INLET	240	240	240	1125	1125	1125

PRELIMINARY
CHECK FRONT
NOT FOR SHOP USE

190320-1-1		190331-1		CALC WEIGHT		REMARKS	
ITEM NUMBER							
QTY	ITEM CODE	EXT NO	PART OR IDENTIFY NO	NOMENCLATURE OR DESCRIPTION			EXT NO
				PARTS LIST			
UNLESS OTHERWISE SPECIFIED				BUREAU OF MANUFACTURING CONTROL OF CALIFORNIA			
BASIC CODE NO				BUREAU OF THE COUNTY ENGINEER			
IDENTIFICATION MARKING PER				THERMAL OPERATOR			
EXT IDENTIFICATION PER PART				RECYCLATOR			
DATE DELIVERED		PROCESS		OUTLINE			
PARTIAL TO FULL		WELD AND SPEC					
MANUFACTURER				J 70210 190930			
J 70210				SHEET 1 OF 1			

3. THIS UNIT IS DESIGNED TO WITHSTAND THE FOLLOWING PROOF PRESSURES:

- 1. HIGH PRESSURE SIDE: 2.0 PSIG @ 10°F
- 2. LOW PRESSURE SIDE: 175 PSIG @ 10°F
- 3. HIGH PRESSURE SIDE MUST ALWAYS BE AT A HIGHER PRESSURE THAN LOW SIDE WITH A MAX ΔP OF 81 PSI

2. ALL OPENINGS ARE PROVIDED WITH SHIPPING COVERS, REMOVE ONLY AT INSTALLATION.

1. ALL DIMENSIONS ARE FOR INSTALLATION PURPOSES ONLY

NOTES, UNLESS OTHERWISE SPECIFIED

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3.4.3.2 Function

The function of the HSA is to receive heat by radiation from a heat source and impart it to the working fluid by forced convection via the HSHX. For the BIPS GDS, the heat source will be an electrical resistance heater; the BIPS FS heat source will be radio isotopes.

3.4.3.2.1 Auxiliary Cooling System (ACS)

The HSA design includes a multifoil superinsulation system designed to function as an effective insulation in the environment of a hard vacuum in space. Auxiliary cooling is required for the HSA immediately after loading of the isotope heat source if the BIPS is to remain idle for more than a short period of time (TBD). The auxiliary cooling system comprises a method of filling the HSA foil superinsulation with helium, thereby short-circuiting the insulation, causing the heat from the isotopes to be rejected through the outer surface of the HSA. This results in a reduction of the radial temperature gradient across the HSA such that the fuel sphere assemblies within the isotope heat source are at acceptable temperatures. The helium gas is retained in the HSA by the sealed beryllium housing. At the same time this sealed design prevents air from entering the refractory and graphitic parts of the HSA. In order to ensure that the exterior surfaces of the HSA are maintained below 380°F, forced convection cooling over the surface must be provided. Recent tests conducted on the MHW-RTG indicate that temperatures well below this limitation can be provided with moderate nitrogen gas flow rates.

Venting the gas from the HSA is effected by ground command, which fires a squib, rupturing a vent disc. Elimination of the gas from the HSA allows the multifoil insulation system to perform as a superinsulation.

The advantages of this auxiliary cooling design approach are:

- (a) High reliability provided by the helium filled and sealed HSA and the use of flowing nitrogen or air cover gas (on-pad)
- (b) Low weight due to a minimum of additional hardware - the vent system
- (c) Minimal heat leaks due to the elimination of insulation penetrations (i.e., piping connections)
- (d) Low development risk since no new technologies are involved
- (e) Use of available launch pad facilities - nitrogen or air
- (f) Capability of being ground tested
- (g) Very low unit costs - the HSIS is required independent of the ACS

3.4.3.2.2 Emergency Cooling System (ECS)

The emergency cooling concept is based on a HSA insulation system with a relatively low melting point which melts during an emergency situation. Calculations have been performed which indicate that the loss in the insulation effectiveness allows safe temperatures to be maintained within the heat source.

In determining the feasibility of the melting insulation system, both transient and steady state temperature response calculations have been performed. The short time required for the insulation to melt (~5 minutes) is responsible for the effectiveness of the ECS in maintaining acceptable heat source temperatures.

The melting insulation ECS design concept offers:

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

3.4.3.3 Design Data

3.4.3.3.1 Heat Source

The HSA 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's working fluid.

3.4.3.3.2 Mini-Brayton HSA/HSX Design Parameters

Specific design parameters are listed below:

- (a) HSX
 - o Design life: 10 years
 - o Thermal cycles: Capability to sustain 100 startup-shutdowns
 - o Power Source: Capability of operating under $2400 W_t$ AEC MHW heat source or electric heat source simulator for ground test demonstration
 - o Working fluid: Xe-He (M.W. = 83.8)

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- o Weight goal: 90 lb
- o Environmental: Capability to operate in a space vacuum and meet conditions specified in Exhibit C of NAS3-18541 and as to be determined.
- o State points: Inlet temperature 1307°F
Outlet temperature 1600°F
Flow 0.12 lb/sec

(b) HSHX

- o Material: Columbium (niobium) alloy C-103
- o Maximum pressure drop: 0.22 psi at flow rate of 0.126 lb/sec and pressure of 35.3 psia
- o Maximum leak rate: 1×10^{-9} standard cc/sec of helium
- o Maximum design life creep rate: 2 percent in radial direction, 1 percent in axial direction

(c) Auxiliary Cooling System

- o Maximum temperature of exposed surfaces: 380°F - assumes forced cooling (ground support furnished) on equipment on exposed surfaces
- o Maximum temperature of refractory alloys exposed to air: 400°F

- (d) Emergency Cooling System - Must maintain heat source at safe temperature in the event of power conversion system failure (maximum temperature of 3000°F on HS surface - tentative). During activation of the ECS, maximum outer surface temperature of the HS shall not exceed 2700°F for more than 15 minutes.

3.4.3.4 Development Status

Under the current NASA contract (NAS3-18029), the preliminary design has been completed and detail design is in progress. The first delivered hardware is expected in early 1977.

3.4.3.5 Physical Data

The HSA and HSHX are defined on Drawings SK No. MB-30-4-75-1 and SK No. MB-13-5-75-1, respectively. Figure 3-16 is an exploded view of the HSA showing the component parts and a materials list is given on Table 3-10.

3.4.3.6 Interface Data

TBD

3.4.4 Radiator Simulator

A vacuum tank with refrigerated walls and the proper emissivity and absorbance would be needed to properly simulate the effective space radiant temperature (217°C or 390°F is the temperature used for all performance estimates in this document) for the space radiator. To simplify the design of the system and test facilities, a heat exchanger system will be designed and fabricated for the GDS.

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CYLINDRICAL HSA DESIGN

FIGURE 3-16

MINI-BRAYTON HEAT SOURCE ASSEMBLY (HSA)
SCALE - FULL SIZE
GENERAL ELECTRIC
SK# MS-30-4-75-1

PRELIMINARY FOR INFORMATION PURPOSES ONLY

HSHX ASSEMBLY
MINI-BRAYTON HSA
SCALE: - HALF SIZE
G.Y. SCHMIDT 13 MAY 75

5K#MB-13-5-75-1

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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 0.003 in. Cb-103; 59 outer layers. 0.0005 in. Ni; End caps, inner layer 0.005 in. Cb-103; 59 outer layers, 0.0005 in. Cb-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 creep life
3	HSHX Mounting Supports ("L" Brackets)	Cb-103	Supports HSHX; permits radial and longitudinal expansion.	Compatible w/HSHX
4	Heat Source End Supports	Graphite	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	Titanium	Preloads end enclosures under compressive load.	MHW/RTG program experience
8	Heat Source Heat Exchgr (HSHX)	Cb-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	Cb-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	Houses heat source, HSHX, and support assembly (Items 4-7 above); transmits launch loads.	MHW/RTG program experience.

3.4.4.1 Design Requirements

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

3.4.4.1.1 Steady-State Performance

The basic performance of the heat exchanger must be such that it meets the steady-state performance criteria as defined by the engine. This analysis has been completed for the initial conceptual design as presented in Drawing L3621495. This design may require modification as determined by further analysis.

3.4.4.1.2 Dynamic Analysis

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

3.4.4.1.3 Structural Analysis

In order to ensure system integrity, a stress and vibration analysis of the heat exchanger will be made. Since this is a simple, non-flight configuration, only the analysis necessary to safety and reliability will be performed.

3.4.4.2 Acceptance Tests

3.4.4.2.1 Structural Test

Tests to obtain pressure drop data and structural integrity confidence by means of a proof pressure test will be conducted. The pressure and temperature will be specified as a result of a stress analysis.

3.4.4.2.2 Performance Test

A heat transfer performance test will be conducted using air on the working fluid side of the heat exchanger. The cooling side temperature control loop shall be in operation during this test to verify the operation of the heat exchanger as a system.

3.4.5 Controls

3.4.5.1 Function

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

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

3.4.5.2 Design Requirements

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

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

The control system reliability requirement is TBD.

3.4.5.3 Development Status

A control system developed by AiResearch for the NASA "B" Engine (a 15 kw_e closed Brayton cycle) has been on test for over 32,500 hours. A follow-on system was breadboarded by the NASA-Lewis Research Center which also conducted initial functional tests and derived performance characteristics of the system. This system has been selected as the baseline reference system to be used for GDS control system design and eventually, with evolutionary improvements, in the IBFS. The baseline design provides considerable latitude for improvements in reliability and functional characteristics through redesign and the addition of redundant components.

3.4.5.4 Physical Data

TBD

3.4.5.5 Description of Operation

Controls and instrumentation required for BIPS GDS ground testing are shown on the block diagram of SKP4639 and schematically in 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.

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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 heat input of an isotope heat source. The laboratory setup contains an argon supply and vacuum system to allow the heat source either to be pressurized and conduct heat to ambient or to be evacuated, thus greatly reducing conduction to ambient and allowing heat to enter the Brayton loop.

The basic loop contains a turbine bypass valve (SV-X) and a pressure relief valve (PRV-X) in the control loop for development testing protection. The bypass is used to take flow directly from compressor discharge to turbine discharge thus bypassing the turbine and reducing engine power. The compressor continues to require energy to compress this gas flow; however, in bypassing the turbine, both power and speed of the rotating group are reduced. This bypass is for fault and over-speed protection only, since normal speed control is provided by the electrical parasitic load which is a function of speed. The pressure relief valve is a safety feature to prevent inadvertently 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 the check valve will be investigated during engine testing.

The radiator (simulator) will be supplied a liquid coolant. Temperatures of the radiator simulator inlet and outlet gas stream will be monitored and an automatic control will adjust the cooling flow to control the outlet temperature.

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

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

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

In addition to the automatic shutdown feature, an alarm is initiated if dc voltage is too high or too low, or if compressor discharge pressure is too low (required make-up gas), or if 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 on a separate control and will be at operating temperature prior to initiation of engine start. With heaters at 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.

It may be desirable to limit the rate at which heat exchangers come to temperature since thermal stress is a major consideration. The rate of heat-exchanger temperature rise 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. That is, the rate of

change of speed and, therefore, temperature will be controlled. Obviously, 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 will be produced by the alternator that forces the engine down below self-sustaining speed. The engine should then roll down rapidly and the heater pressurized with argon or helium to short circuit the insulation and allow dissipation of thermal energy.

The flight monitoring system will be included in the ground 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 is an opportunity to study installation and log endurance time on the proposed flight monitoring equipment.

3.4.5.6 Drawings and Parts List

To date only a preliminary system control schematic has been prepared. See Drawing 306960.

3.4.5.7 Interface Data

- (a) Flight system based on launch requirements of Titan IIIC or the Space Shuttle (Appendix I). GDS components to be flight system oriented.
- (b) Temperature limit of exposed surfaces based on explosive vapor environment limit is 380°F.
- (c) The BIPS-FS sink temperature is that of geosynchronous orbit with the worst case of solar input. The GDS radiator simulator is to have thermodynamic properties equivalent to the space radiator.

- (d) Electrical Power Output - [See Section 3.1, item (f) and Table 3-1]
- (e) Electrical Power Input for EHS - TBD
- (f) Handling and Clearing - TBD

3.4.6 Ancillaries

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

3.4.6.1 Bi-Metallic Joints

TBD

3.4.6.2 Ducting

In order to optimize the BIPS ducting system and facilitate interface design of all components of the system four basic requirements were considered.

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

The approach developed to meet these basic requirements is shown in L3621581. Short lengths of straight ducting was utilized wherever possible to minimize flange loading especially in the area of the turbine plenum where temperature and stress are the highest. By reducing the number of bends the pressure drop is minimized. Also short duct lengths minimize thermal loss. Multiple bellows links are used to absorb the large relative thermal growths of the components.

Two duct diameters were used, 1.50 OD and 2.50 OD. Wall thicknesses remain to be determined.

Fusion welding will be used in joining the system together.

3.4.6.3 Structure

TBD

3.4.6.4 Insulation System

The high operating temperatures of the Mini-Brayton system, the relatively low output power, and the high cost and weight of radio-isotope, require a low loss insulation system. The system tentatively selected for the IBFS and GDS 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 its problems of fabrication is contained in 74-310631(13), Mini-BRU Progress Report. Losses for the GDS, because of the extensive instrumentation required, will be allowed to be as high as $500 W_t$. Design goal for the IBFS is $120 - 200 W_t$.

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 3-17. The oxide particles are selected on the basis of low thermal conductivity and foil compatibility, depending on the application temperature. The oxide particles are optimized with regard to particle size and a real density to minimize thermal transport. The multiple foils are effective thermal radiation shields. The vacuum environment eliminates convective heat transport. The oxide particles provide a high thermal impedance to conduction by:

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

Multi-Foil has demonstrated low heat losses perpendicular to the foils. A thermal conductivity comparison of Multi-Foil and other insulations is shown in Figure 3-18. However, extreme care must be taken in the design and fabrication of Multi-Foil assemblies to minimize heat losses at the joints. Typically, joint heat loss is comparable to that directly through the foil.

Three types of Multi-Foil will be evaluated for the BIPS GDS and IBFS.

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

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PLANAR AND CYLINDRICAL MULTI-FOIL INSULATION

FIGURE 3-17

THERMAL CONDUCTIVITY COMPARISON

FIGURE 3-18

3.4.7 GDS Tests

Test and evaluation of the Ground Demonstration System (GDS) will consist of performance testing followed by what has been termed an endurance test.

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

The endurance test following the performance tests will consist of running the GDS for a period of time yet to be determined; 1000 to 2000 hours is contemplated.

The basic objectives are:

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

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The relatively short term (1000 to 2000 hours) endurance test may be expected to accomplish the following:

- (a) Contribute, to a limited degree, in substantiating the FMEA (Objective a)
- (b) May disclose a system or component weakness not previously discovered in component tests or performance mapping (Objective d)
- (c) Demonstrate the ability to operate the GDS in a given test facility from 1000 to 2000 hours (Objective e)
- (d) Provide an accurate determination of test costs per hour (Objective f), important to follow on program planning
- (e) Provide a reasonable confidence level that the test facilities and procedures developed will permit trouble-free running of the GDS over longer periods if desired.

(It is to be noted that the performance tests will also contribute to satisfying the same objectives.)

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 describes the general ground rules used in design of the BIPS-FS, operating parameters used in the performance parametric studies, and design-point operating conditions. A conceptual system layout (L3621581) is included in the main body of this document, based on 4800 W_t total from two radio-isotope heat sources.

The BIPS-FS design is such that optional features can be easily 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 described at length in Document 74-310831, has been designed to be 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 6-percent weight penalty to the BIPS-FS when integrated into a 0.4 kw_e system designed for a synchronous orbit mission.

Items in the GDS that will not appear in the BIPS-FS include a turbine bypass valve for overspeed protection and a valved fill system. The BIPS-FS will not have any valves with external stems that could result in working fluid (gas) leakage.

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The GDS cooler (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.

BIPS-FS requirements are delineated on Table 3-2. It is derived from table I-1 which forms the basis of a BIPS-FS design. It is similar to Table 3-2 with the essential difference being that a space radiator is described rather than a heat exchanger for GDS purposes.

The radiator may be fabricated from either Al or Be alloys; Be alloys have the potential of reducing the weight of an Al radiator approximately 40 percent. Development of Be fabrication techniques is included as part of Task 9 of the GDS. In any event, the radiator size estimates are based on an effective sink temperature of 217°C (390°R) for a geosynchronous orbit and a surface emissivity of 0.83.

The projected system flow schematic at the design point with operating parameters used in the performance analysis is shown in Figure I-1. The energy balance corresponding to the system is shown in Figure I-2.

TABLE I-1

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 (niobium)

Recuperator

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

Radiator

- o Material (Be, Al, stainless steel or combinations thereof)
- o Cylindrical or conical design, offset fin/tube geometry (heat pipes will be considered as an alternate)
- o Sink temperature, 390°R
- o Micrometeoroid survival, 0.99 (assumed)

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 Heat Exchanger (HSHX)

- o Niobium construction
- o Cylindrical geometry, annular, finned flow passages

Insulation

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

Auxiliary Cooling System

- o Helium Short Circuit

Emergency Cooling System

- o Melting insulation (alternates have been identified)

Controls

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

Piping and Structure

- o Ducting
- o Support structure

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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

MB-IBFS FLOW SCHEMATIC AT 4800 W_t , 12 PERCENT THERMAL LOSS

FIGURE I-1

ENERGY BALANCE - 4800 W_t

FIGURE I-2

2. MISSION ENVIRONMENTS

This portion of Appendix I presents only those data required for the preliminary BIPS-FS design, and in general, does not discuss such items as packaging, transportation, or accidental re-entry of the isotope package. Detailed mission environments for the FS may be found in GE-BIPS-20-001, preliminary draft dated August 8, 1975.

The more significant mission environments are encountered when the BIPS is operated during launch, based on the known maximum requirements of the Titan IIIC and the space shuttle. These are:

- (a) Thermal - Maximum launch vehicle payload fairing temperature will be 300°F with a fairing emissivity of 0.3. Fairing heating is shown on Figure I-3.
- (b) Fuel Hazard - On-pad temperature of any surface exposed to air must be maintained below 380°F.
- (c) Pressure Transients - A typical ascent compartment pressure profile is shown on Figure I-4. Included are altitude, velocity, temperature, and Mach number curves assuming a standard day atmosphere.
- (d) Acceleration - Axial and lateral sustained acceleration g-loads imposed during the launch phase reach a maximum for the Titan IIIC at the shutdown of Stage II. These are anticipated to be -10, +8 axially, and +6 g's laterally, which take into account the effect of the cantilever mounting.

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PAYLOAD THERMAL ENVIRONMENT

FIGURE I-3

TYPICAL ASCENT COMPARTMENT PRESSURE PROFILE

FIGURE I-4

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- (e) Vibration - The vibration environment at the BIPS-FS mounting interface will be higher than either the Titan IIIC or the Shuttle Booster averages as shown in Figure I-5. Since these values may be amplified by resonant vibrations, the values shown in Table I-2 shall be used to qualify the system. The non-operating mode is considered to be potentially more damaging to the gas bearings than the operating mode because of the extra cushion furnished by the gas pressure. The entire IBFS should be vibrated on a shake table in the non-operating mode according to the schedule of Table I-2.
- (f) Acoustic - The random noise spectrum for the BIPS-FS is to be considered equal to that from both the Titan IIIC and the Shuttle Booster. The acoustic spectra for both of these applications are essentially the same and are presented in Figure I-6. The overall level is 145 db.
- (g) Shock - The shock response spectrum for the shock environment of the Titan IIIC and Space Shuttle Booster at the spacecraft/booster interface are similar and are shown in Figure I-7. The component shock attenuation factors as a function of the distance of the individual item from the interface are shown in Figure I-8. Note that the attenuation factor is 0.10 at 30 inches from the interface, which indicates that the net response will be 0.10 or less than that shown in Figure I-7. Shuttle landing shock environments are very low (maximum of 1.5 g, square wave, 260 ms duration) and need not be considered.

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TABLE I-2

IBFS COMPONENT RANDOM
VIBRATION RESPONSE

QUALIFICATION LEVELS
(TITAN IIIC AND SHUTTLE)

Frequency (Hz)	Power Spectral Density (g^2/Hz)	Duration
20 - 100	+6 db/octave	3 min
100 - 1000	0.5 g^2/Hz	per axis;
1000 - 2000	-6 db/octave	3 axes

OVERALL LEVEL 26.8 g_{rms}

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IBFS RANDOM VIBRATION ENVIRONMENT AT BOOSTER/SPACECRAFT INTERFACE
(TITAN IIIC AND SHUTTLE)

FIGURE I-5

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ACOUSTIC ENVIRONMENT FOR THE
IBFS (TITAN IIIC AND SHUTTLE)

FIGURE I-6

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SHOCK RESPONSE SPECTRUM AT BOOSTER/SPACECRAFT INTERFACE
(TITAN IIIC AND SHUTTLE)

FIGURE I-7

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IBFS COMPONENT SHOCK ATTENUATION AS A FUNCTION OF
DISTANCE FROM BOOSTER/SPACECRAFT INTERFACE
(TITAN IIIC AND SHUTTLE)

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- (h) Operational Environments - The operational mission mode begins after separation of the space vehicle from the last stage booster. The data listed in GE-BIPS-20-001 includes many parameters that can be used in determining the design environment for the synchronous earth orbit which will be used for the BIPS-FS as well as some specific design parameters. The data is not reproduced here since they are used only to determine the final design parameters. Until the design parameters for a synchronous earth orbit are clarified, two areas of concern are identified: the mean space radiator sink temperature and micro-meteoroid damage.

A conservative estimate of the mean sink temperature of 217°K (390°R) has been used in all performance calculations to date. This value will remain until redirected by the customer.

The primary radiator environment shall be a synchronous orbit (19,323 n.m.) at 2 1/4 degrees inclination. In addition, the following orbits should be evaluated to define possible sink temperatures:

200 n.m.	50-degrees inclination
200 n.m.	ecliptic
500 n.m.	polar
1100 n.m.	60-degrees inclination

A curve of sink temperature versus radiator area will be generated to encompass this range of temperatures.

Armor damage criteria shall be NASA SP8013. Input values will be defined in updated versions of GE-BIPS-20-001.

The probability of 0.99 that no damage would occur in five years is the primary design criteria. After a radiator design has been selected, the effect on weight of increasing this probability to 0.995 and decreasing to 0.98 should be evaluated.

Earth defocussing and shielding factors shall be used. The radiator fin thickness shall be considered as a bumper for the back side of the tubes. The sum of the value of the tube thickness and fin thickness can be 1/5 of the armor dictated by equivalent success probability without a bumper.

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 Table II-1, and documents that are a part of the Statement of Work by reference are included in Table II-2.

Development contracts with NASA have been in existence since mid-1974 for both the Brayton rotating unit and recuperator. (Table II-3 presents a list of contracts related to the MB-IBFS.) Design and testing of a ground demonstration system (GDS) comprising these GFE components will take place during Phase I of the development program for the MB-IBFS. In addition, 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)

TABLE II-1

DOCUMENTS RELATING TO THE MB-IBFS

Document No.	Company or Agency	Title	Issue Date
74-310831	AIRPHX	System Studies of Closed-Cycle Gas Turbine Engines Utilizing the Mini-Brayton Rotating Unit (Mini-BRU)	August 10, 1974
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 (First issue)
74-311015 -1, -2	AIRPHX	Isotope Brayton Ground Demonstration Testing and Flight Qualification	December 9, 1974
QC-048, Rev. 4	AIRPHX	AiResearch Manufacturing Company of Arizona General Quality Program Plan	October 1, 1974
TBD	AIRPHX	Preliminary System Safety Program Plan	TBD
TBD	AIRPHX	Preliminary Safety Analysis Report	TBD
TBD	AIRPHX	IBFS/GDS Quality Assurance and Reliability	TBD
GEMS-417	GE-ESP	Mini-Brayton Economic RTG Study	January 1974
	AIRPHX	Mini-BRU Design Final Report	May 1975
	AIRLA	Recuperator Progress Reports	
	GE	HSA Progress Reports	
	AIRPHX	System Safety Program Plan	
	AIRPHX	FMEA	
	AIRPHX	Transient Analysis

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TABLE II-2

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- 3

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

9-24-75

PROGRAM SCHEDULE AND MILESTONES

E = EXPECTED
R = REQUIRED

FIGURE II-1

75-311274A
Appendix II
Page 5

BRAYTON ISOTOPE POWER SYSTEM - PHASES II & III																																																											
SUBTASKS	MONTHS A R O →	1978									1979												1980												1981												1982												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48										
		A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M										
FLIGHT SYSTEM DESIGN AND ANALYSIS																																																											
PCS DEVELOPMENT AND FABRICATION																																																											
COMPONENT QUALIFICATION																																																											
HSA DESIGN																																																											
SAR							P																																																				
HSA DEVELOPMENT AND FABRICATION																																																											
SYSTEM QUALIFICATION (ECS PCS)																																																											
(IHS PCS)																																																											
ENDURANCE TEST (IHS PCS)																																																											
FLIGHT SYSTEM FABRICATION																																																											
FLIGHT HS DESIGN AND FABRICATION																																																											
ACCEPTANCE TEST AND DELIVERY																																																											
												PHASE II																				PHASE III																											

FIGURE II-2

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NASA APPROVED SCHEDULE ☐
CONTRACTOR'S WORKING SCHEDULE ☐

NASA APPROVED
SCHEDULE DATE MARCH 25, 1974

S-89650-N

MBR PROGRAM SCHEDULE
FIGURE II-4

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FIGURE II-5

HEAT SOURCE ASSEMBLY (HSA) PROGRAM SCHEDULE