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BRAYTON ISOTOPE POWER SYSTEM (BIPS)
PHASE I
INTEGRATED PROGRAM PLAN (IPP)

75-311574A

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ATTACHMENTS: Appendix I - Tables I-1 through I-3

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ABBREVIATIONS AND ACRONYMS

A		E	
ABS	Auxiliary Battery System	ECS	Emergency Cooling System (for HSA)
ACS	Auxiliary Cooling System (for HSA)	EHS-D	Electrical Heat Source - Dynamic
ACS	Attitude Control System	EHS-S	Electrical Heat Source - Static
AEC	Atomic Energy Commission (now ERDA)	ELS	Eastern Launch Site
AEC PR	Atomic Energy Commission Procurement Regulation	EMS	Material Specification (AiResearch Term)
AIRPHX	AiResearch, Phoenix	EOM	End of Mission
AIRLA	AiResearch, Los Angeles	ESD	Electronic System Division (of Air Force Systems Command)
AFSCF	Air Force Satellite Control Facility	ET	External Expendable Tank
AM	Amplitude Modulation	EPS	Electrical Power System
AOA	Abort-Once-Around	ERDA	Energy Research and Development Administration (Formerly AEC)
ASE	Airborne Support Equipment	EVA	Extravehicular Activity
ARS	Atmospheric Revitalization Subsystem	F	
ATO	Abort-To-Orbit	F	Fahrenheit Degrees
ATCS	Active Thermal Control Subsystem	FBS	Flight Battery System Required for Start in Orbit
a/o	Atomic Percent	FIB	Fuel Impact Body
B		FM	Frequency Modulation
BCL	Battelle Columbus Laboratory	FMA	Failure Mode analysis
BOM	Beginning of Mission	FMEA	Failure Modes and Effects Analysis
BIPS	Brayton Isotope Power System	FMECA	Failure Modes, Effects and Criticality Analysis
BRU	Brayton Rotating Unit	FPR	Federal Procurement Regulation
C		fps	Feet per Second
C	Celsius (Centigrade) Degrees	FS	Flight System
CCAFS	Cape Canaveral Air Force Station	FSA	Fuel Sphere Assembly
CCD	Configuration Control Document	FSAR	Final Safety Analysis Report
CCTV	Closed Circuit Television	FSE	Flight Support Equipment
CFM	Cubic Feet per Minute	FSEC	Fairchild Space and Electronics Company
c.g. or CG	Center of Gravity	FUO	Follow-up Output
CO2	Carbon Dioxide	FT	Feet, Foot
CRT	Cathode Ray Tube	FWW	Food, Water and Waste Management
CSI	Control Servo Input	G	
D		g	Acceleration Due to Gravity
DAS	Data Acquisition System	GDS	Ground Demonstration System - PCS + EHS-S
db	Decibel	GE	General Electric, Valley Forge
DC	Direct Current	GET	Ground Elapsed Time
DCS	Demonstrator Cooling System	GFE	Government Furnished Equipment
Delta-V or ΔV	Velocity Change in Feet per Second	GMS	Gas Management System
DOD	Department of Defense	GMT	Greenwich Mean Time
DOD STS	Department of Defense Space Transportation System	GN2	Gaseous Nitrogen
E		GN&C	Guidance, Navigation and Control
EAI	Engineering Assembly Instructions	GSE	Ground Support Equipment
EAFB	Edwards Air Force Base	GTC	Ground Test Console (a STE/GSE item)
EPFS	Electrically Powered Flight System (PCS + EHS-D)		
ECLS	Environmental Control and Life Support		

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ABBREVIATIONS AND ACRONYMS
(CONTD)

H		M	
HIP	Hot Isostatic Press	MECO	Main Engine Cut-Off
HS	Heat Source (Same as and replaced by IHS)	MHW	Multi-Hundred Watt (AEC/GE IHS Technology)
HSA	Heat Source Assembly (Does not include IHS or HSS. Does include HSHX, structure, insulation, ACS and ECS.)	MHZ	Megahertz
HRHX	Heat Rejection Heat Exchanger (Radiator simulator for GDS)	MM	Millimeters
HSHX	Heat Source Heat Exchanger	MMD	Mean Mission Duration
HSIS	Heat Source Insulation System	MOS	Mission Operation System
HSS	Heat Source Simulator (Same as and replaced by EHS)	MR	Milliradians
HTGR	High Temperature Gas Cooled Reactor	MSS	Mission Specialist Station
		MW	Molecular Weight
I		N	
IBFS	Isotope Brayton Flight System	NA	Not Applicable
IBGDS	Isotope Brayton Ground Demonstration System (PCS + EHS-S)	NASA LeRC	National Aeronautical and Space Administration Lewis Research Center
IHE	Isotope Handling Equipment	NRA	Nuclear Research and Applications, Division of ERDA (formerly SNS)
IHS	Isotope Heat Source		
IMU	Inertial Measurement Unit	OBF	Orbiter Processing System
IUS	Interim Upper Stage	OHA	Operational Hazard Analysis
IVA	Intra Vehicular Activity	ORNL	Oak Ridge National Laboratory
		OMS	Orbital Maneuvering Subsystem
J		P	
JPL	Jet Propulsion Laboratory (Pasadena, California)	PCL	Power Conversion Loop (Use of PCS preferred)
JFC	Johnson Space Center (Houston)	PCM	Pulse Code Modulation
		PCR	Payload Changeout Room
K		PCS I	Power Conversion System (HSA + BRU + MBR + Heat Sink + Controls + Piping and structure)
KB	Keyboard	PCS II	Power Conversion System (HSA + BRU + MBR + Radiator + Controls + Piping and Structure)
Kbaud	Code Elements per Second in 1000's	PGHM	Payload Ground Handling Mechanism
Kbps	Bits per Second in 1000's	PHA	Preliminary Hazard Analysis
KSC	Kennedy Space Center	PLC	Parasitic Load Control System
KW _e	Kilowatts Electrical	P/L	Payload
KW _t	Kilowatts Thermal	PLCC	Payload Control Center
L		PLH	Payload Handling
LASL	Los Alamos Scientific Laboratory	PLM	Payload Management
LCC	Launch Control Center	POP	Perpendicular to Orbit Plane
LES 8/9	Lincoln Experimental Satellite (No. 8 and 9)	PSAR	Preliminary Safety Analysis Report
LF	Load Factor	PSC	Power Supply Console (for RHS)
LH2	Liquid Hydrogen	PSC	Procurement Specification (AiResearch Term)
LiOH	Lithium Hydroxide	PSE	Peculiar Support Equipment
LO2	Liquid Oxygen	PSS	Payload Specialist Station
LPS	Launch Processing System	PSSR	Preliminary System Safety Review
M		PICS	Plutonium Isotope Containment Shield
M	Meters		
MARSCOM	Materials Review and Selection Committee		
MBR	Mini-Brayton Recuperator		
Mini-BRU	350 to 2100 Watts Electrical Brayton Rotating Unit	QA	Quality Assurance
MCC	Mission Control Center		
MDM	Multiplexer-Demultiplexer		

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ABBREVIATIONS AND ACRONYMS
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R

RCS Reaction Control System
RCS Radiator Cooling System
REM Roentgen Equivalent Man
RF Radio Frequency
RM Remote Manipulator
RMS Remote Manipulator System
RSS Root Sum Square
RTLS Return to Launch Site
RTG Radioisotope Thermoelectric Generator
RTS Remote Tracking Station

S

SAMSO Space and Missile System Organization
SNS Space Nuclear Systems (now NRA)
SMAB Solid Motor Assembly Buildup
SRB Solid Rocket Booster
SRM Solid Rocket Motor
SSP Space Shuttle Program
SSME Space Shuttle Main Engine
SSS Space Shuttle System
SSPP System Safety Program Plan
SSV Space Shuttle Vehicle
STDN/ Tracking and Data Net-
TDRSS work/Tracking Data Relay Satellite System
STE Special Test Equipment
STS Space Transportation System
SURVSATCOM Air Force Survivable Communi-
cation Satellite (now AFSATCOM III)

T

TACB Temperature of Cabin
TBD To Be Defined
TDRS Tracking and Data Relay Satellite
TECO Thermo Electron Corporation
TES Teledyne Energy System (for-
merly Teledyne Isotopes)
TIT Turbine Inlet Temperature
TV Television

U

ULT Ultimate Loads
USAR Updated Safety Analysis Report

V

VAB Vehicle Assembly Building
VAFB Vandenberg Air Force Base
VDC Volts Direct Current
VHF Very High Frequency
VRE Voltage Regulator Exciter

W

w/o Percent by Weight

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BRAYTON ISOTOPE POWER SYSTEM (BIPS)
PHASE I
INTEGRATED
PROGRAM PLAN (IPP)

1. INTRODUCTION

1.1 Purpose

This IPP documents the government, AIRPHX, AIRLA, and contractor BIPS program coordination efforts. These coordination efforts are essential for defining program objectives, and achieving these objectives in an efficient manner. The IPP outlines a long range effort intended to:

- (a) Develop end product confidence
- (b) Identify government and contractor activities pertinent and contributory to BIPS development
- (c) Recommend government and contractor activities required to ensure BIPS program success
- (d) Establish activity priorities based on program cost and schedule impacts, and achievement of technical objectives
- (e) Coordinate the efforts of contributing agencies
- (f) Provide general information and, to a limited extent, BIPS program-related development activity status to interested individuals and agencies
- (g) Provide contractor team program planning guidance

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1.2 Methodology

This IPP evolved as follows:

- (a) ERDA identified a need for an Integrated Program Plan (IPP), and, in general terms, formulated content, format, and intended usage
- (b) A preliminary IPP description was given to a variety of contractor and government agency personnel participating in the BIPS program
- (c) IPP input, in the form of ideas and recommendations, was solicited from BIPS program participants
- (d) Input received, reviewed, and organized by AIRPHX formed the IPP first draft nucleus
- (e) The IPP draft was presented to interested parties, and thoroughly critiqued
- (f) From the five steps described above, the IPP first edition was completed and published
- (g) This revision (A) represents the first plan and test program outline update, as evolved since the initial November, 1975 issue.

1.3 Control and Updating

The IPP can be modified and upgraded rapidly to react to changing program requirements. To assure this, formal procedures for document control are followed for periodic IPP revision and distribution.

AIRPHX is established as the control point. A standard ERDA-approved, distribution list has been established.

2. SUMMARY

2.1 IPP Master Schedule (MS)

The MS, shown on Figure 1, depicts all key contractor and government agency BIPS program activities and indicates activity/time relationships. The IPP time frame is shown on the lowest bar.

2.2 Summary Comments

Objective assessment of performance and endurance tests, to be conducted on the GDS, emphasizes that these tests will not demonstrate BIPS reliability. Because of the short testing time when compared to the desired 7-year system life time, additional tests are required to satisfy questions not answered by GDS tests. To attain these objectives, and gain confidence in the BIPS ability to perform as required, reliance must be placed upon good basic engineering, design and development techniques (i.e., analytical studies, definitive and correct materials usage, and special tests) intended to increase confidence in BIPS reliability. These studies and tests are discussed herein. Many additional analyses, tests, and design reviews have already been conducted on the NASA-sponsored GFE component development programs. Although not discussed in this IPP, these past efforts do contribute to BIPS reliability.

Under each heading are identified the studies and tests already a part of the approved Phase I program. Also identified are the studies and tests recommended for inclusion in Phase I. Some are identified as additions to hardware contractors' GFE programs. Other tests and studies are recommended for performance by other agencies, principally ORNL and BCL. All are listed in the tabular summaries, presented in Appendix I, Tables I-1, I-2, and I-3, which cover GFE component Confidence Tests, Materials Studies and Tests, and Reliability Testing and Studies, respectively.

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FIGURE 1

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Subsequent to initial IPP draft preparation (August 28, 1975), and presentation to interested personnel at ERDA-SNS (September 9, 1975), additional study and meetings/consultations among ERDA, NASA LeRC, ORNL, BCL, and AIRPHX representatives resulted in further IPP definition. The result is a systematic, programmed approach for obtaining the test data required to achieve BIPS design confidence.

As with preceding IPP issues, a major portion of this revised edition addresses the need for materials evaluation and testing during Phase I. The chosen materials and fabrication procedures, with emphasis on C-103 columbium alloy, superalloys, and joints (welds, brazes, and bimetallic), are major areas of concern.

The area receiving the greatest comment and attention is a need for hard data that leads to a thorough understanding of BIPS materials long term creep properties in real operating environments. In particular, immediate steps must be taken to broaden the C-103 Columbium alloy data base. While NASA LeRC will continue as the primary source of C-103 baseline data, this IPP defines an integrated program involving ERDA-ORNL, BCL, NASA LeRC, FSEC, AIRPHX, and AIRPHX subcontractors' combined efforts.

The first step for materials investigations is determining the species, and quantities, of contaminants to which hot metals will be exposed. Therefore, alternator, recuperator, and isotope heat source off-gassing tests results are necessary.

Possible difficulties from superalloy usage are recognized. However, except for certain tests planned and/or proposed for the Hastelloy-X in the recuperator and the INCO 713LC turbine wheel, initial reliance will be placed on obtaining needed data from other on-going programs (notably HTGR programs).

A program is outlined that considers joining techniques proposed for the system. Various methods of joining bimetallic sections are being investigated, with parallel development efforts defined for NASA LeRC, ORNL, and AIRPHX.

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Weld and braze assessment work, started at NASA LeRC, will be continued and expanded to include expertise available throughout the technical community. Of importance is the experimental effort required to characterize the solution and diffusion processes, occurring at braze joints, as aging progresses. This IPP proposes weld and braze assessment work by NASA LeRC, AIRLA, ORNL, BCL, and AIRPHX.

Since failure of any of the several bimetallic joints presently included in the BIPS design (even small cracks) could lead to a loss of working fluid, this possibility must also receive high priority. Again, considerable experience with some metal combinations exists, and NASA LeRC has initiated efforts to establish high confidence levels for others. Still, there is a need to carefully define and assess design options, and conduct all possible design verification during Phase I. This IPP details the ongoing program to satisfy this need.

Also requiring special attention are Multi-Foil (super insulation) development, plus ducts, bellows, and flanges fabrication. Programs, proposed to assure that these potential problem areas receive proper attention, are included.

In addition to potential problem areas included herein, other areas of possible concern were considered. These are briefly discussed below:

- (a) Test Facility - The requirement for a highly reliable test facility, for conducting GDS performance and endurance tests, is recognized. Receiving, inspection, handling, storage, assembly instructions, instrumentation, test procedures, and equipment are critical. However, the equipment required falls within state-of-the-art. Equipment quality assurance and facility design reliability are important considerations. However, no major problems, requiring advanced R&D, are currently foreseen.

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- (b) Controls - In establishing BIPS control system requirements, primary concern lies in meeting reliability, stability, efficiency, flexibility, and weight criteria determined early in the program. Once these requirements are known, several candidate control systems will be configured and evaluated.

One control system being considered is the NASA LeRC control, which has the primary advantage of being in existence. A preliminary analysis indicates that this system can furnish a baseline control system to provide a point of departure for GDS, and subsequent BIPS control system design and development.

Should the NASA controls fail to meet any required criteria, new controls will be designed and developed, incorporating the NASA design strong points. The Phase I controls development program objective is to establish and document BIPS control system requirements so that design and fabrication specifications, for flight qualification hardware, will exist at Phase II initiation.

- (c) HSA ECS - Repeated questions, related to the HSA-ECS ability to function as required, have been raised. The need for design verification or back up designs exists, and has general support from most program participants. Recent test data raised doubts of the iridium PICS ability to survive conceivable ECS melt-down thermal transients. For that reason, the HSA-ECS melt-down test is now part of the NASA-funded HSA program. In addition, the MHW heat source program is exploring other iridium and platinum alloys for the purpose of raising the PICS thermal capability.

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- (d) Environmental Tests - NASA contracts for GFE components require that the HSA, recuperator, and Mini-BRU be designed to meet specific environmental conditions (i.e., shock, vibration, and acoustic noise). However, there is no current requirement for design compliance testing. Provisions for environmental testing were considered by NASA LeRC and AIRPHX, while preparing recommendations for ERDA on GFE acceptance and reliability tests. (Reference, Minutes of BIPS Meeting - NASA LeRC, Cleveland, Ohio, July 29, 1975, distributed with the initial draft of this IPP.) It was concluded that any environmental tests conducted can best be done on the entire flight system, as opposed to individual components. Presently, this is considered an early Phase II requirement.
- (e) Hot Flow Performance Tests - Also considered [see meeting minutes referenced in (d) above] was the possibility of adding hot flow tests as part of GFE components acceptance criteria. Such tests were not recommended primarily because of high cost and complexities of running hot tests in the presence of refractory metals and superalloys. Therefore, under the existing program, the first GFE components hot tests will occur as part of initial GDS checkout.
- (f) Flight System Radiator - Although radiator design may present a number of technical problems, none are currently seen as requiring extraordinary effort. Loss of the radiator emissivity coating, as a result of high level radiation exposure or erosion by micrometeoroids are among potential problems that must be considered during the design effort.

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Regarding material selections, alternatives and back up designs are identified. Final selections depend, to a large extent, on the fabrication development results programmed into Phase I.

If analytical assessments of material capabilities to withstand hypervelocity impact by micrometeoroids dictate a need, experimental work will be recommended and added herein.

2.3 Tabular Summaries

Tables I-1, I-2, and I-3 Appendix I, contain tabular summaries of studies and tests, as well as those already a part of the approved program, recommended for inclusion in the BIPS Phase I program. Each entry is keyed to a paragraph number in this report or to a PERT network code. Each entry is further identified relative to program status, in accordance with the following categorization:

- (1) "Approved and Funded" - Already approved as part of the ERDA-BIPS Phase I program, or funded by ERDA or NASA LeRC in supporting efforts
- (2) "Approved, and Funding Anticipated" - Has received ERDA, or NASA LeRC, approval in principle with confidence that funding will be provided.
- (3) "Recommended Addition to Existing Program but Funding not Presently Identified" - Has received general support but funding has not been provided for one of several reasons (i.e., funding agency has not approved the recommended addition, activity occurs in future fiscal year for which funding decisions have not been made, or decision on activity must await results of work in process or already programmed).

3. IPP DISCUSSION

3.1 GDS Tests Objectives

GDS test and evaluation will consist of performance testing, followed by endurance testing.

Performance tests will consist of performance mapping and a series of startup/shutdown tests. The GDS will be instrumented for taking measurements at all key cycle stage points and at selected structural and insulation system locations.

The endurance test will comprise 1000 hours of GDS operation. Basic objectives, as stated by the ERDA Statement of Work, are as follows:

- (a) Substantiate the FMEA
- (b) Determine life-limiting components
- (c) Determine system potential lifetime

AIRPHX has identified the following secondary objectives:

- (d) Detect basic design deficiencies that may exist, including synergistic problems resulting from the interactions of individual components, acting together as a system.
- (e) Detect test facility design deficiencies that could prevent economical long duration system tests
- (f) Determine precise testing costs (dollars/hour for endurance testing).

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When considering objectives and potential values of endurance testing, the limitation of a short endurance test is apparent, when compared with the required equipment life. The BIPS is being designed to operate continuously and reliably over a 5-year (43,800 hours) MMD. An endurance test of any less duration is statistically insignificant, and will not confirm the system potential lifetime. For example, to demonstrate a 5-year life, with 0.95 minimum reliability at the 90-percent confidence level, a total test time without failure, of approximately 2-million hours is required. Five years total test time without failure would provide 0.95 system reliability, but with only a 5-percent confidence level.

Without economic and time restraints, an endurance testing program utilizing many systems operating simultaneously over a long period of time, could be developed. Data obtained from this endurance test experience could then be used to predict the system lifetime potential. Obviously, this type of program is impractical and economically not feasible. Therefore, endurance test limitations in satisfying ERDA stated objectives must be recognized.

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

- (a) Contribute, to a limited degree, to substantiating the FMECA (objective a)
- (b) Disclose a system or component weakness not previously discovered in component tests or performance mapping (objective d)
- (c) Demonstrate GDS ability to operate in a given test facility for 1000 hours (objective e)

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- (d) Provide an accurate determination of test costs per hour (objective f), which is important to follow-on program planning
- (e) Provide a reasonable confidence that test facilities and procedures will permit trouble free GDS running over longer periods

It should be noted that performance tests will also contribute to satisfying the same objectives.

Since the endurance test will not identify life-limiting components (objective b) or the system potential lifetime (objective c), reliance must be placed on good engineering design and development techniques.

3.2 GFE Component Confidence Tests

In this category are tests to be performed on GFE components (recuperator, Mini-BRU, and HSA) to provide design confidence and assure that delivered equipment meets established acceptance criteria. Recommended tests tabulated in Table I-1, Appendix I, are discussed below. Many tests are currently part of the NASA sponsored program to develop these major components with the balance recommended for addition to existing programs.

3.2.1 Recuperator Confidence Tests

The following tests will aid in establishing recuperator confidence:

- (a) Proof Pressure Test - A room temperature acceptance test to confirm the design. The recuperator is designed to withstand the following temperature-compensated proof pressures:

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- o High Pressure (HP) Side 260 psig at 70°F
- o Low Pressure (LP) Side 175 psig at 70°F

HP side pressure must be greater than LP side pressure, with 85 psi maximum allowable pressure drop across the manifold splitter plate.

- (b) Helium Leak Test - An acceptance test requiring leakage of less than 1×10^{-7} standard cc He/sec to the surroundings and less than 1×10^{-7} standard cc/sec between streams.
- (c) Cold Flow Test (Pressure Drop) - A room temperature acceptance test, using clean filtered laboratory air is recommended. LP and HP side pressure drops would be measured over a range of flows that includes the equivalent design point flow. This test will serve to document unit performance and will indicate the presence of flow blockage or bypassing resulting from manufacturing operations. Final pre-storage cleaning procedures will be followed after this test. [Note: NASA LeRc indicated to ERDA (via a letter dated December 23, 1975) that the contract will be modified to include this test.]
- (d) Prototype Hot Flow Performance (Pressure Drop + Heat Transfer) - A prototype heat exchanger will be tested using air as the working fluid, to determine inlet and outlet temperatures and pressures. Testing will be conducted at temperatures and pressures that are as close to design values as possible. This test verifies thermal design, and obviates the requirement to test delivery units.

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- (e) Helium Leak Test - After the above testing, Item (b) will be repeated.

3.2.2 Mini-BRU Confidence Tests

With vibration pickups mounted on the Mini-BRU in three planes, and outputs monitored and recorded, the following tests will be performed to aid in establishing Mini-BRU confidence:

- (a) Cold Spin, 5 Hour, 100 Percent N - An acceptance test requiring a free spin, at design speed, in a shaft-vertical position, for a continuous period of 5 hours (the time requirement is arbitrary since temperature equilibrium will be achieved in about 30 minutes).
- (b) Cold Spin, 5 Minute, 120 Percent N - Immediately following (a) above, the unit will be subjected to free spinning at 120 percent of design speed for 5 minutes.
- (c) Alternator Mode Test - An acceptance test requiring the alternator to be electrically excited to determine the phase sequence and balance, field time constant, and no-load saturation curve.
- (d) Motor Mode Test - An acceptance test requiring motor start of the Mini-BRU, to 13,000 rpm during which, in-rush current, volts/Hertz, and current versus speed characteristics (using a square wave voltage with three phases) will be measured.
- (e) Helium Leak Test - A recommended acceptance test in which the Mini-BRU is leak tested, to assure that total leakage is less than 2.8×10^{-8} standard cc He/sec. This will require special fixtures to seal all compressor and turbine inlet and outlet ports. (Note: NASA LeRC indicated to ERDA (via a letter dated December 23, 1975) that this test will be accomplished.)

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- (f) Compressor Performance Mapping - Compressor performance mapping, with an option of two different diffuser blade angles will be accomplished to ensure proper turbine matching and, therefore, high system efficiency.
- (g) Alternator Motor Start Testing - This test was completed, with the alternator assembled to a dynamic simulator and used for motor start evaluation. Power supply and controls data were obtained from this test.
- (h) Turbine Test Rig - This test, which complements Item (f) above, and which was successfully completed on April 7, 1976, encompassed turbine cold flow performance mapping and thrust load evaluation.
- (i) Alternator Performance Mapping - This test, which is in progress under NASA FY76 funding, encompasses alternator performance mapping in both the alternator and motoring modes.
- (j) Compressor Clearance Tests - These tests are proposed as an extension to compressor performance mapping, Item (f), wherein the effect of shroud clearance would be evaluated. (NASA LeRc funding does not appear to be available.)
- (k) Inspection of NASA BRU - Three BRU engines (larger but similar to Mini-BRU) have operated at NASA-LeRc for over 32,500 hours. High time logged by one engine is 21,208 hours. The BRU was operated for 20,864 hours during an endurance test, with a longest continuous run of 7440 hours. Testing was terminated due to an external leak that appeared in the first generation recuperator. The initial IPP recommended that the BRU be disassembled and all components inspected prior to resumption of

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endurance testing. It was considered that an inspection might disclose evidence of wear, or material degradation that could be directly applicable to the Mini-BRU. NASA LeRC has completed BRU No. 2 (the 21,208 hours engine) disassembly. The engine was in excellent condition. Only evidence of gold plated heat shield deterioration was found. (The Mini-BRU does not utilize these components.) Metallographic examination of specific areas is still being conducted. NASA LeRC intends to perform a similar inspection on BRU No. 4 (identical with BRU No. 2, but with approximately 11,000 hours). A report on the two inspections is scheduled for June, 1976 availability.

3.2.3 HSA Confidence Tests

The following tests will aid in establishing HSA confidence:

- (a) Proof Pressure Test - It is currently intended that a room temperature, proof pressure acceptance test be performed at 1.1 times the maximum 115 psia design working pressure. However, this may change, since precise test parameters have yet to be formulated and recommended by GE. A cold flow test will be included to determine pressure drop.
- (b) Helium Leak Test - An acceptance test requiring leakage to be less than 1×10^{-9} standard cc He/sec to the surroundings.

3.3 Materials Studies and Testing

One very effective method of building a high level of confidence in BIPS reliability and life potentials is through materials testing during Phase I. During the three years of Phase I, considerable materials evaluation work will be accomplished to:

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- (a) Suitably characterize and increase materials knowledge to a level where sound engineering determinations can be made relative to materials suitability for BIPS
- (b) Identify and understand basic failure mechanisms that may exist due to materials interrelations with operating environments
- (c) With the knowledge gained in (a) and (b), modify and improve the design.

Three major BIPS components were under development for over a year prior to BIPS/GDS program initiation. Material selections were based on the best materials properties information available, and on judgments relative to performance, fabricability, and experience. Subsequent changes in system design and operating requirements influenced materials selection and while thoroughly reviewing BIPS system design requirements, a number of other material-related questions developed. The discussion that follows is subdivided into three major topics. These are:

- (a) Refractory metals (with emphasis on Columbium Alloy C-103)
- (b) Superalloys
- (c) Joints (welds, brazes, and bimetallic)

Materials studies and tests included in the IPP are tabulated in Table I-2, Appendix I. Table I-2 includes a cross-reference to the PERT networks used in this discussion (Figures 2 and 3). Task descriptions covered in the following paragraphs are also keyed to Table I-2 and the PERT networks.

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CONTAMINATION EFFECTS

FIGURE 2

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BIPS COMPATIBILITY ASSESSMENT

SYSTEM INTERACTIONS

EXTRAPOLATION
OF
SYSTEM LIFE

BIMETALLICS

SELECT
JOINT
DESIGN

SOLID
PROJECTION
OF
BIPS LIFE

DUCTS AND JOINTS

BEHAVIOR OF
ALL DUCTING
AND STRUCTURE

MULTIFOIL DEVELOPMENT

INSULATION
DATA

FIGURE 3

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3.3.1 Refractory Metals

The reference design substitutes refractory metals for superalloys in locations exposed to both high temperature and high vacuum conditions (specifically the turbine plenum and HSHX). The areas of concern are the strength and stability of the selected C-103 alloy and the possibility of contamination from other parts of the system.

Figure 2 shows the recommended method for evaluating materials compatibility with the planned operating environment. The principal tests objective will be to develop a fundamental data base to permit: Early determination of the limitations of using refractory alloys in a contaminating environment; estimates of permissible impurity concentrations in the system; assessment of the synergistic reactions between C-103 and superalloys; and determination of methods (e.g., gettering, barriers, or substitution of other alloys) that prevent, or minimize, the detrimental effects of impurities. (For possible methods of minimizing contamination effects see Paragraph 3.3.1.5.) Also included in this plan are identification, and initial screening, of alternate refractory metal candidates such as molybdenum and platinum alloys.

3.3.1.1 Strength and Stability of C-103

Questions have repeatedly been raised regarding the quality of present C-103 data. The seriousness of these questions is obvious since the BIPS success depends on all materials performing as predicted. The selection of C-103 was based on the alloy's excellent weldability, high temperature strength, and fabricability. The BIPS application requires that this high temperature strength be maintained for long periods of time (lifetime, 7 years = 61,320 hours) in vacuum.

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Considerable data, which forms the essential data base, have been gathered, however, three deficiencies with these data were identified in the initial IPP:

- (a) The quantity of data is limited in scope.
- (b) Large extrapolation must be made for BIPS design purposes, and extrapolation is undesirable.
- (c) The data may not be applicable by reason of environmental effects. (See 3.3.1.2 for further related discussion.)

A comprehensive series of tests was defined to establish various system contaminant levels, and resultant effects on columbium alloy C-103 creep strength. Contamination levels are being established by BCL, through experiments on graphite outgassing, alternator stator materials outgassing, and C-103 reaction kinetics with the expected impurity species. Tests are planned to determine the extent of the problem of trapped gasses within the Multi-Foil insulation and the C-103. NASA LeRC and ORNL are conducting additional creep testing to characterize C-103 expected strength, relative to BIPS operating conditions.

Efforts are also underway and will be intensified as necessary, to define backup materials for C-103. The data will be analyzed and a numerical assessment of BIPS-FS 7-year life will be made.

Component life predictions should include consideration of load redistribution, through the structure, due to outer fiber relaxation when bending exists. Some loads, such as hoop tension due to pressure, do not diminish with time, while others, such as those that exist due to thermal stresses will relax with time. Although a difficult

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analytical problem results, it is important to account for outer fiber (usually to the point of highest stress) relaxation with time. This was done in the turbine plenum analysis, performed earlier by AIRPHX, and the calculations provide a prediction of stress and dimensional change with time. A similar approach should be followed for all highly loaded structures operating at elevated temperature.

3.3.1.2 Definition of Environment

It was suggested that creep properties, which are conventionally determined in ultra high vacuum, may not be relevant. There is ample evidence that BIPS materials creep properties will depend significantly on the microstructure, geometry, gas medium, and impurities carried by the gas medium.

Before extensive, long-term creep tests are outlined, a definition of the expected environment is required. This includes assessments of heat source and expected alternator stator outgassing, contaminants from the effects of gasses trapped in Multi-Foil insulation, along with nickel foil compatibility with both ZrO_2 and C-103.

Every surface that contacts the working fluid represents a potential source of contamination, which may jeopardize the hot refractory metal parts. These include:

- (a) Mini-BRU alternator and bearings
- (b) Recuperator
- (c) Interconnecting ducting
- (d) Radiator
- (e) Insulation system
- (f) Heat Source Assembly

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Those considered of primary importance are the alternator (due to potting materials used), recuperator (due to 35,000 in.² of internal surface area), and heat source (due to the amount of graphite present).

Current IHS (LES 8/9 Program) offgassing experiments, and alternator offgassing tests being performed at BCL for NASA and ERDA, represent the proper first steps to be taken.

Alternator experiments, planned for NASA FY76 funding, will be designed to determine the rate and species of organic material offgassing from the alternator. This is a vital first step in assessing overall system materials compatibility.

Nickel transport and Multi-Foil insulation system offgassing are recognized as potential contaminant sources. This has prompted a decision to substitute columbium or molybdenum foil for nickel on all foil surfaces expected to exceed 1400°F, except for the HSA. The present HSA design specifies that the insulation system cylindrical section comprise an inner C-103 foil layer (0.005-in. thick) surrounded by 59 outer layers of zirconia-coated nickel (each 0.0005 in. thick). The two end caps are all C-103 foil layers. Nickel transport and Multi-Foil offgassing are being investigated as part of the NASA LeRC HSA contract and the ERDA-BIPS contract with TECO. These efforts are expected to confirm that these phenomena are not significant in the present Multi-Foil insulation system design.

Another potential source of contaminants (perhaps more subtle, but nonetheless insidious) is "virtual leakage". This condition arises from a volume of gas that is trapped during components fabrication. One example, since corrected, was the recuperator, where welding outer plates over a previously brazed assembly could have trapped air and other surface contaminants.

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Subsequent leaks, due to cracks forming in the braze joint, would release these trapped contaminants into the working fluid to be carried to all closed loop system components. System design, and fabrication techniques and methods, must be carefully reviewed to preclude virtual leaks and ensure meticulous cleaning at all stages of manufacture.

3.3.1.2.1 Heat Source Offgassing, Task A

BCL has been running experiments to determine CO offgassing from graphite, due to reactions with absorbed water and oxygen. The work is primarily being done for the MHW heat source and has been slightly expanded to benefit AIRPHX. Initial data shows that the EHS can be outgassed at an elevated temperature, and stored in a manner that will prevent recontamination during storage and subsequent assembly into the GDS. This work is finished and the test report will be issued in the near future.

An additional question remains, relative to IHS handling, which will be answered from MHW experience. This question involves the amounts of CO, and other gasses, produced from isotopic reactions of PuO_2 fuel and interactions between the fuel and graphite PICS. This work will be reserved for the time when Phase II is resumed.

3.3.1.2.2 Alternator Offgassing Task B

When the Rice alternator design was selected, it appeared that thermal and electrical characteristics of the stator assembly could best be maintained by using various organic compounds for insulation and potting. The chemical stability of these compounds has been questioned and indications are that decomposition of these compounds could result in added contamination of the C-103. BCL initiated work to define the problem and magnitude.

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Work was initiated by defining primary temperatures for significant decomposition of each compound. This will be followed by evaluating offgassing species for rate and chemical composition. After a trend is established for individual compounds, work will begin on the alternator stator as an assembly. A preliminary outgassing cycle will be established, with two stator assemblies subjected to that cycle. One stator will be sent to ORNL for use in conjunction with C-103 creep tests. The second stator will be subjected to a long term stability cycle. The compounds will be analyzed and outgassing kinetics determined so that a reasonable extrapolation for the 7-year life is established. Results of this work will be instrumental in establishing the atmosphere for subsequent C-103 alloy tests. Since the tests will be conducted in a helium atmosphere, this data will be particularly useful.

3.3.1.2.3 Foil Insulation Compatibility, Task C

A new test program was defined during this period, to determine the insulation compatibility with C-103 alloy, and the effect of vacuum system procedures. For this test, a C-103 alloy cylinder will be wrapped with Multi-Foil insulation. The assembly will be heated from the interior to simulate the actual heat source. The test will include 20 vacuum-to-air cycles minimum, in the test facility, to simulate stopping and restarting the BIPS-GDS.

After 1000 hours, samples will be taken from the assembly and evaluated by light microscopy, hardness, and interstitial analysis, to determine effects on the C-103. The sample will be carefully prepared so that physical positions of the insulation wraps and stability of the ZrO_2 , and nickel foil can also be evaluated.

3.3.1.3 Effect of Environment on C-103

Environmental effects on C-103 properties are being studied in the following three areas:

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- (a) Contamination rates by CO, O, and hydrocarbons
- (b) Effects on short-term properties, as demonstrated by tensile tests
- (c) Demonstrate the effects on creep as contaminants are gradually absorbed

These areas are further defined in following paragraphs.

3.3.1.3.1 Contamination Rate of C-103 - Task D

BCL is funded to perform 18 kinetic experiments (9 different conditions with two thicknesses of material) on columbium alloy at controlled temperature and CO levels. The following illustrated microbalance facility will be used in measuring contamination rates and estimating the active mechanism.

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Complete microstructural characterization will be performed on 9 samples. In addition, 12 test bars, furnished by ORNL, will be contaminated. Contamination effects will be assessed by resulting microstructure analyses and material tests prior to and after exposure. CO levels will be carefully assessed so that the HSHX working fluid and exterior environment are represented.

The coupons (samples) used in contamination tests will be evaluated by weight change and interstitial chemical analysis. Microstructure and microhardness will also be evaluated to determine the distribution of constituents.

3.3.1.3.2 Short Term Effects of Contamination - Task E

Several C-103 tensile specimens will be contaminated in the BCL apparatus, along with those in Paragraph 3.3.1.3.1. Tensile tests will be conducted on these samples to evaluate short term properties, and the effects on columbium alloy ductility.

3.3.1.3.3 C-103 Design Creep Strength

Initial design criteria for using C-103 in the IBFS system includes a creep restriction of less than one percent in seven years of life. The choice is arbitrary and may be overly conservative, as most areas of the system may be able to sustain much more than one percent creep without failure. The majority of ducting, the turbine plenum, and some other areas may not be considered to fail until rupture occurs after considerable creep extension.

Creep tests were, and will be, conducted at NASA LeRC and ORNL to establish BIPS alloy(s) integrity. Test atmospheres include vacuum and contaminants such as CO and organic volatiles.

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Baseline data (Task F) has been generated by NASA LeRC. Tests were conducted in a vacuum atmosphere at temperatures from 1520° to 2000°F, and stress levels from 3 to 20 KSI. Test specimens were run up to 3000 hours. An interim report (NASA TWX 71895) has been issued on these activities, and the data is already being used for GDS preliminary design. The continuing tests, noted below, may have a slight impact on this data.

In accordance with Task G, NASA is conducting additional tests to evaluate C-103 creep, under various conditions and essentially a common parameter. Seven ksi stress and 1800°F temperature are projected to yield 1-percent creep, in 1000 hours, as a baseline. Configuration tests include fusion welds and diffusion bonds, for comparing joint efficiency with the baseline. C-103 parent metal testing atmospheres will comprise CO and CH₄.

ORNL creep tests (Task H) are intended to explore extreme and real environment effects. Stress and CO level interactions will be studied in detail. This will determine stress level effects on the contamination rate, and should define areas of the GDS system components most susceptible to attack. In addition, the plan requires that C-103 specimens be tested in conjunction with alternator stator out-gassed effluent, a large surface area of Hastelloy X (to simulate MBR surface), and several layers of Multi-Foil insulation. Since the test specimen is resistance heated, and is the only hot portion of the system, full contaminant effects should be obtained.

Depending on results of ORNL contaminated creep experiments, out-gassing studies, kinetics experiments by BCL (Task D), and analytical work, further investigation of pressure and flow effects on contamination may be required. A data review and detailed study will be performed prior to defining the probable experiments to be run by ORNL.

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After assessing environmental effects, long-term creep tests (and other tests) may be required. Prior to initiating the final series of creep tests, the effect of a highly dynamic environment versus a static environment will be established (Task I). MARSCOM will define the tests and environments directed at building confidence in GDS material selections (Task J). C-103 creep tests will encompass up to 15,000 hours to assure the minimum extrapolation necessary for BIPS design requirements (Task K). Defined atmospheres will be used for these tests.

A literature search (Task L) was performed for ERDA by ORNL, defining Mo-33 w/o Re, Mo-46 w/o Re, and Pt3008, as possible alternate alloys that may be less affected by BIPS contaminants than columbium alloy C-103. These potential candidate materials may have other inherent problems when used in the BIPS, or may not be usable for reasons of insufficient technology base, and/or availability; however, all appear sufficiently promising to merit a moderate evaluation effort. Near the end of Phase I (about April 1978), the goal will be to identify and develop certain materials to the point where these materials can be considered as feasible alternatives for use during Phase II BIPS (development and flight qualification phase). The Pt3008 work is essentially being performed for the MHW program (Task M). The Mo-Re work is divided into an early exploratory phase (Task N) and a property development phase (Task O).

3.3.1.4 Relation to Data - Task P

When environment effects are better quantified, and creep rate variations established, a system effects mathematical model will be generated. This model will attempt to quantify the effects of C-103 components (with particular emphasis on contamination and life) on the system. Effects of the high-purity inert gas on the superalloys and the physical configurational relationships of other components to the C-103, e.g., the foil insulation wraps, will also be factored into the study. Extrapolations from tests, and an attempt to project system life beyond

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test data will be made by using the mathematical model. Hopefully, these equations will demonstrate the BIPS ability to meet the 7-years life design criteria.

3.3.1.5 Methods of Minimizing Contamination

If C-103 contamination effects prove to be a serious problem, solutions under investigation, via the IPP, include design approaches that minimize, or eliminate, contamination sources. These design approaches include:

- (a) Getters to clean the working fluid before serious damage can occur in hot refractory metal parts.
- (b) Coatings to prevent outgassing or inhibit attack by contaminants.
- (c) Canning to isolate components that are high sources of contaminants.

The need for applying these methods cannot be determined until contamination sources have been identified and quantified. Efforts are currently underway to perform the required offgassing tests (refer to Paragraph 3.3.1.2). The BIPS program contractor is currently investigating means of isolating contaminant-yielding components, or interjecting methods of gettering system contamination, to minimize subsequent damage to refractory metal parts. Design solutions, derived after the contaminants and associated levels are defined, will be reviewed by MARSCOM for acceptability.

Previous test data will be considered from two approaches. The first relates to BIPS-FS life and any potential limitations due to various contaminant levels. The second defines the atmospheres for creep tests lasting up to 10,000 hours. These will yield better design criteria definitions for BIPS C-103 components.

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3.3.2 Superalloys

While it is generally true that superalloy material properties are better understood, the BIPS application does present special problems. For example, inside surfaces will be exposed to the ultra-pure "noble" gas working fluid, while outside surfaces are exposed to hard vacuum. Long term properties of superalloys, operating at high temperature, under these conditions have not been thoroughly studied.

3.3.2.1 Environment Effects

A consideration that must be included is the apparent inability of superalloys to operate in high temperature, high vacuum environments. It has been observed that certain alloying constituents (having relatively high vapor pressure), such as chromium and aluminum, will evaporate, and serious degradation of structural properties will result. Even in an all superalloy system the turbine plenum and HSA outer surfaces must be protected by applying special diffusion inhibitor coatings, or by providing an inert gas environment. The data indicate that an all-superalloy BIPS system could operate in a vacuum for 5 years at a maximum temperature of 1300°F.

Superalloy strengths in air are well known, but not in pure environments such as monatomic gases. Certain nickel-based alloy constituents such as Cr and Al evaporate because of high vapor pressure in a hard vacuum. From practical observations, material does not evaporate as readily into an ultra pure cover gas as in a vacuum, despite the theory of partial pressures, i.e., each vapor specie develops a partial pressure, independent of other vapors present. It is necessary to determine how severely the selected superalloy creep properties are altered by reaction with contaminants that exist in the working fluid. As previously stated, the starting point for this investigation is the offgassing tests described in Paragraph 3.3.1.2, and definition or working fluid quality requirements.

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Additionally, ORNL data indicates that an oxide coating prevents loss of high vapor pressure constituents at 1400°F, in vacuums of 10^{-9} Torr or better. Work on samples tested in creep in high purity helium, shows the strengths to be equivalent to those measured in air, and there were no surface effects on the material. Possible contaminant effects data sources are the HTGR Safety Program at ORNL, and Gas Turbine HTGR Program at General Atomic and Central Institute for Industrial Research in Oslo, Norway. Specific alloys and temperatures related to the Mini-BRU System will be investigated. The level of contaminants will be carefully assessed to determine data relevance with the Mini-Brayton System. As part of the HTGR Program, ORNL is currently conducting Hastelloy testing. In Oslo, Norway, INCO 713LC tests are underway. A review of HTGR Program data may indicate a requirement for further testing.

To assess the problem magnitude (Task Q), as applicable to BIPS, a relatively simple experiment has been conceived. Hastelloy X and INCO 713LC samples will be run, for 1000 hours minimum, in a high purity helium environment. After testing, the samples will be carefully examined on the surface by SEM, to determine if any evaporation occurred. These observations will be confirmed by conducting a microprobe analysis on a cross-section of each sample, scanning from surface-to-interior for particular elements (i.e., aluminum and chromium).

Even after this data is assessed by MARSCOM, it may be necessary to determine if Hastelloy X (recuperator) and INCO 713LC (turbine wheel) creep properties are altered by reactions with environment impurities, and if so, how severely. For precipitation-strengthened alloys, it may be necessary to assess aging effects, in addition to environmental effects. The test environment will be helium, or argon, containing trace levels of CO as the principal impurity. To accelerate (or magnify) environmental effects, thin sheet specimens would be creep tested initially in varying levels of CO, to establish if the impurity gas concentration dependence, noted for Inconel 617, also applies to Inconel 713. This data should be available from the Dragon project.

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3.3.3 Joining

The BIPS has a number of joints, some of which connect parts fabricated from different metals. Joining techniques include:

- (a) Bimetallic joints (various methods)
- (b) Diffusion welds
- (c) Fusion welds
- (d) Brazes

3.3.3.1 Bimetallic Joints

Loss of working fluid through leakage or failure of any connecting joint in the BIPS closed loop would result in partial, or complete system failure (depending upon the magnitude of leakage). Of special concern are the bimetallic joints between the Mini-BRU and recuperator, as well as between the recuperator and HSA. These join C-103 to Hastelloy X and operating temperatures are 1300° to 1350°F. Of lesser concern (but an area which requires attention) is the recuperator-to-radiator joining (Hastelloy X to aluminum or beryllium at 300°F).

Three parallel development efforts are included in this IPP (refer to Figure 3). Initial development work has been accomplished by the NASA.

- (a) NASA - Task R - NASA LeRC has developed brazed tongue-and-groove (or chevron type) joints, and heavy metal (Ni-Fe-30 to 80 percent W) transition sleeves for joining Hastelloy X to C-103. In an initial screening test of 12 braze alloys, CM-50 looked best (followed by AMI-114 and AMI-400). This is based on evaluation of wetability, flow, and tensile tests on double shear-type sheet specimens. Tensile tests were run at room

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temperature, to 1400°C, on the specimens (as brazed) and after 1000 hours at 1330°F. Bimetallic joints have been successfully made both by direct brazing and the "heavy transition piece" methods.

The 16 direct braze joints (4 joint types, 2 alloys, duplicates) will be evaluated by room temperature tensile tests after 100 thermal cycles (40 1400°F) and 1000 hours aging at 1350°F.

The heavy-metal graded transition sleeves have been made by powder metallurgy. The end that matches Hastelloy X expansion is nominally 30 w/o W-21 w/o Fe and 49 w/o Ni. The end matching the C-103 expansion is 80 w/o W-6 w/o Fe and 14 w/o Ni. CM-50 braze alloy was used for joining to C-103, and direct welding for the Hastelloy X. Tensile strengths show that this combination has good strength and samples have been included for thermal cycling, which is underway.

- (b) ORNL - Task S, T, U - ORNL and BCL will evaluate NASA data (Task S) on development and testing of braze alloys and transition joints. Since NASA LeRC data was developed using Cb-1 percent Zr alloy, ORNL will confirm the brazing techniques in Task T. An evaluation (Task U) will then be conducted on the two most promising joint designs resulting from NASA LeRC activities, and the GDS joints will be fabricated (Task X) in the same run.

Evaluation will include room and elevated temperature mechanical properties, thermal cycling tests, and metallographic examination of as-fabricated and aged (1000 hours at 1350°F) joints. Based on results, ORNL will recommend an optimum bimetallic joint, and a test plan, for long-term aging and evaluation for flight system qualification. This test plan will then be implemented in FY77 (Task aa-bb).

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- (c) AIRPHX - Task V - AIRPHX has assessed co-extrusion of bimetallic joints, and explosive bonding usage. In view of the NASA program success, activities in these areas are currently suspended. Explosive bonded joints may require considerable development, and success is not assured. In addition, co-extruded joints between T-111 tantalum alloy and austenitic stainless steels tend to peel during liquid metal loop tests.

In addition to the tasks outlined above, the following efforts have been initiated:

- (d) Task W - BCL and ORNL have conducted literature surveys on weld and braze methodology and confirmed the NASA approach. Both will review and assess the welds and brazes contained in the current BIPS design. Results of this survey and assessment apply to ORNL tests on ducts and bellows (Task Y) and bimetallic joints (Task T).
- (e) Task aa-bb - After completing Task R, it is recommended that NASA LeRC (or ORNL after Task T) continue aging the most promising bimetallic joints until 5000 hours have been reached (i.e., extend aging from 1000 hours to 5000 hours). The decision would be based on whether or not the Cb-1 w/o Zr would be acceptable as typical of long-term age effects.
- (f) It is recognized that little attention has been directed to the Hastelloy X to aluminum (or beryllium) radiator joint. While primary emphasis must be placed on high temperature joints, it may be necessary to devote additional effort towards investigating the credibility of low-temperature bimetallic joints. The Hastelloy-to-Hastelloy welds, and effects of aging on weld strength, are being covered in the HTGR program.

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3.3.3.2 Diffusion Welding

A major C-103 diffusion welding program is underway at GE, under the NASA HSA contract. To date, welding parameters have been defined using flat specimens. This work indicated that the Hot Isostatic Pressing (HIP) process will be beneficial and except for one sample, future work will utilize this process. GE is now engaged in the next step, welding and subsequent testing, of full size ring sections 2 and 9 inches long. Work is also underway at BCL to diffusion-bond in the HIP facility. After successful completion of this step, GDS HSA fabrication will be initiated.

3.3.3.3 Welding of Like Parent Metal

The failure mode of primary concern is joint failures that result in working fluid loss. Metallurgical changes that weaken the material, and crack formation for any reason, may cause joint failure.

A thorough materials assessment of potential failure modes will be made by MARSCOM. Performance degradation can result from creep rupture, and/or structure thermal fatigue failure, and material yield or weld cracking in the turbine nozzle or HSA. Closed loop working fluid containment integrity can be defeated by leakage, because of crack formation due to such metallurgical action as weld embrittlement (oxidation at large grain boundaries at or near the weld zone) and void formation (caused by diffusion of elements) at grain boundaries resulting from creep.

3.3.3.4 Braze Joints (Like Metals)

The area of most concern, aside from brazed bimetallic joints (which is discussed elsewhere), is the recuperator brazed joints. To some extent brazed joint aging diffuses the braze alloy into the base

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material. This diffusion can cause metallurgical alteration that could lead to joint structural strength degradation (or embrittlement), loss of ductility, and low cycle thermal fatigue failure.

NASA LeRC has a good start, however, the testing that must supplement present work involves evaluating interactions between the gold braze alloy, and superalloy. The gold-nickel alloy used by AIRLA is being extensively evaluated. It has been pointed out by several program reviewers that long-term aging will result in forming Kirkendall voids and joint embrittlement (gold especially embrittles C-103).

There is a significant effort underway at NASA LeRC to evaluate BIPS recuperator braze joints. Details of related work are described in Figure 4. This work includes thermal cycle testing of prototype units, and subsequent aging of samples cut from the prototypes followed by metallurgical examination of aged samples to determine character and rate of diffusion from the braze alloy into Hastelloy X material joint.

- (a) Tasks (2), (3), and (4) Thermal Cycling - These tasks, discussed in more detail in Paragraph 3.4, have been designed to evaluate brazed recuperator core durability when subjected to severe thermal transients. Task (2) and Task (3) thermal cycling have been completed. Task (4) has not yet been initiated.
- (b) Task (5) Aging - Specimens were taken from thermal cycle test units, for 5000-hour aging tests. These tests indicated no measurable braze alloy migration into the base metal, following 1000-hour aging at 1330°F [Task (2)].
- (c) Tasks (6) and (7) Air/Helium Correlation Test - The prototype thermal cycle (200 cycle goal) test, discussed in Paragraph 3.4.2, will be run with air (for

SUPERALLOY/BRAZE EVALUATION

FIGURE 4

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low cost testing) as the working fluid. The MARSCOM was polled and the procedure found acceptable. However, it would be desirable to correlate the effects of oxidation on braze material and braze joint ductility with data from tests in helium. Coupons of Hastelloy-X (single flat plate specimens or overlapping plates brazed together) would be subjected to 500 hours at 1300°F. Half the samples would be aged in air, and half in helium. Tensile tests (ductility and creep rupture) would be performed on the samples and a determination made as to possible different effects on air, and helium.

The following tests are recommended as an extension of work currently being performed at NASA LeRC.

- (d) Task (8) ORNL Property Tests - Hastelloy X material and Palniro 1 and 7 braze alloys have been sent to ORNL for a study intended to expand the mechanical property base for the recuperator braze. Tensile tests and creep rupture measurements will be made at various temperatures, so that the variation in strength over the full range from room temperature to operating temperature can be established.
- (e) Task (9) Creep-Rupture Test (5000 Hours) - The recommended approach is to obtain creep-rupture characteristics data using small plate-fin sections rather than testing the entire recuperator. Plate-fin sandwiches, capable of being sealed, could be fabricated and filled with sufficient helium to simulate system operating pressure, when sealed and heated to 1330°F (system operating temperature). These sealed sandwiches would then

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be subjected to 1330°F in hard vacuum, for 5000 hours. After this aging, samples would be pressurized to the rupture point. This test would provide strength and materials diffusion rates data under simulated conditions of operating temperature, pressure, and working fluid conditions. It is recommended that a 5000-hour creep-rupture test be conducted utilizing specifically prepared plate-fin samples.

Although not recommended, another approach would be to place and test a complete recuperator assembly, pressurized with helium, in a high temperature furnace. The test would be continued for at least 5000 hours with results extrapolated to the design life. Ideally, this test would be run for a longer duration to evaluate the effects of material aging on structural behavior.

3.3.3.5 Ducting, Bellows, and Flanges

Various kinds of joinings will be required to assemble the miscellaneous parts needed for the GDS. When GDS parts are fabricated by vendor shops, typical test sections will be collected and subjected to metallurgical examination. Test samples will be derived from Task Y, Figure 3, and tested to verify the quality of the processes utilized in fabricating the GDS bellows in Task Z.

Launch conditions applicable to the bellows are particularly important and probably the most severe conditions to which the bellows will be subjected. It is recommended that AIRPHX perform an analysis to determine the methods and magnitudes of imposed loads. An accelerated test should then be defined to demonstrate bellows reliability in the system. The test would include subjecting sample bellows to launch vibrations, followed by thermal cycling.

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3.3.3.6 Multi-Foil Development

Three parallel efforts will be initiated, with the primary effort being a major subcontract with TECO from AIRPHX, under the ERDA/BIPS Phase I Program (Task m-n). Tasks P and C complement Task m-n and are designed to define Multi-Foil insulation characteristics. (Refer to Figures 2 and 3.)

The primary work in Task m-n is to develop the turbine plenum and BIPS ducting insulation system. During this work, Multi-Foil system effectiveness will be determined and compared with that theoretically expected. Substitution of refractory metal for the inner five laps of nickel is being explored in Task w-x.

Task o-p addresses emissivity, heat transfer rates, etc. of insulation in a vacuum and in argon at temperatures to 5500°F. These tests will be conducted at AIRPHX on instrumented foil samples. The possible effects of foil insulation on C-103 (Task C) are discussed in Paragraph 3.3.1.2.3.

Task C will define foil compatibility with C-103, by submitting C-103 samples, wrapped with several layers of Multi-Foil insulation, to aging tests at the maximum operating temperature of the HSHX hot end. During this experiment, foil evaporation characteristics will be measured and an attempt made to establish offgassing characteristics.

3.3.4 Post Phase I Tests (Task AA)

The BIPS-GDS system endurance test, although sufficient to demonstrate system capability, may not answer questions of long life effects due to physical degradation. Therefore, it is recommended that, following the conclusion of Phase I testing, follow-on activity be initiated. This task would include post mortem system evaluation including analysis of samples taken through the use of gas taps to

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assess working fluid purity as well as an assessment of vacuum environment quality during the test. It would also include destructive analysis of test samples strategically located within the system. Several tests outlined herein (i.e., C-103 contamination tests, alternator offgassing, insulation compatibility, INCO 713LC stability, braze joint and recuperator aging, etc.) could provide supplemental information.

3.3.4.1 GDS System Analysis at Teardown

The recommended teardown analysis would consist of a careful examination of GDS components. All critical subassemblies would be visually examined at magnifications up to 40X. Also, all deposits, surface coatings, and other apparent foreign materials would be analyzed chemically. In addition, the following components would be subjected to the indicated individual assessments:

- (a) Alternator Stator - A careful visual examination would be made, with electrical mapping if necessary. The stator would be weighed at installation and after the run. If any significant changes occur, the cause would be determined.
- (b) MBR - A section of the recuperator, including a typical braze joint and some parent material at maximum temperature, might be fabricated to include a piece that could be removed without destroying the MBR. A cross-section of this area would be examined microscopically, and a microprobe trace run to evaluate any braze diffusion effects, and any parent metal surface effects.
- (c) Turbine Wheel - A slice of the inducer tip could be taken and mounted in cross-section. Light and scanning electron microscopy would be used to examine the INCO 713LC blade surface. In addition, a microprobe trace for aluminum and chromium could be run from the section surface, to the interior.

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- (d) HSA - Primary concern for HSA degradation is C-103 contamination, from impurities in the working fluid and those trapped in the insulation. Cross-section samples, taken from the HSA, could prevent use of this component for future testing. Therefore, HSA evaluation would be based on metallograph, microhardness, and interstitial analysis of special samples provided for this purpose.
- (e) Turbine Plenum - Concern in this area is the same as for HSA. A sample, for interstitial analysis and microhardness, would be placed in a convenient location in the wall.
- (f) Bellows - One C-103 bellows would be subjected to destructive analysis. Again, examination would be conducted by microhardness and interstitial analysis, to determine the degree of contamination from working fluid impurities and gasses trapped within the insulation.
- (g) Other Areas - The integrity of other system areas, such as bimetallic joints insulation, etc., would be assessed in tests covered herein. These tests would be conducted for up to 5000 hours and should yield more comprehensive data than the GDS endurance test hardware study.

3.3.4.2 Gas Analysis Taps

Only two taps are currently being considered. One tap will be located in the vacuum chamber, and the most repeated use will be to check the gas purities during the backfill cycle. The second tap will be located in the working fluid ducting before entry into the HRHX. This tap will be used to assess working fluid purity.

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Although considered, other gas taps in the ducting have been eliminated because of complexities added to the system, and potential problems in knowing that the gas sample is representative of system gas. Although a sample of gas flowing from the alternator cavity would be desirable, the tap location and sample length line appear to raise a serious logistics problem.

3.3.4.3 Sample Location

Various materials samples will be placed at different GDS locations to determine the possible environmental effects. Particularly for C-103, tests may be more beneficial than gas analyses because contaminant levels may be below the analysis equipment detection capabilities. Test samples will naturally integrate the contaminants absorbed to give a more realistic picture of average pickup rate.

- (a) C-103 Specimens - To assess gas content variations, C-103 specimens will be located in the MBR hot exit, between the HSA and turbine plenum, and in the turbine exhaust. The MBR hot exit specimen will give an indication of desorbed gasses, from Hastelloy X and colder portions of the system. This system can be compared with the HSA exit duct specimen to indicate material absorbed by the HSA structure during test. Specimens located in the turbine exit should indicate any significant outgassing from the alternator stator, since the gas stream and contaminants do not pass through the HSA.

Specimens will be characterized by comparing microhardness measurements, interstitial analysis, room temperature bend, and tensile tests with similar tests conducted on as-received material. Contaminant impacts would be

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more discernible in these tests than during creep. The additional thermal exposure, in a creep test, could alter distribution of interstitials, and affect test implications. Two 0.060-in. thick by 3/4 in. wide by 6-in. long samples should be placed in each location to obtain the specimens necessary for test.

- (b) Superalloys - Superalloy samples (i.e., Hastelloy X and INCO 713LC) are not necessary if the listed system destructive analysis is performed. Primary effects for exploration are surface effects and can best be explored on hardware that has been exposed to true environments. For instance, a sample of INCO 713LC, in the turbine plenum, will not realize the same gas velocity effects that turbine wheel blades will be exposed to. Therefore, samples of these materials are not currently recommended.

3.4 Reliability Testing and Studies

The final category of tests and studies relates directly to BIPS reliability. While there is obvious overlap with a number of tasks already described, it is deemed advisable to establish a category specifically supportive of system reliability. Special tests and analysis, recommended for accomplishment during Phase I, are tabulated on Table I-3, Appendix I, and discussed below.

3.4.1 Recuperator Submodule Test (300 Cycles)

A plate-fin recuperator submodule was tested by AIRLA at conditions corresponding to the predicted cycle life, not exceeding 300 pressure/temperature cycles. This submodule comprises approximately one fourth recuperator volume. The recuperator is designed for 1000

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start cycles, assuming a thermal transient ramp of 400 seconds to 1332°F. The submodule was subjected to accelerated low cycle fatigue test. The thermal ramp at start-up was steepened by decreasing from 400 seconds to 60 seconds. Thermal cycling was stopped after 278 completed cycles. The accelerated test conditions resulted in the unit developing internal and external leakage. Overall, however, the thermal cycling test confirmed the recuperator submodule predicted life. After testing, the submodule was sectioned and metallographically examined to verify the failure mode. A similar test of 80 cycles was completed on a submodule from an earlier recuperator design. Sections (1.5 in.³) of this submodule have subsequently undergone tests at NASA-LeRC. Two samples were maintained at 1330°F for 1000 hours; one in vacuum (10^{-9} Torr), the other in a helium atmosphere (8 psig). The purpose of these tests was to look for aging reactions (i.e., diffusion between gold braze and Hastelloy X, Kirkendall voids, and weight losses). Metallographical examination results were negative. NASA-LeRC indicated a desire to obtain latest submodule samples to perform additional tests and examination.

3.4.2 Recuperator Prototype Thermal Cycle (200 Cycle Goal)

As discussed above, a prototype (first article, production quality) heat exchanger will be tested with the recuperator using air as the working fluid, to determine inlet and outlet temperatures and pressures. After completing this, and a helium leak check test, the prototype will be subjected to a test intended to verify the cycle life. The test cycle will be modeled to fit the most realistic start-up transient(s), and will include; transient ramp, hold at design temperature and pressure for creep relaxation, cool-down transient, and hold at ambient temperature. The prototype heat exchanger will be tested until a failure occurs or 200 cycles is reached. (Working fluid leakage, internal or external, constitutes failure.)

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3.4.3 Alternator Off-Gassing Test

This test, also discussed above, is to be conducted by the Mini-BRU contractor and is included here by reference, because of importance to system reliability.

3.4.4 Inspection of NASA BRU

This inspection, discussed above, is included here by reference because of importance to BIPS reliability.

3.4.5 Low Cycle Fatigue Test of the HSA

On start-up, cold working fluid will enter the already hot HSA. (This is the opposite of thermal stress experienced by the recuperator at start-up.) It is not presently known how susceptible welded C-103 may be to low cycle fatigue. GE has done extensive thermal analyses of transients involved during EHS loading and starting, without ACS or working gas flow, but has not fully considered the cold end start-up transient. NASA LeRC and GE are reviewing the thermal transient analyses to determine the magnitude of this potential problem area. It is recommended that HSA low cycle fatigue tests be conducted to confirm the analysis and AIRPHX has requested a written program from GE.

3.4.6 Bimetallic Joints Testing

The recommended development effort to support bimetallic joints is described above and is included here by reference because of importance to system reliability.

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3.4.7 Bellows and Ducts

This test, described previously, will be performed by AIRPHX with support from ORNL.

3.4.8 Reliability Demonstrations

GDS performance and short term endurance test limitations, in demonstrating long mission life capabilities were discussed in Paragraph 3.1. Use of accelerated aging testing techniques, as a means of demonstrating long term properties of BIPS materials, has limitations. This is discussed in Paragraph 3.3. Thus the burden for substantiating BIPS reliability will rest with analyses of basic design elements, supplemented by the many tests outlined in this IPP. Major emphasis will be placed on confirming long term properties of the most suspect materials, through tests. Tests conducted for long periods (30,000-50,000 hours), in simulated operating environments, are deemed necessary to gain increased confidence in C-103.

3.4.9 Reliability Analyses

Preliminary FMECAs have been completed by contractors supplying BIPS GFE components. A FMECA on the BIPS-FS was completed by AIRPHX. A GDS FMECA is scheduled for completion in June, 1976. Although contributors to this IPP have identified, to the maximum extent possible, the most critical failure modes stemming from possible deficiencies in material properties, these FMECAs methodically look at all BIPS-FS and GDS elements to assure that nothing is overlooked. The FMECAs comprise consolidated lists of critical components and processes. These lists aid in guiding the design effort as well as in alerting quality assurance engineering and inspection personnel of the two systems'

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most critical items. Other analytical techniques will be utilized as required during Phase I. Finally, an analytical assessment utilizing all available data (test program results, materials, design, stress/strength analyses, and historical experience with similar components) will be used to provide reasonable assurance that the minimum acceptable level of reliability has been met or exceeded.

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APPENDIX I

Table I-1	GFE Component Confidence Tests
Table I-2	Materials Studies and Tests
Table I-3	Reliability Testing and Studies

TABLE I-1
GFE COMPONENT CONFIDENCE TESTS

<u>Item Paragraph No.</u>	<u>Test or Study</u>	<u>By Whom</u>	<u>Time Period</u>	<u>Remarks</u>
<u>Recuperator</u>				
3.2.1.(a)	Proof Pressure Test (1)	AIRLA	Jan 77	NASA/AIRPHX will observe
3.2.1.(b)	Helium Leak Test (1)	AIRLA	Jan 77	NASA/AIRPHS will observe
3.2.1.(c)	Cold Flow Test (ΔP) (2)	AIRLA	Jan 77	NASA/AIRPHX will observe
3.2.1.(d)	Prototype Hot Flow Performance (1) (ΔP + Heat Transfer)	AIRLA	May 76-Jan 77	To be followed by helium leak test
<u>Mini-BRU</u>				
3.2.2.(a)	Cold Spin, 5 hr., 100% N (1)	AIRPHX	Dec 76	NASA will observe
3.2.2.(b)	Cold Spin, 5 min., 120% N (1)	AIRPHX	Dec 76	NASA will observe
3.2.2.(c)	Alternator Mode Test (1)	AIRPHX	Dec 76	NASA will observe
3.2.2.(d)	Motor Mode Test (1)	AIRPHX	Dec 76	NASA will observe
3.2.2.(e)	Helium Leak Test (2)	AIRPHX	Dec 76	NASA will observe
3.2.2.(f)	Compressor Test Rig (1)	AIRPHX	May 76	Performance mapping
3.2.2.(g)	Alternator Motor Start Testing (1)	AIRPHX	May 76	--
3.2.2.(h)	Turbine Test Rig (1)	AIRPHX	May-Apr 76	Performance mapping
3.2.2.(i)	Alternator Performance Mapping (2)	AIRPHX	May-Apr 76	--
3.2.2.(j)	Compressor Clearance Tests (3)	AIRPHX	Could be now	Evaluation of shroud clearance
3.2.2.(k)	Inspection of NASA BRU (2)	NASA LeRC	In process	21,208 hours logged
<u>Heat Source Assembly</u>				
3.2.3.(a)	Proof Pressure Test (1)	GE-Valley Forge	Nov 76	NASA/AIRPHX will observe
3.2.3.(b)	Helium Leak Test (1)	GE-Valley Forge	Nov 76	NASA/AIRPHX will observe

- (1) Approved and funded
 (2) Approved, and funding anticipated
 (3) Recommended addition to existing program but funding not presently identified

(For further explanation of these categories, see Para. 2.3.)

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TABLE I-2
MATERIALS STUDIES AND TESTS

<u>ALPHA CODE</u>	<u>TASK DESCRIPTION</u>	<u>RESPONSIBILITY</u>	<u>TIME PERIOD</u>	<u>REMARKS</u>
Refer to Figure 2				
A	Heat Source Offgassing (1)	BCL	Dec. 75 to Apr. 76	Determine EHS handling
B	Alternator Offgassing (1)	AIRPHX (BCL)	Nov. 75 to Aug 76	Funded by NASA
C	Foil Insulation Compatibility (1)	AIRPHX	Mar. 76 to Aug. 76	IR&D Effort
D	C-103 Contamination Rate (1)	BCL	Dec. 75 to Jul 76	Determine uptake rate and dis- tribution
E	Short-term Contamination Effects (1)	ORNL	Apr. 76 to Jul 76	Primarily effort on tensile properties
F	Baseline C-103 Data (1)	NASA	-- to Apr. 76	Work completed. Design based on results
G	Additional NASA Tests (1)	NASA	Nov. 75 to Sep. 76	Effects of fabrication, graphite proximity, etc.
H	ORNL Environmental Creep Tests (1)	ORNL	Nov. 75 to Aug. 76	Effects of CO, CH ₄ alternator insulation
I	Effect of Environmental State (3)	ORNL	Jul. 76 to Oct. 76	Pressure and flow effects of working fluid
J	MARSCOM Definition of Tests (1)	MARSCOM	Oct. 76 to Nov. 76	Define long-term creep tests if still desired after Tasks A-H
K	Long-Term Creep Tests (3)	ORNL	Nov. 76 to Sep. 78	
L	Alternate Alloy Search (1)	ORNL	Nov. 75 to Jan. 76	Preliminary creep and tensile tests of contaminated specimens
M	PT3008 Study (1)	ORNL	Nov. 75 to Nov. 77	Continuing program for MHW
N	Mo-Re Exploratory Work (1)	ORNL	Nov. 75 to Jan. 76	Includes literature search and assessment
O	Mo-Re Property Assessment (1)	ORNL	Jan. 76 to Oct. 76	Develop initial properties

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TABLE I-2 (Contd)

ALPHA CODE	TASK DESCRIPTION	RESPONSIBILITY	TIME PERIOD	REMARKS
Refer to Figure 3				
P	Relation to Data (1)	AIRPHX	May 76 to Oct. 76	IR&D effort
Q	INCO 713 and Hastelloy Environment (1)	AIRPHX	Mar 76 to Sep. 76	IR&D effort
R	NASA Bimetallic Joint (1)	NASA	Aug. 75 to Jun. 76	Technology development
S	ORNL and BCL Evaluation of NASA Joints (1)	BCL/ORNL	Jun. 76 to Aug. 76	
T	ORNL Braze Confirmation (1)	ORNL	Jun. 76 to Sep. 76	Using C-103 sheet
U	ORNL Joint Design Evaluation (1)	ORNL	Sep. 76 to Oct. 76	Tests on cylindrical sections.
aa - bb	Long-term Bimetallic Joint Age (3)	TBD	Sep. 76 to Sep. 77	Study diffusion effects of Cb-1% Zr joints on C-103
V	Co-extruded and Explosive Bond Joints (1)	AIRPHX	Aug. 75 to Jan. 76	Stopped due to success of NASA work
W	Assess Welds and Brazes (1)	ORNL	Jul. 76 to Feb. 77	Continuing design monitoring
X	Fab GDS Joints (1)	ORNL	Oct. 76 to Mar. 77	Concurrent with Task T
* k - l	Ducts and Bellows Assessment (1)	ORNL	Oct. 76 to Jan. 77	ORNL Supervision of Tasks Z and Y
Z	Fab Ducting and Bellows (1)	AIRPHX	Sep. 76 to Jan. 77	Test samples produced with GDS parts
Y	Ducts and Bellows Sample Tests (2)	ORNL	Oct. 76 to Mar. 77	Basically quality assurance tests
m - n	Multi-foil Thermal Insulation (1)	AIRPHX/TECO	Dec. 75 to Jun. 77	ERDA/BIPS program major sub-contract
o - p	IR&D Insulation Development Multi-Foil and Other High Temperature Insulations (1)	AIRPHX	Jan. 76 to Jan. 77	Addresses operating temperatures up to 5500°F in Argon and Vacuum
q - r	Obtain C-103 and Mo Samples (1)	AIRPHX	Jan. 76 to May 76	Aimed at evaluating replacing Ni on inner foils to aid material compatibility
u - v	Fab GDS Insulation System (1)	AIRPHX	Oct. 76 to Jan. 77

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TABLE I-2 (Contd)

<u>ALPHA CODE</u>	<u>TASK DESCRIPTION</u>	<u>RESPONSIBILITY</u>	<u>TIME PERIOD</u>	<u>REMARKS</u>
Refer to Figure 3				
w - x	Apply Insulation to GDS (1)	AIRPHX/TECO	Jan. 77 to Jun. 77	Installation of insulation on GDS at TECO
AA	Post Test Examination (3)	AIRPHX	Mar. 78 to May 78	Analysis of GDS system
Refer to Figure 4				
(1) (2)	Recuperator Braze Joints (1)	AIRLA/NASA	In process	
(3) (4)	Thermal Cycling and Aging Effects (1000 Hours)			
(5)	Aging (Braze Diffusion Rate Tests)	NASA	In process	
(6) (7)	Air/Helium Correlation Tests (2)	NASA	Jan. 76 to Sep. 76	Verification of Low Cycle Thermal Fatigue Air Testing
(8)	ORNL Property Tests (1)	ORNL	Apr. 76 to Aug. 76	Establish braze alloy strength variation over full temperature range
(9)	5000 Hour Creep Rupture Single Plate-Fin Sandwiches (2)	AIRLA/NASA	Jan. 76 to Aug. 76	Evaluate Effects of Temperature, He, and Vacuum

- (1) Approved and funded
- (2) Approved, and funding anticipated
- (3) Recommended addition to existing program but funding not presently identified

(For further explanation of these Categories, see Paragraph 2.3)

*Not shown on Figure 3

TABLE I-3
RELIABILITY TESTING AND STUDIES

<u>Item Paragraph NO.</u>	<u>Test or Study</u>	<u>By Whom</u>	<u>Time Period</u>	<u>Remarks</u>
3.4.1	Recuperator Submodule Test (300 cycles) (1)	AIRLA	Completed	Thermal cycling
	Aging/diffusion Tests (Recup. sections) (1)	NASA LeRC	In Process	and aging effects
3.4.2	Recuperator Prototype Thermal Cycle (1)	AIRLA	Jun 76 - Jul 76	200 cycle goal
3.4.3	Alternator Off-Gassing Test (1)	AIRPHX (BCL ORNL)	Mar 75 - Sep 76	See 3.3.1.3
3.4.4	Inspection of NASA BRU (1)	NASA LeRC	In Process	See 3.2.2.11
3.4.5	Low Cycle Fatigue Test of HSA (3)	GE	Sep 76 - Dec 76	
3.4.6	Bimetallic Joints Testing			
	Joint Development, Braze and Heavy Metal Transition (1)	NASA LeRC	In process	
	Braze Alloy Formulation, Tests and Selection (1)	ORNL	Jan 76 - Jun 76	
	Coextrusion and Explosive weld Methods (1)	AIRPHX	Dec 75 - Jan 76	Part of ERDA/BIPS contract effort
	Bimetallic Joint Esting (2)	ORNL	Jun 76 - Sep 76	
3.4.7	Bellows and Ducts Reliability (3)	AIRPHX/ORNL	TBD	See 3.3.3.5
3.4.9	Reliability Analyses			
	FMECA-BIPS-FS (1)	AIRPHX	1 Jan 76	
	FMECA-GDS (1)	AIRPHX	30 Jun 76-1 Jan 77	Design reviews
	Analytical assessments (1)	AIRPHX, Others	Continuing	As required throughout Phase I

- (1) Approved and funded
(2) Approved, and funding anticipated
(3) Recommended addition to existing program but funding not presently identified.

(For further explanation of these categories, see Para. 2.3)