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VOLUME

ISOTOPE BRAYTON GROUND DEMONSTRATION TESTING AND FLIGHT QUALIFICATION

ATTACHMENT TO:

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REPORT NO. N-30198

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December 6, 1974

DANIEL J FINK
VICE PRESIDENT AND
GENERAL MANAGER

Mr. William G. Orr
Vice President and General Manager
AiResearch Manufacturing Company of Arizona
402 South 36th Street
Phoenix, Arizona 85010

Subject: Isotope Brayton Power Conversion System Program

Dear Mr. Orr:

We in General Electric's Space Division are pleased to team with you in support of the AEC's Isotope Brayton System Development and Test Program. Our confidence in the isotope Brayton system is based upon a careful assessment of the several power conversion technologies available and their relative state of maturity, combined with an evaluation of a broad spectrum of user mission requirements.

General Electric has supported NASA in Brayton technology development and on several mission application studies. In addition, we have been a major contractor to the AEC for over a decade - performing in an excellent fashion on such notable programs as SNAP-27 and the current Multi-Hundred Watt (MHW) RTG Program. The Commission has invested well over \$3-million in facilities at GE's Valley Forge location. In addition, General Electric has invested approximately \$100-million in Valley Forge; a facility dedicated to the development and fabrication of spacecraft and their subsystems.

Our program will be managed by Mr. Wayne Prickett who will report to our Advanced Energy Programs organization managed by Mr. B. J. Tharpe. Both Mr. Lee Farnham, General Manager of the Division's Space Systems Department, and I will review the program on a regular basis to be sure the program is proceeding satisfactorily.

I wish to assure you and the Commission of my personal commitment of the Space Division's full support to this proposal to the Atomic Energy Commission. AiResearch and GE have worked as a successful team in past efforts and I believe this relationship can continue and grow for this lengthy and important new effort. We look forward to an increasingly important General Electric role as the program progresses into later flight phases where GE's demonstrated capabilities as a space nuclear power system supplier are crucial.

Sincerely,

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MGW

A Proposal for:

Isotope Brayton Ground Demonstration
Testing and Flight Qualification Program

VOLUME 1
TECHNICAL PROGRAM

Submitted to

AiResearch Manufacturing Company of Arizona
402 South 36th Street
Phoenix, Arizona 85010

In Response to

U.S. Atomic Energy Commission
Solicitation No. SNS-RFP-75-1-CAO
Dated: November 1, 1974

ACRONYMS AND ABBREVIATIONS

ABS	Auxiliary Battery System (a STE/GSE item)
ACS	Auxiliary Cooling System (for HSA) (a STE/GSE item)
AEC	Atomic Energy Commission
AEC PR	Atomic Energy Commission Procurement Regulation
AIRPHX	AiResearch, Phoenix
AIRLAS	AiResearch, Los Angeles Heat Transfer Systems
BOM	Beginning of Mission
BRU	Brayton Rotating Unit
BRURSA	Brayton Rotating Unit -- Recuperator Sub Assembly, includes connecting ducting and structure, and insulation
CY	Calender Year
DAS	Data Acquisition System
DCS	Demonstrator Cooling System (a STE item)
DOD	Department of Defense
EBFS	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
FBS	Flight Battery System Required for Start in Orbit
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FPR	Federal Procurement Regulation
FSA	Fuel Sphere Assembly (for HS)
FSAR	Fuel Safety Analysis Report
FSE	Flight Support Equipment Required to Protect Hot Refractory Parts in Earth's Atmosphere
FY	Fiscal Year
GDEHS	Graphite Dynamic Electric Heat Source (GE Term for EHS-D)

GDS	Ground Demonstration System (PCSI + EHS-S)
GE	General Electric, Valley Forge
GEHS	Graphite Electric Heat Source (GE term for EHS-S)
GFE	Government Furnished Equipment
GIS	Graphite Impact Shell (for HS)
GMS	Gas Management System (a STE/GSE item)
GSE	Ground Support Equipment
GTC	Ground Support Console (a STE/GSE item)
HRHX	Heat Rejection Heat Exchanger
HS	Heat Source (same as and replaced by EHS)
HSA	Heat Source Assembly (Does not include IHS or HSS. 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
IBGDS	Isotope Brayton Ground Demonstration System (GDS + IHS)
IBS	Isotope Brayton System
IHE	Isotope Handling Equipment
IHS	Isotope Heat Source (Isotope & Re-entry Protection)
JPL	Jet Propulsion Laboratory
LES 8/9	Lincoln Experimental Satellite (#8 and #9)
MB-ERTG	400 Watt Mini-Brayton — Economic Radioisotope Thermodynamic Generator Design (Rate also to IBFS)
MHW	Multi-Hundred Watt (AEC/GE IHS Technology)
MJS	Mariner Jupiter/Saturn
MMD	Man Mission Duration
NA	Not Applicable
NASA LeRC	National Aeronautical and Space Administration Lewis Research Center
PCL	Power Conversion Loop
PCS I	Power Conversion System (HSA + BRU + Heat Sink + Controls + Piping and Structure)

PCS II	Power Conversion System (HSA + BRU + Radiator + Controls + Piping and Structure)
PICS	Post Impact Containment Shell (for HS)
PISA	Post Impact Shell Assembly (for HS)
PLC	Parasitic Load Control System
PSAR	Preliminary Safety Analysis Report
PSC	Power System Console (for EHS) (a STE/GSE item)
QA	Quality Assurance
RCS	Radiator Cooling System (a GSE item)
RTG	Radioisotope Thermodynamic Generator (obsolete, replaced by MB-ERTG or by IBFS)
SNAP	System for Nuclear Auxiliary Power
SNS	Space Nuclear Systems (Division of AEC)
SRS	Space Radiator Subsystem
STE	Special Test Equipment
SURVSATCOM	Air Force Survivable Communication Satellite
TBD	To be Defined
USAR	Updated Safety Analysis Report
VRE	Voltage Regulator Exciter
WBS	Work Breakdown Structure

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SECTION 1

INTRODUCTION

The General Electric Company is pleased to support AiResearch Manufacturing Company of Arizona (AIRPHX) in this proposal for the demonstration, development and production of the Isotope Brayton Flight System (IBFS).

General Electric recognizes the Isotope Brayton System as one of the most promising approaches for supplying reliable, safe and economical electrical power for future space missions. Significant national resources have been invested in the Brayton power conversion technology by NASA and in the required high temperature heat source technology by the AEC. General Electric has actively participated in this effort over the past ten years and has played an important role in bringing the Isotope Brayton System to its current level of development.

The next logical step is a ground demonstration of the type outlined in this proposal. General Electric is interested in continuing its involvement and feels it has proven capabilities and over ten years experience to offer in two key areas: (1) development of high temperature radioisotope heat sources, and (2) development of nuclear space power flight hardware for the AEC. This volume outlines how General Electric proposes to use these capabilities and experience to support AiResearch in conducting a program that will satisfy the AEC's objectives.

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SECTION 2

SUMMARY

The General Electric Company supports AIRPHX in the development of an economic Isotope Brayton Flight System for use in DOD and other earth orbital missions in the 1980's. Applications for outer planet missions are anticipated in the same time frame. In the initial phase of the program, GE recognizes the cost effectiveness to the AEC of the AIRPHX prime/GE subcontractor roles, since the Isotope Brayton Ground Demonstration System does not require the use of an Isotope Heat Source (IHS).

During this period, GE proposes, in conjunction with the AEC, to define and develop improvements in the MHW heat source. These will provide improved safety capabilities beyond those currently demonstrated by the AEC for the MHW RTG for use in the LES 8/9 and Mariner J/S programs. The MHW type heat source, with its high temperature capability, modular fuel containment, impact survival and post-impact containment capability represents the safest radioisotope heat source development by the AEC. GE recognizes that continued improvements in safety and cost aspects will be required. In this proposal, General Electric identifies techniques, for consideration by the AEC and AIRPHX, by which the current capabilities can be enhanced. These include further MHW heat source safety enhancement through:

- Improved Post Impact Containment Shell (PICS) vent systems.
- Utilization of improved iridium technology under development by the AEC.

The General Electric Company will support AIRPHX in the Phase I GDS design through:

- Conceptual delineation of the IBFS flight system design. This will be accomplished by drawing on key aspects of nuclear space power systems integration with the SURVSATCOM spacecraft, and based, in part, on recent studies performed for the USAF/AFSC, Electronics Systems Division.
- Assistance in the definition and development of flight nuclear space power hardware, with emphasis on qualifications and acceptance testing of such hardware.
- Definition and resolution of key problem areas necessary to meet the program performance and schedule objectives established by the AEC; the development and qualification of an IBFS system by June 30, 1980.

Emphasis is placed on the utilization of the MHW-RTG heat source and the directly related Heat Source Assembly (including the Heat Source Heat Exchanger (HSHX), the Insulation System (IS), the Auxiliary Cooling System (ACS), and the Emergency Cooling System (ECS). Included are the heat rejection simulation, heat exchanger, and space radiator design and development, all aspects of spacecraft integration; nuclear, dynamic, electrical, thermal, and structural. Attention is directed toward the use of the space radiator cavity integrated with the SURVSATCOM spacecraft.

This program has been assigned to General Electric's Advanced Energy Programs Operation. As shown in Figure 2-1 this operation is composed of several project offices, reporting to Mr. B. J. Tharpe. Mr. Tharpe has established Mr. W. Z. Prickett as Program Manager. The NASA-LeRC Isotope Brayton Heat Source Assembly program, Mr. D. Wein, Program Manager, is also within the Advanced Energy Programs Operation as illustrated in Figure 2-2. This focus of GE Isotope Brayton programs assures AIRPHX and the AEC of maximum support in the IBFS Program. The Advanced Nuclear Programs function provides a separate management chain for the initial phases of the IBFS program (see Figure 2-2), and simultaneously interfaces with Mr. R. J. Katucki's Nuclear Programs. This assures complete technology exchange and utilization between the IBFS program and the AEC MHW-RTG programs,

Figure 2-1. Advanced Energy Programs Organization

Figure 2-2. Key Program Relationships

LES 8/9 and Mariner J/S, emphasizing isotope heat source technology, and including safety, IBFS/spacecraft integration and mission operations.

As the IBFS program progresses toward flight status, it is planned to reassign the program within Mr. Katucki's Nuclear Programs Operation; near the end of the Phase I IBFS program, or at the initiation of the Phase II effort. The key transfer function is expected to be the DOD/USAF requirement for the IBFS for the SURVSATCOM mission. The organizational structure under Mr. Prickett is shown in the Technical Program, Volume I, with a summary of the key personnel.

Mr. Prickett will have complete authority and responsibility for the direction and control, technical performance, schedules and costs for the GE Isotope Brayton Flight System Program support to AIRPHX. He will provide AIRPHX with a single responsive point of contact within General Electric for the effective conduct of the Program.

Mr. Prickett will have direct access to Mr. Tharpe, and to higher General Electric management through established reporting and management channels for any and all support required. Mr. Prickett will be assisted technically and administratively by task leaders and key technical personnel covering every major area of the program. A synopsis of Mr. Prickett's background is given in Figure 2-3.

The program management and program control procedures necessary to provide AIRPHX and the AEC with the efficient completion of this program are in place and functioning, described in Volume III, Business and Management. These procedures and policies have been and are being successfully employed on similar programs. A summary of the General Electric Reliability and Quality Assurance Program Plan is submitted as Appendix B, Volume II of this proposal. This summary includes a brief description of its implementation to meet the AIRPHX/AEC requirements for the IBS program. A detailed Reliability and Quality Assurance Program Plan will be submitted to AIRPHX for their use and transmission to the AEC when General Electric is selected by AIRPHX for final negotiations.

Since 1970, Mr. Prickett has been Manager of Advanced Nuclear Programs. In this capacity and since joining Space Division in 1966, he has managed or contributed to a wide spectrum of nuclear space power studies including:

- Isotope thermoelectric systems
- Isotope and reactor thermionic systems
- Nuclear electric propulsion systems
- Isotope Brayton dynamic systems
- Other isotope dynamic systems
(Rankine, Stirling)

His activities have included system preliminary design and optimization, spacecraft integration, flight safety, and system detail design, development and operation. He has evaluated system development cost and flight system unit cost during studies and proposals for advanced flight systems.

From 1956 to 1966, Mr. Prickett had a number of engineering assignments in the General Electric Aircraft Nuclear Propulsion Department and its successor, the Nuclear Propulsion and Materials Operation. He was a design engineer on the 710 Reactor Program for space power and propulsion applications. He attended the Oak Ridge School of Reactor Technology in 1958.

Figure 2-3. Background - Mr. W. Prickett
GE Program Manager, IBFS Program
for AIRPHX

General Electric has structured this program to meet the assigned AIRPHX objectives, established within the requirements set forth by the AEC in RFP SNS-75-1 CAO. GE has assembled a highly qualified team which assures continuity with the on-going AEC MHW-RTG heat source program and the NASA Isotope Brayton Heat Source Assembly Program. Program expansion to assure technology development and hardware fabrication availability for the June 1980 IBS qualification is delineated. The necessary GE facilities are committed. GE is confident, because of past successful flight programs conducted for the AEC, that its program organization, phasing and allocation of effort will meet the AIRPHX, and therefore the AEC program objectives.

The General Electric Company has a major and long term interest in the Isotope Brayton System, and therefore in this development effort. General Electric has supplied the highly successful SNAP-27 for the AEC and NASA, and is now developing the MHW-RTG for the AEC, for use on NASA and DOD missions. GE is fully committed to the increased use of economic nuclear power in space and recognize the IBFS as the most promising, next generation space nuclear power system, with the potential to achieve economics superior to solar array systems. The radioisotope Brayton Power System has been under study at GE since 1967. These activities include contracts to the AEC, NASA, and Company-sponsored programs. These system activities assure that General Electric fully understands the IBFS design performance and programmatic requirements that have been established by the AEC. GE knows how to design and build the IBS Heat Source Assembly to meet these requirements because it has been working with NASA and the AEC for the last two years on this key development.

GE is quite familiar with the unique SURVSATCOM spacecraft integration requirements currently established for both solar and nuclear power because of related studies, recently performed for USAF/AFSC, Electronic Systems Division. In particular, GE is cognizant of IBFS heat rejection radiator aspects, as demonstrated in certain example Isotope Brayton Flight System designs which are presented. GE is further cognizant of particular thermal, electrical, nuclear and attitude control (dynamic systems) IBFS/spacecraft integration requirements.

In part, this appreciation of the SURVSATCOM requirements also results from continuous contacts with the DOD, accomplished with AIRPHX support and AEC encouragement over the last two years. This activity leaves little doubt that the IBFS will have wide application.

Experience in many key areas is a required prerequisite to assure that the conduct of this program will meet the AEC and AIRPHX objectives. These include:

- High Temperature Heat Sources
- Aerospace Nuclear Safety
 - Successful Development of Space Nuclear Power Hardware
- Brayton Power Systems
- Heat Rejection Systems
- Spacecraft Integration
- Design, Development and Fabrication; heat exchangers and multi-foil insulation
- Refractory Materials; fabrication and joining
- System Component Integration; structural and thermal
- Nuclear Qualification and Acceptance Test, Test Support Equipment

General Electric brings over 10 years experience in successful space nuclear power hardware development to this AEC program. The success of this program is further enhanced by the use and/or improvement of the high temperature radioisotope heat source technology employed in the MHW-RTG. These include concepts to further enhance safety for the IBFS application.

The development of high temperature plutonium heat source technology has been underway for the AEC for several years on the MHW Program. This program has produced significant advances in high temperature heat source technology. This IHS will be flight qualified for the LES 8/9 mission. Successes achieved in this program include:

- Demonstration of compatibility between the fuel and fuel containment shell at operational temperatures.
- Individual fuel sphere heat source elements have been manufactured and successfully operated at temperatures at least 170° F higher than required by the Mini-Brayton HSA.

- Demonstration of fuel sphere assembly impact survivability at velocities in excess of heat source terminal velocity.
- Adequate margins of safety for all critical components during all applicable heat source reentry conditions.

Further improvements which can readily be implemented for this IBS program are identified as:

- Improved Post Impact Containment Shell (PICS) vent systems.
- Implementation of improved iridium technology through continued liaison with on-going AEC programs in the areas of fabrication and material properties.

The large amount of related experience from these and other programs will be brought directly to bear on the AEC Isotope Brayton System Program. This experience significantly enhances the performance and minimizes the total cost to the government for this and future related activities that may be required. A partial identification of these related programs is presented on Table 2-1.

This proposal is presented in separate Technical Program, Technical Proposal, and Business and Management Volumes (Volume I, II and III, respectively).

The Technical Program Volume contains the proposed program to support AIRPHX. The Technical Proposal emphasizes the application of the MHW-RTG heat source to the IBFS programmatic and safety requirements established by the AEC, including its related integration with the Heat Source Assembly. This is further supported by a thorough discussion of mission and Isotope Brayton Flight System requirements, flight configurations and IBFS-spacecraft integration. The Business and Management Volume contains a summary of the proposed program, the management controls, and the costs associated with performing the proposed program for AIRPHX.

Table 2-1. General Electric Related Experience

Key Activities	Customer	Application to the IBFS Program
<ul style="list-style-type: none"> Mini-Brayton ERTG Study (AEC-SNSO-6) 	AEC	<ul style="list-style-type: none"> Mini-Brayton Power System-to-HSA, to-Radiator Interfaces, Mission operations and requirements
<ul style="list-style-type: none"> Mini-Brayton HSA Development (NAS3-18541) 	NASA	<ul style="list-style-type: none"> Isotope Heat Source Integration and Safety
<ul style="list-style-type: none"> SURVSATCOM Electrical Power Subsystems (SEPS) Study (AF 19628-74-C-0155) 	USAF	<ul style="list-style-type: none"> User Requirements and Spacecraft Integration
<ul style="list-style-type: none"> Mini-Brayton Heat Source Assembly Design Study (NAS 3-16810) 	NASA	<ul style="list-style-type: none"> Heat Source Assembly Conceptual Design
<ul style="list-style-type: none"> SNAP-27 Program (AT(29-2)-2581) 	AEC	<ul style="list-style-type: none"> Beryllium Technology Bi-Metallic Joints Safety
<ul style="list-style-type: none"> MHW-RTG Program (AT(29-2)-2831) 	AEC	<ul style="list-style-type: none"> MHW Heat Source & Support Structure Beryllium Technology Multi-foil Insulation Safety
<ul style="list-style-type: none"> Separately Launched Multi-Use, Space Electrical Power System (NAS 9-7444) 	NASA	<ul style="list-style-type: none"> Isotope Brayton System Design and Operation
<ul style="list-style-type: none"> Isotope Brayton Nuclear Safety Feasibility Study (AT(29-2)-2831) 	AEC	<ul style="list-style-type: none"> Nuclear Safety
<ul style="list-style-type: none"> Liquid Metal-to-Air Heat Exchanger Design Study (F33615-73-C-2065) 	USAF	<ul style="list-style-type: none"> Heat Exchanger Design
<ul style="list-style-type: none"> Methane/Hydrogen Heat Exchanger Program (NAS 3-14319) 	NASA	<ul style="list-style-type: none"> Heat Exchanger Design, Fabrication and Assembly
<ul style="list-style-type: none"> Controlled Heat Energy Management System Development Program 	IR&D	<ul style="list-style-type: none"> Backup ECS/ACS Heat Pipe Technology
<ul style="list-style-type: none"> Ceramic Clad Heat Source 	IR&D	<ul style="list-style-type: none"> Nuclear Safety
<ul style="list-style-type: none"> Space Radiator Development 	IR&D	<ul style="list-style-type: none"> IBFS Space Radiator
<ul style="list-style-type: none"> Design and Fabrication of a Brayton Cycle Solar Heat Receiver (NAS 3-10944) 	NASA	<ul style="list-style-type: none"> Refractory Metal Fabrication and Joining
<ul style="list-style-type: none"> Evaluation of High Strength Columbium Alloys for Alkali Metal Cont. (NAS 3-2140) 	NASA	<ul style="list-style-type: none"> Refractory Metal Technology

Volume I - Technical Program

This volume presents the detailed task descriptions for the Phase I program, summary task descriptions for the Phase II program, and related work definition for the Phase III flight program; in support to AIRPHX, with emphasis on the Phase I program. Task schedules, milestones and work flow are provided.

Key technical problems and exceptions to the AIRPHX/AEC program are presented.

The proposed program organization within General Electric, the key personnel to be applied, and their related experience are established.

SECTION 3

TECHNICAL PROGRAM

3.1 TECHNICAL REQUIREMENTS AND APPROACH - PHASE I

A. PROGRAM SUMMARY

The Phase I Program is directed toward establishing a conceptual Isotope System design, developing and testing a Ground Demonstration System (GDS) to be representative of the System Design and conducting advanced development activities to afford a proper transition into the Phase II Program.

During the Phase I Program, General Electric Company will support AIRPHX in a number of areas as specified below. In particular, GE will provide the heat source/HSA, systems and safety support for Conceptual Isotope Brayton Flight System (IBFS) design, the Ground Development System and the necessary advanced development activities. The GE familiarity with the MHW Heat Source and the MHW Program systems and safety aspects, coupled with the current HSA Development Program for NASA and radiator/heat exchanger programs in recent years assures GE's ability to perform these efforts for AIRPHX and the AEC.

The areas in which GE will support AIRPHX are:

1. Perform conceptual Isotope System design.
2. Conduct advanced development programs for key potential problem areas including the Isotopic Heat Source and HSA.
 - a. PICS Vent improvement
 - b. Beryllium radiator development
 - c. Bi-metallic joint development
3. Provide preliminary design and final design for radiator (or heat exchanger) and HSA interfaces.

4. Support design reviews.
5. Fabrication and assembly of radiator (or heat exchanger), Electric Heat Sources, power supply consoles and heat rejection system test equipment.
6. Assembly of the Heat Source Assembly (HSA) and the Space Radiator Subsystem (SRS) or the Heat Rejection Heat Exchanger (HRHX) to the BRU-Recuperator Subassembly (BRURSA)
7. Design, fabrication and checkout of specified Special Test and Ground Support Equipment
8. Provide program management support, reports and data to AIRPHX.
9. Provide safety, quality assurance and reliability support

In performing the above activities, the General Electric Space Division shall provide an experienced management team, that has successfully delivered flight systems like SNAP 27 and has developed the MHW heat source and will make its facilities and equipment available to execute the program in accordance with the Work Breakdown Structure and Program Schedule.

It is understood that AiResearch, Phoenix (AIRPHX) will provide the data, drawings and specifications necessary to complete the conceptual IBFS study, and the design and test of GE supplied components and test equipment. It is further understood that three complete Heat Source Assemblies will be furnished by the Government for this Phase I program. The term Heat Source Assembly, as used in this proposal, does not include electric or radioisotope heat sources.

The details of conducting the program are discussed by task in the following pages under Work Description. Additionally, key technical problems, recommended changes in scope and equipment and facilities required are discussed in subsequent sections.

B. PHASE I WORK BREAKDOWN STRUCTURE

The Phase I WBS, shown on Figure 3.1. B-1, is completely consistent with that established by AIRPHX and the AEC. Subtasks have been established within this task structure which reflect the GE areas of responsibility and support. These activities

<p>1.0 Program Management</p> <ul style="list-style-type: none"> • Program Direction & Control • Contracts Support • Finance Support • Procurement Subcontracts Support • Liaison with NASA, GFE Suppliers, Potential Users • Travel and Living <p>2.0 Conceptual Isotopic Brayton Flight System Design</p> <p>2.1 Design Requirements</p> <p>2.2 HSA Conceptual Design</p> <p>2.3 Radiator Conceptual Design</p> <p>2.4 System Configuration</p> <p>2.5 FMEA's</p> <p>2.6 Long Lead Development Item Identification</p> <p>3.0 Preliminary GDS Design and Planning</p> <p>3.1 Preliminary GDS Design</p> <p>3.1.1 HSA Interface Requirements</p> <p>3.1.2 Heat Rejection System Interface Requirements</p> <p>3.1.3 Heat Rejection Design & System Support Equipment Requirements</p> <p>3.1.4 GDS Equipment Interface Design</p> <p>3.1.5 Facility Requirements and Definition</p> <p>3.1.6 Preliminary Design Review</p> <p>3.2 GDS Test Plan</p> <p>4.0 Detailed GDS Design and Analysis</p> <p>4.1 Layout</p> <p>4.2 Transient Effects (HSA)</p> <p>4.3 Heat Sink</p> <p>4.4 Control System Detail Design</p> <p>4.5 Structure</p> <p>4.6 Materials</p> <p>4.7 Heat Source (Electrical)</p> <p>4.8 Special Test Equipment and Facilities</p> <p>4.8.1 Power Supply Console</p> <p>4.8.2 EHS Loading Fixture</p> <p>4.8.3 Pressure Leak Test Kit</p> <p>4.8.4 ACS Gas Management Unit</p> <p>4.8.5 HSA Acoustic Fixture</p> <p>4.8.6 Spider Load Fixture</p> <p>4.8.7 Power Console Shipping Container</p> <p>4.8.8 HSA Handling Sling</p> <p>4.9 Detail Design Review</p>	<p>5.0 Fabrication and Assembly - GDS and Test Facilities</p> <p>5.1 Heat Sink</p> <p>5.2 Control System</p> <p>5.3 Structure</p> <p>5.4 Heat Sources</p> <p>5.5 Component Tests</p> <p>5.6 GDS Assembly</p> <p>5.7 Test Facilities</p> <p>5.7.1 Power Supply Console</p> <p>5.7.2 EHS Loading Fixture</p> <p>5.7.3 Pressure Leak Test Kit</p> <p>5.7.4 HSA-ACS Gas Management Unit</p> <p>5.7.5 HSA Acoustic Fixture</p> <p>5.7.6 Spider Load Fixture</p> <p>5.7.7 Power Console Shipping Container</p> <p>5.7.8 HSA Handling Sling</p> <p>6.0 Test and Evaluation</p> <p>6.1 Performance Test</p> <p>6.2 Endurance Test</p> <p>6.3 Component Test (Radiator/HSA Development and Radiator Simulator)</p> <p>6.3.1 Cold Flow Test</p> <p>6.3.2 Proof Pressure Test</p> <p>6.3.3 Leak Check</p> <p>6.3.4 Hot Flow Test</p> <p>6.3.5 Acoustic Test</p> <p>7.0 Quality Assurance, Reliability and Safety</p> <p>7.1 QA and Reliability</p> <p>7.2 Safety</p> <p>8.0 Reports and Data</p> <p>9.0 Advanced Development</p> <p>9.1 Heat Source Technology</p> <p>9.2 Beryllium Radiator Development</p> <p>9.3 Bi-Metallic Joint Development</p> <p>10.0 Flight Design and Engineering Program Plan</p>
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Figure 3.1.B-1. Phase I - Ground Demonstration System and Advanced Development Work Breakdown Structure Consistent with AIRPHX/AEC Program

are detailed in subsequent task and subtask descriptions, which form the basis for the proposed program costs presented in Volume III, Business and Management. Volume III also includes an abstract of these task descriptions to assure its separability from the other proposal volumes.

The Task 2 Conceptual IBFS Design effort will assure AIRPHX that the GDS design and implementation will reflect the current and evolving IBFS requirements. The GE experience in nuclear power flight hardware and power system studies related to the SURVSATCOM application are reflected in the example flight system design (Volume II, Section 6.3) which establishes a point of departure for this activity.

General Electric will support AIRPHX in the Task 2 (Preliminary) and Task 3 (Final) GDS design, analyses and planning. Emphasis is placed on the Electric Heat Source, the Heat Source Assembly (HSA), the Heat Rejection Heat Exchanger (HRHX), and their interface and assembly with the BRU-Recuperator Subassembly (BRURSA). This activity also includes design and fabrication of special Test Equipment (STE) related to the HSA and the HRHX. General Electric is particularly qualified to assist AIRPHX in these areas, having successfully developed the electric and isotope heat sources for the AEC in the MHW-RTG program, to meet the stringent high temperature and safety requirements for the LES 8/9 and Mariner J/S missions.

The GE effort in Task 5, Fabrication and Assembly - GDS and Test Facilities implements the design and development work of Tasks 3 and 4. In Task 6, General Electric will assist AIRPHX in the particular test operations associated with the HSA, the HRHX, and EHS control. The Task 7 effort provides for the quality assurance and reliability for all General Electric activities, and for the Phase I nuclear safety work consistent with the availability of a fully qualified IBFS at the end of Phase II, June 30, 1977.

In Task 9, Advanced Development, General Electric recommends work in the areas of heat source technology, beryllium radiator and bi-metallic joint development. Task 1 provides for management of the GE program and related reports and data are identified under Task 8.

General Electric will strongly support AIRPHX in the Task 10 delineation of the flight design and engineering program plan. General Electric is uniquely qualified to assist AIRPHX in this area because of their experience in the SNAP-27 and MHW-RTG nuclear power system flight programs, including nuclear power spacecraft integration, and SURVSATCOM spacecraft and nuclear power system design studies recently performed for the Electronic Systems Division of the USAF.

C. SUMMARY SCHEDULE - PHASE I GROUND DEMONSTRATION SYSTEM AND ADVANCED DEVELOPMENT

The top level Phase I WBS tasks are scheduled on Figure 3.1.C-1 for the time period April 1, 1975 through June 30, 1977. Both calendar and fiscal years are shown. The '1976 plus 3' fiscal year is indicated. The detailed task schedules are presented separately as a part of each task descriptions.

The interdependence of these tasks and approximate phasing of major program elements in support of AIRPHX is presented in Figure 3.1.C-2.

D. PHASE I WORK DESCRIPTION

This section presents a description of the effort required to perform the Phase I Program. The work tasks are structured in accordance with the November 11, 1974, AiResearch RFP, relative to AEC SNSRFP-75-1-CAO and is based on the Phase I GDS Program Schedule shown in Figure 3.1.C-1. A detailed schedule and definition of effort to be performed is presented where appropriate, for each task and subtask. Also included are the necessary figures required to provide a complete description of the task content.

3.1.1 Task 1 - Program Management

Objective. The Program Office, under the direction of the AiResearch IBFS Subcontract Program Manager, will be responsible to AiResearch, Phoenix (AIRPHX) for providing overall management, project planning and control, financial and contract management, and the preparation and submittal of all subcontractor documentation required to implement the Phase I Program.

Figure 3.1.C-1. Summary Schedule Meets AIRPHX Requirements Phase I Ground Demonstration System and Advanced Development

Figure 3.1.C-2. Phase I - Ground Development System and Advanced Development Program Work Flow

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Approach. The specific GE program efforts to be accomplished in this task are detailed below:

1. Provide a program plan to AIRPHX
2. Direct overall program activity
3. Establish program requirements and schedules
4. Monitor, control and report the technical, schedule and financial status of the program
5. Provide internal program direction and funding
6. Initiate and process Contract Change Proposals
7. Review and approve GE subcontractor program plans and activities
8. Provide GE subcontractor technical direction
9. Conduct internal design reviews and support AIRPHX design reviews
10. Provide contractual documentation
11. Provide contract interface with AIRPHX
12. Negotiate and administer GE subcontracts
13. Provide procurement support
14. Provide liaison with AEC laboratories, NASA and potential user organizations, such as DOD
15. Edit and issue the following documentation:
 - a. Quality Assurance Plan
 - b. Reliability Plan
 - c. FMEA Report
 - d. Configuration Management Plan

- e. Safety Assessment Report
- f. Reliability Assessment Report

Key areas are delineated on Figure 3.1.1-1. The GE program management provides a singular and total company responsibility and authority to direct, in consort with AIRPHX, and program activities.

A schedule of the above activities is presented in Figure 3.1.1-2.

General Electric's broad management capability, including 10 years experience with AEC programs, assures AIRPHX of knowledgeable, comprehensive management for this program, that will be responsible to AIRPHX requirements. GE has conducted innumerable technology development and hardware programs for the AEC and other agencies of the government and has a proven record of successful program management. That expertise includes standard program control and administration techniques which are tailored to particular program requirements. They will be applied to the IBFS development and flight program in the GE role as subcontractor to AIRPHX, and are discussed in more detail in Volume III, the Business and Management proposal.

Figure 3.1.1-1. Comprehensive and Responsive Program Management for AIRPHX

	FISCAL YEAR	1975					1976 PLUS 3					1977					1978													
	CALENDAR YEAR	1975					1976					1977					1978													
	MONTH	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
1.0 PROGRAM MANAGEMENT																														
PROGRAM DIRECTION AND CONTROL																														
CONTRACT SUPPORT																														
FINANCE SUPPORT																														
PROCUREMENT SUPPORT																														
SUBCONTRACTS SUPPORT																														
LIAISON WITH NASA/USERS																														
PROGRAM PLAN																														

Figure 3.1.1-2. Task 1.0 Program Management Schedule

Output. The activities accomplished in this task will provide satisfactory completion of the GE subcontract on schedule and within cost.

3.1.2 Task 2 - Conceptual Isotope Brayton Flight System Design

Objective. The purpose of this task is to (1) identify early in the program those critical problem areas requiring long lead developments to meet the objective of delivering highly reliable flight hardware in June 1980 and (2) to provide a reference for configuring a Ground Demonstration System which conforms as closely as possible to the projected flight hardware and performance requirements, Table 3.1.2-1, per AEC SNS RFP 75-1-CAD.

Approach. General Electric Company will support AIRPHX in performing the conceptual flight design. The methodology for performing the conceptual design study is depicted in Figure 3.1.2-1.

This task will be completed within the first three months of the contract. A schedule for this work is shown in Figure 3.1.2-2.

Table 3.1.2-1. System Performance Objectives

<p><u>Power</u></p> <ol style="list-style-type: none"> 1. The basic system should be capable of any power output from 500 to 2000 watt (EOM) with minimum redesign and requalification. Optimization studies will be done at a nominal 4800 watt BOM thermal input and 1300 electric watt output. 2. 28 volt dc $\pm 2\%$ is reference output voltage. A capability for higher voltage ac output may be advantageous if it can be achieved directly from the generator. 3. Power delivered to the spacecraft shall be variable from 0 to 100% of the power system output with a response time of the order of milliseconds. This may be accomplished by providing a parasitic load. 4. Partial power during launch to parking orbit is desirable but not mandatory. Partial power during boost to final orbit or flight path is even more desirable. Ability to withstand spin stabilized orbital transfer is desirable but not mandatory. 5. Most potential missions for the power system will be on non-spinning spacecraft, but the ability to operate throughout lifetime on a spin-stabilized spacecraft would be advantageous. <p><u>Lifetime</u></p> <p>Lifetime requirements are $L = 7$ years</p> <p>MMD (mean mission duration) = 5 years where</p> $MMD = \int_0^L R dt$ <p>and</p> <p>R = probability of producing design power at time t</p> <p>Contractors should identify failure modes in the prelaunch, launch, and operational phases.</p>	<p><u>Weight and Cost</u></p> <ol style="list-style-type: none"> 1. Cost objective for recurring costs at 1300 watt output is less than \$5000 per watt(e) assuming \$1000 per thermal watt for the GFE heat source. 2. Weight objective at 1300 watt output is 3.5 watt(e) per pound assuming a weight of 1.8×10^{-2} pound per watt for the GFE heat source. <p><u>Interface Requirements</u></p> <ol style="list-style-type: none"> 1. Capable of launch on Atlas/Centaur, Titan IIC, or the Space Shuttle. 2. On-pad temperature limit of exposed surfaces based on explosive vapor environment is 380 °F. 3. The sink temperature is that of geosynchronous orbit. The design must be capable of stable operation with unbalanced solar input. 4. Thermal input to the spacecraft must be controlled. In some cases there may be advantages to the spacecraft from a radiator that operates in the vicinity of 100 °F. 5. Magnetic field at 1 meter shall be (TBD). 6. On-pad biological dose at 1 meter is 0.20 Rem per hour. 7. The power system shall be resistant to natural and man-made radiation. 8. Design flexibility in the size and shape of the power system is desirable. This might include the ability to adapt the radiator to the shroud shape, to utilize radiator interior space for other components, or otherwise integrate the power system with specific spacecraft requirements. 9. On-pad and in-orbit fueling capability should be provided.
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Figure 3.1.2-1. Task 2.0. Conceptual Isotope System Design (Flight)

CY 1975			
	A	M	J
2.0 CONCEPTUAL DESIGN			
2.1 DESIGN REQUIREMENTS	▽		
2.2 HSA CONCEPTUAL DESIGN		▽	
2.3 RADIATOR CONCEPTUAL DESIGN		▽	
2.4 SYSTEM CONFIGURATION			▽
2.5 FMEA'S			▽
2.6 IDENTIFY LONG LEAD DEVELOPMENT ITEMS			▽

Figure 3.1.2-2. Task 2.0 Conceptual Isotope System Design

Output. The output of this task will be a conceptual design of an IBFS. Weight, envelope, reliability, cycle performance, cost estimates and interfaces with the spacecraft will be defined and documented. The concept definition will include definition of all necessary long lead development items.

3.1.2.1 Subtask 2.1 - Design Requirements

The results of HSA, contractual studies performed by General Electric for the NASA-Lewis Research Center, the results of the ERTG Study performed for the AEC, the results of the GE/JPL Mini-Brayton reliability studies, and pertinent inputs from the current on-going hardware development contracts being conducted by GE in consonance with RFP system performance objectives, will be the point of departure for developing preliminary design requirements and guidelines for a plutonium fueled Mini-Brayton power flight system. Mission requirements (defined as accurately as possible) will be factored into the design requirements and integrated into a system concept.

3.1.2.2 Subtask 2.2 - HSA Conceptual Design

Parametric and trade-off studies on heat source concepts will be undertaken as required to support the evolution of the conceptual design.

Heat Source studies will place emphasis on utilizing MHW technology in configuring a lightweight heat source with additional safety margin in surviving explosion, fire, re-entry and impact environments. These 'new generation' heat sources will be traded off against the baseline MHW cylindrical Heat Source Heat Exchanger (HSHX) configurations consistent with the recommended heat source conceptual designs. Additionally the HSA Emergency Cooling Subsystem (ECS) and Auxiliary Cooling System conceptual designs will be developed consistent with the goal to provide on pad and in orbit heat source loading capability.

3.1.2.3 Subtask 2.3 - Radiator Conceptual Design

A conceptual design of a lightweight Beryllium radiator will be developed to provide the heat rejection for the IBFS. Considerations will be given to fabricability, weight, shape, meteoroid protection, power conversion, system integration and spacecraft interfaces.

3.1.2.4 Subtask 2.4 - System Configuration

Preliminary layouts of the power conversion system with all interfacing components will be generated. Emphasis will be placed on minimizing ducting, providing thermal expansion joints and assuring that the system structure is configured for anticipated structural loads. Interfaces with the spacecraft will be defined in sufficient depth to identify any potential problem areas and/or spacecraft constraints on the PCS.

3.1.2.5 Subtask 2.5 - Failure Mode and Effects Analysis

Of particular importance in the system conceptual design subtask will be the failure mode and effects analysis which will identify the potential modes of failure of the system, and highlight approaches to reduce their probability of occurrence and/or their effects on the system. Results of current GE Mini-Brayton reliability studies for JPL will be fully utilized. In the system conceptual design, careful attention will be given to configuring the system to minimize heat loss from ducting and defining all component and system interfaces (thermal, mechanical material compatibility, electrical etc). Interactions with the spacecraft (e.g., momentum coupling, thermal inputs, radiation dose effects, etc.) will receive attention.

3.1.2.6 Subtask 2.6 Identify Long Lead Development Items

Long lead Development Items requiring early start to meet the June 1980 flight qualification milestone identified in this proposal will be reviewed and a final set identified. Recommended programs will be prepared and submitted to AIRPHX for consideration and approval to implement.

3.1.3 Task 3 - Preliminary GDS Design and Planning

3.1.3.1 Preliminary GDS Design

Objective. The objective of this task is to identify, develop and recommend a design approach for the Ground Demonstration System (GDS), configured as closely as possible to the flight conceptual design so that it enhances the effectiveness of the test in simulating a flight system.

Approach. General Electric will provide support to AIRPHX as scheduled in Figure 3.1.3-1, in configuring the GDS Heat Source Assembly and the system heat rejection system, and the associated test support equipment for these two items.

Output. The output of the GE Task 3 effort will be a specification of design requirements, assistance in layout drawings, interface descriptions, and preliminary FMEA's, the definition of the electrically powered HSA's, the heat rejection system, and the associated test support equipment. Inputs to the test plan defining test support equipment usage, facility requirements and recommended facilities to perform the GDS tests will be submitted at the end of this task effort.

3.1.3.1.1 Subtask 3.1.1 - HSA Interface Requirements. Emphasis in this subtask will be placed on assuring ready access to the HSA for loading and unloading the electric heat source(s) and providing the required interfaces with power supply consoles and related instrumentation recorders.

3.1.3.1.2 Subtask 3.1.2 - Heat Rejection System Requirements. Requirements for the heat rejection system for the GDS tests will be defined. Consideration will be given to both transient and steady state test conditions as well as to the range of power system performance variables which are anticipated for the GDS test conduct.

3.1.3.1.3 Subtask 3.1.3 - Heat Rejection System Design; HSA and Heat Rejection System Support Equipment Requirements. Based on the design requirements, preliminary trade-off studies will be conducted to define the recommended heat rejection system for the GDS. Cost, schedule, facility availability and similarity to flight conceptual design will be factors in configuring the recommended preliminary design. Test support equipment requirements for both the HSA and the heat rejection system will be specified. Consideration will be given to handling equipment as well as test performance support equipment.

		CY 1975									
		A	M	J	J	A	S	O	N	D	
3.1	PRELIMINARY GDS DESIGN										
3.1.1	HSA INTERFACE REQUIREMENTS		▽								
3.1.2	HEAT REJECTION SYSTEM REQUIREMENTS		▽								
3.1.3	HEAT REJECTION SYSTEM DESIGN; HSA & HEAT REJECTION SYSTEM SUPPORT EQUIPMENT REQUIRE- MENTS						▽				
3.1.4	GDS EQUIPMENT INTERFACE DESIGN						▽				
3.1.5	FACILITY REQUIREMENTS AND DEFINITION									▽	
3.1.6	PRELIMINARY DESIGN REVIEW						▽				
3.2	GDS TEST PLAN						▽				

Figure 3.1.3-1. Schedule For Task 3 Preliminary GDS Design

3.1.3.1.4 Subtask 3.1.4 - GDS Equipment Interface Design. Integration and preliminary design of the interfaces between the HSA and the heat rejection system with other components of the GDS as well as with test support equipment and the overall test facility will be performed.

3.1.3.1.5 Subtask 3.1.5 - Facility Requirements and Definition. GE will support AiResearch in defining test facility requirements and support equipment requirements for conducting the ground test program.

3.1.3.1.6 Subtask 3.1.6 - Preliminary Design Review. General Electric will participate in the Preliminary Design Review and provide inputs as required to Design Review documentation. The design effort will assure that the electric powered HSA and the heat rejection system closely simulate anticipated flight considerations. General Electric will also support AiResearch in performing a preliminary FMEA on the GDS and in conducting the preliminary design review.

3.1.3.2 Task 3.2 - GDS Test Plan

General Electric Company will support AIRPHX as directed in preparing the test plan for the Ground Demonstration System. Test facility requirements, test support equipment checkout and usage, system parameters to be measured, test sequence, etc. will be addressed.

Schedule. The schedule for conducting Task 3 is shown below. The work will be completed within the first nine months of the program.

3.1.4 Task 4 - Detail GDS Design and Analysis

Objective. The objective of this task is to provide support to AIRPHX in conducting the detailed design analyses and design layouts of elements of the GDS, including test support equipment and facilities.

Approach. GE will provide the following support to AIRPHX as depicted in Figure 3.1.4-1 and scheduled on Figure 3.1.4-2.

Output. The output of this task will be:

1. Tradeoff studies, design analyses and layouts of the Heat Sink system and a specific recommendation along with engineering drawings for the Heat Sink Design.
2. Design drawings and interface definition for the Electric Heat Source, power supply, and other HSA test support equipment to be used in the Ground Demonstration tests.
3. Inputs for the topical report covering the final design of the GDS and test support equipment

3.1.4.1 Subtask 4.1 - Layout

General Electric Company will support AIRPHX as directed, in developing layouts of the components and interfaces of the Ground Demonstration System.

Figure 3.1.4-1. Detail GDS Design

Figure 3.1.4-2. Schedule For Detail GDS Design

3.1.4.2 Subtask 4.2 - Transient Effects

Performance analysis will be conducted for the HSA and the HRHX to determine the thermal, hydraulic and structural response of the HSA during transient conditions, e.g. start up, shutdown and changes in flow conditions during system tests. Particular attention will be given to defining constraints if any, imposed on the test conduct by induced thermal shock effects on the HRHX structure, and on the HSHX structure caused by sudden introduction of cold working fluid after predicted on-pad HSA temperatures are attained.

3.1.4.3 Subtask 4.3 - Heat Sink

Design layouts along with performance and cost analysis will be submitted and recommendations for a specific system. Engineering drawings will be prepared for the selected design to the level of detail required for fabrication. All interfaces with the GDS and test facility will be defined. Detailed performance calculations will be made for the selected configuration.

3.1.4.4 Subtask 4.4 - Control System Detail Design

General Electric Company will support AIRPHX as directed, in designing the Control System for the GDS. In particular those items associated with integrating the electric heat source power supply and heat sink system into the overall GDS control system would be addressed.

3.1.4.5 Subtask 4.5 - Structure

General Electric Company will support AIRPHX as directed, in designing the support structure for components of the GDS. Efforts would be made to configure the GDS as closely to the conceptual flight design as possible.

3.1.4.6 Subtask 4.6 - Materials

General Electric Company will support AIRPHX as directed, in defining the materials for components, interfacing structure, ducting insulation, etc., for the GDS.

Particular emphasis would be placed in assuring materials compatibility, and their equivalency with the conceptual flight design.

3.1.4.7 Subtask 4.7 - Heat Sources

Studies will be performed as required to determine the utility of the MHW Electric Heat Source (EHS) for the Ground Demonstration Test. The capacity of the EHS to perform with high reliability during the test cycle and its compatibility with the HSA materials will receive particular attention.

The MHW Electric Heat Source power supply will be investigated for its suitability, and if required, modifications to existing hardware will be recommended. All interfaces between the test equipment and the GDS test facility and controls will be specified.

3.1.4.8 Subtask 4.8 - Test Facilities

GE shall provide the engineering and related support services required to integrate and establish requirements, and perform the design effort for all component and assembly level test equipment required to support the Phase I GDS testing as related to GE deliverable hardware in accordance with the GDS Test Plan (WBS 3.2).

Specific outputs of this task shall consist of the following:

1. Identification of test equipment and design requirements.
2. Preparation of manufacturing drawings including instrumentation and test equipment interface constraints.
3. Verification analysis of test equipment item as required.

Design effort shall be provided for the following items of GSE test equipment:

<u>WBS</u>	<u>GSE Equipment Item</u>
4.8.3	Pressure Leak Test Kit
4.8.4	ACS Gas Management Unit
4.8.5	HSA Acoustic Fixture
4.8.7	Power Console Shipping Container
4.8.8	HSA Handling Sling

3.1.4.9 Subtask 4.9 – Detail Design Review

GE will participate in the Detail Design Review by providing inputs for the special topical report and partaking in the conduct of the review meetings with AIRPHX and the AEC.

3.1.5 Task 5 – Fabrication and Assembly–GDS and Test Facilities

Objective. To fabricate and assemble the Heat Rejection Heat Exchanger (HRHX) and Special Test Equipment, and to assemble the HRHX and the GFE Heat Source Assemblies to the BRU-Recuperator Subassembly (BRURSA), completing assembly of the GDS.

Approach. In this task, GE will fabricate the HRHX, EHS Assembly, EHS Power Supply Console, HSA Gas Management Unit, plus the associated manufacturing assembly tooling, handling and test fixture to support the GDS Program. This effort is depicted in Figure 3.1.5-1, and scheduled on Figure 3.1.5-2. The following manufacturing controls will be employed:

1. Maintain throughout the manufacturing cycle the reliability inherent in the engineering design by providing the optimum in Manufacturing, Engineering, Producibility Engineering, Equipment and Facilities Planning and design, Shop Planning and Procedures, Process Development, Operator training and Certification, Process Control and Quality Workmanship.
2. Control procurement and manufacturing schedules to allow maximum time for quality workmanship and orderly progress through the manufacturing cycle to meet end product delivery commitments.

3. Operate within a framework of cost controls which will provide prompt identification of excessive costs and accurate matching of dollars spent to elements of work done.
4. Procure raw material, and fabricate:
 - a. Detailed mechanical parts and assemblies and
 - b. The harnessing of electronic parts in the complete subsystem.

3.1.5.1 Subtasks 5.1 thru 5.4 Component Fabrication

General Electric will provide the manufacturing services required to procure fabricate inspect and test the following component equipments in support of the GE inhouse and AIRPHX - GDS test program.

<u>WBS</u>		<u>Quantity</u>	<u>Make/Buy</u>
5.1	Heat Rejection Heat Exchange (HRHX)	2	M
5.2	Controls	NA	
5.3	Structure	NA	
5.4	Electric Heat Sources (EHS and cable assemblies	4	M

3.1.5.1 Subtask 5.1 Fabrication

The stainless steel heat rejection heat exchanger will have two subassemblies. The first assembly consists of two tube sheets, three tube baffles and 241 H. X. tubes. These components are brazed together. The brazed assembly is then slipped into the second assembly of main tubes and welded. The subassemblies are inserted into the main body frame and welded together including gas inlets and outlets. The assembly is cleaned and tested for leaks.

The EHS Power Supply Console, EHS, and EHS Loading Fixture will be the same type of units used on the AEC MHW Program, in function and material. Similar fabrication techniques will be employed. The cable assemblies for the EHS Power Console and Interface Controls will also be shipped with the complete package. The GE supplied hardware will then be prepared for quality assurance buyoff and subsequent acceptance testing. They will then be boxed, packed and shipped to AIRPHX.

The EHS will be the same type of units used as the AEC MHW Program with possible modification to the heater elements to accommodate power level test profiles on the GDS. These units including the supporting power cable assemblies will be shipped as a complete unit to AIRPHX.

3.1.5.2 Subtask 5.5 - Radiator Simulator (HRHX) Component Test

The following tests will be performed on the radiator simulator at the completion of fabrication.

3.1.5.2.1 Cold Flow Test. A cold flow test will be performed over the anticipated operating range of the radiator simulator using a clean inert gas as the fluid. The gas flow will be adjusted to match the fluid characteristics of the GDS.

3.1.5.2.2 Proff Pressure Test. A proof pressure test will be performed to ASME requirements which are:

$$P_t = 1.25 \frac{S_C}{S_H} P_D$$

where S_C = cold stress

S_H = hot stress

P_D = design pressure

P_T = test pressure

3.1.5.2.3 Leak Check. The radiator simulator will be helium mass spectrometer tested to 10^{-9} cc/sec following the proof pressure test.

Output. The results of the component test program will be data verifying the pressure drop and structural integrity of the radiator simulator.

3.1.5.3 Subtask 5-6 - Final Assembly

The assembly of the GFE HSA units and the HRHX to the BRU-Recuperator Subassembly will be accomplished by GE at AIRPHX. The HSA unit will be installed into a welding fixture. The welding will be in an inert gas environment at all times for welding refractories, using a portable glove box. Where transitions joints are superalloy to superalloy, standard welding procedures will be used. If a refractory turbine scroll is required, then a refractory-to-refractory weld will be accomplished.

The HRHX with stainless steel tubes will be mounted in position and the inlet and outlet tubes will be welded to the Compressor Inlet and Recuperator Discharge (cold) Ducts.

Manufacturing has obtained previous experience with portable welding techniques using the inert gas glove box arrangements on the NASA SNAP 8 Program and the Potassium Turbine Program. The output will be a completed GDS Unit at AIRPHX, ready for installation in the GDS Test Facility.

3.1.5.4 Task 5.7 Test Facilities (FAB and Test)

The subcontractor shall provide the manufacturing engineering and support services required to procure, fabricate, test, and check out of the test equipment required to support in house component level testing and GDS system level tests at Air Research for associated GE deliverable hardware. This task shall also include the design and fabrication of tooling required for the manufacture of in house test equipment. Specific items to be fabricated under this task are according to the breakdown shown on Table 3.1.5.4-1.

Table 3.1.5.4-1. GDS Test Equipment

Item	WBS	Make Buy	GE Usage	Deliverable to Air Research	Total	Validation Testing
<u>Electrical</u>						
EHS Power Supply Console	5.6.1	M		3	3	Package Drop
<u>Mechanical</u>						
EHS Loading Fixture	5.6.2	M	1	1	2	Static Proof Load
Pressure Leak Test Kit	5.6.3	M	1		1	Functional Check Out
Gas Management Unit (ACS)	5.6.4	M		1	1	Functional Check Out
HSA Acoustic Fixture	5.6.5	B	1		1	None
Power Console Shipping Container	5.6.7	B		3	3	Rotational Drops
HSA Handling Sling	5.6.8	B	1	1	2	Static Proof Load

3.1.6 Task 6 - Test and Evaluation

Objective. The objective of this task is to conduct the requisite component and Power Conversion System tests that will demonstrate performance and endurance capabilities of the Isotope Brayton System.

Approach. General Electric Company will support AIRPHX in implementing the test plan(s), in conducting the tests and in evaluating the test data. Particular emphasis in the GE support effort will be directed toward the HSA, radiator and associated test support equipment. This test effort and the schedule for accomplishing the work is summarized in Figures 3.1.6-1 and 3.1.6-2.

3.1.6.1 Subtask 6.1 - Performance Tests

Personnel will be located on site at appropriate times to monitor the test program and to assist AIRPHX in the operation and maintenance of the equipment supplied by General Electric. GE will provide maintenance and repair services for the GE hardware.

Output. The results of the performance testing will be data which indicates the "design" and "off-design" characteristics of the General Electric supplied components. In addition, there will be an integration of GE/AIRPHX technologies resulting in a minimal "learning curve" of system operation as well as a set of operating and maintenance instructions for use on future systems.

3.1.6.2 Subtask 6.2 - Endurance Tests

It is anticipated that the AIRPHX personnel will be sufficiently familiar with the GE furnished equipment permitting a reduction in the level of GE surveillance. However, GE will sufficiently monitor the endurance testing to provide consultation on the data, operation and maintenance of the GE equipment.

Figure 3.1.6-1. Test and Evaluation

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Figure 3.1.6-2. Task 6 Test and Evaluation Schedule

Output. The output will be endurance test data and the maintenance of the General Electric supplied equipment.

3.1.6.3 Subtask 6.3 - Radiator Component Test

The following tests will be performed on the radiator simulator at the completion of fabrication.

3.1.6.3.1 Cold Flow Test. A cold flow test will be performed over the anticipated operating range of the radiator simulator using a clean inert gas as the fluid. The gas flow will be adjusted to match the fluid characteristics of the GDS.

3.1.6.3.2 Proof Pressure Test. A proof pressure test will be performed to ASME requirements which are:

$$P_t = 1.25 \frac{S_C P_D}{S_H}$$

where S_C = cold stress

S_H = hot stress

P_D = design pressure

P_T = test pressure

3.1.6.3.3 Leak Check. The radiator simulator will be helium mass spectrometer tested to 10^{-9} cc/sec following the proof pressure test.

Output. The results of the component test program will be data verifying the pressure drop and structural integrity of the radiator simulator.

General Electric will support AIRPHX in evaluating all the test data from the test program and in preparing the test report.

3.1.7 Task 7 - Quality, Reliability and Safety

3.1.7.1 Subtask 7.1 Quality & Reliability

Objective. The purpose of the Phase I effort is to provide a planned program for achieving optimum reliability and quality of all system hardware. Emphasis is to be placed on early identification of reliability and quality problem areas in the design, fabrication or assembly of GE supplied hardware.

Approach. The quality and reliability subtasks are shown in Figures 3.1.7-1. A quality assurance program plan and a Reliability program plan Phase I efforts will be generated and submitted for approval. These will be in conformance to SNS-1 and SNS-2 documents, respectively. The schedule for QA and reliability activities is shown in Figure 3.1.7-2. A description of detailed subtask efforts is given in Figure 3.1.7-1.

Output. The results of the QA and reliability tasks will provide plans for conducting quality and reliability programs for the developmental hardware. By emphasizing reliability in the early design phases, problem areas will be identified and corrected.

The planned Quality Assurance and Reliability programs are in complete accordance with AEC requirements as specified in documents SNS-1 "Quality Assurance Program Requirements". The tasks described in Phase 1 accent obtainment of data beneficial for defining an optimal quality flight system for Phase II and in impacting Phase II design to achieve the highest obtainable reliability.

Figure 3.1.7-1. QA and Reliability Tasks During Phase I

Figure 3.1.7-2. Quality Assurance Reliability and Safety Schedule for Phase I Activities

3.1.7.1.1 Subtask 7.1.1 - Quality Assurance Support. The Quality Assurance support tasks include QA integration with program management, support to design in defining hardware requirements and control of quality of hardware during fabrication and assembly. The specific work elements are itemized below:

QA Integration with program management functions are:

- 1. Provide direction, work definition, and funding for all contract work within produce assurance.**
- 2. Define the applicable quality assurance policies and procedures to be used.**
- 3. Serve as the focal point, interface and information for all quality assurance activities with program management, design, manufacturing and test, and with AIRPHX representatives.**

Quality Control Engineering in support of the hardware design will:

- 1. Review and approve drawings and specifications for the inclusion of quality requirements.**
- 2. Generate supplier quality assurance requirements and define the Quality Assurance Provisions of the produce and process specifications.**

3. In consort with the design engineer, define acceptance requirements.
4. Participate in design reviews, from which planning for measuring and test equipment requirements, inspection and test procedures, vendor surveillance and process control will result.
5. Advise engineering in areas of inspection and test requirements.
6. Provide any required inspection and test support.
7. Provide supplemental inputs to Task 3 and Task 4 for GE hardware support to AIRPHX to include:
 - a. Review of technical documents for adequacy and clarity of quality requirements.
 - b. Participation in design reviews.
 - c. Begin planning for measuring and defining test equipment requirements, inspection and test procedures, vendor surveillance and process control requirements.

During the fabrication, and assembly phase of the program the Quality Control Engineer will:

1. Incorporate quality requirements in purchase orders.
2. Review and approve inspection planning.
3. Participate in operation readiness reviews, to assure that hardware, test equipment, facilities and personnel are available.
4. Participate in the disposition and analysis of non-conformances.

3.1.7.1.2 Subtask 7.1.2 - Reliability Support. In order to insure that reliability is planned in the conceptual design stage and realized in both prime hardware and GSE, supporting efforts to design will be provided in Phase I. This will include the following subtasks:

1. Support design analysis including a stress-strength and material compatibility in use environment.
2. Perform variables analysis evaluation on radiator and isotope heat source performance parameters, worst case analysis as required.

3. Identify test parameters for Phase II reliability demonstration test, generate test plans.
4. Provide necessary program office support for design reviews, technical reports, progress reports.
5. Define a failure reporting system - implement following preliminary design review.

3.1.7.1.3 Subtask 7.1.3 - Failure Modes, Effects and Criticality Analysis (FMECA).

FMECA's will be performed to provide early identification of single point failure effects on proposed designs. FMECA's will analyze the HSA, radiator, ducting and GSE hardware. A report will be issued summarizing the results of the analyses, describing ways of reducing failure effects and eliminating significant failure modes.

3.1.7.1.4 Subtask 7.1.4 - Reliability Assessment. The design effort will be continuously monitored to establish the reliability potential in the proposed hardware. Development tests results will be reviewed. Assessment will be directed toward:

1. Directing necessary efforts to achieve high reliability in the flight hardware designed in Phase II
2. Accounting for any failures and effects which impact Phase I test results

Key elements are illustrated in Figure 3.1.7-3.

Figure 3.1.7-3. Reliability Support Activities in Phase I

3.1.7.2 Subtask 7.2 - Safety

Objective. During the Ground Demonstration System Phase (Phase I) of the program, the purpose of the safety task will be to monitor and review the design and development of the ground system with the objective being to assure that its evolution into a flight system will encompass the optimum in nuclear flight safety capability.

Approach. The effective conduct of this task will involve liaison and integration of activities with the AEC and with Garrett-AiResearch Phoenix (AIRPHX) as the prime contractor to assure that all aspects of nuclear safety are properly considered and implemented. A concurrent part of this task will involve a preliminary safety assessment of the conceptual flight system design with regard to the integrity of the radio-isotope heat source in the potential environments posed by a space mission. The SURVASATCOM mission will be used as the reference application.

The schedule for Phase I Safety Activities is included in Figure 3.1.7-2. The specific items imposing each item in Figure 3.1.7-4 are described as follows:

1. Maintain liaison and integration of safety related activities with the AEC/SNS.
2. Monitor and review all power system design and test activities for applicability to the safety evaluation including those activities at AIRPHX.
3. Recommend changes to the flight system design to enhance nuclear safety capability consistent with the other goals and requirements of the system.
4. Review SURVASATCOM mission characteristics and determine potential environments to which the IBFS can be based on the envelope of conditions represented by the potential launch vehicles: Atlas/Centaur, Titan IIC, and Space Shuttle. Vehicle and mission information will be abstracted from previously flown missions and systems or from previous studies of potential missions.
5. Define specific analysis tasks to supplement those being conducted in the engineering tasks that will be required in the preliminary safety assessment. These analyses will address the response of the power system/heat source to the environments identified.
6. Prepare a Safety Assessment Report (SAR) to present the results to the preliminary safety assessment to the Contracting Officer for review. This report will be published by 1 April 1976 as shown in Figure 3.1.7-4.

Figure 3. 1. 7-4. Phase I Effort Covers Key Safety Elements

7. Coordinate data requirements with the AEC and AIRPHX as needed for the safety assessment.
8. Review information published on other related programs by other AEC contractors for applicable data.

Output. The results of safety activities will be to assess the design, providing a detailed report, to ascertain no nuclear hazard potential exists. Analysis efforts will project present design methods to the development and qualification program as applicable. A SAR will be prepared.

3. 1. 8 Task 8 Reports and Data

Objective. The objective is to provide the necessary program technical, financial and programmatic documentation.

Approach. The following reports will be prepared and submitted to AIRPHX for visibility in realization of milestone events, identification of problem areas, schedule and financial status and technical achievements or discussions:

1. Monthly top summary and financial report
2. Monthly technical report

3. Annual technical report
4. Special technical reports

Output. This procedure is summarized in Figure 3.1.8-1.

Figure 3.1.8-1. All Required Reports and Data Are Provided

3.1.9 Task 9 - Advanced Development

Objective. The objective of this task is to carry out long lead time development efforts on any areas of the system where upgrading, testing or evaluations are required in advance of completion of the GDS program so that high confidence can be established in meeting flight hardware schedules.

Approach. GE will support AIRPHX in this task in specific developmental areas associated with isotope heat source technology, beryllium space radiator technology and bi-metallic joints. These development items will be pursued subject to AIRPHX and AEC approval.

This activity is summarized in Figure 3.9.1-1 and scheduled on Figure 3.9.1-2.

Figure 3.1.9-1. Task 9 - Advanced Development - (GE Support)

Figure 3.1.9.2. Advanced Development Schedule

3.1.9.1 Subtask 9.1 - Heat Source Technology

This effort will be directed to improving the operational margin and safety of the Heat Source which is based on MHW technology. Particular emphasis will be placed in improving the MHW Post Impact Containment Shell (PICS) vent design to enhance its reliability. Two approaches will be investigated: use of a burst disc and utilization of alternate vent materials. Some work has already been started on evaluating a burst disc approach; consequently, this effort will be a logical follow-on. The feasibility of using a porous ceramic filter material instead of the current PICS vent material appears to have merit. This alternative will be pursued and evaluated accordingly.

In addition to the aforementioned liaison with AEC, efforts in the assessment of iridium fabrication and impact performance improvement will be pursued.

Oak Ridge National Laboratory (ORNL) is currently following two iridium development programs. The first program searches for the proper low level dopants that will strengthen the grain boundaries of "pure" iridium. The second program investigates alloying materials that will not only improve grain boundary toughness but also add to the toughness of the base (Ir) material. The first program will not require parallel investigation of the end products compatibility with carbon or PuO_2 as long as the final chemistry meets current specifications. The "dopant" approach, however, may require compatibility testing and the alloy program certainly will require verification of products stability with other materials planned to be in the same system.

In addition, recrystallization temperature, as well as grain size and shape must be controlled if improvement in grain boundary toughness is to be optimized; fabrication methods may have to be changed before the desired improvement is realized. GE will act in a liaison capacity and assist in the selection of additive materials, processing steps and testing programs. All work will be coordinated with ORNL and LASL, since GE is convinced that the LASL type punch test is a necessary "bench test" required to guide program progress and to select prime candidate materials for simulant and fuel impact testing.

3.1.9.2 Subtask 9.2 - Beryllium Space Radiator Development

This effort will be directed toward developing the fabrication process for constructing a beryllium space radiator and assess its capability to withstand a micrometeoroid environment. Factors which will be investigated include the following:

1. Capability of the beryllium industry to produce beryllium mill products adequate in size and quality
2. Ready availability of suitable fabrication equipment within the beryllium manufacturing industry
3. Selection of the most economical fabrication processes within the state of the art for beryllium and related to the total number of units to be manufactured
4. Design and fabrication approaches lending themselves to efficient and economical material utilization
5. Choice of a design approach to limit the extent of part loss in the eventuality of any damage occurring during fabrication
6. Optimization of tooling design to reduce tooling costs, least fabrication risk to obtain high percentage yield of parts

The following design features of the radiator structure will be considered:

1. Structural integrity
2. Known behavior of the chosen beryllium mill products to high velocity micrometeoroid impact damage
3. Requirements of safe-life or fail-safe structural characteristics to micro-meteoroid impact damage
4. Efficient thermal conductivity throughout the structure

At least three manufacturing approaches will be investigated; viz, machined hot pressured block, formed sheet extrusion and formed sheet methods.

Micrometeoroid tests on fabricated samples of candidate radiator designs will be conducted to assess capability to withstand the anticipated space environment.

3.1.9.3 Subtask 9.3 - Determine Bi-metallic Joint Reliability

The long term performance characteristics and life reliability of bimetallic joints between the beryllium alloy and stainless steel or superalloy(s) will be evaluated.

Brazed bi-metallic joints of the type proposed between the beryllium radiator and system ducting will be prepared and subjected to cyclic heating and cooling in vacuum at the thermal rates and to the temperatures predicted during operation for at least 100 cycles. Mechanical property tests will be performed on typical joints without thermal cycling and after such cycling. These tests will include axial tensile tests at elevated temperatures through and above the operating range, and sustained load axial rupture tests. Brazed joints will be thermally aged at and above the anticipated operating temperature for periods of time sufficient to indicate life performance and reliability expectancy. Mechanical property tests similar to those performed after thermal cycling will be used to evaluate any degradation in axial strength as the result of such thermal aging. Non-destruction test methods such as x-radiography and ultrasonic inspection will be used to evaluate all joints after preparation and after cyclic or proof load testing. The microstructural stability of these joints will be evaluated after the thermal cycling tests and after thermal aging tests; void formation, braze alloy diffusion and other effects will be assessed. Joint definition and preliminary evaluation will be made prior to the detailed radiator design effort.

3.1.10 Task 10 - Flight Design and Engineering Program Plan

Objective. The objective is to update the conceptual IBFS design and to structure a Flight System Development and Qualification program which is based on assessments and findings of previous task activities and which will result in a qualified flight system by June 1980.

Approach. General Electric Company will support AIRPHX in this activity. Preparation of the Phase II program plan is depicted in Figure 3.1.10-1. This plan will be consistent with a June 1980 flight readiness system and with this date as a constraint, consideration given to the following:

1. Design to accommodate operation through launch
2. Advanced radiator for flight design

Figure 3. 1. 10-1. Task 10 - Flight Design and Engineering Program Plan (GE Support)

3. Packaging and thermal insulation
4. HSA and radiator environmental testing
5. Safety and reliability assessment
6. Advanced HSA flight design
7. On pad and in orbit Heat Source loading.

The program plan will present detailed task descriptions, schedules, test plans, facility requirements, and costs for conducting Phase II of the program.

Output. The output of this task will be GE inputs for the updated conceptual IBFS and for detailed document containing the plan to implement Phase II.

Schedule The schedule for accomplishing this task has been shown in Figure 3. 1. C-1.

3.2 TECHNICAL REQUIREMENTS AND APPROACH - PHASE II AND PHASE III

A. PROGRAM SUMMARY - PHASE II - IBFS DEVELOPMENT AND QUALIFICATION

The Phase II Program has as its objective the development of the Isotopic Brayton Flight System (IBFS) for flight utilization. During this phase, it is planned that two (2) System Development Models (SDM) powered by electric heaters and the Qualification IBFS powered by an EHS (with an IHS option) will be designed, developed, fabricated, assembled and tested.

General Electric Company will support AIRPHX in the areas subsequently specified. Of particular importance are Isotope Heat Source/HSA design and fabrication, isotope system design and integration, radiator development and fabrication, IBFS final assembly and test and mission/operational safety support. The GE experience in the design fabrication and safety aspects of the MHW heat source and in many spacecraft systems integration programs, including the MHW Program, is significant in performing these efforts in an orderly and cost effective way for AIRPHX and the AEC.

1. Provide design effort for Isotope Heat Source/HSA, heat rejection system, and interfaces for same.
2. Fabricate Heat Source Assemblies and isotopic heat sources.
3. Perform system design, analysis and integration.
4. Provide liaison with AEC fueling, fuel development and testing agencies.
5. Provide mission and operational safety support.
6. Provide reliability, QA, and configuration management for design, fabrication, and test activities.
7. Support AIRPHX for design reviews.
8. Fabricate heat rejection systems.
9. Final assembly of two System Development Models (SDM) and the qualification IBFS.

10. Provide quality, safety and reliability support for design/fabrication of hardware.
11. Provide program management support, reports and data to AIRPHX.
12. Support AIRPHX in developing the Phase III - Flight Design and Engineering Program Plan.

In performing the aforementioned activities, General Electric Space Division shall provide an experienced management team and will make its facilities and equipment available to execute the program in accordance with the Work Breakdown Structure and Program Schedule shown in Figures 3.2. B-1 and 3.2. C-1, respectively. The details of conducting the program are discussed by task in the following pages under Work Description.

During Phase II, it is assumed that AIRPHX will provide all data, drawings, and specifications necessary for GE support to AIRPHX, including heat source, HSA, space radiator design and development; qualification testing of the IBFS; and related ground support and special test equipment.

It is assumed that during Phase II, the Government will furnish the following equipment and services:

1. All noble metals required
2. Simulant spheres (clad) for safety and verification tests
3. Fuel characterization/testing
4. Fuel spheres, PISAs and assembly of heat sources including assembly of ablation sleeve
5. Post-test analysis of fuel or fueled hardware
6. Transportation of fueled heat sources between facilities
7. Heat source shipping containers
8. Safety input data
9. Safety test facilities at Sandia or equivalent

B. PHASE II WORK BREAKDOWN STRUCTURE

The Phase II WBS, shown in Figure 3.2.B-1, is completely consistent with that established by AIRPHX and the AEC. Subtasks have been established within this task structure which reflect the GE areas of responsibility and support. These activities are detailed in subsequent task and subtask descriptions, which form the basis for the proposed program costs presented in Volume III, Business and Management. Volume III also includes an abstract of these task descriptions to assure its separability from the other proposal volumes.

The GE effort in Task 2, System Design and Analyses, will assure AIRPHX that the IBFS design and implementation will reflect the current and evolving IBFS requirements. GE will support AIRPHX by designing, building, and testing the Heat Source Assembly (HSA) and the heat rejection radiator and assembling them with the BRU-Recuperator Subassembly (BRURSA).

GE will support AIRPHX in Task 3, Safety, by that the IHS in the IBFS meets safety requirements established by the AEC in AEC-MC-0524. GE is particularly qualified to develop safe, very high temperature isotope heat sources because it has successfully developed the electric and isotope heat sources for the AEC in the MHW-RTG Program, to meet the stringent high temperature and safety requirements for the LES 8/9 and Mariner J/S missions.

The GE effort in Task 4, Product Assurance, will assure AIRPHX that the SDM and IBFS components it builds will meet AEC reliability, quality assurance, configuration management, and design review requirements and specifications as defined in SNS-1 and SNS-2.

In Task 5, GE will assist AIRPHX in the development of a test plan to establish the Brayton power system as flight qualified.

In Task 6, GE will support AIRPHX by designing the HSA's, the radiators and mounting rings and assisting AIRPHX on structure needed for the two System Development Models (SDM) and the qualification IBFS. The SDM tested at GE will use a radiator

1.0 PROGRAM MANAGEMENT	7.1.6 Spacecraft Interface Controls
2.0 SYSTEM DESIGN AND ANALYSIS	7.1.7 Spacecraft Interface Structure
2.1 SYSTEM DEFINITION	7.2 QUALIFICATION IBFS
2.2 COMPONENT SPECIFICATION	7.2.1 IBFS System Assembly Support
2.3 CONFIGURATION CONTROL	7.2.2 BRU (AIRPHX)
2.4 INTERFACE CONTROL	7.2.3 Recuperator (AIRPHX)
2.5 SPACECRAFT INTEGRATION	7.2.4 Heat Source Assembly
2.6 USER LIAISON	7.2.5 Radiator
2.7 PERFORMANCE ASSESSMENT	7.2.6 Spacecraft Interface Controls
3.0 SAFETY	7.2.7 Spacecraft Interface Structure
3.1 SAFETY PLANNING	8.0 HEAT SOURCE DESIGN
3.2 SAFETY REQUIREMENTS AND ANALYSIS	8.1 IHS DESIGN AND ANALYSIS
3.3 SAFETY TESTING	8.2 EHS DESIGN AND ANALYSIS
3.4 RADIOLOGICAL	8.3 FUEL DEVELOPMENT LAB LIAISON
4.0 PRODUCT ASSURANCE	9.0 HEAT SOURCE DEVELOPMENT AND FABRICATION
4.1 RELIABILITY	9.1 IHS DEVELOPMENT AND FABRICATION
4.2 QUALITY ASSURANCE	9.2 EHS DEVELOPMENT AND FABRICATION
4.3 CONFIGURATION MANAGEMENT	10.0 QUALIFICATION TESTING
4.4 DESIGN REVIEWS	10.1 SDM
5.0 QUALIFICATION TEST PLAN	10.2 QUALIFICATION IBFS
6.0 POWER CONVERSION SYSTEM DESIGN	10.3 COMPONENT TEST
6.1 SYSTEM DEVELOPMENT MODEL (SDM)	11.0 GROUND SUPPORT EQUIPMENT
6.2 QUALIFICATION IBFS	11.1 ELECTRICAL
7.0 POWER CONVERSION SYSTEM DEVELOPMENT AND FABRICATION	11.2 MECHANICAL
7.1 SYSTEM DEVELOPMENT MODEL (SDM)	11.3 COMPONENT TEST EQUIPMENT
7.1.1 SDM System Assembly Support	11.4 SPECIAL TEST EQUIPMENT
7.1.2 BRU (AIRPHX)	12.0 REPORTS
7.1.3 Recuperator (AIRPHX)	13.0 PHASE III PLAN
7.1.4 Heat Source Assembly	
7.1.5 Radiator	

Figure 3.2. B-1. Phase II Flight System Development and Qualification Work Breakdown Structure

and be equivalent to a prequalification IBFS. The SDM tested at AIRPHX will use either a heat exchanger or a radiator, depending upon the size of the facilities available. In Task 7, GE will develop and fabricate the components designed in Task 6.

GE will support AIRPHX in Task 8, Heat Source Design, by designing the electrical heat source simulator and an isotope heat source. To design the isotope heat source, minimum changes will be made to the MHW heat source so that safety qualification tests will not have to be repeated. In Task 9, GE will develop and fabricate the heat sources designed in Task 8.

In Task 10, GE will perform qualification testing on one of the two SDM's while AIRPHX will test the other. Because of the large, nuclear qualified facilities at GE, GE will also perform the qualification testing on the qualification IBFS.

GE will support AIRPHX in Task 11, Ground Support Equipment, by designing, procuring, and fabricating the GSE associated with the isotope fuel, heat source, heat source assembly, the radiator, the mounting rings, and the necessary equipment for the qualification testing performed at GE.

GE will strongly support AIRPHX in the Task 13 delineation of the Phase III Plan. GE is uniquely qualified to assist AIRPHX in this area because of their experience in the SNAP-27 and MHW-RTG nuclear power system flight programs.

C. SUMMARY SCHEDULE - PHASE II - FLIGHT SYSTEM DEVELOPMENT AND QUALIFICATION

The top level Phase I WBS tasks are scheduled on Figure 3.2. C-1 for the time period 1 July 1977 through 30 June 1980. Detailed task schedules are presented separately, as necessary for each task description.

D. PHASE II WORK DESCRIPTION

This section represents a typical summary description of the effort required to perform the Phase II Program. The work tasks are structured in accordance with AIRPHX RFP dated 11 November 1974 and is based on the Phase II Work Breakdown Structure shown

Figure 3.2. C-1. Summary Schedule of Phase II Flight System Development and Qualification

in Figure 3.2. B-1 and the Phase II Flight System Development and Qualification Program Schedule shown in Figure 3.2. C-1. A schedule and definition of effort to be performed is presented for each task together with the necessary figures required to provide a summary description of the task content.

3.2.1 Task 1 - Program Management

Objective. The Program Office, under the direction of the GE-IBS Subcontract Program Manager, will be responsible to AIRPHX for providing overall management, project planning and control, financial and contract management, and the submittal of all contractor documentation required to implement the Phase I Program.

Approach. The specific efforts to be accomplished in this task are detailed below:

1. Provide program plan inputs to AIRPHX.
2. Direct overall program activity.

3. Establish program requirements and schedules.
4. Monitor, control and report the technical, schedular and financial status of the program.
5. Provide internal program direction and funding.
6. Initiate and process Contract Change Proposals.
7. Review and approve subcontractor program plans and activities.
8. Provide subcontractor technical direction.
9. Conduct internal design reviews and support AIRPHX design reviews.
10. Provide contractual documentation.
11. Provide contract interface with AIRPHX.
12. Negotiate and administer subcontracts.
13. Provide procurement support.
14. Provide liaison with NASA and potential user organizations.
15. Edit and issue the following documentation:
 - a. System Development Model (SDM) End Item Specification
 - b. Qualification IBFS End Item Specification
 - c. EHS End Item Specification
 - d. IHS End Item Specification
 - e. PSAR & FSAR Reports
 - f. Qualification RTG Test Plan
 - g. SDM Test Plan
 - h. SDM Test Report
 - i. Qualification IBFS Test Report

- j. Quality Assurance Plan
- k. Reliability Plan
- l. Configuration Management Plan

Key areas are delineated in Figure 3.2.1-1. A schedule of the aforementioned activities is presented in Figure 3.2.1-2. The GE program management provides a singular and total company responsibility and authority to direct, in consort with AIRPHX, the program activities.

Output. The activities accomplished in this task will provide satisfactory completion of the GE subcontract on schedule and within cost.

3.2.2 Task 2 System Design and Analyses (Support to AIRPHX)

Objective. The purpose of this task is to establish all system requirements and interfaces for flight hardware. To this extent this task will prepare detailed system and component specifications, establish configuration control, maintain interface control and integrate the Brayton power conversion system with the spacecraft.

Approach. The GE support to AIRPHX in the performance of this task is as follows.

3.2.2.1 Subtask 2.1 - System Definition

The results of the Phase I Ground Test Program and Advanced Development efforts will be used to establish requirements for incorporation in a system specification for flight hardware.

Figure 3.2.1-1. Comprehensive and Responsive Program Management for AIRPHX

Figure 3.2.1-2. Schedule for Task 1 Program Management

This will include the definition of HSA and radiator flight configurations, their interfaces (mechanical, material, thermal and hydraulic) with the other components of the system, quality assurance requirements, and the methods by which design requirements will be verified on the flight hardware. The specification will adhere to the format of Mil STD-490 - Type B1 - Primary Item Development Specification.

Thermal hydraulic and stress analyses will be conducted as required to support the system definition.

3.2.2.2 Subtask 2.2 - Component Specification

General Electric will prepare component end item (configuration item) specifications for the HSA and the radiator which comply with the Format of Mil-STD-490, Type B2 - Critical Item Development Specification and Type C2 - Critical Item Product Specification. It is anticipated that a two part specification combining the development and product fabrication will be prepared for each of the components.

3.2.2.3 Subtask 2.3 - Configuration Control

General Electric will establish configuration control of the HSA and radiator in accordance with standard practices presently in operation. Maintenance of specifications, drawings and implementation of formal procedures for drawing and specification changes will be effected at the beginning of Phase II.

3.2.2.4 Subtask 2.4 - Interface Control

Interface Control for the HSA and the radiator will be established and maintained throughout Phase II. Approved Interface Control documents (ICD) which specify the mechanical, thermal, hydraulic and electrical (if applicable) interfaces of these components with the rest of the system will provide the basis of design of appropriate interfacing elements. ICD's will be maintained under formal configuration control.

3.2.2.5 Subtask 2.5 - Spacecraft Integration

General Electric will conduct spacecraft integration design with particular attention given to the integration of the space radiator to assure adequate view factors to space.

Thermal, mechanical and dynamic interactions between the power conversion system components and the spacecraft will be analyzed to assure that all interface requirements are satisfied. Radiation dose maps will be prepared to assess effects on sensitive spacecraft electronics.

Flow diagrams will be prepared to indicate the sequence of loading the Heat Source Assembly (or Heat Source) on the spacecraft and for effecting auxiliary cooling of the isotope Heat Source. Additionally, the integration of the gas management system for the HSA with the spacecraft and appropriate ground support equipment will be defined in detail. Instrumentation requirements and the attendant interfaces with spacecraft telemetry and/or data storage systems will be defined.

3.2.2.6 Subtask 2.6 - User Liaison

General Electric will support AIRPHX (see Figure 3.2.2-1) in maintaining appropriate liaison with the user community to assure that the IBFS will meet the requirements of Air Force and NASA missions. It is anticipated that they will take the form of presentations and technical exchange meetings with the users.

3.2.2.7 Subtask 2.7 - Performance Assessment

Performance assessments of the HSA and the radiator will be made to support AIRPHX in the overall assessment of the IBFS. Thermal, hydraulic (pressure drop, Fluid flow control), and mechanical performance of these components will be specified in detail.

Schedule. The overall schedule for the system design and analysis activity is given in Figure 3.2.2-2.

Output. The output of Task 2.0 will be a body of documentation which will assure that the flight system hardware conforms to "as designed" drawings and meets mission and system requirements. This documentation will include but not necessarily be limited to the following:

1. Inputs to the IBFS system specification
2. Component specifications for the HSA and space radiator

Figure 3.2.2-1. Phase II Flight System Design and Analysis (GE Support)

	FISCAL YEAR	1977					1978												80							
	CALENDAR YEAR	1977												1978				1980								
	MONTH	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	M	A	M	J
2.0	SYSTEM DESIGN & ANALYSIS																									
2.1	SYSTEM DEFINITION																									
2.2	COMPONENT SPECS																									
2.3	CONFIGURATION CONTROL																									
2.4	INTERFACE CONTROL																									
2.5	SPACECRAFT INTEGRATION																									
2.6	USER LIAISON																									
2.7	PERFORMANCE ASSESSMENT																									

Figure 3.2.2-2. Phase II System Design and Analysis Schedule

3. Interface control drawings and documents for the HSA and space radiator
4. Configuration control documentation (engineering change notices, etc.)
5. Performance assessment reports

3.2.3 Task 3 - Safety

Objective. In Phase II, the Flight System Development and Qualification Phase, the safety task will be expanded to encompass not only nuclear flight safety considerations but also those safeguards and practices necessary to ensure radiological safety when fueled heat source operations are involved. One of the main purposes of the safety task will be to provide continued surveillance and evaluation of the power system during its development and design finalization for the flight system. The objective will be a continuation of that in Phase I but with added emphasis on the optimization of the nuclear safety capability of the power system for its application to a space mission. The finalized or flight design of the Isotope Brayton Power System will have a goal of attaining the safety objectives listed in the SNS publication, "Heat Source Safety Design Specification for Space Application." (Attachment 10 of SNS-RFP-75-1-CAO.)

Approach. The safety effort will provide adequate documentation, backed by analysis and testing, necessary to obtain Presidential flight approval for the mission using the nuclear power system. Additional testing needed to determine or to demonstrate safety capability will be planned and executed with concurrence by the AEC/SNS Program Office. Finally, a comprehensive program will be established to ensure that all operations involving live (fueled) heat sources at the power system contractors and subcontractors plants as well as applicable field sites will be conducted with appropriate radiological safety controls to assure safe heat source handling, shipping, and test operations. The overall schedule of activities within the Safety Task is shown in Figure 3.2.3-1.

Output. This effort will assure that the flight qualified IBFS meets AEC nuclear safety requirements, substantiated by complete safety analyses, test and documentation.

Figure 3.2.3-1. Schedule for Phase II, Task 3 Safety

3.2.3.1 Subtask 3.1 - Planning, Coordination, and Liaison

Subtask 3.1 will involve the planning and coordination of all activities for the flight safety evaluation and approval operations, including safety testing. Specific efforts to be accomplished are enumerated as follows:

1. Maintain liaison and integration of safety related activities with the AEC (SNS Safety and Reliability) to assure that a complete safety program is implemented.
2. Maintain liaison and integration of safety related activities with AiResearch to assure that all system safety considerations are addressed.
3. Monitor and review and review all program related design and test activities for applicability to the safety evaluation.
4. Coordinate updated and augmented data requirements with the AEC and AiResearch as needed for the safety assessment.
5. Review information published on other related programs by other AEC contractors for applicable data.

6. Prepare and submit to the Contracting Officer for approval by 1 September 77 a Safety Test Program Plan encompassing those tests necessary to determine the safety capability of the heat source as configured for the Isotope Brayton Power System.
7. Plan and prepare for all required safety presentations to be held at GE. Prepare other safety presentations necessary to support the flight approval process.

A work flow diagram of the activities within this subtask is shown in Figure 3.2.3-2.

3.2.3.2 Subtask 3.2 - Analysis and Reports

The purpose of this task is to perform the analyses and evaluations required in the safety review of the nuclear power system and to document the results. The primary output of this task will be the Updated Safety Analysis Report (USAR) which will be published after the design of the flight system is established and the Final Safety Analysis Report (FSAR) is completed. This presents the evaluation of the power system after flight

Figure 3.2.3-2. Safety Planning, Coordination and Liaison

system qualification. Specific efforts to be accomplished in this subtask illustrated on Figure 3.2.3-3 include the following:

1. Select with AEC concurrence the launch vehicle to be used for the detailed safety evaluation of the SURVSATCOM mission.
2. Determine the potential vehicle failure modes and effects as related to the gross effects on the vehicle (e.g., explosion, structural collapse, trajectory error, tumbling vehicle, etc.). Use of available reports on similar missions and with the same launch vehicle will be made to the maximum extent possible.
3. Characterize the potential accident and abort environments to which the power system can be exposed in the system configuration and as integrated with the satellite and launch vehicle.
4. Define specific safety analyses and perform these analyses as needed to determine the response of the power system in the abort environments. These analyses will supplement the analyses conducted in the engineering tasks necessary for design of the system.

Figure 3.2.3-3. Safety Analyses and Reports

5. Incorporate information previously provided by the AEC into the preparation of the SAR's such as demographic, aquatic, and meteorologic data, and models for dispersion, deposition, human uptake, and dose levels.
6. Review and incorporate into the SAR's test data and analyses provided by other government agencies relating to fuel properties, characterization, compatibility, etc.
7. Determine by failure sequence techniques those situations that will result in potential release of fuel to the biosphere and characterize the resulting source terms.
8. Evaluate the potential risks to the general population resulting from the mission accidents that can lead to release of fuel.
9. Prepare an USAR and a FSAR for the SURVSATCOM mission according to the guidelines given in "Safety Documentation Requirements for Space Nuclear Power Systems" and submit them to the Contracting Officer for review according to the schedule shown in Figure 3.2.3-1. Information developed for the MHW (LES 8/9 and MJS-77 programs) will be utilized to the extent applicable.

3.2.3.3 Subtask 3.3 - Safety Testing

The purpose of the safety test subtask is to plan and execute those tests that are necessary to demonstrate the safety capability of the Isotope Brayton Heat Source. Tests that are contemplated pertain to system configuration and mode of operation that differ significantly from those for the LES-MHW or MJS-MHW systems. Specific efforts to be accomplished are as follows:

1. Prepare and submit to the Contracting Officer for review and comment detailed test plans for the following tests identified in Figure 3.2.3-4:
 - BS-1 Pad Abort Sequential Test
 - BS-2 Loss of Cooling Accident Test
2. Design, procure, fabricate, assemble, and checkout test hardware and fixtures as needed to support the tests identified.
3. Conduct tests BS-1 and BS-2. (Note: Test facilities for Test BS-1 will be provided as GFP.)
4. Provide the test HSA to be used in Test BS-1. (The heat sources will contain thorium simulant with the PISA's being provided through the Fueling Agency as GFP.)

Test Designation	Objective	Description	Test Specimens	Facility
Pad Abort Sequential (BS-1)	Evaluate capability of Heat Source Assembly to withstand sequential environments associated with pad abort initiated by upper yield explosion.	Subject HSA to sequential environment of explosion over-pressure and impulse followed by projectile impact, impact on concrete, and exposure to solid propellant fire.	1 HSHX 2 Heat Sources with T-111 PICS 2 Heat Sources with 9 Ir PICS and 15 T-111 PICS	Sandia Corp. Shock Tunnel & Sled Track Albuquerque, NM
Loss of Cooling Accident (BS-2)	Evaluate response of Heat Source in HSHX to complete loss of gas flow and without auxiliary or emergency cooling.	Attain equilibrium operating temperature at full power and then shut off all flow to HSHX and allow Heat Source to reach equilibrium temperature.	1 Heat Source Assembly with electrically heated Heat Source	GE VFSC

Figure 3.2.3-4. Isotope Brayton Safety Test Program

5. Provide the test HSA with electric heat sources to be used in Test BS-2.
6. Provide manufacturing and quality control support required for GE supplied hardware.
7. Process data and prepare test reports within six (6) weeks after completion of all post test analyses.
8. Maintain surveillance of test efforts by other government agencies and programs for applicable information.

A work flow diagram of the activities within this subtask is shown in Figure 3.2.3-5.

3.2.3.4 Subtask 3.4 - Radiological Safety

The primary purposes of the radiological safety task for the ground testing of IBFS Qualification system are to ensure the safe handling of the Isotope Heat Source, to minimize personnel radiation exposure, and to minimize the risk of any accident. A comprehensive program will be conducted so that all Isotope Heat Source operations will be performed with appropriate radiological safety practices to assure safe shipping,

Figure 3.2.3-5. Safety Testing

handling and operation. Before receipt of the Qualification Heat Source(s) an integrated ground safety analysis report must be submitted to and approved by the AEC. All procedures involving Isotope Heat Sources will be checked out by a realistic walk-through to demonstrate readiness for receipt of Isotope Heat Source.

The specific efforts to be accomplished are detailed below and are represented in Figure 3.2.3-6 to indicate the work flow of activities. Figure 3.2.3-7 indicates the schedule for the radiological safety activities.

1. Evaluate and revise as required the radiological safety program developed under Contract AT (29-2)-2831 and AT(49-15)-3066 to factor in design and testing operation modifications specified for the IBFS program.
2. Prepare an integrated ground safety analysis report for all Isotope Heat Source ground handling operations from the time of shipment from the fueling agency to delivery to the launch site which will include:
 - a. Description of reference Isotope Heat Source, the IBFS, available test facilities and handling equipment at GE

Figure 3.2.3-6. Radiological Safety Work Flow

Figure 3.2.3-7. Radiological Safety Schedule

- b. Description of testing operations
 - c. Normal Isotope Heat Source environments
 - d. Accident analysis
 - e. Evaluation of consequences of accident environments
 - f. Contingency plans
- 3. Participate with the AEC in the preparation conduct and reporting of an over-all operational analysis of the Mini-Brayton RTG Program which includes:
 - a. Preparation of functional block diagrams indicating operations sequence
 - b. Identification of responsible organization; test facility; handling equipment; Isotope Heat Source pressure, temperature and ambient gas environment; and time of operation.
 - c. Identification of potential problem areas.
 - d. Review of security, accountability, custodianship, facilities, and handling equipment.
 - 4. Assist in preparation and review and approval of all test procedures involving the use of Isotope Heat Sources by incorporating radiological procedures and emergency operating procedures.
 - 5. Coordinate radiological control program
 - 6. Provide facility, equipment and procedure reviews for AEC/ALO Operational Safety approval to handle Isotope Heat Sources.
 - 7. Implement changes to the Contract AT(29-2)-2831 and AT(49-15)-3066 radiological safety program for the Qualification System Test, on the basis of an evaluation of operational experience, to improve safety by reducing radiation exposures and minimizing the risk of an accident.
 - 8. Provide nuclear safety engineering support and health physics coverage during the testing of the Qualification System with Isotope Heat Source.
 - 9. Coordinate radiological control program for IBFS qualification testing.

3. 2. 4 Task 4 - Product Assurance

Objective. Product Assurance activities during Phase II will emphasize testing to show design conformance and evaluation, and full implementation of the content of AEC requirements found in SNS-1, SNS-2.

Approach. Management efforts, detailed below, provide a single source of responsibility, communications and direction for PA efforts. Support tasks are established to augment hardware development and test activities to assure highly reliable equipment and to verify the procedures for fabrication of flight hardware.

The following subtasks delineate the work scope of this effort.

3. 2. 4. 1 Subtask 4. 1 Reliability

Reliability efforts in Phase II will emphasize the following:

1. Establishment of equipment requirements.
2. Maintaining reliability control through assessment of the design and implementing corrective action when needed.
3. Providing high visibility of equipment reliability status to program management. The reliability program is charted in Figure 3. 2. 4-1. The specific efforts to be performed are itemized in the subtasks below and shown in Figure 3. 2. 4-2 Product Assurance Program Schedule for the Phase II Effort.

The specific reliability tasks are itemized below:

1. Generate a reliability program plan for the Phase II effort.
2. Provide liaison and support to program management (reports, design review participation).

The specific reliability sub-tasks are itemized below:

1. Generate a reliability program plan for the Phase II effort.
2. Provide liaison and support to program management (reports, design review participation).
3. Provide reliability analysis of equipment such as tolerance studies, materials evaluation and bimetallic joint reliability in support of the design efforts.

Figure 3.2.4-1. Reliability Activities for the Phase II Effort

	FISCAL YEAR	1977					1978					1979					1980			
	CALENDAR YEAR	1977					1978					1979					1980			
	MONTH	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
4.1 RELIABILITY																				
4.1.1 RELIABILITY PROGRAM PLAN																				
4.1.2 RELIABILITY PROGRAM SUPPORT																				
4.1.3 DESIGN RELIABILITY ANALYSIS																				
4.1.4 RELIABILITY ENGINEERING																				
4.1.4.1 REQUIREMENTS ANALYSIS																				
4.1.4.2 FMECA																				
4.1.4.3 ASSESSMENT																				
4.1.5 REL. TEST PLANNING/ANALYSIS																				
4.1.6 FAILURE REPORTING/CORRECTIVE ACTION																				
4.2 QUALITY ASSURANCE																				
4.3 CONFIGURATION MGMT																				
4.4 DESIGN REVIEWS																				

Figure 3.2.4-2. Task 4 Product Assurance Schedule for the Phase II Program

4. Provide the following Reliability Engineering efforts.
 - a. Generate reliability requirements for equipments fabricated at GE and provide supporting analyses to define system reliability requirements.
 - b. Prepare FMECA's on all prime and GSE hardware developed at GE. Support system FMECA's as required.
 - c. Continually assess the potential and achieved equipment reliability.
5. Prepare Reliability Test Plans to demonstrate the potential flight hardware reliability. Perform analysis of Phase II test data to aid in reliability projections of flight hardware.
6. Participate in the formal failure reporting, analyses and corrective action programs.

3.2.4.2 Subtask 4.2 - Quality Assurance

Quality assurance tasks elements are categorized as follows:

1. QA management
2. QA design support
3. Qualification test planning

3.2.4.2.1 Subtask 4.2.1 - Quality Assurance Management Tasks. The quality Control Manager will serve as the focal point for interfacing and information for all quality assurance activities with program management, design, manufacturing and test with AIRPHX representatives. In addition during Phase II, he will:

1. Provide direction, work definition and funding for all contract work within Product Assurance.
2. Define the applicable quality assurance policies and procedures to be used on the IBFS Program.
3. Generate a quality assurance program plan in accordance with SNS-1.

3.2.4.2.2 Subtask 4.2.2 Quality Assurance Design Support. QC Engineering will perform the following tasks:

1. Review and sign off drawings to ensure inclusion of quality requirements.
2. Generate the supplier quality assurance requirements and Quality Assurance Provisions of the Product and process specifications.
3. In consort with the design engineer, define acceptance requirements.
4. Incorporate quality requirements in purchase orders.

Before beginning Qualification of IBFS, QCE will participate in operation readiness review to assure that hardware, test equipment, facilities and personnel are ready to test. QCE will:

1. Review and approve inspection planning.
2. Monitor testing and test performance.
3. Participate disposition and analyze any non-conformance.
4. Prepare and present equipment data packages for customer acceptance.

3.2.4.2.3 Subtask 4.2.3 Qualification Test Plan. The Quality Control Engineer will contribute to the Qualification Test Plan by advising engineering in the areas of inspection and test requirements, providing the quality assurance provisions of the test plan, determining the need for special tools, gages or fixtures, and, in consort with the design engineer, defining acceptance requirements.

3.2.4.3 Subtask 4.3 - Configuration Management

Configuration management task will review customer requirements as it pertains to documentation of the program. Standards and procedures will be set up to meet the requirements. Configuration control of all documents, drawings and specifications will be maintained.

Item identification control, through material and part specifications, will be maintained; also, a change control system will be enforced for all drawings and specifications so that end use of hardware is controlled and correct.

Configuration control documentation and reports, including Program Change Proposals (PCP's) are also administered through configuration management.

3.2.4.4 Subtask 4.4 - Design Reviews

Formal viewgraphs covering the program status will be generated. These graphs will include the review of development status and key technical problems. GE will respond to all GE action items, performing such design and analysis required to support those action items. A record of Program Information Requests/Reports (PIR's), which will be a base on which to prepare the design reviews, will be maintained.

Output. The results of the Product Assurance Effort for Phase II will provide a continuous control of quality output of hardware, assuring attainment of the reliability goals of the program. Documentation resulting from the aforementioned tasks are listed as follows:

1. Quality Assurance Program Plan
2. Reliability Program Plan
3. Failure Mode Effects and Criticality Analysis Report on all General Electric developed hardware.
4. Reliability Assessment Report on General Electric development Hardware.

3.2.5 Task 5 Qualification Test Plan

Objective. The objective of this task is to prepare the SDM Development and IBFS Qualification test plan to delineate the test requirements and test sequences leading to qualifying the IBFS approach.

Approach. An integrated test plan, modeled after the RTG qualification test plan (RTG Qualification Test Plan), will be prepared for the system development and qualification test

program. The test plan will show the responsible personnel, the test equipment and the test sequence necessary to demonstrate flight suitability of the IBFS system and related components.

The plan will be based on an orderly transition from development through qualification of end item hardware in order to minimize technical and schedule risks to the program. Through the development phase two system development models (SDM) will be built to evaluate performance parameters and critical design features on the components and IBFS system prior to committing the final design to prime statue for the qualification IBFS. One unit serves as a development test bed for conducting PCS development tests at AIRPHX. The other unit consists of a prototype System Development Model (SDM) containing development hardware components with prime-like Structure and radiator elements.

A typical test flow sequence for the SDM and qual unit IBFS is shown in Figure 3.2.5-1. The intent of the integration development and qual test approach is to utilize the SDM as a test base to:

1. Update and correlate analytical models with test characteristics.
2. Identify critical design performance parameters.
3. Establish technical design base in MB-BRU performance in response to launch and orbital space environments.
4. Minimize technical and schedule task impact to flight qualification program.

Structure testing on the SDM using prime-like structure elements will be used as a basis for qualification of the structural design. Certain structural oriented testing such as the static load test will not be repeated on qualification hardware. Early in the development program the SDM will be utilized to demonstrate and develop operational handling and test procedures for loading an IHS heat source in the IBFS system design configuration utilizing a dummy HS simulation unit. Result of the SDM test program will be utilized to update the design and implement corrective action based on test results in the prime flight hardware design. The flight design will then be subjected to the qualification level testing similar to the tests outlined in Paragraph 3.2.10.

Figure 3.2.5-1. Test Flow Sequence

The integration test plan as developed will be submitted to AEC for approval prior to commencement of testing.

The program manager or his designated representative will have the direct authority and overall responsibility for test procedures, test data and reporting. Quality control will be responsible for the surveillance of the testing to assure compliance with the test plan and the required data is properly measured and recorded. Quality control will also generate the necessary log books for record purposes.

Output. The output of this task will consist of an overall program integrated development and qualification test planning document approved by the AEC.

3.2.5.1 Operational Test

The operational test shall consist of:

1. Motoring the BRU
2. Visual inspection
3. Resistance, continuity and isolation tests

3.2.5.2 IHS Compatibility Test Demonstration

A simulated IHS will be installed in the SDM to assure compatibility of the IHS with the SDM. The IHS loading equipment will be used to establish loading, unloading and safety procedures.

3.2.5.3 BRU Alignment

The design of the SDM will require the alignment of the BRU axis with the module to prevent deleterious effects on the system during space operation. The criticality of such measurements may require special techniques.

3.2.5.4 System Proof Test and Leak Test

Each assembled system will be subjected to a proof test to the ASME code for the weakest component. The code requires the proof test to be calculated as follows:

$$P_t = 1.25 \left(\frac{S_C}{S_H} \right) P_D$$

where

S_C = cold allowable stress for the material

S_H = hot allowable stress for the material

P_D = design pressure

P_T = test pressure

Leak testing of the system will follow each proof test and will be performed using a helium mass spectrometer to 10^{-9} cc/sec to assure a "leak tight" assembly.

3.2.5.5 Operational Test

Each assembly will be given an electromechanical check including motoring of the BRU measuring current inputs and voltages for comparison with receiving data.

3.2.5.6 Weight and Center of Gravity Measurement

The assembly shall be weighed on a balance beam scale to determine total weight. All fixtures and appurtances shall be weighed separately and subtracted from the total weight.

The center of gravity shall be determined in the horizontal "X" and "Z" axis using a CG locator.

3.2.5.7 Spin Balance

The assembly shall be subjected to a spin balance and counter weights added as necessary to maintain the loading within design specifications.

3.2.5.8 Dynamic Momentum Test

The dynamic momentum test requires that the assembly be suspended in a "zero G" condition. The BRU is rotated at design speed and any movement of the test assembly from the axis checked for compliance with system specifications.

3.2.5.9 Shock Test

A shock test will be performed to verify the system capability to withstand specified spacecraft induced shock loads at launch and during transport. Proof testing and performance testing will be performed following this test.

3.2.5.10 Vibration Test

A vibration test will be performed to verify the model response characteristics of the IBFS at spacecraft launch. Proof-leak test and performance test will be made following each vibration test.

3.2.5.11 Static Load Test

A static load test will be performed to verify the capability of the SDM to withstand launch acceleration. This test will be followed by proof-leak testing and performance testing.

3.2.5.12 BRU Alignment

At the completion of the environmental listing the test assembly will be physically inspected for deviations from measurements obtained in test number 3.

3.2.5.13 Post Environment Test

The IBSF shall receive a proof pressure and leak test as well as a complete electrical mechanical checkout before installation in the test vacuum chamber.

At the completion of the environmental testing the IBFS will be installed in an existing vacuum chamber and checked out before the initiation of tests at temperatures.

3.2.5.14 Auxiliary Cooling Test

An auxiliary cooling test will be performed to verify the ability of the HSA, while pressurized with helium, to maintain heat source temperature.

3.2.5.15 Performance Testing

Performance testing of the IBFS over the range of anticipated power output levels will be performed. Also included in this test will be the capability to impose the thermal effects of the sun on the heat rejection system. In addition, the performance testing of the SDM will reflect the short term effects of the environmental test programs on the SDM.

3.2.5.16 Endurance Testing

At the completion of the endurance test program, the IBFS will be placed on a 5000 hour endurance test to determine the long term effects of environmental testing on the IBFS.

3.2.6 TASK 6 - POWER CONVERSION SYSTEM DESIGN*

3.2.6.3, 3.2.6.4, 3.2.6.5 and 3.2.6.6, Subtasks 6.3, 6.4, 6.5 and 6.6 - Heat Source Assembly, Radiator, Control Systems and Ducting, Insulation, Bellows, Bi-Metallic Joints.

Purpose. The purpose of this task is to provide the detail design of the PCS for commitment to fabrication and assembly.

Objective. The objective of this task is to prepare engineering drawings for all components that make up the PCS and to provide the design integration which will assure that the PCS meets system requirements and interfaces.

Approach. General Electric will support AIRPHX in this task as indicated in Figure 3.2.6-1. GE will provide the detailed design for the HSA and space radiator. Engineering drawings for each of these components will be developed along with parts list, to the detail required for fabrication and manufacture. Interface control drawings (prepared in Task 2.) will be included in the design package for the HSA and radiator to assure for an integrated PCS. GE will also support AIRPHX in system layouts, ducting design, insulation design, control system design, nuclear safety and spacecraft integration tasks as required. Costs for Tasks 6.5 and 6.6 have not been included in this proposal; they will be subject to negotiation at the time the scope of effort for General Electric support is defined.

Output. The GE output for Task 6. will be a set of engineering drawings and interface control documents and specifications for the HSA and the space radiator. The latter two items are costed under Task 2.

Schedule. The schedule for the conduct of the Power Conversion System Design is shown in Figure 3.2.6-2.

*No GE input to subtasks 3.2.6.1 - BRU and 3.2.6.2 - Recuperator

Figure 3.2.6-1. Power Conversion System Design
(GE Support to Air Research)

	FISCAL YEAR	1977							1978												1979
	CALENDAR YEAR	1977							1978												
	MONTH	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
3.2.6.3 HSA DESIGN											SDM										QUAL
3.2.6.4 RADIATOR DESIGN											SDM										QUAL

Figure 3.2.6-2. Schedule for Power Conversion System Design

3.2.7 Task 7 - PCS Development and Fabrication

3.2.7.1 Subtask 7.1 - Brayton Rotating Unit

The Brayton Rotating Unit (BRU) will be developed, designed and fabricated by AIRPHX. General Electric has scheduled no effort in this development.

3.2.7.2 Subtask 7.2 - Recuperator

The Recuperator will be developed, designed and fabricated by AIRPHX. General Electric has scheduled no effort in this development.

3.2.7.3 Subtask 7.3 - Heat Source Assembly

Objective. The objective is to develop and fabricate the HSA units necessary for

1. The two System Development Model (SDM) units
2. The IBFS Qual unit
3. The IHS Qual test.

Approach. The current approach recommends that the IBFS utilize two IHS assumed to be furnished GFE. Therefore, the major development work will be in incorporate on-pad fueling capability into the HSA, if required.

The hardware flow for this component is summarized in Figure 3.2.7-1. A total of sever HSA units is required for the two SDM units, the one IBFS Qual unit, and the IHS component qualification. If acceptable, it may be possible to economize by:

1. Conducting the IHS qual test in a HSA that is subsequently used for one of the SDM units.
2. Refurbishing one of the SDM units such that it can be used as the IBFS Qual unit.

These alternatives will be further investigated in the performance of Task 10, Flight Design and Engineering Program Plan, during Phase I.

Figure 3.2.7-1. HSA Hardware Flow

Output. All necessary HSA hardware to assure successful IBFS qualification.

3.2.7.3.1 HSA Fabrication. This task describes the components that comprise the HSA, the procured items, and fabrication and assembly of the complete HSA unit.

The components are:

1. Columbium alloy Heat Source Heat Exchanger (HSHX) with headers and inlet and outlet ports
2. Graphite heat source end supports on each end, which interface with the heat source
3. Titanium end enclosures (spiders) on each end which are preloaded to support the Heat Source during ground handling and launch

4. A multifoil (zirconia coated nickel) insulation blanket (HSIS)
5. Beryllium support housing, with end domes, which provides a sealed enclosure, and takes all launch and ground handling loads

The major procurement items are the zirconia coated nickel blankets and the beryllium support housing.

3.2.7.4 Subtask 7.4 - Radiator

Objective. The objective is to develop and fabricate the beryllium radiator and supporting structure.

Approach. Manufacturing will assist in the design and development of the beryllium radiator and beryllium support structure. GE manufacturing will fabricate the support cone and interface ring for supporting the complete structure. Subcontractor support will be engaged for the beryllium radiator development and fabrication. This approach has been successfully employed by GE on both the SNAP-27 and MHW-RTG Programs.

Output. Beryllium radiators for the SDM unit(s), and the IBFS Qual unit.

3.2.7.5 Subtask 7.5 - Control System

Objective. The objective is to develop and fabricate the control system hardware that interfaces between the IBFS and the user spacecraft or the test GSE.

Approach. GE will work with AIRPHX and the probable IBFS user agency(s). The designs provided in Task 6.5 will be implemented and reduced to hardware. Interfacing harness to match AIRPHX harnesses and the electrical modules will be manufactured. All harnesses will be fabricated onto harness boards which serve as a drawing, packaged and stored. This hardware will be tested as a part of the GDM and IBFS Qual Unit. It is possible that a simulated spacecraft power control system may be required. This STE is not yet firmly identified, and is not costed.

Output. IBFS/spacecraft interface control hardware.

3.2.7.6 Subtask 7.6 - Final Assembly

Objective. The objective is to install the HSA units, the Radiator (or HRHX) on the AIRPHX BRURSA, and other hardware necessary to complete assembly of the SDM units and the IBFS Qual Unit.

Approach. The key elements of this effort are shown on Figure 3.2.7-2. The HSA units, the radiator, spacecraft mounting ring, and interface harness are fabricated by GE. The BRURSA and BRU control unit are received from AIRPHX. Final assembly is completed at GE with assistance from AIRPHX, particularly in the installation of the BRU control unit. The first SDM unit and IBFS Qual Unit are retained for the Qualification test effort at GE. The second SDM unit is shipped to AIRPHX for further testing, including performance and endurance tests.

Output. Output will be two complete SDM units and one complete IBFS Qual unit.

Figure 3.2.7-2. GDM and IBFS Qual Unit Final Assembly

3.2.8 Task 8 - Heat Source Design

Objective. To design a flight system radioisotope heat source and an electric heat source based on the design selection of Phase I and safety considerations resulting from Task 3. An objective is to retain as much of the safety qualification of the MHW heat source as possible.

Approach. Figure 3.2.8-1 shows the work flow logic for the design and analysis of a heat source, and Figure 3.2.8-2 gives the schedule to perform the overall heat source design task.

Output. The output of Task 8.0 will be the preparation of all final design drawings and specifications required to fabricate the flight system radioisotopic heat source and the electric heat source.

3.2.8.1 Subtask 8.1 - Heat Source Design and Analysis

The primary effort of detail design and analysis for the IBS heat source is initiated very early in this task, because of the existing base of technology and understanding of the heat source design requirements achieved through the MHW RTG programs. This foundation provides an appreciation for all the nuances and interrelationships of the various requirements and specifications at mission, system, and safety levels.

By use of MHW heat source design or technology, iterative design and analysis is minimized, allowing design to move through the preliminary design review and into the optimization task relatively quickly.

This Subtask provides for the necessary design analyses, development tests and trade-off studies to formulate the isotope heat source detail design to be used in the IBFS. Major efforts to be accomplished during this subtask are:

1. Establish maximum utilization of existing MHW technology.
2. Establish desired fuel inventory for IBFS heat source.
3. Establish design requirement definition for heat source components.
4. Perform design and analysis to maximize GIS impact capability and verify by test.
5. Perform trajectory/heating/thermal response analysis for heat source.

Figure 3.2.8-1. Subtask 8.1 - Heat Source Design and Analysis Flow Chart

Figure 3.2.8-2. Task 8. - Heat Source Design Schedule

6. Perform design studies and analyses to assess aeroshell margin - Identify characterization data required.
7. Perform design studies and analyses to establish component design margins.
8. Perform heat source/HSA integration and thermal effects study.
9. Perform HSA breakup analyses to determine heat source re-entry conditions.
10. Perform analyses, as required to support the safety analyses, Task 3.

3.2.8.2 Subtask 8.2 - Electrical Heat Source Design and Analysis

The electric heat source design is anticipated to be very similar to the existing MHW design, to the extent that the presently built heaters may be modified to support this program. A reference 4800-thermal-watt system may use two 2400 watt MHW-type heaters for SDM and qualification testing. This cannot be assured until heat source design selection is completed in Phase I.

Anticipation that the MHW heat source design is maintained, and that some MHW electric heat sources are available for use, a cost-effective verification test on a modified MHW EHS will be performed.

This Subtask shall perform the necessary analyses to formulate detail design definition of an Electric Heat Source (EHS) that can be used to simulate the isotope heat source selected for the IBFS. Analyses will be performed to determine:

1. Feasibility of using MHW-type heater
2. EHS mass properties
3. EHS thermal and electrical performance
4. EHS/HSA integration effects

3.2.8.3 Subtask 8.3 - FA/FDL Liaison and Support

Throughout Task 8, liaison with the fueling agency (FA) and fuel development laboratories (FDL) will be maintained. Interface drawings will be exchanged, concurrence on fueling techniques and heat source handling will be sought early in the task.

This subtask provides the necessary liaison with the Fueling Agency. The major efforts to be accomplished during this subtask are:

1. Coordinate FSA and heat source designs, drawings and specifications with Fueling Agency.
2. Provide support/liaison for PICS verification tests.
3. Support Fueling Agency in preparation of specifications and working agreements, as required.
4. Provide engineering liaison configuration control to FA in establishment of FA production capability.
5. Monitor all activities to measure progress against major milestones.

3.2.9 Task 9 - Heat Source Development and Fabrication

Objective. The objective is to develop and fabricate the IBFS Isotopic Heat Source Units.

Approach. The make and buy items will be fabricated into a heat source consisting of fuel spheres, post impact containment shells (PICS), the graphite impact shells (GIS), the graphite integration hardware and the aeroshell. The fabrication methods and procedures for all of these components have presently been developed to a high degree of confidence on the AEC-MHW Program. This activity as scheduled is shown on Figure 3.2.9-1.

The fabrication of the PICS, GIS and aeroshell will be accomplished by manufacturing using previous experience from the LES 8/9 program. This has been demonstrated by several complete assembly operations in the 2400 watt MHW Heat Source.

Figure 3.2.9-1. Task 9 Heat Source Development and Fabrication

The IHS development required in this task is minimal because of the highly developed status of the AEC MHW-RTG IHS. Such development for the IBFS program will be similar to, but less than that now in progress for the MHW-RTG application in the NASA/JPL Mariner J/S mission.

Post Impact Containment Shell (PICS). The matched iridium hemispheres are press formed between two tantalum sheets while sealed in a stainless steel container. The forming occurs after drawing a vacuum in the container and raising the temperature of the iridium and holder. A vent assembly and liquid decontamination cover is welded to each hemisphere. During assembly of the fuel sphere into the PICS, the hemispheres are joined together by an electron beam welding while they are held in a water cooled jacket.

Impact Shell. The energy absorbing impact shell is fabricated by randomly winding carbon yarn on a graphite mandrel. The resin impregnated spheres are then alternately impregnated and cured through several cycles before the final pyrolysis at 2100° C. The sphere bodies and caps are then machined to size.

Integration Hardware. The integration hardware assists the assembly and positioning of the fuel sphere assemblies (FSA's) in the aeroshell. The hardware consists of retainer trays, compliance pads, crush-up discs, sphere locks, nuts and bolts.

The retainer trays are produced by using a rosette lay-up of graphite fabric and resin on a cylindrical mandrel. The tie bolts, sphere locks and spring crush-up discs are molded in flat panels from the same graphite fabric and resin system. These parts are then machined to drawing dimensions.

The end crush-up nuts and bolts are machined from graphite plates.

The resilient compliance pads are fabricated by stitching together several circular layers of graphite cloth with carbon yarn.

Aeroshell. The ablator cylinder is machined from solid, hot pressed graphite billet, while the two end-caps are machined from hot-pressed graphite plates.

Ablation Sleeve. The ablation sleeve is fabricated by laying-up a woven graphite-resin composite on a cylindrical mandrel. The rosette pattern lay-up is then infiltrated with pyrolytic graphite before machining to drawing.

HS Assembly Procedure. The fuel sphere is assemble to the heat source assembly with the aeroshell. This operation involves in a manipulator cell at the fueling agency.

Fuel Sphere Assembly. The steps are as follows:

1. Place fuel sphere in PICS.
2. Weld PICS.
3. Place PICS in graphite impact shell (GIS).
4. Screw on graphite cap to GIS.

To assemble the retainer ring assembly, the required steps for the three assemblies are as follows:

1. Place two planes of four FSA's per plane in retainer ring separated by a compliance pad.
2. Place a sphere lock at the top and bottom of the FSA's.
3. Tie two sphere locks together to hold FSA in ring assembly.

The final assembly sequence involves the installation of the hardware into aeroshell. The aeroshell has the cylinder and bottom end cap and the lower spring crush-up discs already installed before placement in the manipulation box. The three retaining ring assemblies are installed in the cylinder separated from each other by a compliance pad. Then a dimensionally selected end spring is installed, followed by the installation of the top cap. An external preload is applied to the internal assembly thus permitting the snap ring and set screw to lock the end cap in place.

Output. This effort will provide the complete IHS units ready for installation in the HSA component qualification unit.

3.2.10 Task 10 - Qualification Tests

Objective. The objective is to perform the component level development and qualification tests as prescribed by the approved integrated test plan described in Section 3.2.5.

Approach. Qualification and development tests are used to test flight type systems in simulated launch and orbital environments to validate this mechanical and structural capability for space utilization.

Test procedures will be submitted for AIRPHX approval similar to the procedures used by General Electric to qualify the MHW-RTG (RTG) Qualification Test Procedure SI-249240) for flight testing. This procedure will detail the step by step procedures, fixtures and GSE necessary to perform each test. The test procedure will also serve as a Quality Control Document. The use of this test procedure will result in a flight qualified system.

Figure 3.2.10-1 presents a typical test flow sequence of the IBFS system. A brief description of the test, the equipment and expected results for each test follows testing is proposed in accordance with the scheduled events shown in Figure 3.2.10-2.

Section 3.5 summarizes test utilization the GSE equipments and facilities associated with the test flow profile.

Output. The output of these tests will provide the supporting data and analysis which verifies integrity of the qualification IBFS as flight qualified system.

3.2.10.1 System Testing (SDM & Qual IBFS)

The following is a description of the tests to be performed on the IFBS.

3.2.10.1.1 IHS Compatibility Test. A simulated heat source will be trial fitted into the qualification IBFS to establish the compatibility of the Heat Source with the qualification IBFS. The test will be performed on the System Development Model (SDM) to verify and establish methods and procedures for loading of the IHS. These procedures will be developed utilizing a dummy simulated heat source.

The results of this test will be:

1. a definition of Heat Source Loading and unloading procedures
2. the modification of equipment necessary to perform loading and unloading
3. the establishment of safety procedures in the handling of the IHS

3. 2. 10. 1. 2 BRU Axis Alignment. A three axis measurement of the BRU with respect to the Spacecraft Interface axis is required to make certain that the axes conform to the System Spacecraft Interface Alignment requirements.

The IBFS will be mounted to an alignment table and pertinent measurements taken to determine the conformity of the BRU to the spacecraft axis. In addition, physical measurements will be taken alignment integrity following completion of the launch environmental tests.

3. 2. 10. 1. 3 System Proof and Leak Test. The assembled qualification IBFS will be subjected to proof test with subsequent leak detection test.

The proof test pressure will be calculated on the basis of the design pressure of the weakest component. The method of calculating this pressure shall be according to the ASME code which is:

$$P_T = 1.25 (S_C/S_H) P_D$$

where

S_C = allowable cold stress

S_H = allowable hot stress

P_D = design pressure

P_T = test pressure

The proof pressure test will be followed by a helium mass spectrometer test to specification P3CY A 16.

The result of this test will be certification of a "leak tight" system ready for environmental test.

3.2.10.1.4 Operational Test. A functional test will be performed both prior to and subsequent to major environmental load tests to isolate impact of testing on system operating characteristics. Each assembly will be given an electro-mechanical check including visual inspection consisting of electrical circuit resistance, continuity and isolation tests as well as motoring of the BRU, measuring current inputs and voltages for comparison with received data.

3.2.10.1.5 Mass Property Measurement. Mass properties including weight, c. g. and mass moment of inertia will be measured on a newly acquired Miller Research Mark III facility in place of GE.

3.2.10.1.6 Spin Balance. Spin balance will be performed to minimize eccentric loading of the IBFS relative to the spacecraft during launch mission phase.

The IBFS will be mounted in a Spin Balance fixture and rotated on its axis to determine the extent of eccentric loading. Counter weights will be added as required to bring the eccentric loading within specification.

3.2.10.1.7 Dynamic Momentum Test. The dynamic momentum test is to measure the dynamic imbalance effects on the spacecraft due to operational spin-up of the BRU.

This test will be performed by suspending the IBFS in a "zero G" environment over an alignment plate. The IBFS will be motored electrically and the forces measured by load cells.

3.2.10.1.8 Shock Testing. Shock tests are performed to verify the IBFS capability to withstand launch induced shocks which occur at launch vehicle engine staging spacecraft separation and/or apogee kick stage firing if applicable.

The qualification IBFS will be installed in a fixture which will be mounted to a C-220 electromagnetic shaker with a Ling SS6 shock synthesizer coupled to the C-220 table for shock tests. Strain gages, accelerometers, and shock indicators will be attached to the test vehicle at critical points. The test will simulate the specified g loadings for space craft launch in two directions along each axis of the test vehicle. Following each shake operation an operational (3.2.10.1.4) and proof test (3.2.10.1.3) will be performed. The results of this test confirm the structural capability of the qualification IBFS to meet launch shock conditions.

3.2.10.1.9 Vibration Testing. A vibration test will be performed to verify the modal response characteristics of the test assembly at launch. At completion of the shock test acceptance and proof testing, the qualification IBFS will still be mounted to the C-220, electromagnetic shaker and a hydrostatic bearing table. The test will be performed at the system level with an Electric Heat Source on the SDM and utilize an IHS on the qual unit.

The test shall consist of random sine vibrations and modal surveys in each of the three assembly axis. The strain gages and accelerometers mounted for the shake test will record the response of the test assembly.

Following each vibration mode an operational test (3.2.10.1.4) and a proof test (3.2.10.1.3) will be performed.

3.2.10.1.10 Static Load Test. A static load test will be performed on the SDM to verify the ability of the IBFS to withstand launch quasi steady state acceleration. The SDM will be installed in a test fixture and mounted in the static load facility. A specified static load will be applied in discrete increments and strain gage readings taken. A completion of the test the SDM will be operational tested (3.2.10.1.4) and proof tested (3.2.10.1.3).

The completion of this test will conclude the environmental portion of the test program and certify design integrity of the structural system. It is not planned to perform this test on the qualification IBFS.

3.2.10.1.11 BRU Alignment Test. The BRU alignment test (3.2.10.1.2) will be repeated to determine the effects of the environmental testing on the structural alignment of the BRU axis relative to the spacecraft interface.

3.2.10.1.12 Post Environment Test. Following the completion of the environmental test program the IBFS will be installed in an existing vacuum chamber, connected to the GSE and checked out. A complete operational (3.2.10.1.4) and proof test (3.2.10.1.3) will be accomplished prior to the initiation of hot testing.

3.2.10.1.13 Auxiliary Cooling Test. An auxiliary cooling test will be performed to demonstrate the ability of the cooling method to maintain heat source temperature within specification.

The chamber will be evaluated and the HSA pressurized to specifications. During the SDM testing the power level of the EHS will be varied over the anticipated range of powers. At each power level, the HSA will approach thermal equilibrium. At this time, power and temperature data from the HSA will be recorded. On the IBFS

qualification unit this test will be performed with an IHS in the GE nuclear certified thermal vacuum chamber.

3.2.10.1.14 Performance Testing. Performance testing of the qualification IBFS in thermal vacuum will follow the auxiliary cooling test program. This test performance maps the IBFS over the range of power outputs specified. Thermal, pressure, flow, power output, power input data will be recorded. Also included in this test will be a simulation of the solar heating effect on the radiator. The results of this test will show the short term effects of the environmental testing on the IBFS. As before, testing on the SDM will be performed with an EHS, whereas the qualification IBFS will be certified using an IHS.

3.2.10.2 Component Qualification of Isotope Heat Source (IHS)

Objective. The objective of this task is to qualify Isotope Heat Source for flight as the Heat Source to be used in the Isotope Brayton Flight System.

Approach. Prior to qualifying the IBFS system with an actual IHS as described in Paragraphs 3.2.10.1.9, 3.2.1.10.13 and 3.2.10.1.14 the IHS installed in the HSA will be subjected to a series of component level test. These tests will consist of a series of functional checks and environmental tests of the IHS - HSA assembly similar to the qualification testing now performed on the MHW-RTG Program.

This test series will be conducted on an IHS which is separate from the IBFS interface and environments to account for expected response of the IBFS. The correct thermal environment will be created by using a flight type HSA to simulate the effects of mounting within the IBFS.

Output. The output of this task will be a data package and report which verifies that the Isotope Heat Source is qualified for flight as part of the Isotope Brayton Flight System.

3.2.10.2.1 Receiving Inspection & Functional Checks. The IHS will be subjected to a series of incoming inspection checks to verify interface dimensions and assure no shipping damage has occurred. This will be accomplished in an inert gas environment to preclude oxidation of the materials and to preclude contamination of the Heat Source by gases or gas born contaminants. This will be accomplished in a glove box equipped, thermal vacuum loading and assembly station presently in use at General Electric Space Division for processing heat sources on the MHW-RTG Program. Special tooling (preprocessed) for and manufactured from high temperature resisting materials) will be in place inside the loading and assembly station so that the critical interfact checks can be made. Visual inspection will be accomplished through the view ports built into the station.

Transport of the IHS into the loading and assembly station (LAS) will be by means of a sacrificial can and an assumed GFE shipping protection container similar to those currently in use on the MHW program. The IHS will be passed into the LAS via an air lock and removed from its protecting containers in the inert environment of the chamber. Radiological samples will be taken in the chamber to assess radiological safety.

3.2.10.2.2 Environmental Testing. While in the LAS the IHS will be installed in a flight type HSA which will simulate the mechanical attachment to the flight heat source support system of the IBFS, and which on its external supports has attachments for mounting to a shaker (for vibration testing) or to a thermal vacuum test fixture. The container will have feed-through for instrumentation (mounted to IHS) and will be capable of being pressurized with an inert gas (for which there will be fill ports and gases).

Vibration & Shock Testing. The test container will be removed from the LAS and transported to the present nuclear certified vibration facility. It will be mounted to a C-150 shaker and subjected to the vibration and shock environments specified for qualification of the IBFS. Test levels will be amplified to simulate the response of the IBFS so that the levels experienced by the IHS will be realistic.

Thermal Vacuum Testing. The HSA (containing the IHS) will be mounted in a GE nuclear certified thermal-vacuum chamber and exposed to the expected IBFS T/V environment. The thermal heat sink will be adjusted to match the IBFS environment by the use of flight type HSA. The HSA gas management valving system will be attached to a gas management system built into the chamber.

The T/V chamber referred to above is an integral part of the RTG loading and assembly station thereby considerably facilitating handling of the test article without exposure to harmful atmospheric gases.

3.2.10.2.3 Post Test Evaluation. The IHS will be reinstalled in its Shipping Protection Container (SPC) and returned to the fueling agency. The fueling agency will perform a competitive post test tear-down evaluation of the IHS (as is currently done on the MHW program), the fueling agency will inspect for mechanical integrity, radiological containment (within the fuel balls) and general condition of the IHS. The fuel and precious metals will be recovered by the fueling agency for future use.

3.2.11 Task 11 - Ground Support Equipment

Objective. The objective is to provide to AIRPHX the services required to design, fabricate, inspect, test and checkout of all Ground Support Equipment required for development, qualification and acceptance testing of GE-furnished components and the IBFS Test hardware. This task shall also include the maintenance of support equipment and the manufacturing tooling as required to fabricate GSE end items.

Approach. This task is divided into the following subtasks which contain all the associated GSE required for component and system level testing and handling of the assembly, as scheduled on Figure 3.2.11-1.

11.1 Electrical GSE

11.2 Mechanical GSE

11.3 Component Test Equipment

11.4 Special Test Equipment

Maximum utilization is made of GSE equipment in the ground test flow plan as shown in Paragraph 3.2.10 in order to minimize end item quantities.

Furthermore, GSE-related equipment fabricated in support of the Phase I GDS Test Program, Section 3.1.5 will be refurbished as necessary and retained where possible for Phase II use. Table 3.2.11-1 presents a listing of proposed GSE equipment along with planned utilization in the Phase II Ground Test Program.

Output. Specific outputs of this task consist of the following:

1. Definition of Requirements and design of GSE equipments
2. Preparation of manufacturing, drawings, and procurement and design specifications for end item equipment
3. Procurement, fabrication, and inspection of equipments
4. Design and fabrication of GSE tooling
5. Instrumentation, test, and checkout of GSE equipment

Items of GSE normally used in the handling and transport of the IBFS system between factory and the launch site during the Phase III program will be designed in Phase II in accordance with end item GSE and applicable government specifications. These equipment will be validated by analysis and AGE conformance testing as part of the Phase III program before delivery.

GFE Support Equipment. Several items of equipment needed to support the Phase II Test Flow are considered to be Government or Contractor-furnished items.

1. System Gas Management Unit - AIRPHX.
2. IHS Shipping Cask - Mound Research.
3. IHS Loading Fixture - GE MHW
4. RTG-Assembly Station - GE MHW

3.2.12 Task 12 - Reports and Data

Objective. The objective is to provide the necessary program technical, financial and programmatic documentation.

Figure 3.2.11-1. Ground Support Equipment For Phase II

Table 3.2.11-1. GSE Utilization Matrix for Phase II

Item	WBS	Make Buy	SDM-1	SDM-2	Component Qual	System Qual	Validation Testing
<u>Electrical</u>	11.1					Use SDM-1 Refurbished	
EHS Power Supply Console	11.1.1	M	1*Plus 1	2*			Electrical Function & Check Out
Read-Out Console	11.1.2	M	1				Electrical Function & Check Out
Electrical Test Set	11.1.3	M	1				Function, Made and Check Out
Data Handling Equipment	11.1.4	B	1				Function and Check Out
<u>Mechanical</u>	11.2						
EHS Loading Fixture	11.2.1	M	1*	1*			(Performed in Phase I, See Para. 3.1.6, Vol I)
Pressure Leak Test Kit	11.2.2	M	1*				Function and Check Out and Proof Test
Gas Management Unit (ACS)	11.2.3	M	1	1*			Function and Check Out and Proof Test
Safety Alarm Console	11.2.4	M	1				Function and Check Out
Handling Dolly	11.2.5	B	1				Mechanical Function
Handling Sling	11.2.6	B	1				Static Proof Load
Turnover Fixture	11.2.7	B	1				Static Proof Load
Access Stands	11.2.8	B	1				N/A
IHS Handling Sling	11.2.9	M	1				Mechanical Function & Static Proof Load
IHS Envir Canister	11.2.10	M	1				Function and Checkout (Performed in Phase I)
HSA Handling Sling	11.2.11	B	1*	1*			Mechanical Function (Validate Tested in Phase I.)
Power Console Shipping Container	11.2.12	B	1*	2*			Mechanical Function & Proof Load Test
IHS Portable Load Fixture	11.2.13	B	1				Mechanical Function & Load
Mobil ACS	11.2.14	B	1				
<u>Component Test Equipment</u>	11.3				Use SDM-1 Refurbished		Mechanical Function & Fit
Acoustic Fixture	11.3.1	M	1*				
Vibration Fixture	11.3.2	M	1				
IV Fixture	11.3.3	M	1				
<u>Special Test Equipment (System)</u>	11.4					Use SDM-1 Refurbished	
Momentum Balance Fixture	11.4.1	M	1				Static Proof Load & Check Out
Thermal Vacuum Fixture	11.4.2	M	1				None
Vibration Test Fixture	11.4.3	M	1				Static Proof Load
Static Load Fixture	11.4.4	M	1				Static Proof Load
Mass Property Fixture	11.4.5	M	1				Mechanical Function and Proof Load
Spin Balance Fixture	11.4.6	M	1				Mechanical Function and Proof Load
Dummy HS	11.4.7	M					Mechanical Fit & Check Out
Shock Test Fixture	11.4.8	M	1				Mechanical Function
Alignment Fix Adapter	11.4.9	M					Static Proof Load

NOTES: SDM-1 System Tested at GE with Space Radiator

SDM-2 System Tested at AirResearch with Heat Sink Radiator Simulator or Radiator

*Phase I Equipment Refurbished for Phase II Usage (see Para. 3.6.1, Vol I)

Approach. The following reports will be prepared and submitted to AiResearch for visibility in realization of milestone events, identification of problem areas, schedule and financial status and technical achievements or discussions.

1. Monthly top summary and financial report
2. Monthly technical report
3. Annual technical report
4. Special technical reports

Output. This effort is summarized on Figure 3.2.12-1.

3.2.13 Task 13 - Phase III Plan

Objective. The objective is to structure a Phase III Flight Plan which is based on assessments and findings of the Qualification Program.

Figure 3.2.12-1. All Required Reports and Data are Provided

Approach. General Electric Company will support AIRPHX in preparing the Phase III Plan. This plan will be consistent with user requirements.

The program plan will present detailed task descriptions, schedules, test plans, facility requirements, and costs for conducting Phase III of the program.

Output. The output of this task will be GE inputs for detailed document containing the plan to implement Phase III.

Schedule. The schedule for accomplishing this task has been presented in Figure 3.2.C-1.

An example Phase III program is summarized in Section 3.2.14.

3.2.14 Flight System Production - Phase III

3.2.14.1 Program Summary

The Phase III Program has as its objective the production of flight qualified IBFS systems. It is planned that these systems would be provided at a rate of four systems per year.

General Electric, having delivered extremely successful SNAP-27 flight systems and currently working on the LES 8/9 and MJS MHW flight programs, is capable of supporting this phase of the total program. Following the contribution and support provided during Phase I and II, GE would perform the following activities during Phase III:

1. Provide systems liaison and integration.
2. Fabricate Isotopic Heat Sources.
3. Fabricate heat rejection systems and HSA's
4. Conduct system acceptance testing.
5. Provide safety support.
6. Provide design support and evaluation.

7. Design, fabricate and test of any required Ground Support Equipment.
8. Provide reliability, QA and configuration management support.
9. Provide launch support.
10. Provide program management support, reports and data.

The details of conducting a typical flight hardware program structured to deliver four systems per year are presented in summary in the following sections covering a typical Work Breakdown Structure, Program Schedule and summary task descriptions. The WBS is presented in Figure 3.2.14-1 and the schedule in Figure 3.2.14-2.

3.2.14.2 Phase III Work Description

This section represents, in summary, a description of the effort required to deliver Flight Isotope Brayton Flight Systems at a rate of four systems per year. The brief task descriptions identify the general content of the task.

<p>1.0 Program Management</p> <p>The Program Office, under the direction of the Program Manager, will be responsible for providing overall management, project engineering and control, customer and user liaison, financial and Contract Management, Procurement/Subcontract support, and program documentation.</p> <p>2.0 Systems</p> <p>This task covers the technical management and direction in integrating design, analysis and liaison activities related to total system interfaces with the mission spacecraft.</p> <p>All liaison with the user to include interface agreements, environmental specifications, system performance, system design or fabrication changes/variations and all in-house coordination affected by these activities will be performed in this task.</p> <p>3.0 Safety</p> <p>All work pertaining to design surveillance, safety analyses and evaluation, testing, and documentation for flight approval will have been completed in Phase II of the Isotope Brayton Power System program. The remaining work in the safety area will be directed toward radiological control of the flight system production and acceptance activities. A comprehensive program will be established to ensure that all operations involving handling, shipping and testing of life (fueled) heat sources will be conducted with appropriate radiological safety controls to preclude radiation exposure hazards to operating personnel and to the general public.</p> <p>The specific efforts to be accomplished in this task are as follows.</p> <ol style="list-style-type: none"> 1. Implement changes to the Contract AT (29-2)-2831 and AT (49-15)-3066 radiological safety program for Flight System testing and on the basis of an evaluation of operational experience, to improve safety by reducing radiation exposures and minimizing the risk of an accident. 2. Provide nuclear safety engineering support and health physics coverage during the Flight System testing of Isotope Heat Sources. 3. Coordinate radiological control program for Flight System testing. <p>4.0 Product Assurance</p> <p>4.1 Reliability</p> <p>This task covers the implementation of the Reliability Plan approved during Phase II and consistent with the SNS-2 as it applies to delivery of flight systems. Included would be the monitoring of fabrication, assembly and test to assess predicted performance, participation in formal failure reporting and contributing to analyses and corrective action programs as required.</p> <p>4.2 Quality Assurance</p> <p>This task covers the implementation of the Quality Assurance Plan approved during Phase II and consistent with SNS-1 as it applies to delivery of flight systems. Included would be the management and liaison (both with the customer and in-house) required to provide a QA team that rigorously enforces quality requirements on the fabrication, assembly and test of flight hardware, prepares all required documentation and reports, and provides for MRB, calibration and control of gages and equipment and other support activities.</p>	<p>4.3 Configuration Management</p> <p>This task covers the effort required to control all drawings and specifications for the total program as detailed in the Configuration Management Plan submitted during Phase II.</p> <p>5.0 Acceptance Test Plan</p> <p>The task covers the planning for and preparation of an integrated acceptance test plan for all flight components, subsystems and the flight IBFS assembly. The acceptance/qualification test plan prepared during Phase II will provide a frame of reference for preparing this plan.</p> <p>6.0 Power Conversion System Design</p> <p>The task provides the effort required to support the systems integration and fabrication, assembly and test of flight hardware. Included will be the design, analysis and evaluation required to assess all changes, variations and hardware discrepancies prompted by the customer, the user or by in-house changes or problems.</p> <p>7.0 Power Conversion System Fabrication</p> <p>This task covers the procurement, fabrication and assembly of components, subsystems and the IBFS assemblies. All manufacturing support to include production control, manufacturing engineering, shop operations, shipping and receiving and manufacturing management plus all purchased materials required are included in this task. Also included are the quality assurance activities required to support this activity to include receiving inspection, in-process and final inspection, supplier surveillance and documentation.</p> <p>8.0 Heat Source Design</p> <p>This task covers the support required to design, analyze and evaluate all changes, variations and hardware discrepancies associated with the Isotopic Heat Source. Also included is the technical liaison required with the AEC support agencies, primarily the Fueling Agency (FA), to deliver fueled IHS assemblies.</p> <p>9.0 Heat Source Fabrication</p> <p>The task covers the procurement, fabrication and assembly of heat source components required by and delivered to the AEC Fueling Agency (FA) in order to provide fueled IHS assemblies. All manufacturing support, materials procured and quality assurance support is included in this task.</p> <p>10.0 Acceptance Testing</p> <p>This task covers the acceptance testing of all components and subsystems and of the IHS assemblies. This testing will be done in accordance with the Acceptance Test Plan developed in Task 5. All test and quality assurance support activities are included in this effort.</p> <p>11.0 Ground Support Equipment</p> <p>Any additional ground support equipment beyond that provided during the early Program phases would be designed, fabricated and tested in this task. The design, manufacturing quality assurance and test support plus all purchased materials required would be included in this task.</p> <p>12.0 Launch Support</p> <p>This task covers all GE support required in providing a Custodian and support personnel to accept and maintain custody of the IBFS Isotopic Heat Sources at the launch site and to provide field personnel for the maintenance and assembly operations required before launch.</p>
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Figure 3.2.14-1. Phase III Flight System Production Typical Work Breakdown Structure and Description

3.3 ANTICIPATED TECHNICAL PROBLEMS

In assessing the IBFS conceptual design and the system performance objectives, three key technical problems areas have been identified relative to the HSA and flight radiator designs. None of these problems appear to represent an impasse to the successful development of the IBFS.

The desirability for on-pad and in-orbit fueling is recognized, and a conceptual approach to achieving this goal is presented in Section 3.3.1. Risks associated with the development of a beryllium radiator to meet the IBFS weight objective of 3.5 watts/lb is discussed in Section 3.3.2. Finally, Section 3.3.3 describes the bi-metallic joints which will be required in the IBFS.

3.3.1 ON-PAD AND IN-ORBIT FUELING

On-Pad Loading

General Electric Company recognizes the advantages of being able to fuel the IBFS on-pad. Such capability:

1. Facilitates transportation of the IBFS to the launch site
2. Simplifies integration of the PCS with the spacecraft
3. Allows on-pad checkout with an EHS

However, GE also recognizes that such a capability poses key technical problems. Because of the refractory metal components in the HSA and the graphite components in the Heat Source, it is recognized that on-pad fueling must be performed in a controlled environment. Accessibility to the HSA, particularly if fueling must be performed through the shroud, is recognized as a further complication. The General Electric Company will investigate the cost and development risk versus the merits of providing on-pad fueling capability.

A conceptual design of a mobile loading fixture that could be used for HSA on-pad fueling is shown in Figure 3.3.1-1. The conceptual design assumed a horizontal heat source loading with no access limitations. Vertical fuel loading can be accomplished

Figure 3.3.1-1. Mobile Horizontal Loading Fixture

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in essentially the same manner. As will be discussed later, vertical loadings can simplify the design. The major components shown in the design are the HSA, the transfer box, and the heat source shipping module. It is envisioned that the heat source would be packaged in the shipping module as shown. For shipping purposes, this module would be contained in a larger transportation shipping container containing shock and vibration isolators. The heat source will be packaged at the fueling agency with the forward end support pad, preload screw, insulation and end enclosure as shown. To eliminate transportation loads the heat source is preloaded at the forward end by means of the pre-load ring nut. The module is pressurized with inert gas for shipping to lower heat source temperatures and prevent oxidation. The module is shielded and has water cooling capability to maintain acceptable temperatures and radiation levels during loading. Because of the weight involved, the transfer box and heat source shipping module will have to be assembled together on a railed platform or table (not shown in Figure 3.3.1-1). The joined assembly will then have to be railed into position to align with the HSA for attachment. A simple and quick attachment that mates to the extended flange of the HSA is desirable. After hooking up vacuum, backfill and water cooling lines, the on pad fueling operations can begin.

After evacuating and backfilling the HSA and transfer box with inert gas an operator manually (through the glove ports) removes the shipping module hatch, thereby breaking preload on the heat source. The hatch is stored in the storage area of the transfer box. Through glove ports the portable guide rails are installed and the heat source, via the support dolly, is transferred into the HSA using a controlled rate, manual gear drive mechanism. Once in the HSA the rotation lock pins are removed so that the end enclosure can be rotated to seat under the support brackets, and the HSHX attached to the end support pad. After removing the heat source support rod the preload screw is packed with fibrous insulation and preload is applied. A torque multiplier type device will have to be used to facilitate the preloading operation. After preloading, the forward end dome is installed. (The forward end dome is stored in the transfer box.) Experience gained on the MHW-RTG Program has shown this operation to be time consuming because of the time needed to uniformly compress a metallic seal. Quick compression

or alternate sealing methods will be investigated to reduce installation time. The HSA is then pressurized through the ACS and a HSA decay test performed to verify HSA leak tightness. After pressure decay verification testing the transfer box and empty shipping module are removed.

Vertical fuel loadings can be accomplished using essentially the same procedures. However, for vertical loadings, the heat source does not have to be cantilevered and transferred by rail for insertion. This will significantly decrease the complexity of the design.

The key technical problem areas associated with on-pad fueling can be summarized as follows:

1. Accessibility to the HSA — completely remote operations may be required depending on access limitations.
2. Precision alignment of the mobile loading device.
3. A controlled environment in the HSA and mobile loading fixture must be maintained to prevent oxidation of the refractory metal and graphite components used in the HSA design. Similar environmental requirements are applicable to the loading of the heat source into the MHW-RTG. A sophisticated pumping system and gas management system (scrubber, etc.) such as that used for the MHW-Loading Assembly Station, may be required to maintain the required environment.

In-Orbit Fuel Loading

The on-pad heat source loading concept shown in Figure 3.3.1-1 can also be used for in-orbit loading. In order to reduce weight, the transfer box can be replaced by standoffs since environmental control is not needed in the space vacuum environment. If the necessary manual operations needed to complete the loading cannot be performed, a remote loading design will have to be considered. It is recommended that a study be made to define the in-orbit loading requirements and the cost to achieve such a capability.

3.3.2 HEAT REJECTION SUBSYSTEM

The 3.5 watt/lb weight requirement eliminates the use of an aluminum radiator in the Reference Design. Results shown in Section 6.4.3, Volume II, indicate that a substantial weight savings can be realized with a beryllium radiator. However, an effort must be initiated during Phase I to demonstrate the resistance of present-day beryllium to shattering under hypervelocity impact and to withstand launch loads, while maintaining its leak tight integrity, for the flight radiator design geometry.

Beryllium radiators have been studied by NASA-Lewis* and General Electric** over the past 10 years. Initial evaluations indicated that although beryllium could be fabricated in appropriate radiator configurations, the material was susceptible to shattering under hypervelocity impact. Therefore, the utility of a beryllium radiator in the micrometeoroid environment of space was questionable. Figure 3.3.2-1 illustrates the effect of 0.08 gm aluminum projectiles fired at 36,000 ft/sec at 1/8 inch thick beryllium target materials; these tests were conducted at the General Electric Morgantown, Pa., facility.

More recently, the micrometeoroid impact capability of beryllium was evaluated in conjunction with the MHW-RTG program for potentially hazardous missions such as Grand Tour. The first of two sets of hypervelocity impact tests were conducted at NASA-Langley.

The geometry of these targets is shown in Figure 3.3.2-2. The targets were heated to 500° F*** and impacted with nylon projectiles; a typical result of these tests are shown in Figure 3.3.2-3.

A second series of tests were conducted at Wright-Patterson Air Force Base with aluminum sphere projectiles. These tests were conducted at 500° F and also at room temperature.

*Lieblein, S. Diedrich, J. H., "Material and Geometry Aspects of Space Radiators" Nuclear Applications, Vol. 3, February 1967.

**Hagen, K. G., Woldstad, R. N., Terrill, W. R. and Bilodeau, D. E., "Radiator Design and Development for Space Nuclear Powerplants", G. E. TIS 64SD224A, Feb. 1964.

***The IBS radiator will operate in the 50° - 250° F temperature range.

Figure 3.3.2-1. Photo of:

- 1) Recoverable 1/8" thick pieces from shot #1120 are shown on right, and
- 2) Shattered remains of shot #1121 are shown on back-up plate

Figure 3.3.2-2. Beryllium Hypervelocity Impact Specimens

Figure 3.3.2-3. "Beryllium Does Not Shatter"
AEC/General Electric, Circa 1970

In all cases, whether the target was heated or cold, there was no shattering or cracking. Obviously, these results lend support to pursuing this technology for the IBFS radiator.

During the recent Brayton ERTG Study (AEC Contract SNSO-6) current beryllium fabrication technology was assessed and a radiator fabrication procedure was developed which was compatible with the IBS design. An illustration of an example section of a radiator panel is shown in Figure 3.3.2-4.

In light of the apparent progress made in beryllium it is recommended that this technology be pursued for the Reference Design; however, during Phase I a program must be initiated to verify the feasibility of this approach. The following is recommended for Phase I:

1. Perform hypervelocity impact tests on a representative beryllium radiator geometry.
2. Further evaluate beryllium fabrication techniques pertinent to a radiator configuration.

Figure 3.3.2-4. Brazed Beryllium Radiator Panel

3. Assess the ability of a beryllium radiator to maintain its leak tight integrity under SURVSATCOM Mission launch loads.

3.3.3 BI-METALLIC JOINTS

Bi-metallic joints will occur at the high and low temperature sections of the system. In the high temperature section, refractory-to-superalloy joints are required. In the low temperature section, beryllium-to-stainless steel joints will be required. Both of these types of joints have been made by the General Electric Company on previous programs; however, the ability to apply these joining techniques in the IBFS geometries must be demonstrated.

3.3.3.1 High Temperature Section

One refractory-to-superalloy joint will occur at the HSA inlet port. This joint will be made during the HSA development program; therefore, eliminating one refractory-to-superalloy weld during the GDS Assembly.

The location of the second high temperature joint depends upon the decision to have a refractory or superalloy turbine plenum. If a superalloy turbine plenum is used, General Electric will provide a second refractory-to-superalloy bi-metallic joint on the HSA during the NASA development program, thereby, eliminating the need for refractory-to-superalloy welds during the GDS assembly.

If a decision to use a refractory turbine plenum is made, then a refractory-to-superalloy bimetallic joint will be required at the turbine exhaust nozzle.

3.3.3.2 Low Temperature Section

The recommended radiator material for the IBFS is beryllium; this decision is based upon the stringent weight objectives listed in Table 6.2-1.

The radiator must be joined by connective ducting to a Hastelloy-X recuperator and to a 347 compressor inlet port. Stainless steel ducting was assumed to be the preferred material on the basis of:

1. Beryllium-to-SS joints have been made
2. Hastelloy-X to-SS joint is easily made
3. The compressor inlet port is made of SS

A discussion of General Electric experience in Be to JJ joints is presented in Section 6.5.5.4, Volume II.

3.4 SUGGESTED CHANGES IN SCOPE

General Electric Space Division has not identified any necessary changes in scope for the Isotope Brayton Program.

3.5 REQUIRED EQUIPMENT AND FACILITIES

3.5.1 GROUND SUPPORT EQUIPMENT

Ground Support Equipment provided in the Phase I GDS program (reference Section 3.1.5) will be utilized to the maximum extent possible in the Phase II Program. These equipments will be modified and upgraded as necessary to support the Phase II testing activity.

Additional GSE will be provided by GE in Phase II to support the ground test flow (reference Section 3.2.11) for the System Development Model (SDM) and Qual IBFS hardware as outlined in Table 3.2.11-1. During Phase II, these equipments will be maintained and upgraded from development through qualification to reflect requirement changes during the system design process. Table 3.5.1-1 presents a summary of the GSE equipment utilization in the SDM development and IBFS qualification test flow. Equipment provided by the Phase I program (Section 3.1.5) will be integrated into the test matrix as shown. Characteristics of the GSE provided in throughout the Phase I and Phase II are as follows:

1. EHS Power Supply Console - Test operations involving environmental temperature testing of the HSA (i.e. vibration and thermal vacuum) as well as orbital performance and endurance testing require a console supplying controlled electrical power to each EHS to encompass performance testing between 2400 and 7200 watts thermal output of the EHS. Three consoles will be delivered to AIRPHX to provide the following type of functions:
 - a. Provide, maintain and control input power to each EHS.
 - b. De-energize power input to the EHS upon command from readout devices which sense out of tolerance parameters.
 - c. Measure EHS input current and voltage.

Table 3.5.1-1. GSE Assembly and Test Utilization Matrix

<div> <div>Test Operation</div> <div>GSE Equipment</div> </div>	Component						System													
	Performance	Vibration	Acoustic	Pressure	Thermal Vacuum	Pack & Ship	Final Assembly	Pressure	Performance	Vibration	Shock	Acoustic	Static Load	Mass Property	Spin Balance	IHS Demonstration	Vacuum Leak	Thermal Vacuum	Dynamic Momentum	Alignment
<u>Electrical</u>																				
EHS Power Supply Console	X	X			X	X			X								X	X		
Read-Out Console	X	X			X				X								X	X		
Electronic Test Set	X	X			X	X			X								X	X		
Data Handling									X	X	X						X	X		
<u>Mechanical</u>																				
EHS Loading Fixture		X			X	X														
Pressurization Leak Test Kit				X				X									X			
ACS Gas Management	X	X			X	X														
Safety Alarm Console	X								X									X		
Handling Dolly							X	X	X	X	X		X	X	X	X	X	X	X	X
Handling Sling							X	X	X	X	X		X	X	X	X	X	X	X	X
Turnover Fixture							X	X	X	X	X		X	X	X	X	X	X	X	X
Access Stands							X			X						X				X
IHS Handling Sling							X													
IHS Envir. Canister		X			X					X								X		
HSA Handling Sling	X	X	X	X	X	X														
Power Console Ship. Container						X														
IHS Portable Load Fix							X									X				
Mobile ACS							X									X				
<u>Component Test Equipment</u>																				
HSA Acoustic Fix			X																	
HSA Vib Fixture		X																		
HSA TV Fixture					X															
<u>Special Test Equipment</u>																				
Momentum Bal Fix																			X	
Thermal Vacuum Fixture																	X	X		
Vibration Test Fix										X										
Static Load Fixture													X							
Mass Property Fixture														X						
Spin Balance Fixture															X					
Dummy HS							X		X	X	X		X	X	X					
Shock Test Fixture											X									
Alignment Fixture Adapter							X													X
<u>GFE Equipment</u>																				
System Gas Management Unit									X								X			
IHS Ship. Cask	X	X			X											X	X			
IHS Loading Fixture	X	X			X											X				
RTG Loading Station	X	X			X											X				
HSA Shipping Container						X														

Design of these consoles capable of performing the functions identified have currently been fabricated and used in testing at GE on the MHW-RTG program (reference Figure 3.5.1-1).

2. Readout Console - Testing of the Mini-Brayton system requires a readout console capable of performing the following functions:
 - a. Maintenance and control of an external variable RTG load.
 - b. Readout device to convert temperature sensor voltages, pressure pick up and BRY electric output into meaningful engineering data.
 - c. Circuiting and voltage reading device to measure current and voltage.
 - d. Readout device to measure and record test support auxiliary instrumentation.

The readout consoles constitute a new design similar to those which have been certified and are in use on the MHW program (Figure 3.5.1-2).

3. Data Handling Equipment - Data handling and acquisition system will be procured to accurately process test data into meaningful parameters from thermocouples, pressure instruments, and other test data instrumentation monitors. The equipment will have capability to time log and record up to 500 channels of input data at various selectable scan rates and record data on a suitable output medium computer processing equipment. The equipment will be utilized to establish test conditions, permit facility checkout and monitor operations during testing.
4. Safety Alarm Console - During testing operations a safety alarm console is provided to protect the primary equipment from test overload and malfunctions within the equipment. Functions of the alarm console consist of:
 - a. Monitoring critical threshold pressures and temperatures within the system power conversion loop
 - b. Providing auxiliary overrides and provisions for automatic pressure dump and power dump to the EHS thereby causing shut down of the system.
 - c. Interfacing directly with the Gas Management Unit, Readout console and data handling equipment

Figure 3.5.1-1. EHS Power Supply Console (Left) RTG Readout Console (Right)

Figure 3.5.1-2. Readout Console

5. Handling Slings and Equipment - The following handling slings and equipment will be provided in support of the component, assembly and system test flow:

- a. Handling Dolly
- b. Mini-Brayton Handling Sling
- c. EHS Loading Fixture
- d. HSA Handling Sling
- f. Turnover Fixture
- g. Access Stands
- h. Pressure Lear Test Kit
- i. IHS Handling Tool
- j. HSA Environmental Canister
- k. Power Console Shipping Container
- l. IHS Portable Loading Fixture
- m. Mobile ACS

This equipment is provided to perform the following functions:

- a. Transport of the Mini-Brayton System from one test area to another.
- b. Rotation of the assembly between vertical and horizontal orientations.
- c. Transport and loading of the EHS and IHS onto the test setup.
- d. Maintain storage and protective environment for the IHS and HSA loaded with the IHS.

The IHS is provided as GFE and comes self contained within its own storage protective container designated as the IHS shipping Cask which is also assumed as GFE. The first six items are conventional in-station handling tools for transporting and setting up the Mini-Brayton RTG assembly in the test configuration. Following is a description of the remaining items of special usage equipment.

The Pressure Leak Test Kit will be a commercial, laboratory-type mass spectrometer used in conjunction with a plastic enclosure. It will be designed to be air-tight and will enclose the pressurized test unit. The mass spectrometer sensitized to detect helium leakage will be attached to the enclosure and will measure leakages as low as 1×10^{-10} Torr.

The IHS Handling Tool is essentially a three-legged sling used to install and remove the IHS from the IHS shipping Cask. Its function and design is essentially the same as used for similar purposes on the MHW.

The HSA Environmental Canister is used to transport the HSA containing a loaded IHS between the HSA loading station and in-house test facilities. The container is closed to maintain protection from environmental elements and vented with a self-contained circulating system to reject heat generated by the HSA. The container wall will have provisions for nuclear radiation shielding by means of either water and/or paraffin encapsulated cells. The container contains provisions for measurement, readout and control of temperature and pressure within the HSA and IHS with provisions for periodic venting of helium from the IHS.

Power Console Shipping Containers are provided for each power supply console. Containers will be designed in a conventional manner providing support and cushioning to the equipment and contain dessicants as necessary to protect the equipment from moisture. Containers will be designed for handling by conventional fork lift and/or sling, and will be subjected to normal handling rotational packaged drops.

Shipping containers for the HSA are assumed to be provided as GFE in Phase I.

The IHS Portable Loading Fixture, discussed in Section 6.3.3, Volume II, will be designed to provide for loading the IHS and assembling the HSA on site at the pad. As such, the unit is completely sealed to accept inert gas environments during the glove box assembly process. During Phase II, the unit will be used to perform similar functions within the in-house test flow. A live Heat Source demonstration program is planned in the SDM test flow making use of an electrical heat source to simulate actual loading conditions. As such, the training methods and check out of the equipment will be completely performed in Phase II. It is currently planned to accomplish loading of the fixture with an IHS in the currently existing MHW-RTG Loading Assembly station and deliver the IHS contained in the Portable Loading Fixture to the launch site for field installation. The fixture as designed will provide the following functions.

- a. Mounting and self containment of the IHS within the fixture.
- b. Maintaining sealed inert gas environments and storage protection of the IHS, including shielding for on-pad installation.

- c. Align IHS and Fixture with unassembled HSA conister housing.
- d. Provide loading and assembly tools for complete assembly of HSA within a glove box operating environment.
- e. Interface with the Mobile ACS.

The Mobile ACS is a portable and mobile gas management system for the ACS environmental control to the HSA which interfaces directly with the IHS Portable Loading Fixture. Its function is to provide

- a. Evacuation of the portable load fixture containing the HSA housing.
 - b. He-Xeon Gas Purification and Supply to the Portable Load Fixture.
 - c. Monitoring and control of temperatures and pressure within the Portable Loading Fixture and the self-contained IHS.
 - d. Provisions for monitoring of gas pressures internal to the IHS and periodic bleed off as required.
6. Component Test Equipment - Before delivery of the GFE HSA assemblies to AIRPHX proof pressure, leak and acoustical vibration testing is performed on the HSA to certify the design integrity prior to usage in the system test. The following holding and mounting fixtures adaptable to the GE test facility equipment will be fabricated to support these tests.
- a. Pressure Leak Test Kit
 - b. Acoustic Fixture
 - c. Vibration Test Fixture
7. Special Test Equipment - System level special test equipments are provided in support of the Qualification and SDM development test. Characteristics of these equipments are as follows:
- a. The Momentum Balance Fixture provides elastic support to the Mini-Brayton system vertically oriented in the fixture. Mass Counter balances are provided to simulate free space zero "G" effects on the IBFS. Means are provided within the elastic foundation to monitor and record dynamic imbalance effects at Spacecraft Interface of gyroscopic forces during BRU start-up and system operating modes.

b. The Thermal Vacuum Fixtures consists of instrumentation and equipment contained within the GE 10x12 foot vacuum facility during thermal vacuum testing. Function of the equipment consists of:

- (1) Mounting of the MB-RTG within the chamber
- (2) Simulation and control of orbital transient temperature conditions by means of IR lamps and controls
- (3) Providing means for heat rejection of the space radiator to nitrogen cooled chamber walls
- (4) Interfacing with other GSE test equipment

The Thermal Vacuum Fixture supports the spacecraft during thermal vacuum tests. The fixture will be based on an existing design used on Nimbus and ERTS programs and will interface with the 10x12 foot vacuum chamber. It will include an IR array controlled from Research Incorporated solid state controllers.

The Vibration Test Fixture Adapter provides a round mounting arrangement simulating the MB-RTG to Spacecraft interface. The fixture interfaces with the laboratory C-220 shaker facility with provisions for three axis sine random vibration inputs.

The Vibration Fixture will be used for both vibration and launch shock. The Mini-Brayton assembly will be maintained in a vertical orientation for all vibration and shock testing. For vibration and launch shock, the assembly will be attached to the vibration fixture through the prime mounting holes in the interface mounting ring. The Vibration Fixture is attached directly to the head of the shaker for vertical vibration and is supported on team bearings and attached to the head of the shaker (rotated 90 degrees) for X and Y axis vibration. The vibration fixture will modify an existing unit which was designed for the Nimbus spacecraft and has been used for both Nimbus and ERTS spacecraft tests.

The Static Load Fixture consists of loading tree fixtures and a strongback adapter which interfaces between the laboratory strongback and the GDS/IBFS Structure Assembly. The Strongback and the Strongback Adapter set will be used only in conjunction with the static load test of the Structural Dynamic Model (SDM). The Laboratory Strongback is a box frame, made up of 14 inch I-beams with a length of 14 feet on each side. The Strongback Adapter set consists of brackets that support the SDM/IBFS in the Strongback and the group of wiffle trees used to apply the required load patterns to the structure.

The Mass Property Fixture provides interface mounting between the GDM/IBFS system and the Miller Research Mark III facility for determining weight, center of gravity and mass moment of inertia characteristics of the assembly. The Mass Properties Fixture will support the GDM/IBFS Assembly either vertically or horizontally on the mass properties measurement system at VFSC. The fixture will be used during both mass properties measurement and operational spin balancing tests. The fixture design consists of a truncated cone with flanges at both ends for vertical support, and a yoke for horizontal support.

The Alignment Fixture and supporting equipment is used in conjunction with the GDM/IBFS Assembly cycle to align the BRU turbine axis with the spacecraft reference axis. The fixture will be designed to interface with an existing +8-inch diameter rotary table used on Nimbus/ERTS Programs. The Alignment Equipment will be used to perform the alignment of the turbine axis. This Equipment will consist of optical tooling bars, transits, alignment scopes, precision levels, and targets, which are all commercial equipment presently available at VFSC.

8. GFE Support Equipment - Several items of equipment needed to support the Phase II Test Flow are considered to be Government or Contractor-furnished items. These consist of:

- a. System Gas Management Unit - AIRPHX
- b. IHS Shipping Cask - AEC Fueling Agency
- c. IHS Loading Fixture - GE MHW
- d. RTG Assembly Station - GE MHW
- e. HSA Shipping Container - NASA - Heat Source Assembly Technology Program

Functional description and user of these equipment are as follows:

- a. System Gas Management Unit - A gas management unit is required to support system test operation and provide the following functions:
 - (1) Means of evacuating and purging the system gas pressure control loop through the BRU/HSA and associated ducting
 - (2) Purifying, filling, and pressurizing the Helium-Xeon system
 - (3) Maintaining controlled gas management pressure during operational performance testing

- (4) Maintaining auxiliary pressure dump safing provisions as interfaced with the Safety Alarm Console monitor

It is assumed this equipment will be provided to GE by AIRPHX as a spinoff of the Phase I GDS test program activity.

- b. The Heat Source Shipping Cask is assumed to be provided to the IBFS Program or Government-Furnished Property (GFE) in conjunction with the IHS. The unit is currently furnished in a like manner to the MHW Program by Mound Research Center (MRC). The container is designed to provide inert atmospheric and nuclear safe storage protection for an Isotopic Heat Source Assembly.
- c. The IHS Loading Fixture is part of the MHW-RTG Loading and Assembly Station. This facility for loading the RTG is currently certified in place facility for the MHW-RTG Program and will also be used for loading the IBFS-IHS in the HSA in a similar manner. The purpose of the Loading Fixture in conjunction with associated interface equipment in the loading station is to:
 - (1) Remove the IHS from the IHS Handling Fixture.
 - (2) Locate the IHS over the graphite emissivity sleeve and lower into the sleeve for final installation.
 - (3) Lift and transport the assembled IHS and sleeve to the HSA and install in the HSA.
 - (4) Remove the IHS or EHS from the HSA.

The fixture physically attached to the three lifting lugs located on the IHS flange. It is equipped with a motorized system that provides for 24 inches of vertical motion within $\pm .001$ inch. The latter is attained by use of a digital control system. Emergency movement of the fixture in the event of power failure is provided by a manual backup.

The fixture has a total capability of 30 inches vertical travel, 360 degrees rotation and ± 2 inches radial movement within $\pm .001$ inch when combined with the loading station.

RTG Tooling and Assembly Station (RTG-LAS) - Protection experience on the MHW-RTG program has provided GE with a unique facility with trained personnel for the handling and loading of the IHS within the HSA which is directly adaptable to the Mini-Brayton Program.

A description of the facility follows:

The RTG Loading and Assembly Station's (Figure 3.5.1-3) purpose is to provide an area in which an IHS can be loaded into a converter in a controlled inert gas environment. The inert gas prevents oxidation of such components as the graphite emissivity sleeve and converter thermal foil insulation in addition to other sensitive components. The second major purpose of the station is to provide a capability for processing (outgassing) the converter in a vacuum environment after installation of a heat source. The basic design for the MHW-RTG program is predicated on the following requirements:

- (1) Removal of the Isotope Heat Source (IHS) from the Storage Container (SPC)
- (2) Inspection of the IHS
- (3) Installation of the graphite emissivity sleeve over the IHS outer clad
- (4) Removal of an Electric Heat Source (EHS) from the converter
- (5) Installation of the IHS into converter
- (6) Application of heat source support pre-load
- (7) Processing of the converter in an oil-free vacuum environment
- (8) Final assembly of the RTG

The station design is such that the sequence previously identified is completely reversible.

The utilization of this RTG loading facility for the IBFS program, including definition of required modification, will be evaluated in the IBFS program.

3.5.2 FACILITIES

GE has all the necessary facilities required to perform the fabrication assembly test and checkout of the Mini-Brayton RTG on location at the Valley Forge Space Center. These include currently in-place nuclear certified facilities for handling and loading Isotopic Heat Sources (IHS) such as the MHW-RTG, as well as vibration and thermal facilities for testing of IHS components and HSA assemblies. With minor modification,

Figure 3.5.1-3. RTG Testing Station

potential also exists for nuclear vibration and thermal testing of the GDM/IBFS containing an IHS, should such an approach be deemed desirable.

No unique facility requirements are needed to support the GDS program phase. All laboratory and test equipment necessary to conduct the tests are currently in place within GE. Table 3.5.2-1 presents a summary matrix of the Test Facility usage and characteristics as they will be used to support the test program.

Table 3.5.2-1. VFSC Test Facility Characteristics

Level of Assembly	Test Requirement	Test Phase		Test Facility	Location	Facility Status	Comments
		I	II				
System	Thermal Vacuum		II	Component Test Laboratory Thermal Vacuum Chamber Size: 10' dia x 12' long Vacuum 1×10^{-7} Torr Pumping Mechanical Blower LN ₂ Trapped DP's Temperature LN ₂ walls & IR heating	VFSC Building 100	Existing	
System	Vibration & Shock		II	Dynamic Simulation Laboratory Dual MB C-220 Vibration System Force Rating Sine 70,000 lb Random 70,000 lb Displacement 1" peak to peak Auxiliary table Team hydrostatic bearings Instrumentation Acquisition: 100 channels Storage Wideband FM mag tape Reduction 10 channels real time	VFSC Building 400	Existing	Can be modified for nuclear certification
System	Mass Properties Spin Balance		II	System Test Laboratory Table size: 24 inch dia Capacity: 5000 lb Speed: 500 rpm MOI & POI: $\pm .039$	VFSC Building 100	Newly Acquired	Capital expenditure for Broadcast Satellite Experiment
System	Static Test		II	Dynamic Simulation Laboratory Strongback Size: 14' x 14' x 25' H	VFSC Building 400	Existing	
System	Alignment		II	Final Assembly Area 48 inch diameter rotary table Tooling bars Optical tooling	VFSC Building 400	Existing	
System & HSA	Acoustic	X	X	Acoustic Test Cell Type: Reverberant Size: 15'W x 20'H x 40'L Level: 155 dB re $\frac{.002 \text{ dynes}}{\text{cm}^2}$ Frequency: 20 to 10K Hz Power: 10,000 watts Data: 100 channels	GE-RESO	Existing	
System & HSA	Vibration		X	Dynamic Simulation Laboratory MBC-150 Vibration System Force Rating Sine: 17,500 lb Random: 17,500 lb Displacement: 1 inch Frequency: 5 to 3000 Hz Auxiliary team: 1830T	VFSC Building 400	Existing	Nuclear certified
HSA	Thermal Vacuum	X	X	Long Life Laboratory Thermal Vacuum Chamber Size 4' dia x 5' long Vacuum 1×10^{-8} Torr Pumping LN ₂ trapped mechanical blower ion Temperature LN ₂ & FREON walls	VFSC Building 300	Existing	Nuclear certified

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SECTION 4

PROGRAM ORGANIZATION AND PERSONNEL

The General Electric Company recognizes the need to provide a high level of technical and managerial competence to the IBS Program, particularly in the areas of high temperature heat source technology and in the design, development and fabrication of space flight hardware. To provide this competence, General Electric has organized and committed a team which is fully qualified and knowledgeable through experience in a number of related programs, the most recent of which are:

- Mini-Brayton Heat Source Assembly (HSA) Design Study, NASA-Lewis.
- Mini-Brayton HSA Design, Development, Fabrication & Test Program, NASA-Lewis.
- Mini-Brayton Economic RTG Study, AEC.
- MHW-RTG Program, AEC.
- SUBVSATCOM Electric Power Subsystem (SEPS) Study, USAF/ESD.

4.1 PROGRAM ORGANIZATION

4.1.1 POSITION WITHIN CORPORATE STRUCTURE

The IBS program will be implemented in the Advanced Energy Programs (AEP) operation of General Electric's Space Systems Department. This Department is part of the Companys' Space Division which belongs to the Aerospace Business Group. The Aerospace Business Group is one of ten major business entities which comprise the General Electric Company. This organizational structure is illustrated in Figure 4.1-1.

4.1.2 ADVANCED ENERGY PROGRAMS OPERATION

As shown in Figure 4.1-2, the Advanced Energy Programs Operation consists of five sections under the direction of Mr. B.J. Tharpe. Mr. Tharpe has designated Mr. W.Z. Prickett as Program Manager of the Isotope Brayton Systems Program. In this capacity Mr. Prickett will report directly to Mr. Tharpe.

Figure 4.1-1. Position of Space Systems Department in Corporate Structure

Since 1970, Mr. Prickett has been Manager of Advanced Nuclear Programs. In this capacity, and since joining Space Division in 1966, he has managed or contributed to a wide spectrum of nuclear space power studies, including:

- Isotope thermoelectric systems
- Isotope and reactor thermionic systems
- Nuclear electric propulsion systems
- Isotope Brayton dynamic systems
- Other isotope dynamic systems (Rankine, Stirling).

His activities have included system preliminary design and optimization, spacecraft integration, flight safety, and system

Figure 4.1-2. Advanced Energy Programs Organization

detail design, development and operation. He has evaluated system development cost and flight system unit cost during studies and proposals for advanced flight systems.

From 1956 to 1966, Mr. Prickett had a number of engineering assignments in the General Electric Aircraft Nuclear Propulsion Department and its successor, the Nuclear Propulsion and Materials Operation. He was a design engineer on the 710 Reactor Program for space power and propulsion applications. He attended the Oak Ridge School of Reactor Technology in 1958.

Mr. Prickett will have complete and singular authority and responsibility for the planning, direction, and control of all activities for the IBS Program. He will provide AIRPHX and the AEC with a single responsive point of contact within General Electric for the effective achievement of all performance, cost, and schedule objectives of the program. Through Mr. Tharpe, Mr. Prickett will have access to higher General Electric Management through established management channels for any and all required support and resources.

4.1.3 KEY PROGRAM RELATIONSHIPS

General Electric is currently conducting two programs which have important relationships to the Isotope Brayton Systems Program — the NASA-LeRC HSA Program and the AEC Multi-Hundred Watt Program. Figure 4.1-3 shows the close organizational relationship between these three programs and the benefits the Isotope Brayton Systems Program will derive from this relationship.

The Isotope Brayton Heat Source Assembly development program being conducted for NASA-LeRC and GE under Contract NAS3-18541 is also assigned to the Advanced Energy Programs Operation. This provides concentration of all GE Brayton activities to assure an integrated GE effort in support of the prime AIRPHX IBFS Program.

The focus of the total GE Isotope Brayton effort within Advanced Energy Programs provides both separate upper management participation in the IBS Program, and ready access and utilization of the MHW-RTG heat source developed for the AEC by GE, including any improvements associated with the use of this heat source technology in the NASA-JPL Mariner J/S mission.

Approach. General Electric Company will support AIRPHX in preparing the Phase III Plan. This plan will be consistent with user requirements.

The program plan will present detailed task descriptions, schedules, test plans, facility requirements, and costs for conducting Phase III of the program.

Output. The output of this task will be GE inputs for detailed document containing the plan to implement Phase III.

Schedule. The schedule for accomplishing this task has been presented in Figure 3.2.C-1.

An example Phase III program is summarized in Section 3.2.14.

3.2.14 • Flight System Production - Phase III

3.2.14.1 Program Summary

The Phase III Program has as its objective the production of flight qualified IBFS systems. It is planned that these systems will be produced at a rate of four systems per year.

Figure 4.1-3. Key Program Relationships

General Electric, having delivered extremely successful SNAP-27 flight systems and this assures complete technology exchange and utilization between the IBFS Program currently working on the LES 8/9 and M55 MHW flight programs, is capable of and the AEC MHW-RTG programs, LES 8/9 and Mariner J/S, emphasizing the MHW-RTG isotope heat source technology and safety, and including spacecraft integration provided during Phase I and II, GE would perform the following activities during Phase III.

1. Provide systems liaison and integration.

As the IBFS program progress toward flight status, it is planned to re-assign the program within Mr. R. J. Katucki's Nuclear Programs Operation (see Figure 4.1-3);

2. Fabricate Isotopic Heat Sources.
3. Fabricate heat rejection systems and HSA's near the end of the Phase I IBFS program, or at the initiation of the Phase II effort.

The key transfer function is expected to be the DOD/USAF requirement for the IBFS for the SURVSATCOM mission.

4. Conduct system acceptance testing.
5. Provide safety support.
6. Provide design support and evaluation.

4.1.4 GENERAL ELECTRIC ISOTOPE BRAYTON SYSTEM PROGRAM ORGANIZATION

The GE organization established to support AIRPHX in the Isotope Brayton program is shown on Figure 4.1-4. The GE Program Manager is supported by:

1. Space division functional organizations established to support space nuclear power programs in the areas of engineering, manufacturing, and quality assurance.
2. Space Division Nuclear Programs office in the area of aerospace nuclear safety.
3. All necessary assistance from Space Division Contracts and Finance, and from the GE Project Control Function, which assists the Program Manager in developing detailed program plans and measures of technical, cost and schedule performance, and which assists in the measurement and evaluation of actual performance vs. planned performance.

General Electric Space Division functional organizations are established and operating to support the demonstrated current and long term Division management support and interest in space nuclear power. Established outer planet and probable earth orbital

Figure 4.1-4. GE Isotope Brayton System Program Organization

mission requirements are recognized. Economics, competitive with solar power and related spacecraft integration costs, is clearly identified as the key to the use of nuclear power in earth orbital applications. These applications include both DoD and commercial utilization, upon the demonstration that cost effective space nuclear power can be achieved through the isotope Brayton technology.

Within the Space Division functional organization, key personnel have been assigned to support the isotope Brayton program for AIRPHX. These include talents particularly required for this Brayton technology implementation, as well as those developed within the GE Space Division with broad capability in space nuclear power programs.

One notable application is the use of the nuclear safety technology and expertise developed for the AEC by Mr. Katucki's Nuclear Programs Operation, for the AEC MHW-RTG heat source. This heat source technology has prime application to the Isotope Brayton Program. The participation of the Nuclear Programs Operation in this key safety area assures AIRPHX and the AEC of full and complete technology transfer to the Isotope Brayton Program. This will be accomplished with no impact on the current MHW-RTG programs being conducted by the GE Space Division for the AEC.

4.2 PERSONNEL QUALIFICATIONS

The assigned personnel, their current security clearance status, and the approximate percentage of time to be devoted to the Isotope Brayton Program (by quarter) is summarized on Figure 4.2-1 for the key GE personnel previously shown on the GE program organization, Figure 4.1-4.

Mr. W.Z. Prickett, the GE Program Manager will be assigned full time to the program during the first five quarters of the program, April 1, 1975 through June 20, 1976. This covers the bulk of the GE Program in support to AIRPHX, the conceptual IBFS and GDS design, and the fabrication of GE supplied hardware, GSE, STE and its installation in the integration with the GDS. Program economies reduce Mr. Prickett's participation to about 50 percent after the initiation of the GDS performance tests, and to about 20 percent during the first half of CY 1977, unless a DOD requirement letter results in program acceleration beyond the scope of this proposal. During

			FY 75		FY 1976 PLUS 3				FY 1977			FY 78				
			CY 1975				CY 1976				CY 1977					
KEY PERSONNEL	PROGRAM RESPONSIBILITY	SECURITY CLEARANCE	QUARTERS													
			2	3	4	1	2	3	4	1	2	3	4			
W. PRICKETT	PROGRAM MANAGEMENT	Q	100				50				20				PERCENT OF TIME DEVOTED TO PROGRAM	
R. KILLEN	SYSTEM ENGINEER	Q	100				20									
R. BEVERLY	MANUFACTURING	DOD	50				10									
T. BRADSHAW	NUCLEAR SAFETY	Q	10													
P. BROWN	RADIOISOTOPE FUELS	Q	20	50				20								
J. BUNKER	HEAT SOURCE DESIGN AND DEVELOPMENT	Q	50				10									
R. FULLER	GDS TEST SUPPORT	DOD					50				20					
M. HAMMER	QUALITY ASSURANCE	DOD	30				10									
J. LOFFREDA	NUCLEAR SPACECRAFT INTEGRATION AND MATERIALS	Q	20	50												
R. McCARTHY	HEAT REJECTION SUBSYSTEM DESIGN	DOD	50	100												
H. STRAUB	GSE AND SPECIAL TEST EQUIPMENT	L	50													
R. TURBYFILL	SPACECRAFT INTEGRATION AND IBFS DESIGN	DOD	25	50				25								

Figure 4.2-1. Key Personnel Responsibilities and Participation

the last year of the Phase I program, Mr. Prickett will be primarily concerned with test data related to IBFS definition, the performance of GE hardware in the GDS test, and long term GE development items such as heat source and beryllium radiator technology.

Mr. Killen, the GE System Engineer, will be assigned full time to the program during the first five quarters, also. Mr. Killen has been Program Manager of the Mini-Brayton Economic RTG Study conducted for the AEC by GE in 1973, and was a major contributor to the SURVSATCOM Electrical Power Subsystem (SEPS) study conducted for the USAF Electronics System Division by GE in 1974, and has been a major contributor to the IBFS preproposal and proposal efforts.

Messrs. Turbyfill, McCarthy, Loffreda and Bunker, under the leadership of Mr. Killen will be responsible to Mr. Prickett for providing primary definition of the Conceptual IBFS design for AIRPHX during the first quarter of the program. These same key personnel will support AIRPHX in the definition of the preliminary and final GDS design.

Mr. Beverly will participate primarily (50 percent) in FY 1976, when the GE manufacturing activities in support of AIRPHX are at their peak. Similarly, the quality assurance activities of Mr. Hammer are greatest (30 percent) during this same period. Mr. Hammer's current responsibilities under the AEC MHW-RTG program will not conflict with his participation in the Isotope Brayton Program in this time frame. His MHW-RTG program experience will enhance the value of this program to AIRPHX and the AEC.

Mr. McCarthy will have primary responsibility for the Heat Rejection Heat Exchanger (HRHX) design, and will support the development efforts directed toward the flight radiator.

Mr. Bradshaw's commitments to the AEC MHW-RTG program do permit his desirable participation in the Isotope Brayton Program, as to the direction and scope of the safety effort, about 10 percent. The actual work will be performed by supporting personnel. His current responsibility for the AEC MHW-RTG heat source safety evaluation and analyses, together with its projected use in IBFS applications, assure a cost effective safety assessment of the AEC MHW-RTG heat source technology in this application for AIRPHX and the AEC.

Mr. Bunker, together with Mr. Brown, provide the lead capabilities to incorporate the AEC MHW-RTG heat source in the IBFS, and to direct related, long lead, heat source technology improvements as identified in this proposal (Volume I, Paragraph 3.1.9).

Mr. Straub will be responsible for the design and development of all GE GSE/STE supplied to AIRPHX. His participation is about 50 percent during the first year of the program.

Mr. Fuller is designated as the GE on-site representative during the GDS ground test to assist AIRPHX, as required, in the installation, checkout, and operation of GE supplied hardware. His maximum participation (about 50 percent) is expected to occur during the GDS checkout and performance tests. Mr. Fuller will be available, as required by AIRPHX, during the GDS endurance test activity.

These key GE personnel assignments for the Phase I GDS development and test assure AIRPHX, and the AEC, of experienced, demonstrated performance on the Isotope Brayton Program. These personnel maximize the technology transfer from previous and on-going space nuclear power programs. This will be accomplished at minimum cost, and with no identified impact on the AEC MHW-RTG program.

4.3 RESUMES

Key personnel assigned to the GE Isotope Brayton Program are presented in Paragraph 4.3.1.

Key GE personnel currently assigned to the AEC MHW-RTG program are presented in Paragraph 4.3.2. Although their current commitments prevent their direct assignment to the GE Isotope Brayton Program, they constitute a resource of space nuclear power technology which is available to the GE Isotope Brayton Program personnel for consulting and advice.

W.Z. PRICKETT - Program Manager

Education

AE, Aeronautical Engineering, University of Cincinnati, 1956

MS, Engineering, University of Cincinnati, 1961

Oak Ridge School of Reactor Technology, 1958

Experience

The design and evaluation of advanced nuclear space power systems has been Mr. Prickett's responsibility since 1970. This work includes static thermo-electric and thermionic power conversion systems, and dynamic systems; Brayton, Rankine and Stirling, coupled with either radioisotope or reactor thermal energy sources. The scope includes preliminary system design, weight, power and efficiency definition and optimization, the electrical, thermal, nuclear, structural and dynamic aspects of spacecraft and launch vehicle integration. System development cost and unit cost assessments are accomplished, and preliminary nuclear safety aspects are assessed. Advanced power system comparisons are performed to establish the preferred system(s) for a wide range of evolving NASA and DOD missions. In this capacity, Mr. Prickett is responsible for the identification and recommendation of the next generation space nuclear power systems for development by General Electric, including direction of related nuclear Independent Research and Development Programs. Mr. Prickett also provides the necessary space nuclear power system support for all Space Division spacecraft and mission studies where such expertise is required.

From 1966 to 1970, Mr. Prickett managed or contributed to a wide range of nuclear space power system studies, including isotope and reactor thermionic systems, and their spacecraft integration and related nuclear safety. Mr. Prickett performed candidate MHW-RTG concept evaluations which led to the current SiGe Approach, and directed studies evaluating use of RTG units on the Voyager lander.

From 1961 to 1966, Mr. Prickett was a member of the Nuclear Materials and Propulsion Operation where he was responsible for the design and evaluation of advanced nuclear reactor powerplant systems. In this capacity, Mr. Prickett led a graduate Nuclear Engineering Reactor Design Seminar at Purdue University in 1964. Prior to 1961, Mr. Prickett was a staff engineer in the General Electric Aircraft Nuclear Propulsion Department where he participated in the evaluation of advanced gas cooled reactors.

R. E. KILLEN

Program Responsibility - System Engineer

Education

BS, Chemical Engineering, City College of New York, 1963

MS, Engineering Science, Rennsselaer Polytechnic Institute, 1966

Experience

Mr. Killen was program manager of the Mini-Brayton Economic RTG study, performed by General Electric for the AEC, as monitored and assisted by Mr. R. Carpenter. This successful program was accomplished with AIRPHX support, and contributed to the initiation of the AEC RFP SNS-75-1-CAO for this procurement.

Mr. Killen provided significant contribution to the recent SURVSATCOM Electrical Power Subsystem (SEPS) study conducted by General Electric for the USAF/AFSC, Electronics Systems Division, in the area of static and dynamic nuclear space power system options. His role in this program is expected to be of significant value in formulating the conceptual Isotope Brayton Flight System design to meet mission requirements. He has provided program management for the "Mini-Brayton Cycle Application to Outer Planets Class of Mission" being conducted for NASA-JPL by General Electric.

Mr. Killen has been involved in the development of space nuclear power for over 10 years. His activities include management and engineering responsibilities in the areas of space radiator development, reverse Brayton cryogenic refrigeration, and the SNAP-27 and MHW-RTG Programs.

Mr. Killen provided technical program management on NASA-Lewis' vapor chamber fin radiator development programs for the Brayton and Rankine systems. This program involved the design and test of low temperature heat pipes using fluids such as ammonia and high temperature heat pipes using sodium working fluid. These tests involved the use of accurate high temperature measurement techniques and multifoil insulation systems.

Mr. Killen was the responsible Space Division interface with General Electric's Corporate Research and Development Center for the reversed Brayton cycle cryogenic refrigerator for advanced space missions. Within this capacity, he was responsible for reversed Brayton cycle trade studies, system contamination evaluation, and the management of a successful Space Division IR&D program which developed the technology for a high effectiveness recuperator.

Mr. Killen has also had experience on the SNAP-27 and Multi-Hundred Watt Programs with specific efforts in the area of reentry and gas management systems.

Prior to joining General Electric in 1966 Mr. Killen was employed at Pratt & Whitney Aircraft, Reactor Engineering Group, at the Connecticut Advanced Nuclear Engineering Laboratory in Middletown, Connecticut. His responsibilities consisted mainly of conducting reactor parametric studies for the SNAP-50 reactor advanced Rankine power cycle. These studies were primarily concerned with reactor thermal and hydraulic analyses as well as nuclear considerations.

R. W. BEVERLY

Program Responsibility - Manufacturing Engineer responsible for Producibility, Fabrication and Assembly

Education

Mont Pleasant High School, Schenectady, New York
GE Apprentice Training Program
Drexel Institute of Technology

Experience

Mr. Beverly is responsible for design review for producibility, interface tooling requirements, fabrication/assembly techniques and methods. He provided manufacturing interface with Design Engineering, Product Assurance Engineering and customer counterpart on the following mechanical devices: Mariner 71 RCA System, ERT's Mechanical Devices, S-193 (Skylab) Articulated Antenna. He also directed manufacturing activities directed toward the development and fabrication of Nuclear Electric Propulsion stages.

From 1962 to 1965, Mr. Beverly was Manager, Planning and Tool Engineering, Space Vehicles and Structures. In this capacity he was responsible for all structure fabrication, mechanical assembly and standards for a classified program. He was responsible for final assembly of classified spacecraft and prime interface with Design Engineering, Product Assurance and Manufacturing Engineering.

From 1935 to 1962, Mr. Beverly was Manager, Planning Methods and Time Standards, at the General Electric Light Military Electronics Department, Johnson City, New York. He was responsible for all machining to support Gyro Manufacture, Engine Control Manufacture, Servoed Optical Sights and Antennas. At the GE Ordnance Department, Schenectady, New York, Mr. Beverly was responsible for design and fabrication of tools, dies and gear-checking fixtures.

C. T. BRADSHAW

Program Responsibility - Nuclear Safety

Education

BNE, North Carolina State College, 1952

Nuclear Safety Training Program, ORNL Reactor School, 1959

Graduate Study in Nuclear Engineering, Georgia Institute of Technology, 1964-65

Experience

Mr. Bradshaw, Manager - RTG Safety, is responsible for all nuclear safety activities associated with RTG Programs and at the present time is managing the nuclear safety program for the Multi-Hundred Watt RTG. He recently participated in the safety studies for the separately launched power module. Prior to these programs, he completed the nuclear safety evaluation and reporting for the SNAP-27 RTG system, resulting in Presidential flight approval for application of the system in the Apollo program.

Mr. Bradshaw's previous experience included six years at Lockheed's Nuclear Products Division where he was responsible for core physics and analysis, shielding studies, hazards analysis, and development of computer codes. In this position, he was responsible for the shielding and core designs for Lockheed-built reactor facilities and for the hazards analyses. Mr. Bradshaw also participated in the installation and startup of Lockheed-built reactors. In addition, his experience included work on the preliminary hazards analyses for the RIFT (Reactor In-Flight Test) project and in the design and safety evaluation of compact military power systems and propulsion reactors.

Mr. Bradshaw was employed at the Savannah River Plant prior to employment at Lockheed. His work included shielding studies, radioactive contamination problems, and design and development of special instrumentation used in radiation monitoring and fuel element failure detection.

P. E. BROWN

Program Responsibility - Radioisotope Fuel and Materials

Education

AB (Magna Cum Laude), St. Joseph's College

Graduate studies at Villanova University, University of Pennsylvania, University of Tennessee, Oak Ridge School of Reactor Technology, Graduate School of Nuclear Engineering (University of Washington - Richland, Wash.), International School of Nuclear Science and Engineering (Argonne National Laboratory), Pennsylvania State University

Experience

Mr. Brown has an extensive background in the areas of isotope and reactor power systems and associated technologies. Currently, he is involved in the management of a company-funded program to evaluate the practicality of a heat source using a ceramic fuel clad. This program is investigating fabrication techniques and impact protection requirements for this heat source concept.

Prior to this, Mr. Brown was a major contributor to the development of the MHW heat source. In the MHW-RTG program he coordinated the heat source development work at GE with the AEC fuels development, testing and production efforts at LASL, DWDL, and MRC/MIL. His activities focused on helium vent development, PuO₂ fabrication technology and materials compatibility evaluations.

Upon joining General Electric in 1963, he was given the responsibility for the direction of the design and development effort on SNAP-17B. He carried on the technical liaison with USAEC laboratories and GE Vallecitos Nuclear Center in the development and manufacture of the SNAP-27 heat source.

He had responsibility for liaison with USAEC laboratories supplying isotopic fuels and correlation of high temperature materials work with GE-Evendale and others.

Mr. Brown is a member of IEEE and Professional Technical Group on Nuclear Science, the ANS, the American Physical Society, and the AIAA, and was (1963-65) director of the Nuclear Industries Division of the Instrument Society of America. He is the author of numerous classified and unclassified technical reports and has presented over a dozen papers to national and international meetings of technical societies. He is also the author of Section 12, "Nuclear and Penetrating Radiation," in the Transducer Compendium, Plenum Press, 1963. In 1956 he was a U.S. Delegate to the Fifth Tripartite Conference on Nuclear Instrumentation.

J. F. BUNKER

Program Responsibility - Isotope Heat Source Design and Development

Education

BS, Mechanical Engineering, 1961

MS, Nuclear Engineering, University of Arizona, 1963

Experience

Mr. Bunker joined the GE Space Division in 1966 and has been engaged primarily in design and analysis of advanced radioisotope heat source systems. His primary work included:

- High temperature materials and fuels compatibility and effects
- Helium retention and release from radioisotopic fuel
- Heat Source integration with thermoelectric generator
- Heat Source safety, with respect to handling
- Heat Source shipping cask and ground handling hardware design

His previous AEC Program experience included SNAP-27 heat source and shipping cask design; and MHW heat source design, heat source/converter integration and storage protection container design.

Since 1972 Mr. Bunker has been lead engineer for heat source design, and has had overall heat source design responsibility for the application of MHW heat source to the MJS program.

Mr. Bunker has also participated in heat source design analyses of the SNAP-27 fuel capsule, 250 Watt RTG Heat Source, Large Isotope Heat Source, and has performed design analyses on proposed Pu-238, Co-60 and Sr-90 heat sources.

Before joining General Electric, Mr. Bunker was with the Electric Boat Division of General Dynamics where he was project engineer in the nuclear fueling department. In this assignment he directed fueling operations and was responsible for nuclear fuels handling and safety procedures associated with pressurized water reactors.

R. A. Fuller

Program Responsibility - GDS Test Support

Education

New York State College for Teachers -
San Jose State University
General Electric Heat Transfer Course

Experience

Mr. Fuller is presently responsible for test and instrument services. His responsibilities include test facility preparation, test operation and evaluation of results. Key testing goals include accurate performance data, high test availability and minimum cost test operations.

He has designed, supervised, supervised construction and operated test facilities used for thermal and hydraulic development of General Electric nuclear reactors. He has had design responsibility for heat transfer components and for a variety of advanced test facilities associated with the development of refractory metal boilers for space power systems. He was responsible for the successful SNAP-8 refractory metal boiler test program which accumulated in excess of 15,000 hours of test time. In addition he suggested several modifications to the boiler design to improve flow distribution and tube bundle support.

M. HAMMER

Program Responsibility - Quality Assurance

Education

BS, ChE, University of Houston, 1963

Completed GE courses in Non-destructive Testing, 1968, and Product Assurance Concepts, 1969

Experience

Mr. Hammer was assigned to the MHW Program in 1972 as Quality Control Engineer responsible for ETG and RTG Assemblies and Converter piece parts.

Mr. Hammer has been a Quality Control Engineer with General Electric Space System Organization since 1966. Responsibilities have included all aspects of quality assurance engineering on spacecraft components and subsystems. Mr. Hammer has performed Quality Control Engineering functions on various programs such as AEC's MHW; NASA's Skylab S-193 Microwave Radiometer - Scatterometer - Altimeter Experiment; OSO-H EUV and X-ray Spectroheliograph and Nimbus, ERTS and ATS Subsystems. Member of Material Review Board on several programs and chairman on OSO-H Program.

From 1963 to 1966, Mr. Hammer was Test Engineer with Rocketdyne Division of North American Rockwell in Large Rocket Engine Test.

J.A. LOFFREDA

Program Responsibility - Materials
- Nuclear Spacecraft Integration Aspects

Education

BA, Physics, Connecticut University, 1957
MS, Physics, Trinity College, 1963

Experience

Mr. Loffreda joined the General Electric Company in 1967. He has supported GE programs in the areas of heat transfer, nuclear radiation, and material related problems. He developed the analytical tools and computer programs used for the design and analysis of heat pipes. He designed and supervised the construction of liquid metal/stainless steel and ammonia/aluminum heat pipes, including material considerations.

In the MHW-RTG program, Mr. Loffreda was responsible for the development of the analytical tools and computer programs required to predict the long life degradation of the RTG. This work included the investigation of the sublimation, transport and condensation of various RTG materials and the consequent effects upon the RTG performance.

Mr. Loffreda has been responsible for the nuclear aspects of the integration of radioactive sources with spacecraft, including space power reactor programs, and recently, the Mini-Brayton ERTG study. This work has included interference with spacecraft instrumentation and the effects of radiation upon spacecraft materials.

From 1957 to 1967, Mr. Loffreda was employed at the Pratt and Whitney Aircraft Company, Connecticut Advanced Nuclear Engine Laboratory. In the experimental area, he was responsible for the design and construction of critical assemblies. He was also in charge of the design of the instrumentation for and the conduct of the gamma ray heating experiments.

R. L. McCARTHY

Program Responsibility - Heat Rejection Systems Design and Development

Education

BME, Syracuse University, 1959

MBA, University of New Hampshire, 1973

Graduate courses in heat transfer and fluid flow, Rensselaer Polytechnic Institute,
1960-1961

Experience

Mr. McCarthy's responsibilities at General Electric have centered on heat exchanger performance analysis. The scope of his work has involved space radiators and nuclear heat sources in addition to more conventional exchangers. Tasks have included material selection and interfacing with other components in addition to exchanger heat transfer rate, pressure drop and flow distribution.

Prior to joining General Electric, Mr. McCarthy was employed from 1959 to 1971 at the Hamilton Standard Division of United Aircraft Corporation. His responsibilities included the thermal design of heat exchangers and their integration into the pneumatic and hydraulic systems of aircraft and space vehicles. Specific designs include the main cooling heat exchanger on the Boeing 747, oil coolers on the F-111 aircraft and several heat exchangers in the Lunar Module (LEM) Environmental Control System. Mr. McCarthy had responsibility for on-going test programs to update heat exchanger basic data and developed extensive computer techniques for heat exchanger design and analysis. Optimization of heat exchanger designs required familiarity with the cycle analysis of aircraft and spacecraft environmental control systems.

H. STRAUB

Program Responsibility - GSE/Special Test Equipment

License

Licensed Professional Engineer in the State of Pennsylvania

Education

Temple University Technical Institute - Mechanical Design Certificate

Villanova University - Electrical Engineering

Experience

Mr. Straub is presently the responsible engineer for the mechanical and electrical Ground Support Equipment for the Multi-Hundred Watt Program. His responsibilities include the design, development and all phases of testing of the mechanical support equipment, including the Shipping Container and Handling Sling for the RTG.

Since joining the General Electric Company Missile and Space Division in 1956, Mr. Straub has been employed in a broad range of design and development work on spacecraft and re-entry vehicle primary and secondary structure, equipment packaging, deployment mechanisms and ground support equipment on both NASA and Military Programs.

Specific tasks include the responsibility for the design, analysis and integration of the structure and antenna for the S-193 Skylab experiment. He also was responsible for the design, analysis and fabrication of space thermal vacuum test and handling fixtures for two large military space program major components, and the design and test fixtures for a deployable antenna dynamic test program. He served as a member of a team responsible for the integration and evaluation of experiments on the MOL vehicle, providing subsystem analysis and integration.

R.O. TURBYFILL

Program Responsibility - Spacecraft Integration

Education

BS, Civil Engineering, Iowa State University, 1951

Experience

Mr. Turbyfill has over twenty three years of progressive experience in the aerospace industry in the field of Airborne Systems and Missile and Space Systems development. His key role of assignments have included:

- Mechanical Systems design, development and technical direction for major communication satellite programs (i.e., ATS-FG, Fleet SAT Com, DOMSAT and AEROSAT).
- Organized and directed Mechanical Systems design and integration effort on the NSF Solar Heating and Cooling Study.
- Managed Structures Technical Office for ATS F&G Program
- Manager multimillion dollar subcontracts on the MOL Program
- Organized and directed development of Re-entry and Space System structural/mechanical subsystems
- Designed and developed state-of-the-art Airborne and Space System structures for defense applications.
- Led group of engineers and technicians in design and development of airframe and control system equipment.

Mr. Turbyfill joined GE-MSD in 1961 after serving ten years with Chance Voght as a Lead Structures Design Engineer responsible for design and development of major airframe components and mechanical systems on supersonic fighter aircraft. As a Vehicle Project Engineer with RESD, he was responsible for directing the design, development and integration of several major Re-entry Vehicle programs that accomplished major state of the art advances and technical breakthroughs in re-entry system technology. These programs included the Nike-Zues TVX, Maneuvering Ballistic Re-Entry Vehicle (MBRV), Mark 12 Advanced Minuteman Systems, Apollo and Voyager Lander.

In 1966 Mr. Turbyfill joined SSD as Manager and Technical Director of several multimillion dollar major subcontracts involving development of mechanical Aerospace and Ground Support Equipment for the Manned Orbiting Laboratory Program (MOL).

Subsequent assignment as Mechanical Systems Engineer have included technical direction and spacecraft integration roles on numerous communication satellite systems and more recently survivability and system design studies on the MHW and Mini-Brayton Program, NASA-LeRC's Heat Source Assembly Design Study (NAS 3-16810) and the AEC's Mini-Brayton Economic RTG (AEC SNSO-6).

4.3.2 KEY MHW-RTG PROGRAM PERSONNEL

These personnel are available to the GE Isotope Brayton Program personnel for consultation purposes.

G.R. AMBROSE

Education

BSME, West Virginia University, 1951

GE Advanced Engineering Program, 1954

Experience

Mr. Ambrose is presently Manager, HHW Systems Analysis. Prior to this assignment, Mr. Ambrose was Manager, Stress and Dynamics Analysis, Isotope Power Systems Operation. He was responsible for the structural analysis of radioisotope thermal electric generators and supporting structures as well as structural analysis support of spacecraft studies such as nuclear reactor powered ion-propelled spacecraft. Before joining the Isotope Power Systems Operation, Mr. Ambrose was Manager, Structural Dynamics, MOL Program. He was responsible for structural dynamic analysis of the Manned Orbiting Laboratory vehicle system and for providing design and test requirements. In addition, he was responsible for integration of structural dynamic activities of all major contractors.

From 1963 to 1969, Mr. Ambrose was Supervising Engineer, Structural Dynamics, General Electric Spacecraft Department. In this capacity, he was responsible for the structural dynamic analysis and test support for a wide range of spacecraft programs and studies including OSS, GGTS and Voyager.

J. CALLENDER

Education

Binghamton North High, Binghamton, New York, Technical Mechanical, 1947-1950
General Electrical Apprentice, Schenectady, New York, Drafting, 1955-1958
General Electric Night Courses and Schooling in the Navy

Experience

Mr. Callender currently has the Project Engineer responsibility of the Outer Clad and assisted in Producibility Engineering on the MHW Program.

Prior to this on the APU Program (commercial product in development stage), Mr. Callender performed the function of Manufacturing Engineer and was responsible for scheduling and fabrication of development hardware.

On the Electrophoresis Program, Mr. Callender was manufacturing Project Engineer and coordinator.

Previous experience included work in the Manufacturing Producibility Engineering Group on Nimbus, ERTS and VO 75.

V.J. DESANTIS

Education

BS, Chemistry, Seton Hall University, 1941
Newark College of Engineering

Experience

From 1971 to the present Mr. DeSantis has been acting as Materials and Process Consultant in the engineering function of Advanced Energy Systems. His major responsibilities in this position are associated with the development of the Multi-Hundred Watt RTG. He has defined and characterized materials and materials compatibility associated with electric and isotope heat sources designed to operate at temperatures up to 1400° C for periods in excess of 5 years. He successfully demonstrated a means of preventing excessive evaporation of silicon from MHW thermoelectric elements by means of forming thin film silicon nitride surface coatings. Mr. DeSantis was responsible for the development of a series of stable high emissivity coatings applicable to surfaces that operate at temperatures in excess of 800° C in high vacuum.

From 1967 to his current assignment, Mr. DeSantis managed the IPSO Materials Technology Unit and was responsible for material development, qualification and testing. He was a leader in the development of materials for the SNAP-27 program. He made major contributions to development of graphite for the fuel re-entry cask and to beryllium work performed for the generator and re-entry cask. He perfected an elaborate, high temperature emittance, oxidation resistant coating for the beryllium sleeve in the fuel re-entry cask which was an important factor in the re-entry performance of the cask. He has also developed a whole series of high emittance, iron titanate coatings, applicable to a broad range of substrate materials.

From 1961 to 1967, Mr. DeSantis worked as a Consulting Engineer-Scientist in the Material Sciences Section of the Space Sciences Laboratory, GE-MSD. From 1951 to 1961, Mr. DeSantis served as Manager of the Electron Tube Technology Engineering Section, GE-Power Tube Department. From 1941 to 1951, Mr. DeSantis was a Project Engineer with Federal Telecommunication Laboratory, where he was responsible for installation of the electron tube research and development laboratory and design of specialized facilities.

A. F. GARAWITZ

Education

BSME, Polytechnica Institute of Brooklyn, 1956

Experience

Since 1964 Mr. Garawitz has been Project Engineer and Manager, Quality Control and Test and Product Assurance Operations. He has been responsible for the integration, organization, and operation of programs within the quality organizations to provide proper personnel and disciplines to perform the quality tasks. He has provided direction and managed quality control funding and work activities in addition to providing customer and internal liaison for quality requirements.

Mr. Garawitz is presently assigned as Quality Control Manager of the MHW Program in which he is responsible for the control of product quality from initiation of design through fabrication, assembly, and test, including documentation. He performed similar responsibilities previously for S-193 and oxygen sensor programs on Skylab, MM-73 Program, NASA-Langley's Re-entry "F" Program, Manned Orbiting Laboratory, Mark 12, Re-entry Measurements Vehicle and Re-entry Vehicle Technologies Programs.

From 1960-1964, Mr. Garawitz was responsible for quality requirements on mechanical and electromechanical components on Mark 3, Mark 3CTP, Discoverer, Mark 6, MBRV, Mark 12, TVX, WAC, GTV and PRESS Programs.

Mr. Garawitz was employed by GE's Flight Propulsion Division from 1958 to 1960 where he served as Test Engineer on J-79 and J-93 Jet Engine Programs and as Development Engineer on the T-58 and T-64 engines.

R.F. HARTMAN

Education

BS, Physics, St. Joseph's College, 1964

Experience

Mr. Hartman joined the General Electric Company, Missile and Space Division, in June 1966. His present responsibility is the design and development of the MHW-RTG gas management system as well as GSE and flight instrumentation and cabling for the RTG. He has also participated in the development of fabrication methods for the MHW Isotope Heat Source. In addition, he has been directly involved with the testing of the MHW-RTG and, in particular, the development of procedures for IHS receipt and subsequent IHS installation into the converter.

Prior to MHW, Mr. Hartman was the responsible design engineer for the Isotope Thermionic Module Development Program. His duties included the design and development of a tri-layered composite module housing, the design of the thermionic converter, vent selection, and the planning, costing and scheduling of all support tasks.

Prior to this time, Mr. Hartman provided technical support for advanced fuel capsule studies and proposals. Specifically, he performed an investigation into the use of refractory metals and coatings for use in high temperature heat sources and co-authored a paper summarizing his findings. Mr. Hartman also participated in the SNAP-27 Program where his duties included vent design and development and liaison with Sandia Laboratory for heat source safety testing. He also served as GE representative at the fueling agency (Mound Laboratory) for the fueling of all SNAP-27 heat sources. Mr. Hartman was one of the recipients of the GE Professional Recognition Group Award for his participation in the SNAP-27 Program.

From 1964 to 1966, Mr. Hartman was employed at Mound Laboratory, a subsidiary of Monsanto Research Corporation, as a research physicist. Mr. Hartman is a member of the American Institute of Aeronautics and Astronautics, Inc. He has received a Certificate of Achievement for his participation in "Technical Presentation Workshop", a Company-sponsored course.

D. MATTEO

Education

BME, Villanova University, 1956

Graduate work in Engineering Science, Penn State University, 1967-1968

Experience

Mr. Matteo is currently Manager of Engineering on the Multi-Hundred Watt RTG Program which GE is producing for the AEC. This includes responsibility for all design and analytical engineering effort on the program. Prior to this assignment, Mr. Matteo was Manager of Electromechanical Subsystem Engineering, where his responsibilities included the design and development of all spacecraft borne mechanism elements produced by the department.

Mr. Matteo has been lead mechanical engineer on the following projects: Mechanical/Structural Subsystem for Skylab S-193 Microwave Radiometer, Chief Mechanical Engineer: two axis gimbal, experiment structure, antenna structure, RF rotary joint, flex-harness, component and waveguide installation for a mechanically scanned, earth mapping, microwave antenna (42.5" dia. paraboloid) and associated electronics.

Mechanisms and Structure for NASA's OSO-H Spectroheliograph Instrument, several precision mechanisms functioning in conjunction with optical instruments for an extended period in space after exposure to a severe vibration environment, including extensive use of beryllium in structure and optical element mounts.

Gravity-Gradient Boom Mechanism for NASA's ATS Satellite, a system of 120 ft long erectable tubular booms which are deployed in space for passive attitude stabilization of the spacecraft.

Deployment Actuator for JPL's Roll-Up Solar Array, an actuation mechanism that deploys a tubular structure which supports and actuates a "window-shade" type solar array.

Mr. Matteo's earlier experience at Vertol Aircraft Corporation included stress analysis work on helicopter rotor blades, airframes and alighting gear, landing load studies, and structural and fatigue testing of helicopter components. This included the FAA certification test program on V-44 helicopter controls.

Mr. Matteo has been appointed to the Material Review Board both at GE and at Vertol.

E. SARDARO, JR.

Education

Embry Riddle Aeronautical Institute, Miami, Florida, 1956-1958

BS, Aeronautical Engineering, Indiana Institute of Technology, Fort Wayne,
Indiana, 1958-1960

Experience

Mr. Sardaro has been a Quality Control Engineer with the General Electric Company Space Systems since 1966. He has been a QC Engineer on Nimbus, SNAP-27, and MHW Programs.

Mr. Sardaro has provided plans and implementation of service to control the quality of purchased material, as a support to Procurement and vendor for assigned components of the SNAP-27 and MHW radioisotope power systems. He has provided vendor integration and liaison on quality matters pertinent to assigned components as well as standing instruction to perform environmental and functional testing of assigned components as required and requested by design engineering and has provided assistance to Quality Control and Manufacturing planners responsible for the quality of hardware fabricated and assembled in house.

Mr. Sardaro participated in the investigation of significant failures and contributed to tear-down analysis reports. He has reviewed customer inspection and test requirements pertinent to assigned components and assured procedural compliance and provided assistance to Program Planning in reporting the status of the Quality Control function; devised and initiated corrective action when schedules were not met within the component assignments.

Mr. Sardaro has submitted assigned components to the customer for buy-off after acceptance of assigned hardware.

Mr. Sardaro was the responsible Quality Control Engineer for Bendix and General Electric integrated testing of Apollo Lunar Surface Experimental Package consisting of qualifications and acceptance testing of the ALSEP Cask Assembly.

R. L. WILEY

Education

BSME, University of Maryland, 1966

MSME, Drexel University, 1972

Experience

Since joining General Electric's Energy Systems Programs in July 1969, Mr. Wiley has primarily been involved in the thermal analysis of the Multi-Hundred Watt Radioisotope Thermoelectric Generator (MHW-RTG). He was primarily responsible for the MHW-RTG insulation system design and performed the RTG performance trade-off study to determine the design point. His work included interface with the MHW user concerning the thermal aspects of the RTG-spacecraft integration. Mr. Wiley has been closely involved in the coordination of MHW-RTG component and system thermal and environmental testing. He also participated in an effort aimed at providing a low cost RTG for undersea applications.

From June 1966 through June 1969, Mr. Wiley was employed by Isotopes Nuclear Systems Division (formerly Martin Marietta Nuclear Division) in Middle River, Maryland. At Isotopes, Mr. Wiley was primarily engaged in thermal analysis, both transient and steady state, particularly for re-entry heat shield design, and also plasma arc testing liaison and data correlation work. He also performed parametric electrical performance analyses of thermoelectric modules. He has experience in scientific FORTRAN programming, specifically for IBM 360, 7094 and 1130 digital computers. Among Mr. Wiley's specific assignments were re-entry temperature and ablation predictions for the SNAP-29 RTG, assistance in heat shield design for SNAP-29, launch pad abort fireball temperature predictions for SNAP-29, and thermoelectric parametric studies for the SNAP-29, and thermoelectric parametric studies for the SNAP-19 RTG.

F.J. WITT

Education

BChE, Brooklyn Polytechnic Institute, 1953

MChE, Rensselaer Polytechnic Institute, 1959

Experience

1965-Present. Since joining General Electric's Space Division in December 1965, Mr. Witt has been involved with several Radioisotope Thermoelectric Generator (RTG) and reactor systems hardware and study programs for space and terrestrial applications. These include the SNAP-19 RTG on NIMBUS B, SNAP-27 RTG's implanted on the moon by Apollo astronauts, Multi-Hundred Watt RTG's for Lincoln Laboratory communication satellites and for Mariner Jupiter and Saturn missions, RTG's for Sea Robin buoys, thermionic and zirconium hydride reactors for a space base, radioisotope heat sources for waste management, cryogenic engines, cathode emitter, artificial heart pump, and Apollo Lunar Experiment heater. In conjunction with these assignments, he has performed hazards evaluations, determined necessary radiological safety procedures, specified safety requirements for RTG systems and system test facilities, coordinated program requirements for health physics. Mr. Witt's duties include radio-isotope fuel technology, fuel capsule design and safety analysis, operational safety evaluation, safety test planning and safety analysis report preparation for flight approval, ground testing and RTG shipping containers. Mr. Witt has been responsible for integration the plutonium-238 radioisotope heat sources in the RITE Waste Management System. He is presently responsible for operational safety for all ground operations on the Multi-Hundred Watt RTG Lincoln Laboratory and Mariner Jupiter and Saturn applications. He is also conducting radiological consequence calculations to the public and environment and evaluating the subsequent risk to the public in the event of an accident involving nuclear reactors and radioisotope heat sources.

1956-1965. Prior to joining the Space Division, Mr. Witt spent ten years with the General Electric Knolls Atomic Power Laboratory, where he provided design concepts and performed experimental and analytical work to minimize radioactive contamination and radiation in nuclear reactor plants.

Mr. Witt is a member of the American Nuclear Society and the Health Physics Society.

N.K. YERGER

Education

BS, Electrical Engineering, Drexel Institute of Technology, 1958

Special courses in Computer Programming and Statistical Quality Control, Temple University

GE-sponsored course in Manufacturing Problems Analysis

Military course - Basic Officer's Military Orientation Program, Ft. Belvoir, Va.

Experience

Mr. Yerger has been Quality Control Engineer with GE Space Systems Organization since 1962. Responsibilities have included all aspects of quality engineering in electromechanical, electronic and nuclear components and subsystems; quality representative on government approved configurative control and material review boards. He has been the recipient of numerous commendations from customer(s) for ability to "get the job done" under difficult conditions at remote locales. Specific experience includes:

- Recently completed 2-1/2 years service as Resident Quality Assurance Engineer at RCA Corporation on the Multi-Hundred Watt LES 8/9 and MJS programs. Experience obtained in this program directly transferrable to the Isotope Brayton System Program.
- Quality Control Engineer on SNAP-27 and SNAP-27 follow-on programs. Responsible for fuel cask and radioisotope thermoelectric generator (RTG).
- Quality Control Engineer on Mariner '71 program. Responsibilities included integration of environmental (qualification) testing of Attitude Control Electronics/ Inertial Reference Unit.

Prior to joining GE, Mr. Yerger was employed as Quality Control Engineer at International Resistance Company, where his chief responsibilities included supervision of long life tests on high reliability resistors and supervisor of data processing unit which functioned to produce test histories on IBM cards.

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SECTION 5

GENERAL ELECTRIC CAPABILITIES AND EXPERIENCE SUMMARY

(Please Refer to Section 5 of Volume 1 of the AiResearch Proposal)