DOE/SF/01123--T47M&L 1123-8-1

VOLUME

REPORT NO. 74-311015-1
DECEMBER 9, 1974

ISOTOPE BRAYTON GROUND DEMONSTRATION TESTING AND FLIGHT QUALIFICATION

MASTER

TECHNICAL PROGRAM

Prepared for:
UNITED STATES ATOMIC
ENERGY COMMISSION
SPACE NUCLEAR SYSTEMS DIVISION
SOLICITATION NO. SNS-RFP-75-1-CAO

AC03-76SF01123

MS 3568-0A

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

December 4, 1974

U. S. Atomic Energy Commission
Washington, D. C. 20545

Subject: AiResearch Proposal for Development of the
"Isotope Brayton Ground Demonstration System"

Gentlemen:

The Garrett Corporation offers a background of thirty years of gas turbine technology, extensive space systems experience in the Mercury, Gemini, Apollo and Skylab programs, and over fifteen years of closed cycle gas turbine and heat exchanger experience directly applicable to the AEC Isotope Brayton Ground Demonstration System. Our most recent contracts with the NASA will provide the Brayton rotating assembly and recuperator for the Isotope Brayton Ground Demonstration System Program.

Our proposed program includes as subcontractors, the General Electric Space Division and the Teledyne Isotopes Energy Systems Division. These highly qualified contractors will each provide their technical expertise to the isotope heat source requirements. We recommend that both subcontractors' efforts be funded through Phase I. Based on the Phase I analyses and the status of the heat source development at that time, a Phase II recommendation will be made by Garrett.

Our technical team has provided this proposal for Phases I, II, and III and is fully qualified to perform the proposed effort through flight test and production. I have assigned Mr. James McCormick as my manager to direct the program effort. He will head the Garrett/General Electric/Teledyne team that has developed the Brayton Rotating Units, Turbo-Alternator-Compressor, the Mini-Brayton Rotating Units, recuperators, the Multi-Hundred Watt Heat Source, the Apollo and Pioneer space nuclear power hardware, SNAP 3A, and 9A, and numerous other related efforts.

I wish to extend to the AEC the assurance that the Isotope Brayton Ground Demonstration System program will receive the manpower, technology, and managerial expertise required for meeting the program objectives.

Very truly yours,

AIRESEARCH MANUFACTURING COMPANY
OF ARIZONA
A Division of The Garrett Corporation

W. G. Orr
Vice President and Manager

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MGW

VOLUME 1

ISOTOPE BRAYTON GROUND DEMONSTRATION TESTING AND FLIGHT QUALIFICATION

TECHNICAL PROGRAM

74-311015-1

DECEMBER 9, 1974

Prepared By: ENGINEERING STAFF

Approved By: J.E. McCormick
J.E. McCORMICK, PROJECT DIRECTOR

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

REPORT NO. 74-311015-1

TOTAL PAGES 254

ATTACHMENTS: The Garrett Corporation
Organization Chart, after Page 4-4

AiResearch Manufacturing Company of Arizona
Functional and Product Line Chart, after Page 4-4

AiResearch Manufacturing Company of Arizona
General Quality Program Plan, QC-048, Rev. 4,
October 1, 1974, after page 5-31-B.

REV	BY	APPROVED	DATE	PAGES AND/OR PARAGRAPHS AFFECTED

TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION	(4 pages) 1-1
2. SUMMARY	(8 pages) 2-1
2.1 Phase I - Ground Demonstration System and Advanced Development	2-1
2.1.1 Schedule	2-1
2.1.2 Technical Approach	2-1
2.1.3 Exceptions to RFP	2-3
2.2 Phase II - Flight System Development Qualification	2-3
2.2.1 Schedule	2-3
2.2.2 Technical Approach	2-4
2.2.3 Exceptions to RFP	2-7
3. TECHNICAL PROGRAM	(86 pages) 3-1
3.1 Technical Approach - Phase I	3-1
3.1.1 Program Management	3-1
3.1.1.1 Project Engineering	3-5
3.1.1.2 Contract Administration	3-6
3.1.1.3 Engineering Sciences	3-7
3.1.1.4 Manufacturing Engineering	3-7
3.1.1.5 Design Office	3-7
3.1.1.6 Materiel	3-8
3.1.1.7 Laboratory	3-8
3.1.1.8 Purchasing Department	3-9
3.1.1.9 Accounting	3-10
3.1.1.10 Cost and Schedule Control	3-11
3.1.1.11 Reliability and Quality Assurance	3-12
3.1.1.12 Safety	3-13
3.1.1.13 Liaison	3-13
3.1.2 Conceptual Isotope Brayton Flight System Design	3-14
3.1.2.1 Requirements	3-14
3.1.2.2 Identification of Long Lead Items	3-16
3.1.2.3 Conceptual Design	3-17

TABLE OF CONTENTS (Contd)

	<u>Page</u>
3.1.3 Preliminary GDS Design and Analysis	3-21
3.1.3.1 Preliminary GDS Design	3-21
3.1.3.2 GDS Test Plan	3-25
3.1.4 Detailed GDS Design and Analysis	3-28
3.1.4.1 System Layouts	3-28
3.1.4.2 Transient Effects	3-29
3.1.4.3 Heat Sink	3-29
3.1.4.4 Control and Instrumentation Systems Detail Design	3-31
3.1.4.5 Structure; Bellows, Valves, and Joints	3-35
3.1.4.6 Materials Compatibility	3-36
3.1.4.7 Electric Heat Source Analysis	3-36
3.1.4.8 Test Facilities	3-37
3.1.4.9 Detail Design Review	3-38
3.1.5 Fabrication and Assembly of GDS and Test Facilities	3-39
3.1.6 Test and Evaluation	3-41
3.1.6.1 GDS Performance Testing	3-41
3.1.6.2 GDS Endurance Testing	3-43
3.1.7 Quality, Reliability and Safety	3-44
3.1.7.1 Quality Assurance and Reliability	3-44
3.1.7.2 Safety	3-46
3.1.8 Reports and Data	3-49
3.1.9 Advanced Development	3-49
3.1.10 Flight Design and Engineering Program Plan	3-51
3.2 Technical Approach - Phase II	3-60
3.2.1 Program Management, Phase II	3-60
3.2.2 System Design and Analysis	3-60
3.2.3 Phase II Safety	3-66
3.2.4 Product Assurance	3-67
3.2.5 Qualification Test Plan	3-68

TABLE OF CONTENTS (Contd)

	<u>Page</u>
3.2.6 Power Conversion System Design	3-71
3.2.7 PCS Development and Fabrication	3-71
3.2.8 Heat Source Design	3-73
3.2.9 Heat Source Development and Fabrication	3-73
3.2.10 Qualification Testing	3-74
3.2.11 Ground Support Equipment (GSE)	3-74
3.2.12 Reports	3-76
3.2.13 Phase III Plan	3-76
3.3 Anticipated Technical Problem Areas	3-79
3.3.1 Bearing for Operation During Launch	3-79
3.3.2 Refractory Metals	3-79
3.3.3 Radiator Construction	3-79
3.3.4 Insulation	3-79
3.3.5 On Pad System Cooling	3-80
3.3.6 Bimetallic Joints	3-80
3.3.7 Fueling	3-81
3.3.8 Controls and Instrumentation Systems	3-81
3.4 Suggested Changes of Scope	3-82
3.5 Required Equipment and Facilities	3-83
3.5.1 Facility	3-83
3.5.2 Test Chamber Pump System	3-83
3.5.3 Residual Gas Analyzer	3-84
3.5.4 Heat Source Simulator Power Supply	3-84
3.5.5 Controls and Instrumentation	3-84
3.5.5.1 Digital Data Acquisition and Processing	3-85
3.5.5.2 Panel Instrumentation	3-86
3.5.5.3 Protection	3-86
3.5.6 Cleanroom Assembly Area	3-86
4. PROGRAM ORGANIZATION AND PERSONNEL	(41 pages) 4-1
4.1 Program Organization	4-1
4.2 Personnel Qualifications	4-9
4.3 Resumes	4-9

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

TABLE OF CONTENTS (Contd)

	<u>Page</u>
5. SUBCONTRACTOR CAPABILITIES	(111 pages) 5-0
5A General Electric Capabilities and Experience Summary	
5B Teledyne Isotopes Capabilities and Experience Summary

AIRESARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

ISOTOPE-BRAYTON 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
AIRLA5	AiResearch, Los Angeles Heat Transfer Systems
BOM	Beginning of Mission
BRU	Brayton Rotating Unit
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
FIB	Fuel Impact Body
FMA	Failure Mode Analysis
FBS	Flight Battery System Required for Start in Orbit
FMEA	Failure Modes and Effects Analysis
FPR	Federal Procurement Regulation
FSA	Fuel Sphere Assembly
FSAR	Final Safety Analysis Report
FSE	Flight Support Equipment Required to Protect Hot Refractory Parts in Earth's Atmosphere
GDEHS	Graphite Dynamic Electric Heat Source (GE Term for EHS-D)
GDS	Ground Demonstration System - PCS + EHS-S
GE	General Electric, Valley Forge
GEHS	Graphite Electric Heat Source (GE term for EHS-S)
GFE	Government Furnished Equipment
GMS	Gas Management System (a STE/GSE item) Special Test Equipment

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

ISOTOPE-BRAYTON ACRONYMS AND ABBREVIATIONS (Contd)

GSE	Ground Support Equipment
GTC	Ground Test Console (a STE/GSE item)
HS	Heat Source (Same as and replaced by EHS)
HSA	Heat Source Assembly (Does <u>not</u> 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)
IHE	Isotope Handling Equipment
IHS	Isotope Heat Source (Isotope and Reentry Protection)
JPL	Jet Propulsion Laboratory, Pasadena, Ca.
LES 8/9	Lincoln Experimental Satellite (No. 8 and No. 9)
MBR	Mini-Brayton Recuperator
MB-ERTG	400 Watt Mini-Brayton-Economic Radioisotope Thermo-dynamic Generator Design (Refer also to IBFS)
MHW	Multi-Hundred Watt (AEC/GE IHS Technology)
MMD	Mean Mission Duration
NA	Not Applicable
NASA LeRC	National Aeronautical and Space Administration Lewis Research Center
OHA	Operational Hazard Analysis
ORNL	Oak Ridge National Laboratory
PCL	Power Conversion Loop (Use of PCS preferred)
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)
PHA	Preliminary Hazard Analysis
PLC	Parasitic Load Control System
PSAR	Preliminary Safety Analysis Report

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

ISOTOPE-BRAYTON ACRONYMS AND ABBREVIATIONS (Contd)

PSC	Power Supply 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)
SNS	Space Nuclear Systems (Division of AEC)
SSPP	System Safety Program Plan
STE	Special Test Equipment
SURVSATCOM	Air Force Survivable Communication Satellite
TBD	To Be Defined
TI	Teledyne Isotopes (Division of Teledyne)
TIT	Turbine Inlet Temperature
USAR	Updated Safety Analysis Report
VRE	Voltage Regulator Exciter

1.0 INTRODUCTION

The AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, is pleased to submit this proposal to the AEC in response to solicitation SNS-RFP-75-1-CAO. The proposed program includes the ground demonstration, development, and flight qualification of a radioisotope nuclear heated dynamic power system for use on space missions beginning in the 1980's. This type of electrical power system is based upon and combines two aerospace technologies currently under intense development; namely, the MHW isotope heat source and the closed Brayton cycle gas turbine. This power system referred to hereafter as the IBFS (Isotope Brayton Flight System) represents the next generation of reliable, efficient economic electrical power equipment for space.

The IBFS will be capable of providing 0.5 to 2.0 kW of electric power to a wide variety of spacecraft for earth orbital and interplanetary missions. The immediate design will be based upon the requirements for the Air Force SURVSATCOM mission.

This proposal is presented in three volumes plus an Executive Summary:

- Volume I - Technical Program (Task Descriptions)
- Volume II - Technical Proposal (Technical Discussions)
- Volume III - Business Management (Management and Costs)

The above volumes are supplemented by attachments provided by subcontractors, General Electric and Teledyne Isotopes.

The Garrett Corporation considers the proposed program a high priority effort worthy of its top quality management, technical talent, and facilities. The program will be performed by personnel who have vast experience and background in the disciplines necessary to

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

successfully accomplish the program objectives. The key people who will be assigned to this program have participated in the Government sponsored programs (NASA, USAF and AEC) for the past fifteen years which have formed the strong technology base for the IBS. Most recently, the AiResearch technical team has been involved in the AEC/USAF sponsored 400 W_e Economic Radioisotope Thermodynamic Generator (ERTG) studies and the supporting NASA funded Mini-BRU and recuperator hardware programs.

To complement this prime contractor experience, AiResearch has obtained the support of the two most qualified nuclear heat source development organizations in the country as subcontractors. They are the General Electric Company Space Division (GE) and the Teledyne Isotopes Space Systems Division (TI). GE has extensive knowledge and expertise in safe high temperature nuclear heat sources. Recent GE experience includes the Mini-Brayton Economic Radioisotope Thermodynamic Generator (MB ERTG) studies, the NASA sponsored Heat Source Assembly (HSA) hardware contract, and prime contractor to the AEC for the Multi-Hundred Watt (MHW) and SNAP 27 programs. Current space flight program involvement includes the DOD Lincoln Experimental Satellites 8 and 9 (LES 8/9) and the NASA-JPL Mariner Jupiter/Saturn (MJS) flight series.

Likewise, TI has approximately 20 years of nuclear space power experience. Their history includes an impressive list of space flight successes particularly the use of the SNAP-19 RTG on the NASA Nimbus, Viking, and Pioneer missions.

The talent, background, experience and facilities that AiResearch and its subcontractors bring to this program are unparalleled in industry, and all elements of the AEC program are within the contractors' capability. The AEC can be assured that all three phases will be successfully completed on schedule in the most economical manner.

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

The proposed program is composed of three phases:

Phase I - (27 months) - Three major activities are entailed:

- (a) IBFS conceptual design
- (b) A Ground Demonstration System (GDS) design, development and test program
- (c) "Long lead" technical activity which is required to insure that qualification is completed by June, 1980.

Phase II - (36 months) - The cost effective development and qualification of the IBFS by June, 1980.

Phase III - Production of IBFS units at the rate of four per year.

During Phase I both subcontractors (GE and TI) will make contributions in the use of the MHW heat source for the IBFS, including safety. GE will also provide substantial support in conceptual flight system design, spacecraft integration, and in all of the activities (i.e., design, fabrication, assembly, and testing) included in the GDS program.

At the end of Phase I, the IBFS design will be reviewed and updated to reflect:

- (a) The GDS engineering data
- (b) The information generated from the long lead item efforts
- (c) Any revisions that have been made during Phase I, regarding expected flight requirements, that may result from a firm DOD requirements letter.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

A detailed Phase II program plan will also be prepared and submitted to the AEC for review and approval.

Because it appears at this time that the AEC MHW heat source and the HSA being developed for its safe integration in the IBFS (a) meet the established IBFS performance objective, and (b) represent the most cost effective approach for Phases II and III, these key elements are included in the baseline program proposed herein. GE Space Division has considerable experience, knowledge and background with the components, and it is anticipated that GE will provide major subcontractor support to AiResearch during Phase II.

Advanced or new generation AEC heat source technologies will be carefully examined and their development progress monitored for possible integration into the IBFS to upgrade the already excellent performance. Those developments which demonstrate the potential for a substantial improvement in the superior performance already projected for the baseline (IBFS Phase II and Phase III) approach will be considered for integration with the IBFS. Key criteria include their cost effective, timely implementation to meet the AEC June, 1980 IBFS flight qualification requirement.

AiResearch takes no technical exceptions to the RFP.

2.0 SUMMARY

2.1 Phase I - Ground Demonstration System (GDS) and Advanced Development

2.1.1 Schedule

Garrett, during the conducting of Phase I, will be supported by two subcontractors, General Electric (GE) and Teledyne Isotopes (TI). General Electric, it is anticipated, will assume the role of a major subcontractor providing support through the Phase I program. TI will provide new heat source (HS) concepts for the IBFS design while assisting in HS safety issues.

The major tasks during Phase I consist of:

- (a) The Isotope Brayton Flight System (IBFS) Conceptual Design
- (b) The GDS Test Program
- (c) The long lead item activity necessary to effect the IBFS design in Phase II, Flight System Development and Qualification

The summary schedule encompassing the Phase I effort is presented at the conclusion of Section 2.

2.1.2 Technical Approach

The objectives of the Phase I program, which reflect in the major tasks previously mentioned, are:

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

- (a) To conduct a three-month conceptual design effort which will characterize the IBFS in every category
- (b) To design, fabricate and assemble the GDS and to accomplish performance and endurance testing with this unit
- (c) To conduct in parallel with GDS development, the long lead development activity required to effect the delivery of the first production flight system by June 30, 1980.

Through the integration of GDS test data, long lead development and updated mission requirements, a program plan for the Flight System Development and Qualification will be generated.

The testing identified in Paragraph (b) will be conducted using one GDS unit at an existing AiResearch, Phoenix test facility. G E will support AiResearch in the areas of component design, fabrication, and test support.

The Phase I program will consist of the following tasks:

1. Program Management - Project Director will integrate prime and subcontractor activities
2. Conceptual IBFS Design - Preliminary Flight System Design
3. Preliminary GDS Design and Analysis - GDS design and test plan
4. Detailed GDS Design and Analysis - Layouts, analyses, trade-off studies, component detail design, etc.
5. Fabrication and Assembly of GDS and Test Facilities - Receive GFE components, modification, fabrication, and assembly of GDS and test facility

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

6. Test and Evaluation - Performance and endurance testing, data reduction, etc.
7. Quality Assurance, Reliability and Safety - Activities for both IBFS and GDS
8. Reports and Data - Technical, financial, and special topical reports
9. Advanced Development for Phases II and III - Long lead development activity
10. Flight Design and Engineering Program Plan for Phase II - Accumulate test data, long lead development items, and updated requirements to effect IBFS design and Phase II program plan

2.1.3 Exceptions to RFP

AiResearch takes no technical exception to the RFP.

2.2. Phase II - Flight System Development Qualification

2.2.1 Schedule

The major tasks during Phase II consists of:

- (a) The modification of GDS components in regard to facilitating an IBFS design or a simulation thereof
- (b) The conducting of the longest possible endurance test prior to first flight

- (c) The design and fabrication of ground and flight support equipments (GSE and FSE)
- (d) The further development necessitated by updated mission requirements
- (e) The initiation of the production (Phase III) program plan

The summary schedule for the Phase I, Phase II and Phase III efforts is presented at the conclusion of Section 2.

2.2.2 Technical Approach

The objectives of the Phase II effort are:

- (a) To combine the GDS and early IBFS test data, long lead development items, and the updated mission requirements into a qualifiable IBFS design
- (b) Perform advanced design and fabrication as required by (a)
- (c) Conduct the required spectrum of qualification testing including the longest endurance test practicable prior to first flight
- (d) Design, fabricate, and assemble all necessary GSE to support Phase II testing
- (e) Generate a production program plan based on a production rate of four IBFS units per year, with the first delivery by June 30, 1980

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

In the baseline program, two system development models will be fabricated, and both will include a prototype space radiator. One system will be operated at AiResearch, Phoenix for the dual purpose of low cost component upgrade testing and long endurance testing prior to the first flight.

The second system, the structural design model (SDM), will be operated in the G.E., Valley Forge, space simulation test chamber. This will serve as a shakedown operation of the G.E. qualification test facility. This facility features a hard vacuum environment with an artificial sun to simulate the effects of solar radiation on the heat rejection system and is a nuclear certified facility. Qualification testing will subsequently be conducted when a qualifiable system is fabricated and assembled.

The AiResearch facility containing the first IBFS development system will also function as a backup facility should the G.E. facility experience excessive "down time" during the qualification testing.

Additional facilities have been investigated during the preparation of this proposal with the intent being to provide the Government the latitude of selecting the qualification test site consistent with maximum utilization of existing facilities, minimizing program costs. The baseline program cost was estimated assuming that the qualification testing would be performed in the existing G.E. space simulator (thermal-vacuum) test facility. However, other facilities which were surveyed include:

1. Lawrence Livermore Laboratory, Livermore, California
2. Oak Ridge National Laboratory, Oak Ridge, Tennessee
3. Jet Propulsion Laboratory, Pasadena, California
4. NASA Plumbrook Test Facility, Sandusky, Ohio

Further description of these facilities can be found in the TI Volume 1.

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

Through the successful completion of the Phase II effort, a (Phase III) production program plan will be developed to efficaciously initiate delivery of production hardware by June 30, 1980.

The Phase II program tasks are as follows:

1. Program Management - Consistent with Phase I
2. System Design and Analysis - Component specifications, configuration control and GDS performance assessment
3. Safety - PSAR, USAR, FSAR
4. Product Assurance - Reliability, quality assurance, and configuration management
5. Qualification Test Planning - Qualification test plans and procedures
6. Power Conversion System (PCS) Design - Design system less heat source
7. PCS Development, Fabrication and Assembly
8. Heat Source Design - EHS, IHS
9. Heat Source Development and Assembly
10. Qualification Testing - Performance, environmental, endurance
11. Ground Support Equipment (GSE) Design, Fabrication and Assembly - Off-site test support equipment
12. Reports - technical, financial, and special topical reports
13. Phase III Planning - Phase III program plan

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

2.2.3 Exceptions to the RFP

AiResearch takes no technical exception to the RFP.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

▼ DENOTES PROGRAM MILESTONES

FIGURE 2-1

3. TECHNICAL PROGRAM

The program schedule for Phase I (Figure 3-1) is enclosed on the following page to give an overall view of the program tasks to be performed with the appropriate time scheduling. The Phase I schedule has been constructed to ensure timely completions of each task and subtask culminating in successful completion of the Isotope Brayton Ground Demonstration System (IBGDS).

Throughout Phase I Garrett, in the accomplishment of the program, will be supported by the two subcontractors, General Electric (GE), and Teledyne Isotopes (TI). GE will provide major subcontractor support in virtually every task included in the Phase I program. Garrett will draw heavily on the GE background and intimate knowledge relative to the MHW heat source technology as GE represents a direct source of information from the HSA contract currently under NASA sponsorship. GE will also provide strong support in spacecraft integration, mission analysis, GDS design (with particular emphasis on the HSA and simulated heat sink), and GDS testing.

Participation by TI will provide an excellent opportunity to explore alternate HS design ideas which are compatible with the IBFS. The considerable nuclear experience that TI brings to this program provides the total capability to assure that AEC safety requirements are met.

3.1 Technical Approach - Phase I

3.1.1 Program Management (Task 1)

A project director will be assigned the authority and responsibility for the complete program and will have direct access to the division manager.

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

The project director will be responsible for control and monitoring of program activity including the subcontractor effort. The method of subcontractor control will include:

- (a) Weekly verbal reports to the project director by subcontractor program managers.
- (b) Preparation and submission of monthly technical and top summary (includes financial and schedular progress) reports to the project office by the subcontractors.
- (c) Monthly meetings (may include visit to subcontractors' facility) between the project director and the subcontractor.

A project team has been identified with key individuals designated from all participating departments responsible to the project director (see enclosed organization chart in Section 4). In addition, major subcontractors will be responsible to the project director through the purchasing department.

The project director is responsible for coordinating and directing all aspects of the program including:

- (a) A clear understanding of the program requirements and objectives as stated in the RFP and the capability to respond rapidly to these requirements.
- (b) The assignment, to key positions in the program organization, of carefully selected, senior personnel who are experienced in the analysis, design and development of systems substantially the same as those required in this program.

- (c) Provision for direct communication channels is made between program management and higher levels in the Garrett Corporation. This assures rapid compliance with directives from the AEC SNS and that top management is closely involved in the successful conduct of the program.
- (d) Program control and financial reporting. This is done through PERT or modified PERT networks for internal control, a cost and schedule control system (CSCS), progress schedules and data collection and display. Details of this reporting is contained in Section 3.1.1.2 and Volume III - Business and Management Proposal.
- (e) The Master Work Order System which establishes an Accounting Department charge number, describes the planned activity, the total dollars estimated to complete the activity, and the dollars allocated at the time of release of revision provides the basic authorization and control instrument. Release of the Master Work Order automatically authorizes work to proceed and places the activity under the scrutiny of the Accounting Department. This subject is considered in more detail in Volume III - Business and Management Proposal.
- (f) Technical recommendations are made to the Purchasing Department on the selection of subcontractors. The technical and schedule performance of the subcontractors is monitored by the Project engineering team. The financial performance of the subcontractors and consultants is monitored by use of the Master Work Order System as in (e).
- (g) Follow-up of implemented work by conducting technical, financial, schedule, manpower, and facility reviews of progress.

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

- (h) Initiation of corrective action as required.
- (i) Planning and preparation of reports, meetings, and other communications with customers.
- (j) Review and approval of reports, major drawings, and other publications.

Program management personnel will utilize the supporting groups as necessary for the timely completion of program tasks. The following paragraphs summarize the key departments and supporting functions required in the program.

3.1.1.1 Project Engineering

The project engineers are responsible for the soundness and performance of equipment to be designed, built, and tested for the customer. This responsibility includes:

- (a) Technical supervision and coordination of all support groups.
- (b) Technical approval of vendors.
- (c) Preparation and/or approval of procurement and test plans and instructions.
- (d) Preparation and approval of technical reports including documentation control through the engineering files system. Data distribution within AiResearch and its divisions is performed by engineering; data distribution outside the Garrett corporate structure is effected by contract administration.
- (e) Providing for adequate inspection and quality control support.
- (f) Technical approval of drawings and development reports.

The project team engineers are responsible for supplying designs, technical information, test results, hardware deliveries, report material, and consultation. This includes:

- (a) Scheduling the internal design and development work load to meet commitments.
- (b) Implementation and follow-up of fabrication and testing as required to meet schedules.
- (c) Technical contributions to and support of meetings.
- (d) Providing material for incorporation in reports, schedules, and planning documents.

3.1.1.2 Contract Administration

The contract administrator will provide total support to the Project Director in all contractual requirements. He will be responsible for monitoring AiResearch compliance with all AEC requirements. His specific duties will include:

- o Monitoring of program tasks to ensure completion within program schedule
- o Monitor cost and schedule of major subcontracts
- o Updating and submittal of network and program schedules
- o Contract negotiations, documentation, and close-out of contract requirements
- o The interpretation and resolution of all contractual requirements
- o The formal communicating liaison focal point

3.1.1.3 Engineering Sciences

This department includes specialists that provide electrical, materials, aerodynamic, stress, mechanical, thermal and cycle analyses necessary for the successful conduct of this program. The department also provides the preparation and technical editing of the required engineering reports.

3.1.1.4 Manufacturing Engineering

Manufacturing engineers are responsible for providing support to assure the manufacture of the engineering design including:

- o Initial design input regarding producibility, cost impact, and material selection.
- o Issue and maintenance of the detail manufacturing operations and tooling requirements for each part, subassembly and/or assembly.
- o Participation in make-buy decisions

3.1.1.5 Design Office

The design office provides design support to the program and is responsible for all preliminary design, detail design, and manufacturing drawings. The design office provides the following services:

- o Supervises the designers, detailers, and checkers assigned to this program.
- o Controls drawing format and preparation to the appropriate MIL STDs.

- o Provides document control, change records, and filing and distribution service.
- o Participates in design reviews and serves as a major checkpoint in the configuration control system.

3.1.1.6 Materiel

This group provides for fabrication and procurement of all parts and items as implemented by the project engineers. This includes:

- (a) Initiation of purchase orders or shop hardware orders.
- (b) Initial recommendations regarding vendors and suppliers.
- (c) Scheduling and following parts through the fabrication, inspection, and quality-control areas as required.
- (d) Providing fabrication status reports on a weekly basis, cost estimates, and parts cost reports.

3.1.1.7 Laboratory

The laboratory group provides engineers and technicians to supervise and coordinate all activities as required to support the program. This support includes:

- (a) Readiness of facilities, including all test and recording equipment.
- (b) Buildup and instrumentation of test rigs.

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

- (c) Instrumenting components and units to be tested.
- (d) Implementing tests in accordance with schedule.
- (e) Maintaining logs of all test activities.
- (f) Readyng all development and research units for shipment.

3.1.1.8 Purchasing Department

The objective of the AiResearch subcontracting policy is to initiate make-or-buy studies for all equipment manufactured in order to control fabrication and procurement expenditures to the degree that maximum economy will be afforded to the customer consistent with program delivery and quality requirements.

To assure quality and reliability, AiResearch utilizes a comprehensive system for surveying and selecting prospective suppliers. The purchasing and quality control organizations approve prospective suppliers on the basis of ability to supply products meeting the required standards in accordance with the concepts stated in the AiResearch quality control manual. Specific areas of supplier activity monitored by the quality control member of the survey team include the suppliers' quality control organizational structure, receiving inspection, shop control (with emphasis on the control of parts in process), nonconforming material control, functional testing, supplier subcontract control (for special processing facilities), shipping, and general housekeeping.

Control of subcontractors is accomplished by the following methods:

- o Review of procurement documents to ensure that quality provisions meet contractual requirements.
- o Maintenance of supplier performance ratings.
- o Performance inspection of supplied items, both at source and upon receipt at AiResearch.
- o Inspection of test methods and equipment to ensure full compatibility between suppliers and AiResearch.
- o Coordination with subcontractor contract administrators to ensure compliance with prime contract requirements, funding arrangements, and any special considerations peculiar to the program.
- o Subcontractor submittal of fiscal status, manpower status, program progress, percentage of completion, and final reports as well as other required special reports.

Control of subcontractor processing methods is a part of the quality control procedures.

3.1.1.9 Accounting

The Accounting Department is the gathering point for all charges against the Master Work Order. Manpower (Engineering, Laboratory, and Shop) charges are reported on IBM cards against each individual Master Work Order. Purchased parts and those fabricated in outside shops are reported by invoice. All charges are tallied and issued weekly with a breakdown by Master Work Order, each Work Order tally showing a breakdown by department, facility charges, energies, purchased parts, etc. In addition, a weekly summary sheet of all Master Work Orders is issued. This up-to-date reporting allows the Program Director to compare actual charges against each task with the projected expenditure for the amount of the task completed.

3.1.1.10 Cost and Schedule Control

AiResearch will utilize an existing cost and schedule control system (CSCS) to provide a single integrated cost, schedule, and technical performance system. Cost, schedule, and performance control are applied by using the computerized WBS, (Work Breakdown Structure) which defines the divisions of work.

The AiResearch cost and schedule control system is based upon the premise that a primary task of management is to plan and control internal resources and activities in a way that will ensure an effective balance among the parameters of cost, schedule, and technical performance.

Cost and schedule controls utilized by the program office and supported by computerized management information systems, program analysts, and cost accounting, has as its objectives to:

- o Provide cost and schedule supporting data in the detail required for cost, schedule, and technical performance status reporting and analysis.
- o Provide development plan alternatives and supporting data to resolve technical, cost, and schedule problems.
- o Provide required monthly schedule and status reports for management use in fulfilling contract reporting requirements.
- o Provide effective schedule control and technical evaluation information.
- o Provide technical performance monitoring with the use of written progress reports at set intervals by cognizant personnel.

Through schedule and reporting methods, the system provides continuous visibility of the program to all levels of management. This results in early problem identification and the availability of supporting data for analysis of alternative corrective action.

3.1.1.11 Reliability and Quality Assurance

The basic responsibility for the quality, reliability, and conformance of products is vested within each of the contributing departments of the organization. These departments and their procedures are provided to assure the achievement of quality and conformance.

Reliability Program

The reliability organization, with its access to the Division Manager for ultimate authority, provides the talent and direction for the performance of those specific tasks required to provide assurance that the AEC reliability objective is achieved in service.

Reliability is inherent in the design of a project; therefore, the prime responsibility is best vested in the engineering organization that identifies the reliability design requirements at the start of the program and coordinates and monitors the activities necessary to ensure and demonstrate full achievement of these requirements. For these reasons, Reliability at AiResearch, Phoenix, is the responsibility of the Engineering Project that interfaces with all the engineering functional groups and other departments in the company.

Quality Assurance Program

The Quality Program Plan presented in the proposal package will be reviewed with the AEC to assure it conforms to AEC guidelines. The plan is based on Garrett Corporation policies and describes the standard practices utilized to assure the manufacture of conforming products at this division. These products are complex, functional end items for which AiResearch has design control and/or engineering responsibility.

The Manager of Quality Control reports to the Division Manager.

The Quality Control organization is equivalent in stature to other major departments of the Division. The Manager of Quality Control has full responsibility and jurisdiction in all matters involving standards of workmanship, quality of materials, conformance to Engineering standards, and the relationship with customer Quality Control personnel. Commensurate with these responsibilities and authority, the Manager of Quality Control implements the necessary Quality Control policies by means of control procedures designed to assure that the Division produces and delivers quality products. The Quality Control organization, operating in accordance with the established system, is responsible for assuring that the quality standards established for any given product are met and maintained. This responsibility is discharged by the physical measurement of product and by continuous assessment and correction of all other activities contributing to product quality.

3.1.1.12 Safety

AiResearch will prepare a System Safety Program Plan (SSPP) similar to that described by MIL-STD-882 for submission to the AEC. A more detailed discussion is contained in Paragraph 3.1.7.2 regarding the scope of this SSPP. System Safety Engineering is accomplished within the Engineering Project. A separate System Safety Staff, reporting to the Division General Manager through the Director of Product Integrity monitors the adequacy of the plan and its implementation. Resolution of major conflicts takes place within the Product Integrity Committee, made up of the senior managers of the Division.

3.1.1.13 Liaison Activities

One of the prime objectives of AiResearch will be to maintain an effective system of communication with the NASA, GFE suppliers, and potential user organizations with AEC participation. This task will be greatly facilitated because Mr. J. E. McCormick is both the

IBGDS Project Director and the NASA Mini-BRU Project Director, and AiResearch, Los Angeles is the GFE recuperator supplier with direct communication channels in existence between the two divisions.

Other liaison functions will be developed between the Program organization, the HSA subcontractors, and potential user organizations.

AiResearch/SNS liaison activities are described in Volume III - Business Management Proposal.

3.1.2 Conceptual Isotope Brayton Flight System Design (Task 2)

3.1.2.1 Requirements

The purpose of this task is to:

- (a) Review and update the requirements which will apply to the IBFS design
- (b) Identify the long lead items which require effort during Phase I and
- (c) Perform a conceptual design study of the IBFS

GE and TI will support Garrett in this effort to explore several optional HS and HSA designs for use in the IBFS. These will range from the use of the existing MHW hardware to new advanced concepts. GE will also provide substantial support in the areas of mission requirements definitions, spacecraft and launch vehicle design and integration and flight radiator conceptual design.

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

The objective of this task is to incorporate flight requirements into the IBFS design in order to establish meaningful objectives for the GDS phase of the program.

In response to current and evolving DOD requirements, the contractor will conduct a design study of a plutonium fueled Brayton power flight system meeting the system performance objectives as stated in Section 6.2.1. Basic design goals established by the AEC are:

- o 500 - 2000 W_e output
- o 7 year lifetime
- o 3.5 W_e per pound
- o \$5000 per W_e
- o High reliability and safety design
- o Compatible spacecraft and launch vehicle integration

Reliability

Detailed Failure Modes and Effects Analyses (FMEA) will be an integral part of the conceptual flight system design. GE will provide key contributions in the areas associated with the HSA, the radiator, and the MHW heat source. Derating criteria will be established to assure that all components are properly designed to attain the system objectives. Analysis of failure modes and their synergistic effect will be conducted with the primary objective being the identification and elimination of singular failures that would degrade system performance.

Envelope

The component arrangement for the IBFS will be that which represents the optimum packaging scheme while conforming to space limitations existing for potential launch vehicles. The IBFS envelope will be a base for the selected IBGDS configuration.

Efficiency

The design objective will be to better the efficiency goal of 27 percent (BOM) specified for the 1300 W_e power level, consistent with the weight goals established by the AEC.

Nuclear Safety

The major goal of this task will be the attainment of the applicable safety objectives listed in the "Heat Source Safety Design Specification for Space Application."

With major assistance from GE knowledge of the MHW heat source, a nuclear systems safety document will be provided and will conform to the safety design specification for ²³⁸Pu heat sources as developed by the Space Nuclear Systems Division (SNS) of the Atomic Energy Commission.

3.1.2.2 Identification of Long Lead Items

A review of the conceptual IBFS design conducted during the proposal preparation has led to the conclusion that there are several long lead items which could have an impact on assuring completion of the IBFS qualification program by June, 1980. These are listed below:

- (a) High Load Capacity Bearing Development - Providing operation through launch capability
- (b) High Performance Vacuum Insulation Systems Development
- (c) Space Radiator Development

- (d) Advanced IHS Development - (Includes launch pad and in-orbit fueling capability, vent development, materials compatibility, and weight reduction design modifications)
- (e) Flight controls

Specific recommendations and priorities are discussed in detail in Volume 3 and selection (i.e., approval to proceed with individual tasks) will be made by the AEC.

3.1.2.3 Conceptual Design

This section describes the cycle and component characteristics of the Conceptual Isotope Brayton Flight Design. The design approach will be to utilize technologies and, wherever possible, presently available component design concepts identified in previous programs.

During the creation of the IBFS Conceptual Design, the broadest possible investigation will be made of the design alternatives. Garrett, GE, and TI will address those radiator concepts dictated by system reliability requirements. These translate to loss-of-coolant probabilities imposed on the space radiator component of the IBFS. Radiator survival probability requirements will be established with AEC participation, and transmitted to all participants for their implementation.

In the IHS area, TI and GE as subcontractors will submit design concepts which will range from optimum use of the existing AEC MHW design to new advance designs using either the 100 W_t Fuel Sphere Assembly (FSA) (MHW technology) or AEC advanced technologies.

The major components included in the IBFS conceptual design are listed along with their prominent features in Table 3-1.

TABLE 3-1

IBFS Conceptual Design Components

Mini-BRU

- o 1600°F turbine inlet temperature (working fluid is XeHe, $M = 85.8$)
- o Single shaft turbine, Rice alternator and compressor supported on foil bearings with compressor bleed cooling
- o Alternator cooled by compressor discharge
- o Refractory metal turbine plenum (Niobium)

Recuperator

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

Radiator

- o Material (Be, Al, stainless steel or combinations thereof)
- o Cylindrical or conical design, offset fin/tube geometry (heat pipes will be considered as an alternate)
- o Sink temperature, refer to Section 6.5.2, Volume 2
- o Micrometeoroid environment, NASA SP-8013
- o Probability of micrometeoroid survival, 0.99 (assumed)

Heat Source

- o AEC Multi-Hundred Watt (MHW) heat source, (advanced AEC HS concepts will also be investigated)

TABLE 3-1 (Contd)

- o Electrically heated heat source simulator (EHS)

Heat Source Heat Exchanger (HSHX)

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

Insulation

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

Auxiliary Cooling System

- o Helium Short Circuit

Emergency Cooling System

- o Melting insulation (alternates have been identified)

Controls

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

TABLE 3-1 (Contd)

Piping and Structure

- o Ducting
- o Support structure

3.1.3 Preliminary GDS Design and Analysis (Task 3)

A preliminary Ground Demonstration System (GDS) design and analysis will be conducted to identify, develop, and recommend the final design approach for the GDS to satisfy the requirements listed in the conceptual IBFS Design. Key program objectives of this task are:

- o Effectively simulating the Flight System Conceptual Design for Phase II
- o Minimizing Program Costs and Time
- o Planning and Scheduling Phase I and II Programs

Because of GE's background and knowledge relative to the MHW and their participation in the current NASA Heat Source Assembly development, GE will make an important contribution in such activities as FMEA, test facilities design, and preparation of the GDS test plan.

A description of the IBGDS design selection is presented in Section 6.6.

3.1.3.1 Preliminary GDS Design

The recommended GDS design will evolve with AEC participation from the conceptual design of the Isotope Brayton Flight System configuration. This will lead to a selected IBGDS reference design for the Phase I program. The program will contain interacting tasks for the fulfillment of the Phase I program as shown in Figure 3-2, Phase I Program Approach.

The activities discussed below describe the effort included in C and D of the program approach shown in Figure 3-2.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

PHASE I PROGRAM APPROACH DIAGRAM

FIGURE 3-2

Failure Mode and Effects Analysis

The GDS failure modes and effects analysis (FMEA) conducted during this task will be a modification of that accomplished during Task 2 of the Phase I program. The FMEA will consider all failure modes and their related effects in accordance with the reliability objectives in SNS-2, "Reliability Engineering Program Requirements Publication," June 17, 1974.

Reliability Objectives

The life requirement of the IBFS is a seven year operation with a mean mission duration (MMD) of five years. All reliability objectives outlined in the SNS-2 publication are applicable to this program. GDS reliability objectives are those commensurate with achieving the performance of endurance testing on schedule in a cost effective manner.

Packaging Layouts

The major components (i.e., BRU, recuperator, heat source assembly, cooler, ducting, controls, etc.) will be arranged to facilitate spacecraft integration with respect to the vehicle launch and operational limitations. The preliminary packaging layout SKP 32518, shown in Section 6.5.1.1 of Volume 2, will be used for further refinement in support of this subtask.

Interconnecting Ducting Optimization Studies

Techniques for minimizing pressure loss and thermal losses will be integrated using existing AiResearch computer programs. The results of these analyses will result in the optimized duct sizing and insulation schemes. This will involve costs of insulation and isotope trade-off studies and will use the selected IBFS single inlet and discharge ducting scheme as a baseline.

Piping and Instrumentation (P&I)

A P&I diagram will be generated to define flow directions, control device input and output signals, energy flow, and the general location of all instrumentation. The P&I diagram will represent the major components and control subassemblies as block diagrams and will be the primary document for maintaining a common system definition.

Control Schematics and Approach Definition

Control schematics will be constructed to assist in the design of control system concepts showing sufficient redundancy to ensure fulfillment of the reliability objectives over the desired lifetime.

Test Facility

The test facility used for the IBGDS testing will include a modified existing vacuum test chamber. The test facility will not only be used for GDS testing but also for the design verification of prototype flight system hardware during Phase II. This test chamber is described in detail in Section 3.5.

The complete IBGDS design concept will resemble the IBFS as closely as practicable. The GDS will contain the following:

- o GFE Mini-BRU
- o GFE recuperator
- o A simulated radiator heat sink
- o An electrical heat source simulator
- o GFE heat source assembly
- o Ducting and insulation
- o Development controls

As part of this task the following specifications and requirements will be updated and firmly established in support of the Phase II program:

- o Test objectives and data requirements
- o Facilities and test equipment specifications
- o Component specifications
- o Controls specification
- o GFE supplementary requirements
- o IBFS component specifications

Design Review Meeting

Following completion of the preliminary design of the GDS, a document will be prepared summarizing the results of this design effort. Included in this document will be: all data necessary, including conceptual drawings, to clearly define the recommended GDS design approach and the rationale for its selection; a failure mode and effects analysis and definition of reliability objectives; and alternative GDS packaging layouts.

The preliminary design summary document will be submitted in a design review meeting to the AEC for their approval 30 days following completion of the design effort.

3.1.3.2 GDS Test Plan

The GDS test plan will consist of a comprehensive document detailing all aspects of the GDS test program including cleanroom assembly and test hardware, test procedures, test facilities, controls and hardware protection devices and test instrumentation.

Test Objectives

The test objectives for the GDS, as specified below, will be the demonstration of the ability of the system to meet the requirements as specified in Section 3.1.2 with strong emphasis placed upon sufficient data acquisition to support the IBFS design.

Specific test objectives are:

- (a) The accumulation of IBGDS operational time and data
- (b) The test of components and subsystems under simulated operating conditions of the IBFS
- (c) Verification of performance at design point, off design, and in transient regimes
- (d) Verification of subsystems reliability and safety characteristics
- (e) Demonstration of IBFS prototype life capability with 5000-hour endurance test

Test Facility Functional Requirements

The test facility for the IBGDS will house a thermally regulated vacuum chamber capable of performance and endurance testing of the GDS system which will include:

- o Mini-BRU (GFE), with refractory metal turbine plenum
- o Recuperator (GFE)
- o Heat source assembly (GFE), with a refractory metal heat exchanger

- o Heat sink simulator
- o Prototype thermal insulation system
- o Prototype system ducting
- o Control system including parasitic load

Controls and Instrumentation

A control system will be implemented for the IBGDS which will:

- o Start the engine
- o Provide engine protection
- o Shut down the engine
- o Provide electrical power and power management
- o Provide loop gas management
- o Provide engine speed control

These functions will be accomplished with a system located outside the vacuum chamber.

The instrumentation components must be accurate to a degree sufficient to monitor the system performance, and utilize transducers compatible with the environmental conditions of this test.

The reliability of the controls and instrumentation will be commensurate with the costly preparation for testing which should not be interrupted because of control or instrumentation malfunctions.

The controls and instrumentation required for the IBGDS are discussed in detail in Section 6.6.2.

Special Test Equipment (STE)

The acquisition of necessary special test equipment will be accomplished on a timely basis as requirements become firm. Current requirements for STE include:

- o Auxiliary battery system for starting and controls
- o Auxiliary cooling system gas (Helium) supply and controls
- o Data acquisition system, multiplexer, processing, and readout
- o Cooling system for heat sink
- o Electrical interface harnesses from PCS to tank wall
- o Gas management system for processing and charging PCS with working fluid
- o Ground test console
- o Power supply console
- o Clean assembly area

3.1.4 Detailed GDS Design and Analysis (Task 4)

Detailed design and analysis will be conducted to support the timely development of the IBGDS. The following tasks are to be completed in fulfillment of this portion of the program:

3.1.4.1 System Layouts

Detailed manufacturing layout and assembly drawings will be generated to support the fabrication and assembly activities of the IBGDS. The layout drawings will reflect the selected IBFS design features such as the ducting configurations (size, length, and routing), which will result in reduced IBFS pressure drop and insulation complexity and weight while maximizing reliability. Structural interfaces will be defined with mounts designed to accommodate typical launch loads.

3.1.4.2 Transient Effects

The start-up and shutdown procedures to be used for the flight system will be determined from a combination of analytical studies and laboratory experimentation. A prime objective of determining recommended starting and shutdown procedures is to ensure that the system is not damaged from thermal stresses. This objective is best met by computerized transient studies which will determine problem areas and viable solutions to these problems. An existing computer model of the IBFS will be used to perform this study. A common problem is the rate at which the recuperator can be heated. All anticipated starting and shutdown procedures will be analyzed by means of computer programs described in Sections 6.5 and 6.6 in Volume 2, and the extent to which thermal stresses are imposed on the HSHX, BRU, and recuperator will be determined. GE will provide a model of the HSA thermodynamic characteristics and will assist in performing the study.

The scheduling of speed and load in relation to the electrical output requirements will be established for the IBGDS in support of the IBFS (Phase II) program. System pressure scheduling will be included in this task by use of computer analyses and performance testing of the IBGDS with the three, one, and finally the two HSA configurations. All three of these configurations utilize differing state point values of pressure, temperature, and fluid flow. Information gained in this task will be included in FMEA considerations and will assist in the modifications of the prototype IBFS.

3.1.4.3 Heat Sink

A tradeoff study will be performed with GE support considering alternative GDS heat sink designs. A preliminary selection procedure has been formulated to evaluate the cost effectiveness of candidate design approaches through the completion of Phase I. The initial procedure includes the influence of each approach on the following:

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

- o Hardware cost (both recurring and nonrecurring)
- o Facility cost (both recurring and nonrecurring)
- o Hardware maintenance (based on FMEA)
- o Facility maintenance (based on FMEA)
- o Direct operating cost

The procedure will subsequently be refined to include:

- o Overall program cost impact
- o Overall program schedule impact
- o Determination of optimum spare component requirement
- o Use of existing facilities which meet requirements

The heat sink design approaches which will be evaluated will range from a low cost, liquid cooled radiator simulator to a prototype space radiator with full space environmental simulation. All components and subcomponents evaluated for use in the heat rejection system will conform to one of the following categories:

- o Commercially available hardware
- o Existing or modified version of state-of-the-art hardware
- o Existing or modified version of hardware common to the system

All approaches considered will be subject to analytical verification of performance. Predicted performance of all components will satisfy the heat sink specification over the entire engine operating range as described in Figures 2, 3, and 4, Exhibit II of the Statement of Work.

The proposed tradeoff procedure described herein is described in greater detail in Section 6.5.2.5, Volume 2.

A preliminary tradeoff study has been completed for nine candidate design approaches. The selected configuration utilizes an identical Mini-BRU recuperator as the primary heat sink heat exchanger. This heat rejection approach incorporates an intermediate gaseous argon loop within the confines of the vacuum environment.

3.1.4.4 Control and Instrumentation Systems Detail Design

The detail design of the IBGDS control and instrumentation systems will be accomplished after the final preliminary design has been accepted by the AEC. The controls detail design activities will evolve from that subsystem selected for the IBFS and will include all safety features necessary for IBGDS testing. Output from this task includes:

- o Circuit schematics
- o Circuit diagrams
- o Detailed parts lists
- o Assembly drawings
- o Wiring diagrams

The controls system will be the prototype of that designed for the IBFS and will consist of the following functionally discrete components:

- o Motor Start Inverter
- o Power Supply
- o Parasitic Load Speed Control (PLSC)
- o Voltage Regulator Excitor (VRE)
- o Rectifier/Filter

A tester will also be provided for fault isolation. The control components are shown on the block diagram of Figure 3-3.

ELECTRICAL SYSTEM BLOCK DIAGRAM

FIGURE 3-3

The philosophy proposed for developing flight qualified hardware is shown on Figure 3-4. Prototype controls for the Mini-BRU have been developed at the Lewis Research Center and are described in NASA TMX 3084. These controls will be utilized for initial GDS testing. Modifications will be made to these controls if necessary to effect control functions defined by the system analysis to be performed during the initial effort of Phase I. Once fabricated, the controls will be checked as a system using a duplicate of the air turbine driven bearing test rig built for the Mini-BRU. Results from the test rig and system tests will be incorporated into the preliminary flight control definition. After the baseline flight circuits are functionally defined, detailed stress, FMEA, and reliability analyses will be performed. The circuits will be iterated until a satisfactory circuit is defined, at which time a prototype control will be fabricated and tested with the electrical system test rig and subsequently with the GDS. Results of these tests will be incorporated into the flight control design requirements and detailed procurement specifications for hybridized circuits will be prepared.

A major concern during the design will be to assure that sound design techniques, such as power supply decoupling and grounding, are adhered to and that sufficient test points and testing procedures are defined to readily identify and isolate faults. Evaluation of these techniques during the IBGDS will assure rapid, rigorous performance evaluation during pre-flight system checkout.

The detail design will assume high reliability employing methods of:

- o Component derating (voltage, current, temperature, stress)
- o Critical circuit redundancy with the establishment of preferred failure modes

CONTROL DEVELOPMENT PROGRAM

GDS CONTROLS

SYSTEM
AND
CIRCUIT
ANALYSIS

FLIGHT CONTROLS

Reliability
FMEA
Hybridization
Compatibility
High Voltage

Environmental

PHASE
II

FIGURE 3-4

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION

All potential failure modes will be identified and sufficient redundancy will be provided to assure that no single component failure will degrade system performance.

3.1.4.5 Structure; Ducting, Bellows, Valves, and Joints

The design and analysis of bimetallic joints, thermal insulation, ducting bellows, and valves will be accomplished in this task. Bimetallic joints design considerations are discussed in detail in Sections 6.5 and 6.6 of Volume 2.

Ducting

Ducting length, routing, and insulation will be designed. Potential problems with thermal insulations are encountered in the use of refractory metals in the IBGDS. Design and analysis will be conducted to minimize the effects associated with outgassing and complex geometric configuration.

Bellows

Bellows will be used to counter the effects of ducting expansion and contraction. State-of-the-art bellows technology will be utilized, where applicable.

Valves

The IBGDS will employ the following valves (refer to Section 6.6.2) to facilitate development testing:

- (a) Turbine Bypass Valve - This is used in the IBGDS only for overspeed and fault protection should the parasitic load need development modification.

- (b) Pressure Relief Valve - This valve will prevent inadvertent overpressurization of the test system.
- (c) Check Valve - This valve assures one-way flow of the working fluid. This can be critical during the system start-up as the turbine will perform as a compressor until the working fluid is sufficiently heated.

Assembly

This task will include the construction of a wooden mock-up of the IBGDS to work out assembly structure and interface details.

3.1.4.6 Materials Compatibility

During the detail design and analysis task, special consideration of material compatibilities will be accomplished to ensure all subsystems once assembled, will operate for the lifetime requirement without experiencing the adverse effects associated with dissimilar metallic joints. The anticipated bimetallic joints for the IBFS are listed in Sections 6.5 and 6.6 of Volume 2. Included in this task will be the fabrication of the bimetallic joints which will be used in the assembly of the GDS. Of particular importance is the usage of the refractory metal parts, such as the turbine plenum and HSHX, which require special consideration. Vendor fabrication techniques and contractor laboratory testing will be used to aid in the design of bimetallic joints and perhaps refractory metal coating materials.

3.1.4.7 Electric Heat Source Analysis

Electric heat source analysis and design will be performed and will be consistent with the GFE EHS or a contractor procured electrical heat source simulator. The EHS must simulate the physical and thermal characteristics of the Multi-Hundred Watt (MHW) Isotope Heat Source.

The EHS developed for the MHW program for the AEC by GE is directly applicable to the IBGDS. The single area of concern is that the current design requires about 16 hours to achieve operating temperature. However, it is identified that the heat up time can be reduced by opening up the EHS tolerances for this static (no shock and vibration) application. An alternative "Glo-Bar" resistance heater system will be evaluated for initial development testing. This heater will be designed to simulate the IHS as nearly as practicable. When development "bugs" have been worked out of the GDS system and endurance testing is scheduled, this heater assembly could then be replaced (if used) by the more sophisticated MHW simulator.

Included with either system will be:

- o Heater power supply consoles (PSC)
- o System control interfacing (cables, contactors, etc.)

These are already designed, and have been built for the MHW EHS.

3.1.4.8 Test Facilities

The test facilities for the IBGDS will be detail designed with respect to those resulting from the preliminary design phase. The test facility's equipment includes the following:

- o The use of existing vacuum chamber which is a 6 ft dia x 8 ft vacuum chamber with 10^{-8} Torr with cold wall capability
- o Vacuum pumping equipment consistent with the vacuum chamber capabilities
- o The use of a heat sink (perhaps a Mini-BRU recuperator) to simulate the end-item space radiator

- o Fast response tape recorders for transients and dynamic data acquisition
- o Long-term response equipment for long-term trends, etc.
- o Electrically heated heat source simulators, two per test system ($2400 W_t$ each)
- o Gas management system for storing, purifying, and reclaiming the working fluid
- o Assembly tools and fixtures
- o Instrumentation harnesses and cables
- o 100 inventories of working fluid
 - 90 Krypton
 - 10 Xenon-Helium (M.W. = 83.8)
- o Cleanroom handling equipment and facilities (including bake out and ultrasonic cleaning equipment)

3.1.4.9 Detail Design Review

Following completion of the detailed analysis and design of the IBGDS, a summary of this design will be presented to the AEC for their approval in a design review meeting. A topical report documenting the final design of the IBGDS will be issued 30 days following AEC design approval. This report will highlight IBFS commonality, differences, and rationale.

Included in the topical report will be: a complete system ducting layout; system transient behavior and FMEA studies; results of a heat sink design trade-off study; detailed control system design; detailed structural design including materials selection and system mock-up; a comprehensive bimetallic joining program and materials compatibility studies; electric heat source design, including power supply and controls; and complete test facility and data management system design.

3.1.5 Fabrication and Assembly of GDS and Test Facilities (Task 5)

Fabrication and assembly of the GDS and the test facilities will be accomplished following the conclusion and AEC approval of the detail design task. Checkout of the test facility will be completed to prepare the test facility for the execution of the prescribed performance and 5000 hour endurance testing plans. Receipt of all GFE hardware is anticipated by April 1976.

GDS Assembly Procedure

The primary problem to be encountered during assembly of the GDS is the welded connection of components with dissimilar materials.

The preferred approach is shown in Figure 3-5. A hot end assembly which includes all of the columbium components; turbine plenum with bimetallic joints, HSAs and ducting with bimetallic joints will be welded together into a single unit at a facility specially equipped to perform Cb welding. Such facilities are not uncommon and exists at AiResearch, G. E., Wah Chang, and Fansteel. This hot end assembly will then be assembled with the BRU/Recuperator subassembly at the GDS assembly room, and the Hastelloy X and stainless steel welds made to complete the assembly.

A desirable modification to the above approach involves inserting a Hastelloy X section into the turbine inlet duct. This section with high strength at high temperature would be somewhat life limited, but it provides additional convenience in that the BRU with plenum can be removed from the HSAs by simply cutting a Hast X-to-Hast X weld.

GDS ASSEMBLY SEQUENCE

FIGURE 3-5

3.1.6 Test and Evaluation (Task 6)

3.1.6.1 GDS Performance Testing

During the first four months of the test and evaluation task, the performance testing of the GDS will be completed. Testing will be conducted for the following:

- o Startup and Shutdown - The startup and shutdown testing will consist of determining the most effective methods for achieving start and shutdown of the IBFS. Results from this activity will facilitate the determination of the effects of the following identified phenomena of interest:
 - o Thermal stress effects on HSHX, BRU and recuperator
 - o HS operation during shutdown and its effects
 - o Reverse flow of working fluid
 - o Start method
 - o Recuperator and HSHX pre-heat
 - o Heat soak-back after shutdown
 - o HSA Auxiliary Cooling System Operation

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

- o Performance Mapping at 1300 W_e - The PCS will be tested with the design thermal input of 4800 W_t . The initial test conditions will be that of the predicted operating point from the performance analysis in Section 6.6.3. Provisions will be made for variable loop inventory (i.e., pressure level) to obtain the maximum performance and for fine tuning the system. Compressor inlet temperature will also be varied to obtain the empirical trade-off between system performance and radiator size. Sufficient instrumentation will be provided to establish the efficiency level of the compressor, turbine, recuperator, cooler, and heater and the overall pressure loss.

This will allow performance deficiencies to be readily identified. The data will be recorded on Sanborn strip recorders and (DDAS) digital equipment. The operating point defined by this testing will be that which will be used in the endurance testing.

- o Off Design Performance Mapping - Since the IBFS design addresses a 4800 W_t configuration, the proposed GDS includes two 2400 W_t HSA's. This will limit the electrical output of the GDS to about 1600 W_e depending upon the compressor inlet temperature (i.e., the cycle efficiency level).

For a system designed to use a three-HSA configuration with the capability to modulate the heat release of each EHS, the off design performance could be mapped continuously from 0 to 2000 W_e .

Performance Test Topical Report

A topical report will be prepared and submitted to the AEC 30 days after completion of performance testing. The report will describe in detail the results of: a complete performance mapping at 1300 W_e output; system capability to provide power output over a range; and start-up and shutdown testing. The report, further, will present data in the depth necessary to permit a comprehensive cycle evaluation and loss analysis.

3.1.6.2 GDS Endurance Testing

The endurance testing will accommodate both design and off design testing sequences as described in Section 6.6.7 by employing a gas management system and redundant electrical circuits of parasitic loads for speed control. The proposed gas management system will have refill, gas purification, and reclamation capabilities as a means of regulating mass flow through the pressurized loop.

To minimize costs while maximizing reliability and safety, the unit to be tested will be welded at all duct connecting interfaces to provide hermetic sealing.

The endurance testing will be fully automatic and will include digital readout, automatic shutdown, alarms, and diagnostic capabilities. The endurance tests will require seven months of "continuous" operation. The test will be monitored by the test conductor or his designee every 1/2 hour for the first 100 hours, every hour for the

next 650 hours, and once every eight-hour shift thereafter. Long-term continuous, trend recordings (slow rate) will also be made.

All data from the endurance testing will be documented and evaluated by the AEC and the contractor.

3.1.7 Quality, Reliability and Safety (Task 7)

3.1.7.1 Quality Assurance and Reliability

Quality assurance and reliability program activities will be conducted through the program (Phase I). Considerations for follow-up activity in support of Phase II planning will be a continuation of information obtained from the Phase I support activity. The QA and reliability program plans will use as applicable documents the following SNS publications: SNS-1, "Quality Assurance Program Requirements for Space Nuclear Systems," April 1972; SNS-2, "Reliability Engineering Program Requirements Publication," June 17, 1974. The task effort will include the requirements of Table 3-2.

The AiResearch General Quality Program Plan QC-048, Rev. 4, dated October 1, 1974 is provided in the proposal package for review. This plan details the standard practices employed to assure the quality of products and systems manufactured and tested at this facility.

It is recognized that those portions which pertain to Quality Control are, in general, consistent with the objectives of SNS 1 and SNS 2. This document will be modified to reflect the specific requirements of the GDS. In turn this document will establish the background data for Phase II.

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

TABLE 3-2

PHASE I REQUIREMENTS

	<u>Due End of Month ARO</u>
Reliability Program Plan (RPP) (including System Reliability Equations)	4
Preliminary FMEA for IBFS	4
GDS Quality Assurance Plan	4
GDS FMEA (and reliability objectives)	13
QA Assessment of Hardware	16
QA Input to GDS Pre-Design	
QA Input to GDS Design	
Reliability Assessment of Test Program	20
FMEA, Transient Effect Studies (including Performance Parameter Equations Related to Confidence Limits)	
Reliability Input to GDS Design	
Reliability Assessment of Phase II IBFS Design	26

3.1.7.2 Safety

The contractor will plan and conduct a System Safety Program to provide assurance, with a high degree of confidence that: (1) isotopic fuels and radioactive products, emanating from either the fuel or its daughter products will not interact with humans or the environment during normal operations or in the event of credible, foreseeable accidents, (2) all other hazards to man or the system will be identified and controlled. Nuclear safety activities for Phase I are detailed in Paragraph 3.1.7.2, Volume 1 of the GE and TI proposals.

In general terms, the System Safety Program Plan (SSPP) will provide for the following:

- (a) The IBGDS and IBFS Program will have a specific individual, selected from the System Safety Staff, who will be responsible for defining and conducting the System Safety Program. He will report to the Program Director.
- (b) Two independent checks of the System Safety Engineering activities will be made, one by the Program Director and one by the Director of Product Integrity, to provide assurance that the safety program is both adequate in scope and timely in execution.
- (c) Assurance will be provided that System Safety Engineering is integrated effectively with other disciplines through the efforts of the Director of Product Integrity. Program Safety Monitors will be appointed in each functional area to insure adequate coordination.

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

- (d) Final resolution of safety-related conflicts is accomplished by the Product Integrity Committee.
- (e) Safety considerations will be extended from the system level down through the subsystems and components, through all tiers of subcontracting and throughout the Divisions of AiResearch.
- (f) The appropriate hazard analysis will be performed at the system, subsystem and component levels for all phases of the program.
- (g) The progress of the safety effort will be reported regularly at management meetings.
- (h) Occupational Safety and Health (OSHA) activities will be incorporated into the program at the same levels as Engineering Safety.

The program safety objectives will be achieved through analysis and testing, relating to time and system level, in accordance with the matrix shown in Table 3-3. Data derived from activities in each segment will be used for subsequent phases of the program. Reports will be submitted in accordance with Table 3-4 of Section 3.1.8.

The IHS subcontractor will be monitored in the performance of his nuclear safety studies to insure adequate compliance with all specification requirements and to assure that no interface effects reduce the level of nuclear safety.

All applicable safety requirements will be identified, including DOD, AEC, and OSHA. Appropriate measures will be taken to eliminate or control all identified hazards, both with the GDS Program and the flight systems.

TABLE 3-3

ANALYSIS, TEST, AND REPORT MATRIX

	<u>Conceptual IBFS Design</u>	<u>Preliminary GDS Design</u>	<u>Detailed Design and Development</u>	<u>Test Operations</u>	<u>Flight Design For Phase II</u>
System	Develop System Safety Program Plan	Refine Safety Plan	Participate in Quality Assurance Program		Phase II SSPP
	Conduct Preliminary Hazard Analysis	Preliminary Hazard Analysis	Systems Integration Prepare preliminary safety analysis report (PSAR)	Participate in System Testing Incident Investigation	Phase II PHA Phase II FMA
	Determine environmental envelope	Establish contingency and emergency procedures		Accident Investigation	Phase II OHA
			FMEA	Refine FMEA	Flight Safety Assessment Report
	Develop safety criteria in terms of analyses and testing	Conduct failure mode analysis and establish criticality of occurrence Conduct operational hazard analysis on GDS			
Subsystems		Prepare subsystem specifications	Participate in heat sink tradeoff study	Coordinate with vendors and subcontractors	
		Establish subcontractor requirement			
		Develop subcontractor controls	Participate in control system design		
		Establish test facility safety requirements	Participate in design review		
Components		Prepare component specifications	Establish subcontractor and vendor controls	Coordinate with vendors and subcontractors.

3.1.8 Reports and Data (Task 8)

Reports and data submissions will be made during the entire Phase I and Phase II programs. The types of reporting include:

- o Monthly top summary reports
- o Monthly financial reports
- o Monthly technical reports
- o Annual technical reports
- o Final reports
- o Special reports as listed in Table 3-4

3.1.9 Advanced Development (Task 9)

A development program for long lead development of flight system hardware will be initiated during Phase I. The effort, in support of the AEC approved Phase I program plan, will be conducted in any system or component area where such an effort is deemed necessary before the completion of Phase I. Considerations will include:

- o Those listed in Sections 3.1.2, 3.1.4, and 3.3 of Volume 1
- o Component upgrading
- o Special component or system testing

A Garrett Radiator design and development program plan is appended at the conclusion of Section 3.1.10.

Both subcontractors will provide substantial support for Task 9, consistent with their unique expertise and according to those efforts recommended by AiResearch and approved by the AEC.

It is expected that GE will work in such areas as development of the beryllium radiator manufacturing methods, bi-metallic joint development, and HS developments involved with further improving the operational margin and safety of the AEC MHW heat source, beyond the high level already achieved.

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

TABLE 3-4

<u>Title</u>	<u>Due End of Month ARO</u>
Phase I Program Plan	3
IBFS Design Report	4
IBFS Preliminary FMEA	4
IBFS Preliminary Safety Analysis Report	4
GDS Reliability Plan	4
GDS Quality Assurance Plan	4
Preliminary Design Review Data	7
GDS Test Plan	7
GDS Facility and Equipment Specifications	5
GDS Components Specifications (less controls)	13
GDS FMEA (and reliability objectives)	13
(GDS Safety Review)	TBD
GDS Detail Design Topical	13
QA Assessment of GDS Hardware	16
Performance Test Topical	20
Reliability Assessment of GDS	20
Phase II Flight Design and Engineering Plan	26
Endurance Test Report	27
Reliability Assessment of IBFS	26
Safety Assessment of IBFS	26
Program Plans for Long Lead Items	TBD

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

It is anticipated that TI will be required to be involved in activities relative to advanced HS technology such as materials compatibility, testing, helium vents development, and HS safety analysis.

3.1.10 Flight Design and Engineering Program Plan (Task 10)

Recommended design and program plans for Phase II, Flight Development and Qualification, will be submitted. The program plan and cost estimates will be updated and improved. Appropriate consideration and recommendations regarding the following will be made:

- o Design to accommodate operation through launch
- o Advanced recuperator, BRU, and radiator for flight design
- o Packaging and thermal insulation
- o Spare part requirements
- o Advanced alternator flight design (material upgrade)
- o Component environmental testing
- o Component upgrading (see Phase II Program Plan)
- o Safety and reliability assessment
- o Advanced HSA flight design
- o Advanced HS flight design

Phase II qualification testing will include the following test activities (refer to Section 3.2.5):

(a) EBFS Development Testing and IBFS Qualification Testing

- o High vacuum performance with space radiator
- o Remote startup and shutdown
- o Launch and orbital inertia loads
- o Vibration
- o Shock
- o Control system function

- o Emergency shutdown
 - o Orbital shutdown and restart
 - o Performance verification
 - o Off-design performance
 - o Verify maintainability
 - o Endurance test
 - o Other electrical tests -
 - Short circuit
 - Sudden load
 - Frequency regulation
 - Harmonic distortion
 - o Performance degradation with partial loss of gas
 - o MIL-STD-810B tests
 - o System safety
- (b) IHS Development and Qualification Testing
- o Thermal Vacuum Testing
 - o Verification of load and unload procedures
 - o Testing to required performance criteria
 - o Safety
 - o Vibration and Shock
 - o Post test evaluations by fueling agency

The IBFS design will be reviewed and modified to reflect:

- (a) The information gathered from GDS testing
- (b) Data produced by the advanced development efforts
- (c) Updated flight requirements model

A preliminary Phase II Engineering Program Plan (EPP) will be prepared at the conclusion of Phase I activity. The EPP will include the design and analysis, testing, fabrication and assembly, quality assurance, reliability, and safety information from the IBGDS program. The EPP will serve as the outline for the initiation of the IBFS program (Phase II).

RADIATOR PROGRAM PLAN

The radiator design and development during Phase I of the program has been divided into four major tasks. These tasks together with their interrelationships interface with the system level studies as shown in Figure 3-6, Radiator Development Task Logic Program. During Task I, Preliminary Design and Tradeoffs, radiator designs will be generated for a range of system requirements, surface coatings, and materials of construction. These data will be supplied to the systems studies effort, and by iteration, the most promising radiator designs will be identified. It is anticipated that two radiator designs will be carried beyond this point, one based on aluminum construction and a second based on beryllium construction.

Task II, Design Layout, will perform the function of detailing the designs selected as a result of the Task I effort. This task will also provide input to Task III on detail elements of the design requiring development. Under Task III, component development, design verification testing will be conducted in areas which could impede development of the radiator in Phase II of the program. Task III will receive input from both Task I and Task II. Task I input will consist of early identification of surface coatings to be tested, Task II will identify additional testing requirements as mentioned above.

Task IV, Final Design, will provide for revision of the design based on the results of the development work performed under Task III.

Task I - Preliminary Design and Tradeoffs

The primary function of this task is to supply radiator design data for system trade-offs and provide early identification of items requiring advanced development. To effectively accomplish this function, analysis must be conducted in several areas; these are briefly discussed below.

RADIATOR DEVELOPMENT TASK LOGIC DIAGRAM

FIGURE 3-6

1. Radiator Environment Determination

The effective sink temperature over the vehicle surface and its variation with time will be established. These computations will be carried out using AiResearch computer program H1200, Orbital Radiant Heat Transfer, which is specifically designed for this application.

2. Radiator Surface Coatings

In the design effort of Task I, the entire subject of spectrally-selective radiator coatings will be reviewed. Both government and industry sources will be contacted for the latest data and developments in this field. From this survey, one or more candidates for the surface coating will be chosen. After this selection is made there are several areas which must be investigated to ensure that the selected coating and the radiator properly function over the intended life of the system.

The coating tentatively selected and used in the preliminary proposal design effort is a silver-coated Teflon film manufactured by the Schjeldahl Co. of Northville, Minnesota. This coating has a nominal emittance of 0.8 and solar absorptance of 0.08; or α_s/ϵ ratio of 0.1.

Coating application techniques will be reviewed, and the best adhesive will be selected for test evaluation. These selections will be made early in Task I to allow the maximum test duration in Phase I.

3. Parametric Radiator Designs

Generation of radiator designs for system tradeoff studies will be greatly aided by the use of an existing computer program, H0000 Single Phase Radiator Design Program. This program systematically varies the numerous design parameters involved in a radiator specification, and produces printed output that allows the program user to

choose a minimum-weight/minimum-power-penalty design. In effect, the program deals with a flat, unwrapped radiator panel. The designer through input data can vary the following parameters over a specified range:

- o Working Fluid Flow Rate
- o Panel width
- o Panel length
- o Materials of construction
- o Allowable pressure drop
- o Panel thickness (radiator fin thickness)
- o Tube spacing (number of parallel tubes)

Also, the user may specify the inside tube diameters which are allowed; and the tube wall thickness is determined based on the protection provided by adjacent radiator elements and the meteoroid protecting criteria.

Various meteoroid protection schemes will be evaluated to determine a minimum overall weight. Concepts to be evaluated include center tube-fin with armor, center tube-fin with bumper, and offset fin.

In establishing tradeoff designs, the materials of construction have a strong influence on weight and hence the major tradeoff variable. Aluminum and beryllium are the most promising candidate materials. Aluminum radiators can be considered state-of-the-art from the viewpoint of fabrication processes, whereas the use of beryllium will require development of fabrication processes. Designs based on both or combinations of both materials will be carried through Task I. The best material to use is not obvious at this time.

4. Off-Design Performance

During the parametric design study, a preliminary system integration analysis will be conducted. For radiator designs of high merit, off-design performance analyses will be conducted to establish preliminary control requirements and their impact on system operation. This effort will be greatly aided by use of an existing radiator performance prediction computer program (H0300, RADPER).

Task II - Design Layout

Under this task the selected designs will be refined and detail layouts prepared. The overall radiator design will be established including the following items:

- o Tube and fin configuration
- o Meteoroid protection
- o Structural supports and critical joint design
- o Manifolding
- o Differential thermal expansion provisions
- o Component mounting provisions
- o Bi-metal transition
- o Spacecraft interface

These layouts will serve to tie all of the above factors together into an integrated design. The overall radiator assembly weight and reliability can then be realistically evaluated. The tradeoff between beryllium, aluminum, steel, and combinations of these materials can be accurately determined. When these baseline designs are established, the radiator assembly weight can be compared to the weight goal, and an accurate determination of the relative merits of beryllium, aluminum, titanium, and steel can be established.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

As the details of the design are derived, areas requiring advanced development will be identified for fabrication and test in Task III.

Task III - Component Development

The activities proposed in this task are concerned with developing long lead-time items or technology that will not be developed as part of the GDS effort but will be required for the flight system. Development for the radiator is proposed in the following areas:

- o Surface Coating Development
- o Detail Element and Fabrication Process Development

1. Radiator Surface Coating Evaluation

To verify the coating properties and bond strength, it is recommended that screening tests be conducted during Phase I. Small-scale specimens using different bonding agents or techniques will be prepared and subjected to an integrated neutron dose equivalent to that predicted for the IBFS radiator. Both aluminum and beryllium substrates will be evaluated. It will be assumed that the sample irradiation will be performed by the Government at no cost to the contractor.

After irradiation the samples will be placed in a vacuum chamber maintained at $< 10^{-7}$ torr. The samples will be subjected to a range of temperatures, from 40 to 300°F and will be thermal cycled. The samples will be periodically checked for any evidence of bond delamination such as blistering or cracking. Testing will be continued until the specimens have accumulated 10,000 hours exposure. Testing can be extended into Phase II if required.

Coating optical properties will be measured at the beginning and completion of each test.

2. Detail Element and Fabrication Process Development

This activity will be concerned with the development of the fabrication processes to be used in the fabrication of the radiator assembly. As the detail design is evolved in Task II, elements of the design will be identified for development. Fabrication processes as well as metal joining techniques will be established and executed under this task. The samples evolved will be tested to verify their major function whether it is structural or thermal.

This task is primarily concerned with development of a beryllium based design since the experience in fabrication of beryllium components and assemblies is limited. The basic plan is to test critical joints and structural sections; full-size radiator panel fabrication will be accomplished in Phase II.

Task IV - Final Design

The function of this task is to update the flight design radiator to reflect the results of the Task III effort. The Task III data will be analyzed for its design implications. The radiator design analysis will be revised and updated. The results of these analyses will be incorporated into the design and the drawings revised. The design definition provided by the drawings together with the development experience gained in Task III will be utilized to develop Phase II plans.

3.2 Technical Approach - Phase II

The objective of the Phase II program is the development and subsequent flight qualification of the Isotope Brayton Flight System (IBFS). Subcontractor support, in the areas of heat source design, safety, fabrication and integration with the GFE heat source assembly will continue from the Phase I effort. Qualification testing may be a major subcontractor activity being conducted at either contractors facility or a government operated facility chosen by the AEC.

3.2.1 Program Management, Phase II (Task 1)

The program management for the Phase II Flight System Development and Qualification program will be consistent with the Phase I effort. Program management functions will encompass the following sub-tasks as set forth and described in Section 3.1.1.

Program Direction

Planning and Scheduling

Implementation and Technical Direction

Schedule, Cost and Manpower Evaluation

Documentation Control and Distribution

Configuration Control

Liaison with NASA, GFE Suppliers and Potential Users

The preliminary program schedule for Phase II is enclosed on the following page (Figure 3-7).

3.2.2 System Design and Analysis (Task 2)

Task 2 includes all activity required to define the IBFS; from preparation of detailed specifications, to detailed design, and analysis of the components. Throughout this task, close contact and liaison must be maintained with the user agencies and the members of the nuclear community.

System Definition

The preliminary design and analysis of the IBFS will define the total flight system and will use the IBGDS performance and endurance testing as an information base. All aspects of the total flight system will be evaluated to produce a qualifiable flight system configuration. The IBFS definition will include:

- o System specification
- o Subsystem definitions
- o Component nomenclature
- o Component function
- o Component use with respect to higher tier subsystems
- o Component sizing
- o Component performance characteristics

The IBFS system definition will be accomplished with respect to the design factors and requirements discussed in detail in Volume 2, Section 6.2.

Component Specifications

During the course of the proposed program, the contractor will prepare and publish detail component specifications for all components and equipments including:

- o Controls
- o Heat Source Assembly (HSA)
- o Electrically Heated Heat Source Simulator (EHS)
- o Isotope Heat Source (IHS)
- o Recuperator
- o Ducting and Insulation
- o Radiator
- o Brayton Rotating Unit (BRU)

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

- o Ground Support Equipment (GSE)
- o Flight Support Equipment (FSE)
- o Structure and miscellaneous

The specifications will include requirements for the controls corresponding to each of the major subsystems and support equipment. The specifications for flight system hardware will set forth the requirements for performance, environmental design criteria, subsystems interfacing, volume and weight, reliability, safety, and quality assurance.

The component specifications will contain the following sections and any appendices required to define the equipment.

- (a) Scope
- (b) Applicable Documents
- (c) Requirements
- (d) Quality Assurance Provisions
- (e) Preparation for Delivery
- (f) Notes
- (g) Appendix(es)

Style, format language, abbreviations, numbering, symbols, and phrasing will conform to established AEC and DOD practices.

Initially, these specifications will be used for the design, procurement, development, and test of the subject items. As required, the specification will undergo revision and be utilized for procurement and acceptance of identical units in production quantities. The methodical development of these specifications will, therefore, serve as a guidepost in early phases of the program, and subsequently, as an integral part of the production item procurement package.

Configuration Control

The existing AiResearch, Phoenix configuration control system procedures will be utilized to maintain the design drawing configuration. Refer to Section 3.1.1 for a description of the configuration control system. In addition, a configuration control document (CCD) will be established for the systematic definition and control of the Isotope Brayton Flight System (IBFS) qualification configuration consistent with Section 3.1.1. This document will completely define the IBFS performance and endurance testing configurations, and also indicate those areas to be defined in the future and the data required for this definition. The CCD will contain all information necessary to assure effective control of the development of all IBFS components. The following information will be contained in the CCD:

- (a) Layout and top assembly drawings of all components and subsystems
- (b) Physical data for each component
- (c) Materials list
- (d) Physical and functional interrelationships
- (e) Interfaces (mechanical and electrical)
- (f) Start up and shutdown procedures
- (g) Instrumentation
- (h) Handling procedures

Interface Control

Interface control is required to assure a design and functional consistency of each component with its mating component and the overall system. Four areas of interface are important:

- (a) Mechanical Interface - The mechanical interface in the PCL includes the duct connections between the mating components and all structural support information.
- (b) Controls Interface - The BRU and the heat source will have a controls interface with the spacecraft. This would most easily be achieved by a single plug-in type interface. This is discussed in Section 6.5.1, Volume 2.
- (c) Instrumentation - Each component will have certain instrumentation requirements (pressures, temperatures, accelerations, etc.). Again, this will be achieved with a plug-in type interface. In some cases the instrumentation taps will also be used as controls interface, as in the case of overtemperature alarms.
- (d) Structural Interface - Each component will have structural attachments with the system. This will be in the form of bolt and weld joint attachments.

Overall interface control will be achieved in conjunction with the configuration control and component specifications described above. A procedure will be established whereby the system configuration will be continually monitored and updated with the latest configuration for each component. Each component change that, in turn, affects the interface will be forwarded to the designer in charge of the master system layout and the CCD for evaluation and inclusion therein.

Spacecraft Integration

Spacecraft integration will be a vital part of the IBFS design activity and will initially depend on the DOD flight requirements to be established, and subsequently upon development of IBFS specifications. Design considerations are discussed in detail in Section 6.5, Volume 2.

User Liaison

Potential IBFS user liaison with DOD and potential commercial users will be essential during this task as well as throughout Phase II. Through this effort, IBFS specifications, performance characteristics, and general capabilities will be continuously reviewed and compared to user needs.

3.2.3 Phase II Safety (Task 3)

To perform this task Garrett will draw heavily upon nuclear HS subcontractor expertise and experience. A Phase II SSPP will be prepared, specifying the type and extent of analysis required during Phase II. All safety related testing will be identified and recommended. Specific nuclear safety requirements will be identified and design criteria to meet them will be established. The scope of the SSPP will be designed to insure that the IBFS meets all the nuclear safety objectives and that no other hazards to man or equipment will be unidentified or uncontrolled. Included in this task will be all safety design analysis, planning, and reporting required to conduct the following:

- o Development tests
- o Qualification tests
- o USAR
- o FSAR

The IBFS will have as a design goal the attainment of all safety objectives listed in the SNS publication "Heat Source Safety Design Specification for Space Application." The safety program for the IBFS will be consistent with that specified in Section 3.1.7.2.

3.2.4 Product Assurance (Task 4)

Product assurance activities in the areas of reliability, quality assurance, configuration management, and design reviews be conducted to assure that the end-item flight system hardware meets the requirements and specifications of the following AEC documents:

SNS-1 "Quality Assurance Program Requirements for Space Nuclear Systems," dated April, 1972.

SNS-2 "Reliability Engineering Program Requirements Publication," dated June 17, 1974.

The quality assurance and reliability plans for the IBFS will be based on the prior plans generated for the IBGDS as stated in Section 3.1.7.1. To support the reliability effort, an FMEA, consistent with that of the Phase I effort, will be prepared. The FMEA generated under current NASA contract for the PCS will aid this task.

Configuration management activities will be conducted to assure reasonable traceability and control of the evolving IBFS design with the aid of a configuration control document (CCD). The CCD will be consistent with the requirement stated in 3.2.2.

The contractor will also conduct timely design reviews to review and augment, as necessary, the product assurance activities within the Phase II and III programs.

3.2.5 Qualification Test Plan (Task 5)

Early in Phase II, the Qualification Test Plan document (QTP) will be drafted to delineate overall test procedures and requirements necessary to establish the Isotope Brayton Flight System (IBFS) as flight qualified. This plan will be presented to the AEC for approval and will completely define the following:

- o Inspection criteria and procedures (leak, pressure, functional, etc.)
- o Quality Control Procedures
- o Test facilities
- o Quantity and configurations for all hardware to be qualified
- o All appropriate specifications and regulations (such as MIL-STD-810B)
- o Detailed test procedures

The procedures shall cover all phases of the qualification program including start-up methods, launch environment test methods, abort situations, environmental testing, design point and off design point performance verification, and endurance testing.

The QTP will contain provisions for a special iterative process of testing, design modification, and retesting for the purpose of successfully completing the qualification requirements in regard to the objective of a flight hardware delivery in June, 1980.

The preparation of the QTP involves a systematic analysis of:

- o The DOD flight requirements specification
- o The hardware configuration which must be proven flight ready
- o The design characteristics of interest

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

To the greatest extent possible, system tests requiring changes in environment, power, and test duration will be accomplished using the electrical heat source (EHS) simulator in lieu of the isotopic heat source (IHS). This approach will reduce program costs while enhancing utility and program safety. Component and subsystem testing of the IHS will proceed in parallel with the remaining component and subsystem testing.

The testing of non-isotopic components and subsystems will conform to the applicable sections of MIL-STD-810B and, particularly, those applicable tests and test sequences as outlined in Table I, Recommended Test Sequences. In addition, the space simulation testing for unmanned vehicles, Method 517, will depend on the particular environmental conditions to be simulated.

For complete system testing, two power conversion systems (PCS) each requiring two 2400 W_t EHS simulator elements will be used. Required test facilities for a "full up" operating system will include:

- o Clean room assembly areas
- o Ground support equipment (GSE) for off-site testing relating to heat source handling, loading, testing and transport (if an IHS is later used for system qualification)
- o Vacuum chamber capable of 5×10^{-8} Torr and temperatures down to -70°F (for anticipated geosynchronous orbit simulation)
- o Digital readout capability, fast response tape recorders for transient and dynamic data and long term recorders for long term trends
- o Environmental testing capabilities (refer to MIL-STD-810B)

- o All special equipment necessary for contractor on-site assembly and disassembly; e.g., etchers, bellows expanders and contraction devices, lubricants, turbine wrench assembly, dials, gauges, sweepers, etc.
- o Gas management system capable of purification and reclamation of the working fluid and its return to the high pressure accumulator
- o Pressure vessel for enclosing the IBFS (less radiator) in an inert atmosphere

Flight Qualification Test Sequence

The Flight Qualification program shall conclude with a complete flight qualification test sequence that will demonstrate flight readiness of the IBFS for a specified mission.

The IBFS requirements will be carefully analyzed to determine the type of tests which should be included in the flight qualification test sequence.

From that analysis, a test sequence will be generated. As part of the planning, a qualification test and facility schedule will be generated. An example is shown at the conclusion of this section.

The QTP will include, as applicable, the procedures and related information of the following documents:

MIL-G-6099A	Generators and Regulators, Air Cooled, A-C Aircraft General Specification For
MIL-STD-810B	Environmental Test Methods
MIL-STD-202C	Test Methods for Electronic and Electrical Component Parts
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-SP-78	The Meteoroid Environment and Its Effect on Materials and Equipment

NASA TMX-53957

Space Environment Criteria
Guidelines for Use in Space
Vehicle Development

3.2.6 Power Conversion System Design (Task 6)

The preliminary design of the IBFS power conversion system (PCS) will be based upon the results of the IBGDS program and the specific mission power and configuration requirements. The completed design will include the interfacing of the following sub-systems:

- o Brayton Rotating Unit (BRU)
- o Recuperator
- o Heat Source Assembly (HSA)
- o Structure
- o Ducting and Associated Hardware (bellows, etc.)
- o Control Systems
- o Space Radiator

3.2.7 PCS Development and Fabrication (Task 7)

Necessary component development, procurement, fabrication, and assembly efforts will be completed and will demonstrate the attainment of the specified mission requirements.

Brayton Rotating Unit

The development and fabrication of the IBFS BRU will be largely derived from the IBGDS of the Phase I program described in Section 3.2.6. An exception to this will be the development and subsequent fabrication of necessary modifications forthcoming from the evaluation of IBGDS testing.

Controls

The controls subsystems and circuits will be derived largely from those demonstrated on the IBGDS control system. The only anticipated potential changes would be those resulting from future flight system requirements. The circuits will be fabricated into miniature circuitry where practicable under quality control standards equal to the best standards of current state-of-the-art technology.

Recuperator

The recuperator developed for the IBFS will be similar to the GFE recuperator with appropriate modifications as dictated by the GDS testing. The GFE recuperator is a viable candidate for the IBFS due to its overall performance, especially at the higher power levels ($>1300 W_e$). A smaller, lighter unit may be required to meet the weight requirement of $3.5 W_e/lb$.

Heat Source Assembly (HSA) (Primarily a Subcontractor Effort)

Modifications to the HSA and the included MHW heat source will be minimized in an effort to avoid, or at least reduce, any additional component and/or subsystem safety qualification activities.

Radiator (Primarily a Subcontractor Effort)

The preliminary selection for an IBFS radiator will be one fabricated from either aluminum or beryllium. Beryllium may be required to reduce the specific weight to $286 lb/kW_e$. Cylindrical, conical, and flat plate designs will be considered. Envelope considerations with respect to the protective shroud of launch vehicles will be studied before the final radiator configuration is selected.

Ancillaries

Using a mockup for optimization of ducting and instrumentation will provide a low cost, expedient method for determining ducting, electrical harness, and instrumentation location and routing.

3.2.8 Heat Source Design (Task 8)

The current baseline design uses the AEC MHW heat source and the cylindrical HSA configuration with the wrap-around solid-to-gas HSHX. The AEC may elect to employ an alternate approach involving either a reconfiguration of the MHW or the utilization of an entirely new HS design based upon cost, performance, and safety data generated during Phase I. If this occurs, this task will provide for the redesign effort. Detailed description of proposed heat source designs are presented by Teledyne and General Electric along with their respective program plans in Section 6 (attachments to Volume 2) and Section 3 (attachments to Volume 1).

3.2.9 Heat Source Development and Fabrication (Task 9)

The heat source for the IBFS will be either the isotope heat source (IHS) and/or the electrically heated heat source simulator (EHS). The EHS will, except for modifications, be that used for the Phase I testing.

The reference IHS will be the MHW heat source with the final design changes for emergency cooling provisions incorporated. The information from the PCS design (Section 3.2.6) will bear heavily on the final development and ultimately the fabrication of the IBFS qualifiable heat source.

Nuclear safety factors will be considered throughout the heat source design and development.

3.2.10 Qualification Testing (Task 10)

The qualification program includes all program activities and tests during Phase II directly involved in establishment of the IBFS as flight ready. It involves a number of systems in an iterative process of testing, redesign, and retesting. The qualification program will conclude with a special "Flight Qualification Test Sequence".

A qualification test sequence will be conducted on a minimum of one complete Brayton Power System using the IHS and/or the EHS. The qualification test program will be executed according to the appropriate provisions of the QTP described in Section 3.2.5. The qualification test will verify the capability of the system to fulfill SURVSATCOM mission requirements. It is anticipated that qualification testing will be performed at the GE, Valley Forge test facility. GE has a large, nuclear qualified facility operated by experienced engineering and technical personnel. An alternative is use of GFE facilities.

Endurance testing, the last phase of the qualification tests, will be conducted continuously for a specified number of hours as set forth by the AEC. The endurance testing will be fully automatic and will be monitored as specified in the GDS endurance testing of Phase I (Section 3.1.6.2).

3.2.11 Ground Support Equipment (GSE) (Task 11)

All necessary GSE for meeting the requirements of the off-site Brayton Flight System Development and Qualification program will be designed, procured, and fabricated by the contractor. The GSE will include equipment required for the nuclear heat source handling, loading, testing, and transport and that equipment listed in Table 3-5. Use of the GFE facilities will be anticipated in advance of their use, allowing proper intervals for their organization and funding.

AI RESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

TABLE 3-5

GROUND SUPPORT EQUIPMENT (GSE)

AUXILIARY BATTERY SYSTEM, SUPPLIES ELECTRICAL
POWER TO INVERTERS FOR STARTING & CONTROL

AUX COOLING SYSTEM GAS SUPPLY & CONTROLS,
SUPPLY COOLING GAS TO HSA

DATA ACQUISITION SYSTEM, MULTIPLEXER, PROCESSING
& READOUT (THAT WHICH IS NOT ALREADY PART OF
EACH FACILITY)

DEMONSTRATOR COOLING SYSTEM, SUPPLIES COOLANT
FOR GDS HEAT SINK

HARNESS FROM PCS TO TANK WALL

GAS MANAGEMENT SYSTEM FOR PROCESSING AND CHARGING
PCS WITH WORKING FLUID

GROUND TEST CONSOLE, OPERATES GDS, EBFS OR IBFS.
(SAFETY CIRCUITS, SWITCHES, INSTRUMENTS, & POWER
CONDITIONER, ETC)

ISOTOPE HANDLING EQUIPMENT FOR HANDLING, LOADING
& TRANSPORT OF IHS

UNIT ASSY FIXTURES, UNIT SUPPORT IN CELL, DUCTING
FROM UNIT TO TANK WALL

POWER SUPPLY CONSOLE, SUPPLIES ELECTRICAL POWER TO
EHS (INCLUDES CABLES & CONNECTORS). EHS SUPPLIES
THERMAL ENERGY TO PCS

RADIATOR COOLING SYSTEM, HEAT RECEIVER & COOLANT
SYSTEM FOR RADIATION

SHIPPING CONTAINERS FOR ALL GSE

3.2.12 Reports (Task 12)

The reporting methods and requirements consistent with those of Phase I will be in effect for the Phase II and III programs. Special reports concerning safety, testing, material properties specifications, and operating procedures will be published when appropriate.

3.2.13 Phase III Plan (Task 13)

A detailed plan for the conducting of Phase III will be submitted and will include the procurement, fabrication, assembly and the acceptance testing of deliverable flight power systems. The delivery schedule will be based on a preliminary estimate of four units per year. The initial flight qualified power system will be delivered by June 30, 1980.

The acceptance test procedures (ATP) by which each flight system is tested before delivery to the customer will include provisions set forth to verify that the prescribed quality control provisions are in effect, and each complete system meets specific critical predetermined ATP requirements.

A sample Phase III plan is presented below.

SAMPLE PHASE III PROGRAM PLAN

The program management for the Phase III Production Program will be consistent with the Phase II effort as described in Section 3.2.1. A detailed Phase III program plan will be reviewed and updated throughout the Phase I and II programs with the objective of attaining a production rate of four Isotope Brayton Flight Systems per year. One of the key elements of the program will be the continued user liaison as predicated on the preceding two phases of the program. The Phase III

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

effort is anticipated to be initiated approximately five quarters prior to the first unit delivery target date of June 30, 1980. This would be accomplished through a production go-ahead decision and the establishment of updated flight vehicle and mission definition requirements at that time. Three months following go-ahead, the IBFS production and the launch pad GSE designs would be released. During the flight system production phase, all components of the IBFS will be fabricated under the established provisions of the quality assurance, reliability and safety programs approved by the AEC in conjunction with the using agencies. All components for each system including required GSE and FSE will be assembled and acceptance tested using the qualified facilities, tools, and procedures as established during the two previous phases. Having successfully completed these phases, the initial flight system will be delivered to the using agency in June, 1980.

The contractor will furnish launch pad support including prelaunch checkout. Post launch support will include activities pertaining to (1) system status during launch and (2) the monitoring of system performance during specified phases of the mission.

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

Refer to the previous page for an explanation
of why this page was omitted.

3.3 Anticipated Technical Problem Areas

The anticipated technical problem areas are briefly discussed in the following paragraphs. A more detailed discussion on each problem area is presented in Section 6.5.5, Volume 2.

3.3.1 Bearings for Operation During Launch

The current bearing design for the Mini-BRU is for minimum loss "zero g" and "one g" operations. Bearing designed for operation during launch must be capable of withstanding launch accelerations of the approximate magnitude of 5g lateral and 10g longitudinal.

3.3.2 Refractory Metals

To meet the lifetime objective of seven years, the HSA, HSHX, and the BRU turbine plenum have been determined to require fabrication from a refractory metal (specifically the columbium alloy, Cb-103) to minimize the effects of thermally induced stresses. Cb-103 is a material with good high temperature strength, but its major drawback is that organic compounds are extremely corrosive to it at elevated temperatures.

3.3.3 Radiator Construction

Until the flight requirements have been issued, the basic geometry of the space radiator is uncertain as is the material to be used for construction. The material candidates are aluminum, beryllium, stainless steel, and combinations thereof.

3.3.4 Insulation

Two insulation schemes are currently being considered along with their respective disadvantages. These are:

- (a) Fibrous insulation for the GDS with outgassing the major problem area at high temperatures and low pressures.
- (b) Super Insulation (Nickel foil) for the IBFS with the inherent difficulty of application to complex geometries.

3.3.5 On Pad System Cooling

Cooling schemes for both the system non-operational and the system operational modes have to be designed to minimize overtemperature of the system from the heat generated (directly or indirectly) from the decaying plutonium fuel. In addition, the temperature in the payload compartment must be kept below 380°F to preclude auto-ignition of spacecraft or booster hypergolic propellant.

3.3.6 Bimetallic Joints

The constraints imposed on joining dissimilar metals are the differences in thermal expansion and the metallurgical stability of the higher temperature joints.

The anticipated bimetallic joints for the IBFS are the following:

- (a) Compressor discharge plenum (stainless steel, SS347) to turbine plenum (refractory metal, Cb-103).
- (b) Turbine diffuser (refractory metal, Cb-103) to recuperator inlet duct (Hastelloy X).
- (c) Recuperator (Hastelloy X) to HSA inlet ducts (refractory metal, Cb-103).
- (d) HSA inlet and outlet ducts (refractory metal, Cb-103) to outer structure shell (titanium).

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

3.3.7 Fueling

The key problem areas associated with on-pad fueling are as follows:

- (a) Impact on current HSA design
- (b) Auxiliary cooling system design impact
- (c) Emergency cooling system design impact
- (d) Nuclear safety

A detailed discussion of these topics is presented in Section 6.5.5.2.

The technical ramifications associated with in-orbit fueling are discussed in Section 6.5.5.3.

3.3.8 Controls and Instrumentation Systems

As discussed in Section 3.1.2.1 and described in detail in Section 6.6.2 the evolution of flight qualified control circuitry by 1980 requires advanced planning and development. In addition, the possibility exists that analysis to be performed during the early stages of Phase I may identify additional controls and instrumentation requiring long lead development.

3.4 Suggested Changes of Scope

The proposal package contains no contractor suggested changes in scope for Phase II. For Phase I the following change in scope is suggested.

A proposal for an advanced Isotope Heat Source was solicited by AiResearch from Teledyne Isotopes Energy Systems Division. The proposal Report Number IFSD-5062 is attached hereto. It discusses a concept for the isotope heat source based upon the technology currently being developed by ESD under AEC Contract SNSO-3, and offers the possibility of weight and safety advantages.

During the three months Conceptual Design Task 2 of Phase I, work effort by Teledyne Isotopes has been included in the proposed Phase I program to better define other advantages of this concept.

Subject to a review of the results from Task 2 in July, 1976, it is suggested that the Phase I scope of work then be increased (a) to permit continued work by Teledyne Isotopes on this isotope heat source concept, and (b) corresponding work required on the Heat Source Assembly and balance of the system should the concept not be physically and functionally interchangeable with the referenced heat source.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

3.5 Required Equipment and Facilities

The major equipment and facilities required to effect the successful completion of the GDS program have been identified to include those items described in the following sections. Refer to Volume 3, Business and Management Proposal, for cost and reimbursement aspects.

3.5.1 Facility

The recommended facility design approach utilizes an existing AiResearch vacuum tank and pump system capable of maintaining a pressure of 10^{-5} torr, backfilled with an inert gas, during extended durations of testing. The GDS test facility is discussed further in Section 6.6.6, Volume 2.

3.5.2 Test Chamber Pump System

The high vacuum technology of the design approach utilizes dual turbo-molecular (mechanical roughing) pumps in parallel with a back ion pump for increasing overall pump capacity.

The preliminary selection of the turbo-molecular pumping units is the Sargent-Welch Model 3116D or 3117D. These units have a pumping capacity of 3400 cfm each in the range of 10^{-4} to 10^{-8} torr.

NASA-Houston has a similar pump which has accumulated approximately 10,000 hours of trouble free operation including one year of continuous operation.

The recommended ion pump is a National Research Corporation ORB-ION Pump Model 204 or 206.

3.5.3 Residual Gas Analyzer

For added protection, a residual gas analyzer (RGA) is recommended to monitor test chamber gas constituency. The RGA will aid in diagnosing leak sources thus acting as a warning system against test system failure. The recommended RGA is a consolidated Electrodynamics Corporation (CEC) Type 21-614. For further details refer to Section 6.6.4, Volume 2.

3.5.4 Heat Source Simulator Power Supply

The EHS power supply console (PSC) will be furnished by GE. The PSC will supply controlled electrical power to the EHS. The EHS PSC is described in detail in the GE attachment to Volume 1.

3.5.5 Controls and Instrumentation

The recommended equipment for the GDS in the area of controls and instrumentation is shown on Drawing 306960, appended to Volume 2. Some of the facility control requirements are further discussed in Section 6.6.2 where the operation of the control system during testing is described.

Instrumentation will be required to provide extensive monitoring of the loop by the data acquisition system. Data acquisition is of three forms: (1) a digital data system, (2) meter displays of critical parameters, and (3) a trend recorder. The digital data system will record all of the parameters tabulated on Drawing 306960. These parameters allow performance to be determined and also provide information sufficient to troubleshoot and pinpoint any problem. The trend recorded can provide instantaneous information on up to 30 variables. The variables on the trend recorder may be changed as various portions of the testing are conducted.

3.5.5.1 Digital Data Acquisition and Processing

Two fully computerized data acquisition systems are provided. One of these systems consists of a Systems Engineering Laboratories Model 810A. This unit, along with its peripheral equipment, is a fully mobile system. The system has the capability of data acquisition at a rate of 200 samples per second. This data can be converted into engineering units and displayed on a KSR35 teletype or CRT. Alarm capabilities for up to 16 parameters are possible on real time conditions. The system's hardware and software are fully compatible with the central computerized data acquisition system permitting maximum flexibility, economy, and rapid turnaround of data.

The computerized data acquisition system consists of a Systems Engineering Laboratories Model 810B computer with 32,000 words of memory. Its peripheral equipment consists of a 400 card/minute card reader, 600 line/minute printer, Gould 5000 printer-plotter, ASR33 teletype, eight CRT's, three magnetic tape recorders, two disc storage units (one movable head and one fixed head) and five remote, portable multiplexers. The multiplexers can be located anywhere within the facilities where required. Communication between the computer and its remote multiplexers is achieved through a network of coaxial cables used as serial transmission links. Where cables are not possible, an infrared link is used.

Simultaneous data is acquired at the rate of 200 samples per second from any of four multiplexer test locations. With special equipment, sampling rates may go as high as 250,000 samples per second. Data is recorded on magnetic tape for permanent storage. On-line data output coupled with quick look capabilities of selected performance calculations is available. This data is displayed at the test site by means of CRT systems. Complete data logging in engineering units, performance calculations and plots are available within seconds of test completion.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

A flightworthy digital-data-acquisition system is available for acquiring data during flight tests on AiResearch experimental aircraft. This system outputs its data on magnetic tape in a format compatible with both the SEL 810A and 810B.

3.5.5.2 Panel Instrumentation

The instrumentation to monitor the flight type parameters will consist of an Anadex counter to indicate BRU rotor speed and Doric digital meters to read temperature and pressure. The Doric indicators will be supplied with either pressure transducers or thermocouples to provide the appropriate input. The voltages will be indicated with digital voltmeters. In order to obtain trend data, the above parameters will also be recorded on a multichannel Sanborn recorder.

3.5.5.3 Protection and Alarms

The protection and alarm indicators will permit easy adjustment of high or low set points and will provide visual and/or audible annunciation as well as control switching. The onset of the alarm will either attract the attention of the operator and permit him to rectify the "out-of-specification" operation condition (for non-critical conditions) or effect a shutdown for the critical parameters as shown on Drawing 306960.

3.5.6 Cleanroom Assembly Area

A special cleanroom assembly area, which features the latest equipment for ultraclean handling, leak detection, final processing and assembly, will be provided. Extensive electronics manufacturing and assembly facilities also are available. These facilities are dust limited and utilize the latest in component manufacturing, assembly, calibration and functional checking equipment.

4.0 PROGRAM ORGANIZATION AND PERSONNEL

4.1 Program Organization

The Garrett Corporation has been involved in aerospace activity since its formation in 1936, a period during which the company has produced a multitudinous variety of aircraft and space vehicle components and systems and is the dominant free world supplier of small turbomachinery power systems. Since 1948 we have pioneered small open cycle gas turbine power systems of all types including aircraft propulsion engines for a wide array of government and civilian applications. The Garrett Corporation is unique in the concentration of high level technological specialties and program management to solve complex total system and interface application problems.

Extensive space system experience exists within the AiResearch Divisions due to strong participation in the NASA manned space program where environmental and valve control systems were successfully supplied for the Mercury, Gemini, Apollo and Skylab programs and the Atlas, Titan and Saturn booster vehicles. An abundance of clean rooms and space test facilities with trained personnel to operate them are available, as needed, for the Isotope Brayton Flight System.

Garrett entered the space power arena in 1956 when it conducted the Pied Piper satellite dynamic power system study that defined the subsequent SNAP 2 program. A small mercury vapor turbopump was tested and considerable liquid mercury lubricated bearing development was accomplished at the AiResearch Phoenix facility. Subsequently, numerous USAF dynamic power system study and test programs were performed at this facility culminating in the award in 1960 of the SPUR (Space Power Unit Reactor) program that later became the AEC/USAF SNAP 50/SPUR Program. During this program extensive design and testing of potassium vapor and liquid turbines, boilers, bearings and a complete turboalternator was accomplished.

During 1961 The Garrett Corporation fully recognized the potential of the closed Brayton cycle, particularly for smaller space power systems, to be developed in a time frame consistent with the rapid development of space boosters and vehicles. This concept was actively pursued with company funding because it represented a direct extension of standard company product lines and system capabilities with the exception of nuclear heat sources. These include small high speed turbomachinery, heat exchangers, alternators and controls. In particular, The Garrett Corporation, being the world's largest producer of small open cycle gas turbines and aerospace heat exchangers, has in place a multi-million dollar facility (including large high vacuum chambers) for manufacturing, instrumentating, and testing closed or open cycle gas turbine systems.

Within one year, 1963, Garrett constructed a 3 kilowatt electrically heated closed Brayton cycle unit with essentially off-the-shelf hardware and designs to demonstrate the feasibility of this concept and this unit was extensively tested later at the NASA Johnson Space Center. As a result of these efforts, Garrett acquired numerous closed Brayton cycle development contracts as listed in Figure 4-1 and is the world leader in this technology.

Of particular interest is the 10 kW Brayton engine built for the NASA Lewis Research Center that has logged over 28,000 hours of successful operation at the NASA Cleveland facilities. The success of this program led to the NASA commitment to support the development of hardware for the 0.5 to 2.0 kW_e Mini Brayton space power system. The AEC "Mini Brayton Economic RTG Study", contract SNSO-6, performed by General Electric and AiResearch confirmed the selection of this technology as a viable space power system candidate.

Consequently, by maintaining continuity in the team of people who performed all of the above efforts, a highly qualified and dedicated staff of managerial and technical personnel are available to perform

CLOSED CYCLE CONTRACTS

CUSTOMER	DATE	TYPE OF PROGRAM	\$ VALUE
NASA AND USAF	1963 1965	ADVANCED COMPONENT DESIGN DEVELOPMENT AND FABRICATION	638,000
NASA LEWIS	1963 1965	DEVELOP AND CONSTRUCT 10 KWE TWO-SHAFT ENGINE	1,579,000
NASA, NR, MCD-DOUGLAS	1964 1971	SPACE STATION/BASE POWER SYSTEM STUDIES	206,000
NASA HOUSTON	1963 1971	DESIGN-CONSTRUCT-TEST 3 KWE DEMONSTRATOR ENGINE	164,000
NASA LEWIS	1966 1972	DESIGN-CONSTRUCT-TEST 10 KWE SINGLE-SPOOL ENGINE (BRU)	6,491,000
NASA LEWIS	1970 1972	DESIGN-CONSTRUCT-TEST 100 KWE TURBO-ALTERNATOR-COMPRESSOR FOR REACTOR HEAT SOURCE (TAC)	3,118,000
NASA/AEC/USAF/GE	1972 1974	STUDY OF 0.5 TO 2.0 KWE MINI-BRAYTON SYSTEM FOR SATELLITES	128,000
NAVSHIPS NSRDC NAVSEC	1969 1974	STUDY AND DEVELOPMENT OF TWO EXPERIMENTAL PROPULSION ENGINES (CCPS 40-1 & CCPS 10-1)	5,174,000
NAVSHIPS	1970	CONCEPTUAL DESIGN 50 KWE POWER SYSTEM FOR DEEP SUBMERGENCE VEHICLE	50,000
AEC/WECO	1972	DESIGN-CONSTRUCT-TEST 3 KWE DEMONSTRATOR ENGINE FOR USE WITH CO60 HEAT SOURCE	100,000
MARAD	1973	STUDY OF A 9,000 HP ENGINE FOR LNG REFRIGERATION AND A 40,000 TO 80,000 HP SHIP PROPULSION ENGINE	310,000
AECL	1973	STUDY OF A 30 KWE UNDERWATER POWER SYSTEM	25,000
PFE	1973	25 HP REFRIGERATOR RAILCAR GENERATOR SET DEMONSTRATION UNIT	450,000
AGA	1973	10 HP ROOFTOP REFRIGERATION DEMONSTRATION UNIT	750,000
NASA LEWIS	1974	500 TO 2500 WATT MINI-BRAYTON TURBOALTERNATOR AND RECUPERATOR (MINI-BRU)	2,207,000
TOTAL			21,390,000

FIGURE 4-1

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

the Isotope Brayton Ground Demonstration System program and the follow-on Flight System Development, Qualification and Production. To meet the specific tasks in this program, the best technical talent will be drawn from the two major divisions of The Garrett Corporation in Arizona and California and the major subcontractors, the General Electric Company and Teledyne Isotopes.

The first attached foldout is an organization chart of The Garrett Corporation which is a wholly owned subsidiary of the Signal Companies and consists of eight operating divisions and five subsidiaries with over 10,000 people. The greatest number of these people, more than 8500, are employed in the AiResearch Manufacturing Divisions in Arizona and California under the Aircraft and Aerospace group Vice President Mr. I.E. Speer who reports directly to the office of the President, Mr. H.H. Wetzel and Senior Executive Vice President Mr. J.V. Crawford. This chart delineates the corporate operational and corporate staff responsibilities.

The Isotope Brayton Ground Demonstration System program will be conducted by the AiResearch Manufacturing Company of Arizona. Mr. W.G. Orr, Corporate Vice President and Manager reports to Mr. I.E. Speer. The organization chart for this division is shown in Figure 4-2.

The second attached foldout is a functional and product line chart, which shows how the lateral organizational units support the four basic Product Lines in this division, namely Power Systems, Aircraft Propulsion Engines, Pneumatic Systems and Industrial Engines. The Isotope Brayton Ground Demonstration System program will be part of the Power Systems Product Line, managed by Mr. R. Bodemuller. Functionally reporting to Mr. Bodemuller are all of the lateral organizations in the Division including Sales, Contract Administration, Engineering, Quotations, Material, Purchasing, Manufacturing (these latter three groups have been combined under Manufacturing Operations since July 22, 1974), Quality Control, Accounting, Product Support and Field Service.

ORGANIZATION CHART

THE GARRETT CORPORATION

FUNCTIONAL AND PRODUCT LINE CHART

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

ORGANIZATION CHART

PHOENIX DIVISION

*FUNCTIONS RESPONSIBLE TO CORPORATE OFFICES

**REPORTS TO ASSISTANT DIRECTOR, PROPULSION ENGINES
AS CHIEF, FLIGHT ENGINEERING AND AIRWORTHINESS

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

The Isotope Brayton Ground Demonstration System program will be managed by Mr. J.E. McCormick, who has been a member of the Closed Cycle Project since 1961. He has direct control of the program technical, cost and schedule requirements and he is completely versed in the requirements for the successful conduct of this program. The organization planned for this program is shown in Figure 4-3.

The priority for this program within the corporation is stated in the letter from Mr. W.G. Orr, Corporate Vice President and Division Manager, appearing at the beginning of this document. Mr. McCormick has direct access to divisional and corporate management through the Power Systems Product Line Manager, Mr. R. Bodemuller. Mr. McCormick will devote his entire time to management of this program except for management through completion of the NASA Lewis Research Center Contract NAS3-18517 for the development of the Mini-Brayton Rotating Unit, a component that will be an integral part of the Isotope Brayton Ground Demonstration System and follow-on programs. Therefore, he will be directly in control of the development of the demonstration system and the most important component in that system. He will spend full time on these two programs, dividing his time as necessary to achieve the maximum efficiency in developing the Isotope Brayton Ground Demonstration System.

Mr. R. Stark, Contract Administrator, will provide the necessary support in meeting the contractual reporting requirements. Mr. Stark is also the contract administrator for the NASA Mini-BRU. This function is completely described in the Business Management volume.

Directly supporting Mr. McCormick are the project team engineers shown in Figure 4-3. These engineers will perform the sequential tasks as needed and will draw on the broad base of specialists in the divisions who are located in the Reliability and Quality Assurance groups, Engineering Sciences groups, Laboratory, Design Office, Controls Project, Heat Transfer Project and Manufacturing Engineering. Support

PROGRAM ORGANIZATION

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION

FIGURE 4-3

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

will also be given by the Heat Transfer Project in the AiResearch California Division which is developing the recuperator for the IBGDS under NASA Contract NAS3-18029. In addition, Mr. McCormick will have the support of the Isotope Heat Source technology subcontract suppliers.

We have chosen the two leading AEC isotope heat source system contractors, the General Electric Company Space Systems Organization and the Teledyne Isotopes Energy Systems Division, to participate in this program to assure that the isotope heat source design requirements are met for the Phase I Conceptual Isotope Brayton Flight System Design and Engineering Program Plan, the Phase II Flight System Development and Qualification, and the Phase III Procurement, Fabrication, Assembly and Acceptance Test of the Flight Power Systems. In addition, they will participate in the Isotope Brayton Ground Demonstration System per their attached proposal documents.

The General Electric Company Space Systems Organization, located in Valley Forge, Pa., has over ten years of successful experience in the development of space nuclear power hardware including the Apollo missions. The success of this program is enhanced by the use and/or improvement of the high temperature radioisotope heat source technology, the MHW-RTG, being developed for the AEC by General Electric for use on DOD and NASA missions. General Electric is familiar with the SURVASATCOM spacecraft integration requirements currently established for both solar and nuclear power because of related studies, recently performed for the DOD, Electronic Systems Division. General Electric is thoroughly familiar with the Isotope Brayton Flight Power System, having studied it under contracts with the AEC and NASA and development of the Heat Source Assembly (HSA) for the IBFS under NASA Contract NAS3-18029. They have assembled a highly qualified team headed by Mr. Prickett that assures continuity with the ongoing AEC MHW-RTG and the NASA HSA programs. The General Electric organization that will support this program is shown in Figure 5.3-4, appearing in Section 5A. Further details of this program organization is contained in the attached General Electric Proposal No. N-30198.

The Teledyne Isotopes Energy Systems Division, located in Timonium, Md., has over eighteen years of experience in the design, development and production of radioisotope thermoelectric generators and other compact independent power sources for space, terrestrial and undersea use. Teledyne Isotopes has pioneered the first Systems for Nuclear Auxiliary Power (SNAP) on behalf of the AEC. These include the SNAP 3A's and SNAP 9A's for the Navy Navigational Satellites launched during 1961 to 1964. Recent experience has been with the SNAP 19 generators aboard spacecraft Pioneer 10 and 11. They have assembled a highly qualified team headed by Mr. Robert Buxbaum who reports to Mr. G.F. Linkous, Power Systems Department Manager. The Teledyne Isotopes organization that will support this program is shown in Figure D appearing in Section 5B. Further details of this organization are shown in the attached Teledyne Isotope Proposal No. IESD-5062.

We believe that this combination of organizations, which has complete familiarity with the Isotope Brayton Ground Demonstration System requirements, is especially well suited to conduct this program successfully, having demonstrated the capability of performing such programs on schedule and within allocated budgets.

4.2 Personnel Qualifications

Figure 4-4 identifies the key technical and management personnel who will be assigned to this program. Included is their security clearance, degree of scholastic achievement, years of engineering and related experience, percent of time devoted to the program and their planned contribution to the program.

4.3 Resumes

Resumes of the key management and technical personnel are included in the following pages.

TABLE 4-1
SUMMARY OF KEY PROGRAM PERSONNEL

<u>Individual</u>	<u>Security Clearance</u>	<u>Highest Degree</u>	<u>Years of Experience</u>	<u>Percent of Time*</u>	<u>Area of Responsibility</u>
A. F. Anderson	DOD	BSE	17	25	Radiator Design
G. W. Bowers	DOD	MSME	25	10	Stress Analysis
O. A. Buchmann	DOD	MSME	16	10	Heat Exchanger Supervision
A. G. Buehman	DOD	BSAA	3	25	Laboratory Engineering
R. T. Caldwell	DOD	MSChE	22	10	System Analysis
F. X. Dobler**	DOD	MSME	14	100	Mini-BRU
J. Eberhardt	DOD	AAMPT	22	AR	Manufacturing Engineering
D. H. Edmonds	DOD	BSE	9	100	System Design
H. R. Fisk	DOD	BSMET	24	10	Materials
R. D. Gable	DOD	BSE	3	50	System Analysis and Reports
J. R. Hadley	DOD	BSE	15	25	Materials
D. S. Hall	DOD	MSSM	17	100	Safety Analysis
T. T. Hamrick	DOD	MSAE	26	10	Static Structures Analysis
T. G. Howell	DOD	BSME	13	AR	Applied Mechanics Supervision
F. E. Johnson	DOD		39	25	Quality Control
J. J. Killackey**	DOD	BSE	17	100	Heat Exchanger Supervision
C. A. Larson	DOD	MSE	11	25	Thermal Analysis
H. J. Lloyd	DOD	BSAE	6	100	Configuration Control
H. W. Longee	DOD	BSEE	16	50	Controls Analysis Supervision
S. E. Maynard	DOD	MSME	22	50	Reliability Analysis
J. E. McCormick	DOD	MSE	17	100	Program Management
J. M. McVaugh	DOD, AEC "Q"	MSE	12	10	Stress and Critical Speed Analysis
A. D. Meshew	DOD	BSME	24	25	Transient Analysis
B. J. Minshall	DOD, AEC "Q"	MSME	15	100	Controls
E. A. Mock	DOD	MSME	13	AR	Systems Analysis Supervision
J. A. Pehrson	DOD	BSAE	9	AR	Design Supervision
R. J. Ruch	DOD	BSE	26	AR	Laboratory Supervision
R. L. Stark	DOD, AEC "Q"	J.D.	8	AR	Contracts Administration
L. A. Strattan	DOD	BSE		25	Recuperator Analysis and Design
S. W. Trimble	DOD	BSE	3	50	Reports

*During Phase I

**Includes time devoted to supporting Mini-BRU and recuperator hardware contracts to be GFE for this program.

AR - As required

ALEXANDER F. ANDERSON

Assistant Group Supervisor
Heat Transfer and Cryogenic Systems

Education

B.S., University of Strathclyde, Glasgow, Scotland, 1956

Work History

1959 to date: AiResearch Manufacturing Company of California

1957 to 1959: Avro Aircraft Company, Malton, Ontario, Canada

Responsibility/Experience

Mr. Anderson is assistant group supervisor, Heat Transfer and Cryogenic Systems. He directs all design effort for environmental control system heat transfer equipment and for engine heat transfer components. Mr. Anderson's experience includes the following:

Designed compartment heat exchangers for the Dyna-Soar space vehicle.

Studied the transient response of the Boeing B-52 precooler.

Designed the heat transfer circuit for a thermionic converter.

Prepared design studies for the air coolers and condensers for Project LACE.

Designed a space radiator system for RCA (Boston), and studied system transient response.

Performed preliminary investigations into space radiator designs for Project Apollo.

Performed empirical study of flow distribution in tubular heat exchangers for aerospace plane applications.

Conducted study to reduce size and weight of space radiators for Brayton cycle space power applications.

Conducted studies of tubular and plate-fin recuperators for gas turbine and Brayton cycle applications.

Conducted studies in the use of thermoelectrics for aerospace applications.

Prepared digital computer programs for heat exchanger design.

Performed spacecraft thermal control system optimization studies.

Conducted heat transfer equipment optimization studies for the environmental control systems for the Douglas DC-10 and Grumman F14.

Designed the precooler cabin air electric heater and the CSD surface oil cooler for the Boeing 747 jet transport.

Designed and conducted trade-off studies for the heat transfer equipment in the environmental control systems for the DC-10, F14, F15 and S3A airplanes.

Prior to joining AiResearch, Mr. Anderson was employed by Avro Aircraft Company where he designed and made performance studies on the air conditioning system for the CF-105 (Avro-Arrow).

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

Membership

Institution of Mechanical Engineers (U.K.)

Publications

Technical Source Book, "Thermal Radiators for Space Vehicle Environmental Control Systems," AiResearch Report STC-20-R, July 1962.

"Thermal Management of Spacecraft Equipment," AiResearch Report STC-112, April 23, 1964.

"Recuperator for Solar Brayton Cycle System" NASA Report NASA CR 1150, August 1968.

"Future Development of Fixed Boundary Recuperators for Advanced Gas Turbines," presented to U.S. Navy, Bureau of Ships.

"Problems in the Use of Direct Gas Radiators of Spacecraft Brayton Cycle Systems."

G. W. BOWERS

Assistant Supervisor
Engineering Mechanics, Engineering Sciences

Education

B.S., Mechanical Engineering, North Carolina State University, 1949

M.S., Mechanical Engineering, San Diego State College, 1963

Work History

1966 to date: AiResearch Manufacturing Company of Arizona

1957 to 1966: Solar Division of International Harvester

1949 to 1957: General Electric Company

Responsibility/Experience

Mr. Bowers is primarily responsible for the solution of stress problems in the hot components of both current and advanced engine designs. His background experience includes the structural, stress, and dynamic analysis of numerous pressure vessels, ducting, and related aerospace components.

Memberships

Tau Beta Pi and Pi Tau Sigma honorary societies
Registered Professional Engineer, State of Arizona

Patents

Framed Aluminum Honeycomb Rotor Rub-In Shroud, Patent No. 3,126,149. Awarded jointly with two others.

Publications

"Photoelasticity, An Important Design Tool," presented at ASME student convention, Birmingham, Alabama, 1949

O. A. BUCHMANN

Project Engineer
Heat Transfer and Cryogenic Systems

Education

B.S., Mechanical Engineering, Drexel Institute of Technology, 1957

M.S., Mechanical Engineering, Stanford University, 1958

Work History

1958 to date: AiResearch Manufacturing Company of California

Responsibility/Experience

Mr. Buchmann is presently Project Engineer, Heat Transfer and Cryogenics Systems. He is responsible for the conduct of programs involving the design, fabrication, and testing of heat transfer equipment for advanced applications. His experience includes the following:

Performed analytical investigations on heat exchangers for aerospace and gas turbine recuperator applications.

Designed electronic equipment cooling units, including the application of thermoelectric cooling to electronic equipment.

Conducted experimental investigations of the performance of high-surface-density heat exchanger matrices, of fluid flow in heat exchangers, and of basic correlations for liquid hydrogen and liquid nitrogen heat transfer.

Supervised manufacturing development and fabrication of heat exchangers for air collection and precooled engine systems.

Performed structural and reliability evaluation of lightweight high-temperature heat exchanger components.

Conducted analytical and experimental investigations of regeneratively cooled structural panels for use on hypersonic vehicle and engine surfaces.

Responsible for structures and cooling development on the NASA hypersonic research engine project.

Responsible for testing in the NASA-Langley 8-Foot High Temperature Structures Tunnel of a flightweight hydrogen-cooled model of the NASA hypersonic research engine.

Conducted programs for analysis, design, and fabrication of advanced, cooled mirrors for high energy laser applications.

Publications

Structural Evaluation of Lightweight Heat Exchangers for an Aerospace Propulsion System," RTD Technical Documentary Report APL TDR 64-33, June 1964.

"LACE-ACES Heat Exchanger Design Study," RTD Technical Documentary Report APL TDR 64-79, November 1964.

"ATE Precooler and Regenerator Study," RTD Technical Report AFAPL-TR-65-66, July 1965.

"Application of Regeneratively Cooled Flat Panel Studies to the X-15 Hypersonic Research Engine," presented at the AIAA Third Annual Joint Propulsion Specialist Conference, Washington, D.C., July 1967.

"Development of Manufacturing Processes for a Lightweight Heat Transfer System," Technical Report AFML-TR-67-300, December 1967.

"Exploratory Development of High Temperature Heat Exchangers (U)," Technical Report AFAPL-TR-67-144, March 1968.

"Heat Transfer and Fluid Flow Analysis of Hydrogen-Cooled Panels and Manifold Systems," NASA CR-66925, July 1970.

"An Analytical Study of Hydrogen Cooled Panels for Application to Hypersonic Aircraft," NASA CR-1650, April 1971.

"Design of Actively-Cooled Hypersonic Engine Structures," presented at the AIAA/SAE 7th Propulsion Joint Specialist Conference, Salt Lake City, Utah, June 1971.

Registration

Registered Mechanical Engineer, State of California

R. T. CALDWELL

Senior Engineering Specialist,
Advanced Systems Analysis, Engineering Sciences

Education

B.S., Applied Chemistry, California Institute of Technology, 1951

M.S., Chemical Engineering, California Institute of Technology, 1955

Work History

1955 to date: AiResearch Manufacturing Company of Arizona

1952 to 1954: U.S. Army Medical Corps

1951 to 1952: Stoddy Company

Responsibility/Experience

Mr. Caldwell has extensive experience in the compilation of working fluid physical and thermodynamic properties, preliminary design of power-conversion system heat-transfer components, and thermodynamic analysis of closed-cycle power systems. His responsibilities also include transient thermal analysis of energy storage components used in conjunction with closed-cycle power plants and thermal analysis of aircraft pneumatic control installations. Mr. Caldwell has also conducted engineering evaluations of on-site total energy systems, including heat-driven refrigeration equipment. Mr. Caldwell is responsible for conducting computerized mission analysis studies pertaining to gas turbine and closed Brayton cycle vehicular engines.

Publications

"System Optimization of Brayton-Cycle Space Power Plants," ASME Paper No. 63-WA-87.

"Solar-Energy Receiver with Lithium-Hydride Heat Storage," Solar Energy, Volume 9, No. 1, Page 48 (1965).

Patents

Engine Cooling System, No. 3,358,457

F. X. DOBLER

Senior Development Engineer
Closed Cycle Engines Project

Education

B.S. Mechanical Engineering, University of Texas, 1960

M.S. Mechanical Engineering, University of Pittsburgh, 1961

Work History

1965 to Date: AiResearch Manufacturing Company of Arizona

1960 to 1965: Westinghouse Electric Corporation

Responsibility/Experience

Mr. Dobler is presently a task engineer for the development of the Mini-BRU Compressor-alternator-turbine unit. Prior to this, he was task engineer on various study programs to apply the closed gas turbine engine system in various industrial and marine situations.

Mr. Dobler was also a task engineer on the NASA TAC development program with responsibility for the bearings and rotating group design.

Mr. Dobler has had broad experience with AiResearch gas turbine engines including the TPE-331 and T-76 turboprop engines, the TSE-231 turboshaft engine, the IE 831 industrial gas turbine, the GTP36, the JFS100 jet fuel starter, the GTCP990 and the GTCP660 APU.

Mr. Dobler was a task engineer on the SNAP50/SPUR program with responsibility for the development of bearings and seals for this space power system.

Prior to joining AiResearch in 1965, Mr. Dobler was employed by the Westinghouse Electric Corporation with responsibility for the development of space electrical power generating machinery for the SNAP50/SPUR program.

Professional Affiliations

Registered Professional Engineer

Publications

Has authored or coauthored three technical papers.

J. EBERHARDT

Manufacturing Engineer (Cmgf E)
Gas Turbine Unit

Education

A.A., Manufacturing Process Technology, Mesa Community College
Certified Journeyman Machinist, Augsburg, West Germany
Oberrealschule, Illertissen, West Germany, two years

Work History

1955 to date: AiResearch Manufacturing Company of Arizona
1957 to 1959: U.S. Army
1952 to 1955: Manfield Screwmachine Company

Responsibility/Experience

Mr. Eberhardt's responsibilities include reviewing engineering designs and detail-part prints for materials, processes, and producibility, providing piece-part cost and tooling estimates, and shop and vendor liaison. While in Production Engineering, he was involved in process planning of manufacturing operations and tooling for production hardware, preparing overhaul routings, and providing liaison between Manufacturing Engineering, Engineering, and the production shop. As Group Supervisor in Process Planning, he was responsible for gears, shafts, small castings, and forged parts. Mr. Eberhardt has also worked as an automatic screwmachine operator and set-up man.

Mr. Eberhardt's previous background includes the U.S. Army where he was in charge of a division-level machine shop and all related functions.

Memberships

Senior Member, Society of Manufacturing Engineers

DAVID H. EDMONDS

Design Engineer
Gas Turbine Design

Education

A.A., Design Engineering, Phoenix College, 1966

B.S. ME Design, Arizona State University, 1969

Work History

1965 to Date: AiResearch Manufacturing Company of Arizona

Responsibility/Experience

Mr. Edmonds is currently responsible for the design of closed loop Brayton cycle systems being developed for industrial and aerospace applications. The industrial systems utilize low emission radiant surface combustors and low maintenance, production hardware. The aerospace systems include sophisticated, high reliability control design for five to ten year space operation.

Previous experience includes responsibility for design of auxiliary power units, Advanced High Pressure Ratio Compressors, Advanced Bearing Designs, and a Closed Cycle Power System for Navships, Contract No. N00024-74-C-1017.

H. R. FISK

Assistant Supervisor
Materials Engineering, Engineering Sciences

Education

B.S., Metallurgical Engineering, Rensselaer Polytechnic Institute, 1950

Work History

1966 to date: AiResearch Manufacturing Company of Arizona

1955 to 1966: Aerojet-General Corporation, Sacramento, California

1950 to 1955: Curtiss-Wright Corporation

Responsibility/Experience

Mr. Fisk has the responsibility of advising on the materials and processes utilized for gas turbine designs, and system and control devices. Mr. Fisk has had extensive experience in materials engineering including the research and development of high-temperature, nickel-base braze alloys, and a hydrogen furnace brazing process for fabricating aircraft engine components. In addition, Mr. Fisk was involved in developing process systems for furnace brazing large tubular thrust chambers and turbine rotors for Titan and Gemini propulsion units, as well as a new system of braze alloys commercially designated as the Palniro series. Mr. Fisk was associated with the development of photoetched lamellar-flow platelets diffusion-bonded for throttling injector assemblies of advanced liquid rocket engines.

Memberships

Registered Professional Engineer in the State of California

R. D. GABLE

Preliminary Design Engineer Associate
Technical Analysis and Performance, Engineering Sciences

Education

B.S.E, Mechanical Engineering, Arizona State University, 1971

Work History

1974 to date: AiResearch Manufacturing Company of Arizona

1971 to 1974: Rockwell International Corporation

Responsibility/Experience

Mr. Gable is currently responsible for system and component performance analysis, test data reduction and systems optimization studies for the NASA-sponsored closed cycle Mini-Brayton Power Conversion System. These duties include the preparation of technical documentation in support of the Advanced Closed Cycle Engines Project. At Rockwell International's B-1 Division, Mr. Gable was the responsible engineer for the design, performance analysis, and testing of deployable aerodynamic decelerators for advanced military aircraft. This task included liaison with subcontractors, the USAF, and the purchasing department.

J. R. HADLEY

Senior Metallurgist
Applied Materials Engineering, Engineering Sciences

Education

B.S.E., Northwestern University, 1959

Post graduate courses in Metallurgical Engineering, Rensselaer Polytechnic Institute

Work History

1969 to date: AiResearch Manufacturing Company of Arizona

1967 to 1969: Olin Mathieson Metals Research Laboratories

1962 to 1967: Pratt & Whitney Aircraft, East Hartford

1960 to 1962: Lycoming Division Arco Corporation, Stratford

1959 to 1960: Bridgeport Brass Company

Responsibility/Experience

Mr. Hadley's responsibility involves choosing materials for various engineering designs, defining programs to apply new materials and processes, and defining the work involved in analysis of problem areas. The work involves coordination with Manufacturing, Purchasing, Quality Control, and Project groups.

In the past, Mr. Hadley has been involved with gas turbine hardware fabrication, alloy processing, and metal alloy development. He has also had experience with refractory metal fabrication and exotic power conversion systems such as MHD, thermionic converters and fuel cells.

Professional Affiliation

American Society for Metals

D. S. HALL

Senior Product Safety Specialist

Education

B.S., Electrical Engineering, Illinois Institute of Technology, 1957

Naval Aviation Safety Officers Course, University of Southern California, 1961

M.S., Systems Management, University of Southern California, 1972

Responsibility/Experience

Senior Product Safety Specialist, AiResearch Manufacturing Company of Arizona.

Identification and evaluation of hazard-producing conditions and practices, including design review and accident investigation activities; development of methods, procedures, and programs to eliminate or minimize product-related hazards; communication of accident-prevention information to those concerned, including conduct of training course for company personnel.

Guest Lecturer, Safety Center, Arizona State University. Conducts classes in safety management, system safety, and accident investigation.

Member of the faculty, University of Southern California, Institute of Aerospace and Management.

Taught courses in accident prevention and accident investigation to U.S. Air Force, U.S. Army, and civilian students. Participation as a team member of Multi-Discipline Highway Accident Investigation Team under DOT contract. Conduct feasibility study for Republic of China resulting in establishment of Taiwan Safety Institute at National Taiwan University. Participated in training of Chinese faculty.

Other experience includes assignments as a flight test engineer on various aircraft, including the F-104, YF-12, and SR-71 at Lockheed and various aircraft using AiResearch turboprop engines. Former Naval Aviator. Currently holds Airline Transport Pilot Rating.

Professional Societies

Society of Air Safety Investigators, System Safety Society, American Institute of Aeronautics and Astronautics, University Aviation Association.

Publications

"Analytical Techniques for Effective Maintenance," D. Hall and E. Holt, Seventh Annual FAA International Aviation Maintenance Symposium, Oklahoma City, December, 1971.

"The Problem in Human Factors is Human," Second Annual Seminar, Society of Air Safety Investigators, Los Angeles, October, 1972.

Chinese Air Force Safety School Feasibility Study, March, 1972.

"Everything You've Always Wanted to Know About Accident Prevention but Were Too Busy to Ask," Fourth Annual Seminar, Society of Air Safety Investigators, Toronto, Canada, August, 1973.

T. G. HOWELL

Supervisor
Engineering Mechanics, Engineering Sciences

Education

B.S., Engineering Mechanics, University of Illinois, 1961

General Electric Advanced Engineering Course, 1966

Work History

1973 to date: AiResearch Manufacturing Company of Arizona

1962 to 1973: General Electric Company Engine Group

1961 to 1962: International Harvester Construction Equipment Division

Responsibility/Experience

Mr. Howell supervises the Engineering Mechanics Group which provides technical support to Power Systems Projects. In this capacity, analysis and computer programs of general vibratory, rotational, and static systems are developed as design implements. His experience is extensive in the area of aircraft turbine mechanical design and analysis, and supervision of the design and development of turbine components.

Prior to joining AiResearch, Mr. Howell was Manager of the F100 Turbine Design in the Engine Group of the General Electric Company.

T. T. HAMRICK

Assistant Supervisor
Engineering Mechanics, Engineering Sciences

Education

B.S., Aeronautical Engineering, Mississippi State University, 1942

M.S., Aeronautical Engineering, University of Michigan, 1948

Work History

1950 to date: AiResearch Manufacturing Company of Arizona

1948 to 1950: Douglas Aircraft Company

Responsibility/Experience

Mr. Hamrick has directed the efforts of engineers responsible for stress analysis and structural testing of AiResearch gas turbine static structures, i.e, gearcase, compressor housings, turbine plenums, combustors, and turbine stators, as well as gas turbine installations. He is responsible for the use and development of computer models, finite element and finite difference, and in the training of personnel in the use of NASTRAN, a Government owned computer program for all-purpose structural analysis. While staff engineer, he specialized in the industrial application of gas turbines.

As a member of the Stress and Vibration Group, Mr. Hamrick was concerned with the analysis of gas turbine engines for transient and steady-state temperature calculations of turbine rotors and structures, centrifugal and thermal stress analysis of radial and axial turbine wheels, critical speed and bearing load analysis of high-speed rotors, torsional vibration analysis of turbine and compressor blades by means of strain gages and slip rings, experimental stresscoat work on rotating components and turbine structures, design and analysis of pressure vessels, including high- and low-temperature heat exchangers, and engine mounting analysis for shock and vibration loads.

While at Douglas, Mr. Hamrick gained valuable experience in the analysis of landing gears and fuselages for the A3D, XA2D, F3D, and F4D Airplanes.

F. E. JOHNSON

Quality Assurance Engineer
Quality Control Department

Education

Three years, Mechanical Engineering, Northwestern University, 1935

Management Studies at Illinois Institute of Technology and Arizona State University

Work History

1959 to date: AiResearch Manufacturing Company of Arizona

1951 to 1959: Reynolds Metal Company

1940 to 1951: Sheller Manufacturing Company, Chicago, Illinois

1937 to 1940: A. C. Neilsen Company, Chicago, Illinois

1935 to 1937: W. C. Braun, Chicago, Illinois

Responsibility/Experience

Mr. Johnson is responsible for providing assurance that the contract requirements are fulfilled in all respects. He plans, controls, evaluates and reports all necessary quality assurance activities for training, quality standards, measurement and analytical facilities, methods, and procedures, and program audit.

Prior to joining AiResearch, Mr. Johnson was an Assistant Plant Manager for the Reynolds Metal Company.

J. J. KILLACKEY

Assistant Project Engineer
Heat Transfer and Cryogenic Systems

Education

B.S., Engineering, University of California at Los Angeles, 1957
Postgraduate work in fluid flow and thermodynamics, UCLA
Company sponsored courses in Transistors and Digital Electronics

Work History

1957 to date: AiResearch Manufacturing Company of California

Responsibility/Experience

Mr. Killackey is presently Assistant Project Engineer, Heat Transfer and Cryogenic Systems. He is responsible for the design and development of heat transfer equipment for advanced applications. His experience includes the following:

Directed the development of high performance condensers and fans for Rankine cycle automotive engines.

Responsible for development of high temperature heat exchangers for closed Brayton cycle power systems.

Installation engineer for the ATF3 turbofan engine.

Program engineer for the NASA hypersonic research engine.

Responsible for development of a 5000 gph, trailer-mounted, vapor-compression desalination plant.

Responsible for the development of sublimation-type heat exchangers for space applications.

Designed and developed heat transfer equipment for space environmental control systems including boilers, condensers, and water separators.

Designed and developed an air-to-exhaust gas regenerator for the 4000 hp T-78 turbo-prop engine.

Designed and developed high-temperature, refractory metal, liquid metal heat transfer equipment for the SNAP-50/SPUR space power unit.

Designed and operated test equipment for studying the boiler and condensing of liquid metals in a zero-gravity environment.

Preliminary design of heat transfer equipment, including boilers and condensers, for a nuclear dynamic space power unit.

Designed heat transfer equipment for electronic cooling, aircraft, and missile applications.

Analyzed the transient behavior of a missile auxiliary power unit.

Principal investigator for the design and test of a fuel evaporative engine oil cooling system for advanced aircraft.

Analyzed aircraft environmental control systems.

Membership

American Institute of Aeronautics

Former Offices

President and Treasurer, Engineering Society of UCLA (800-member student organization)

Publications

"Study of Fuel Evaporative Engine Oil Cooling Systems for High Performance Aircraft," WADD Technical Report 60-47.

"SPUR Phase I, Conversion Loop Heat Transfer Analyses," ASD Technical Report 61-656.

"An Experimental Investigation of Forced-Convection Vaporization of Potassium," proceedings of the 1963 high-temperature liquid-metal heat transfer technology meeting, Oak Ridge National Laboratory, ORNL-3605.

"Perforated Plate-Fin Heat Transfer Surfaces for Rankine Cycle Automobile Condensers," 7th Intersociety Energy Conversion Engineering Conference, September 1972.

Patents

Adhesive comprizing polymerizable monomeric mixture peroxide, cobalt naphthenate, and ethyl cellulose sorbate.

Fuel evaporative engine oil cooling system.

C. A. LARSON

Engineering Specialist,
Engineering Mechanics, Engineering Sciences

Education

B.S., Mechanical Engineering, Kansas State University, 1963

M.S.E., Mechanical Engineering, Arizona State University, 1972

Work History

1966 to date: AiResearch Manufacturing Company of Arizona

1963 to 1965: General Dynamics, Ft. Worth, Texas

Responsibility/Experience

Mr. Larson's responsibilities include analysis and component design relating to heat transfer, fluid mechanics, stress, and life in turbomachinery, specifically in turbine, combustor, structure, and bearing design, and intermittently directs others engaged in these activities.

His previous experience has been in turbine mechanical design and heat transfer analysis. Specific areas are turbine cooling design and analysis, stress and thermal analysis of both structures and rotors, analysis and development of analytical tools in fluid mechanics as applied to rotating machinery, and thermal analysis of gas bearings. Earlier, Mr. Larson participated in thermodynamic performance and design analysis of aircraft environmental control systems.

Past Memberships

ASME, Associate Member
Member of AIAA
Member of ASTM

H. J. LLOYD

Development Engineer
Closed Cycle Engines Project

Education

B.S., Aerospace Engineering, The Pennsylvania State University, 1968

Work History

1971 to Date: AiResearch Manufacturing Company of Arizona

1968 to 1971: Pratt and Whitney Aircraft

Responsibility/Experience

Mr. Lloyd is currently responsible for the thermodynamic design and analysis of the Mini-Brayton System. His experience has included coordination of the mechanical design of the Mini-BRU engine between the design, project and engineering sciences groups. He has been involved with the Mini-Brayton System since the preliminary design study and in addition performed the cycle analysis for the MB-ERTG study. Other duties have included preliminary design studies of several Closed Brayton Cycle Engines including optimization of engine matching and heat exchanger weight. He has also been involved in aerodynamic fan design and development testing of a high speed torque converter.

Prior to joining AiResearch, Mr. Lloyd was involved in the design and performance analysis of single stage and multistage compressors for propulsion engines. He was also associated with thermodynamic cycle analysis of high impulse liquid rocket engines with supporting turbomachinery.

Professional Affiliations

Tau Beta Pi
Sigma Gamma Tau

H. W. LONGEE

Development Specialist
Controls and Accessories Project

Education

B.S., Electrical Engineering, Southern Methodist University, 1962

Additional Courses in Controls and Nuclear Theory

Work History

1966 to date: AiResearch Manufacturing Company of Arizona

1962 to 1966: Atomics International, Division NAA (Rockwell International), Systems and Controls Group Operations Department

1958 to 1962: Southwestern Bell Telephone Company, Engineering Department

Responsibility/Experience

Mr. Longee is currently responsible for the analysis design and development of advanced technology controls and accessories including closed loop control systems being developed for industrial and aerospace applications. The industrial systems utilize low emission radiant surface combustors and low maintenance, production hardware. The aerospace systems include high reliability controls, high speed alternators and power conditioning designed for 5 to 10 year space operation.

His previous experience includes responsibility for the Brayton control system developed for the NASA LeRC, Contract NAS3-10943, as well as for the design and development of electrical and electronic support equipment for auxiliary power units, generators, propulsion engines and special projects. He assisted with the design and development of the speed control for the NASA LeRC Brayton Rotating Unit (BRU) (NAS3-9427).

Prior to joining AiResearch in 1966, Mr. Longee was employed by Atomics International. He was directly responsible for the design, reliability review, construction and checkout of the facility process and environment systems for the SNAP-8 Development System (S8DS) tests. Mr. Longee assisted with the design, safeguards review, installation and checkout of process and control systems and instrumentation for the S8DS. He also assisted with electrical and mechanical checkout of a prototype of the first nuclear auxiliary power supply to be launched and operated in space (SNAP-10A).

Patent Application

Closed Brayton Cycle Power Control Valve

S. E. MAYNARD

Supervisor
Reliability Engineering

Engineering

B.S., Mechanical Engineering, University of Arizona, 1948

M.S., Mechanical Engineering, University of Arizona, 1951

Work History

1955 to date: AiResearch Manufacturing Company of Arizona

1948 to 1955: University of Arizona

1952 to 1953: Convair, San Diego, California (summers)

Responsibility/Experience

Mr. Maynard has been responsible for various AiResearch components on commercial aircraft. He supervised all design and development activities of high-temperature, high-pressure, and cryogenic valves and controls. He has also coordinated all reliability activities between the various Engineering Projects, Quality Control, and other departments. He is responsible for the essential technical aspects of predicting, controlling, and measuring reliability on various projects.

At the University of Arizona, Mr. Maynard taught internal combustion engines, thermodynamics, machine design, fluid mechanics, petroleum, power plant, and mechanical laboratory.

Professional Affiliations

Tau Beta Pi and Phi Kappa Phi honorary fraternities
A.S.M.E., Past Chairman and Director
Arizona Council of Engineering and Scientific Association, Past Chairman
Registered Professional Engineer, State of Arizona

J. E. McCORMICK

Project Engineer
Closed Cycle Engines Project

Education

B.S., Mechanical Engineering, Kansas State University, 1959

M.S., Mechanical Engineering, Arizona State University, 1967

Work History

1961 to date: AiResearch Manufacturing Company of Arizona

1959 to 1961: The Bendix Corporation

Responsibility/Experience

Mr. McCormick is currently responsible for the NASA Mini-BRU program (Contract NAS3-18517). Prior to this he had prime responsibility for the following programs:

- o Mini Brayton-Economic RTG Study
- o NSRDC Laboratory Engine (CCPS40-1)
- o WANL CO⁶⁰ Isotope Heat Source
- o Space Station/Base Power System Studies (under subcontract to North American Rockwell and McDonnell Douglas)

Mr. McCormick has performed extensive cycle analysis for the closed Brayton cycle power system and its components. The development work includes testing of an advanced homopolar inductor axial gap alternator, the voltage regulator and exciter and the speed control for the NASA-Lewis Research Center Brayton Rotating Unit (BRU), and the system design and test of the corporate-sponsored 3 KW closed Brayton Cycle Demonstrator.

Prior to joining AiResearch, Mr. McCormick was employed by the Bendix Corporation where he was responsible for the initial design, including materials and stress analysis, of electromechanical devices.

Publications

"A Space Power Conversion System Utilizing the Brayton Cycle with a Direct Coupled Reactor" AIAA-64-454, July 1964 (coauthor).

"Development Status of Closed Brayton Cycle Systems for Space Power Applications," Intersociety Energy Conversion Engineering Conference, Los Angeles, California, September 26-28, 1966 (coauthor).

"3 KW Recuperated Closed Brayton Cycle Electrical Power System," Intersociety Energy Conversion Engineering Conference, Miami Beach, Florida, August 13-17, 1967 (coauthor).

"Low Temperature Reactor Brayton Cycle for Space Station/Base Application, "Intersociety Energy Conversion Engineering Conference, Las Vegas, Nevada, September 1970.

J. M. McVAUGH

Assistant Supervisor
Engineering Mechanics, Engineering Sciences

Education

B.S., Mechanical Engineering, Arizona State University, 1960

M.S., Mechanical Engineering, Arizona State University, 1964

Additional Graduate Courses in Engineering Mechanics at Arizona State University

Work History

1962 to date: AiResearch Manufacturing Company of Arizona

Responsibility/Experience

Presently, Mr. McVaugh provides technical leadership in vibration control of high-speed turbomachinery mechanical design of compressor rotors to withstand centrifugal force, thermal gradients, irregular aerodynamic forces, and fluid film bearing design, etc. Analytical and experimental techniques in this work include analyses for rotor dynamics, torsional dynamics, compressor rotor hub centrifugal and thermal stress, compressor blade centrifugal stress, and aerodynamically excited compressor blade vibration.

In addition, previous work included thermal analysis of turbomachinery, centrifugal and thermal stress analyses of turbine wheels, containment of high-speed rotor bursts, and analytical and experimental stress and vibration analyses of turbomachinery structure.

Memberships

American Society of Mechanical Engineers
Registered Professional Engineer, State of Arizona

A. D. MESHEW

Senior Engineering Specialist
Technical Analysis and Performance, Engineering Sciences

Education

B.S., Mechanical Engineering, Oklahoma State University, 1950

Work History

1962 to Date: AiResearch Manufacturing Company of Arizona

1956 to 1962: The Boeing Company, Wichita, Kansas

1950 to 1956: Various positions with a consulting engineer and contractors in the commercial air conditioning field.

Responsibility/Experience

Mr. MesheW is a Senior Engineering Specialist in charge of updating and operating the Thermodynamic Brayton Cycle Transient Analysis Computer Program. Prior to this, he was a Senior Preliminary Design Engineer in charge of gas turbine performance analysis, and technical report editing for the Advanced Auxiliary Power System Program, a technology development program. Mr. MesheW has also had responsibility for systems, gas turbine performance, and performance of other turbomachinery. His first duty with AiResearch was as a Project Engineer in charge of the San Tan remote test site operation where cryogenic and supersonic combustion tests were conducted.

Prior to joining AiResearch, Mr. MesheW was a lead engineer in the Air Systems Group of The Boeing Company that included analytical, laboratory, and design experience for air-conditioning systems, equipment cooling, pressurization systems, anti-icing systems, windshield anti-frost systems, and proposal and preliminary design assignments. He was responsible for the nitrogen purge system for the Dyna-Soar vehicle while attached to the B-52 mother ship as well as the hydrogen-rich APU exhaust system through the pylon and wing of the B-52.

B. J. MINSHALL

Senior Development Engineer
Controls and Accessories Project

Education

B.S. in Mechanical Engineering, University of Wisconsin, 1959

M.S. in Mechanical Engineering, University of Wisconsin, 1960

Numerous graduate courses in engineering and business administration at Arizona State University

Work History

1960 to date: AiResearch Manufacturing Company of Arizona

1959 to 1960: University of Wisconsin, Madison, Wisconsin

Responsibility/Experience

Mr. Minshall's present responsibilities include concept selection and analytical evaluation of controls designs for advanced engines. In particular, analysis, component selection and evaluation, and system sizing on closed Brayton Cycle Engines has been performed on several engines. The analysis performed includes transient response as well as steady-state control performance and includes the use of digital computer programs. As a member of the systems integration group, he is responsible for carrying designs through hardware selection and implementation of the control into the final product, estimating financial budgeting, and defining work statements for electrical, electronic, and mechanical support groups.

In his prior position as Senior Preliminary Design Engineer, he spent 6 years performing pneumatic system analysis. His responsibilities included analytical support of all phases of pneumatic control component and system performance, including transient and steady-state performance and stability analysis, and laboratory support. The systems analyzed include: Environmental controls for the F-14, F-15, DC-10, Boeing 747, thrust reverser air motors and fluidic systems.

Prior to this, Mr. Minshall spent 5 years as a Preliminary Design Engineer, Controls Group, engaged in the analysis and hardware development of propulsion gas turbine engine fuel control and power management systems. This work included development of an advanced adaptive fuel control with a high contamination tolerance. (Reference ASME paper). This control was designed to burn various fuels from aviation gasoline to diesel fuel without fuel control adjustment and also to use highly contaminated fuel without filtration.

As development engineer in Pneumatic Systems, he was responsible for development work on valves used on the Boeing 727, Lockheed C141, and McDonnell Gemini space capsule environmental control systems, as well as other components.

Registration

Registered Professional Engineer in the State of Arizona.

Societies

Pi Tau Sigma honorary society.

Patents

Patents currently pending.

Publications

ASME Paper 68-GT-45, Co-Author, "A Turboprop Engine, Advanced Adaptive Fuel Control with a High Contamination Tolerance"

E. A. MOCK

Assistant Supervisor
Technical Analysis and Performance, Engineering Sciences

Education

B.S., Mechanical Engineering, Montana State University, 1961

M.S., Mechanical Engineering, Montana State University, 1962

Additional courses at Arizona State University

Work History

1963 to date: AiResearch Manufacturing Company of Arizona

1962: American Air Filter

1961: Fuller and Webb Company

Responsibility/Experience

Mr. Mock is responsible for cycle design, off-design, and transient analyses of closed-cycle power systems and closed-cycle program technical documentation. These activities include selection of the system for a particular application, development of computer programs for system and component analyses, and the conduct of analysis on closed Brayton and Rankine cycle systems. He has participated in the NASA-Lewis Research Center Gas Generator, Brayton Rotating Unit (BRU), Potassium Turboalternator (KTA), and Turboalternator-Compressor (TAC) programs as well as the USAF/AEC SNAP 50/SPUR and the U.S. Navy Brayton-Cycle Deep Ocean Technology programs.

Mr. Mock's prior experience included work as an engineering field office supervisor for American Air Filter and as an installation engineer for Fuller and Webb during construction of Minuteman Missile Silos.

Memberships

Tau Beta Pi and Pi Tau Sigma

Publications

"Potassium Rankine-Cycle Power Plants from 10 kw to 1000, kw" Intersociety Energy Conversion Engineering Conference, Los Angeles, California, September 26-28, 1966 (coauthor).

"Design of Vapor Turbines Including Effects of Supersaturation", Fourth Intersociety Energy Conversion Engineering Conference, Washington, D.C., September 21-26, 1969 (coauthor).

"Closed Brayton Cycle System Optimization for Undersea, Terrestrial, and Space Applications", Lecture Series 24 on Closed Cycle Gas Turbines, von Karman Institute for Fluid Dynamics, Brussels, Belgium, May 11-15, 1970.

"Undersea Application of a Closed Brayton Cycle Power Plant" SAE Paper 710828, National Combined Fuels and Lubricants, Power Plant and Truck Meetings, St. Louis, Missouri, October 26-29, 1971.

"Co⁶⁰ Isotope Fueled Closed Brayton Cycle Engine for Underwater Application", Second International Ocean Development Conference and Exhibition, Tokyo, Japan, October 4-9, 1972 (coauthor).

J. A. PEHRSON

Supervisor
Design Unit

Education

B.S., Aeronautical Engineering, University of Minnesota, 1965

Graduate Courses, University of Minnesota

Graduate Courses, Arizona State University

Work History

1969 to date: AiResearch Manufacturing Company of Arizona

1967 to 1969: Honeywell Ordnance Division

1965 to 1967: AiResearch Manufacturing Company of Arizona

Responsibility/Experience

Mr. Pehrson is responsible for the design activity of Secondary Power, Advanced Power, and test rigs associated with power systems.

R. J. RUCH

Engineering Supervisor
Control Systems and Components Laboratory

Education

B.S., General Engineering, University of Wyoming, Laramie, 1952

Work History

1956 to date: AiResearch Manufacturing Company of Arizona

1954 to 1955: American Independent Oil Company, San Francisco, California

1952 to 1954: Stanolind Oil and Gas Company, Wyoming

1948 to 1950: Stanolind Oil and Gas Company, Wyoming

Responsibility/Experience

Mr. Ruch is currently engineering supervisor of the Control Systems and Components Laboratory. Prior to joining AiResearch, Mr. Ruch was responsible for all petroleum engineering functions in the Kuwait-Saudi Arabian neutral zone, for the American Independent Oil Company.

R. L. STARK

Contract Administrator, Contracts

Education

B.S., Business Administration, University of Nebraska, 1966

Air Force Officer's Training School, 1967

Juris Doctor, Washburn University School of Law, 1973

Work History

1973 to Date: AiResearch Manufacturing Company of Arizona

1967 to 1971: U.S. Air Force

Responsibility/Experience

Mr. Stark has responsibility for contract terms and conditions negotiations, customer liaison, and control of contract schedules, cost, and deliveries. His activities relate to production, research, and development programs for the government and commercial applications. These programs consist of auxiliary power units, advanced component technology, compressors, turbines, bearings, and seals.

The majority of Mr. Stark's experience has involved administrative duties related to program, contract, and cost factors.

Prior to joining AiResearch, Mr. Stark was an Administrative and Training Officer, Strategic Missile Wing, U.S. Air Force.

S. W. TRIMBLE

Preliminary Design Engineer, Associate
Technical Analysis and Performance, Engineering Sciences

Education

B.S.E., Mechanical Engineering, Magna Cum Laude, Arizona State University, 1971

Work History

1973 to date: AiResearch Manufacturing Company of Arizona

1971 to 1973: Texas Instruments Incorporated

Responsibility/Experience

Mr. Trimble has recently been involved in the performance analysis and technical documentation of several closed Brayton cycle power systems. His activities include engine design and candidate heat source investigations as well as technical data management. Mr. Trimble has also authored several flow and transient heat analysis computer programs.

Prior to joining AiResearch, Mr. Trimble was a production and design engineer on advanced weapons systems at Texas Instruments.

Memberships

Tau Beta Pi and Pi Tau Sigma

Publications

"Viscometric Properties of Blood," presented at AIAA regional student convention, San Francisco, California, 1971.

"Artificial Heart Design," presented at ASME regional student convention, Los Angeles, California, 1971.

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

5.0 SUBCONTRACTOR CAPABILITIES

The following section is divided into two parts. Section 5A presents General Electric Capabilities and Experience Summary. This section is page numbered 5-1 to 5-78. Section 5B presents Teledyne Isotopes Capabilities and Experience Summary. This section is page numbered 5-1-B to 5-31-B.

Both sections are arranged in the following order.

- o Related Background
- o General Facilities
- o Program Organization
- o Personnel Qualifications
- o Resumes

SECTION 5A

GENERAL ELECTRIC CAPABILITIES AND EXPERIENCE SUMMARY

SECTION 5

GENERAL ELECTRIC CAPABILITIES AND EXPERIENCE SUMMARY

In Phase I the General Electric Space Division will be responsible for:

- The Heat Source Assembly, the Heat Source Simulator, the Gas Management System for auxiliary and emergency cooling and the associated power supplies, control, instrumentation and handling equipment.
- The Heat Rejection System, including the Heat Sink Heat Exchanger or simulated radiator and associated instrumentation.
- Assembly of the Heat Source Assembly and the Heat Rejection System to the Power Conversion Loop.
- Design of the conceptual Isotope Brayton Flight System.
- Providing broad support to AiResearch in systems engineering, component design, vehicle interfaces, safety, ground support, Ground Demonstration System Test and Planning Phases II and III.
- Identification of long lead development items related to the heat source and heat rejection systems and joining these systems to the power conversion system (e.g., bi-metallic joints).

The GE on-going work and extensive experience in spacecraft and nuclear space power will enable them to bring a highly qualified team to this effort. One measure of this experience, as related to nuclear space power, is shown in Table 5.1-1. The projects listed represent almost \$65,000,000 over a period of about 10 years, with much of it current or in the recent past.

Spacecraft experience includes such successful programs as Nimbus, ERTS, various DoD satellites and subsystems for a variety of spacecraft. These programs, along with SNAP-27 and MHW-RTG provide for realistic requirements and design approaches needed for the development of a flight system. Bringing this experience to bear on the conceptual Isotope Brayton Flight System will assure that it will be a reliable basis for the design of a fully relevant ground demonstration.

Table 5.1-1. General Electric Related Experience

Key Activities	Customer	Application to the IBFS Program
Mini-Brayton ERTG Study (AEC-SNSO-6)	AEC	Mini-Brayton Power System-to-HSA, to-Radiator Interfaces, Mission operations and requirements
Mini-Brayton HSA Development (NAS 3-18541)	NASA	Isotope Heat Source Integration and Safety
SURVSATCOM Electrical Power Subsystems (SEPS) Study (AF 19628-74-C-0155)	USAF	User Requirements and Spacecraft Integration
Mini-Brayton Heat Source Assembly Design Study (NAS 3-16810)	NASA	Heat Source Assembly Conceptual Design
SNAP-27 Program (AT(29-2)-2581)	AEC	Beryllium Technology Bi-Metallic Joints Safety
MHW-RTG Program (AT(29-2)-2831)	AEC	MHW Heat Source and Support Structure Beryllium Technology Multi-foil Insulation Safety
Separately Launched Multi-Use, Space Electrical Power System (NAS 9-7444)	NASA	Isotope Brayton System Design and Operation
Isotope Brayton Nuclear Safety Feasibility Study (AT(29-2)-2831)	AEC	Nuclear Safety
Liquid Metal-to-Air Heat Exchanger Design Study (F33615-73-C-2065)	USAF	Heat Exchanger Design
Methane/Hydrogen Heat Exchanger Program (NAS 3-14319)	NASA	Heat Exchanger Design, Fabrication and Assembly
Controlled Heat Energy Management System Development Program	IR&D	Backup ECS/ACS Heat Pipe Technology
Ceramic Clad Heat Source	IR&D	Nuclear Safety
Space Radiator Development	IR&D	IBFS Space Radiator
Design and Fabrication of a Brayton Cycle Solar Heat Receiver (NAS 3-10944)	NASA	Refractory Metal Fabrication and Joining
Evaluation of High Strength Columbium Alloys for Alkali Metal Cont. (NAS 3-2140)	NASA	Refractory Metal Technology
Brayton Cycle Heat Pipe Radiator Development	NASA	Heat Rejection System

Since GE is the designer for the heat source, the simulated heat source and the heat source assembly, its intimate knowledge of these components will assure that they will be employed properly in the Brayton system. Performance capabilities, material and other constraints, detailed configurations, structural and thermal limitations and detailed component weights and costs will be taken into account in the integration of these parts. Such factors will also be considered in defining the test program, instrumentation and controls.

An important aspect of proper heat source integration and usage is the need for auxiliary and emergency cooling. These requirements and methods for satisfying them have been studied in detail by GE; this background will be utilized in designing the Gas Management System for these purposes.

Heat rejection systems - active and passive - for nuclear space power systems has been the subject of extensive study and development work at GE for over a decade. These programs have been related to both isotope and reactor systems, coupled with Brayton, Rankine,

thermoelectric and thermionic power conversion. Materials have ranged from aluminum and stainless steel to beryllium. Sizes have been as small as a few watts to as high as hundreds of kilowatts.

In most cases, for space applications, the radiator is the major structural element and, therefore, the main structural interface with the spacecraft. A thorough understanding of this important element is necessary both for the flight system design and for the ground test which must simulate the flight system parameters, operational modes and response. The extensive GE experience in this area will assure that the ground system will adequately represent the flight system to obtain the test data required to design a flight-qualified unit.

Utilization of General Electric, with its singular familiarity with the MHW heat source and heat source assembly, to support the GDS assembly has some important advantages. Material and tolerance limitations, allowable distortions and stresses and acceptable, proven joining techniques must all be taken into account. This is especially true of the Heat Source Assembly, which is refractory and requires specifically developed joining techniques. General Electric has extensive experience in these areas, as well as the applicable specific experience associated with the heat source assembly.

Nuclear safety - both for flight and for ground handling - are especially important in attaining a proper configuration. The safety qualification of SNAP-27 and MHW and the many safety studies conducted by GE will be an important ingredient in assisting AiResearch in the overall system design.

By its participation in SURVSATCOM system planning, GE has an understanding of the probable spacecraft requirements and will continue to develop this understanding. In addition to frequent consultations with the USAF and its contractors, GE has conducted the SURVSATCOM Electrical Power Subsystems and the Mini-Brayton ERTG studies (see Table 5.1)

An important element of Phase I is the identification of long-lead development items. GE's understanding of the components of the heat source and heat rejection systems and of the overall

performance requirements of the system will enable it to assess the need for such development. Specific areas in which this expertise will be valuable include on-pad cooling, bi-metallic joints, heat source improvement and beryllium (or alternate alloy) radiator development.

The background described above will be translated into performance on the isotope-Brayton development program by a team of people carefully chosen for this purpose. Each member will bring an important element of highly related experience. The overall program will be directed and monitored by management with extensive background in nuclear space power and in other aspects of spacecraft development.

5.1 A WEALTH OF SUCCESSFUL EXPERIENCE.....

General Electric's comprehensive heat source background (specifically GE's knowledge of the heat source in the AEC's MHW program (AT(29-2)-2831) and our knowledge of space power systems are particularly significant to the successful accomplishment of the Isotope Brayton Ground Demonstration program.

General Electric's recent participation in NASA's Mini-Brayton Heat Source Assembly Design Study (NAS3-16810) followed by GE's current performance on NASA's Mini-Brayton Heat Source Assembly Development Program (NAS3-18541) assure Garrett and the AEC of the most up-to-date capability available in all the key areas required. In addition, General Electric recently provided to the AEC an Evaluation of an Economic RTG based on Brayton Cycle Power Conversion (AEC SNS-6), which provides timely specific related total system design experience.

General Electric's heat source background coupled with its extensive capability in such other relevant areas as nuclear safety, heat exchanger technology, refractory and other high temperature materials development, and nuclear power/spacecraft integration provide AiResearch with the complement of technological know-how essential for encompassing and successfully fulfilling the AEC's proposed program requirements. Demonstrated success

on programs such as SNAP-27 attests to General Electric's capability to produce high quality hardware, which exceeds design requirements, for the AEC.

Section 5 summarizes General Electric's capabilities and experience in each of the following pertinent areas:

1. User Integration Activity
2. Heat Source Development
3. Nuclear Safety
4. Heat Exchanger Technology
5. High Temperature Materials
 - a. Refractories
 - b. Superalloys
 - c. Ceramics
6. Space Nuclear Power Systems
7. Spacecraft Integration
8. Thermal Control Insulation and Coatings
9. Space Division Spacecraft Flight Programs Overview

Programs representing these capabilities are described for each area under the heading, Related Background. These background programs are also listed by area on Table 5.1-2. The Data Location line on this chart provides a rapid means of locating specific programs of interest in the text. The applicability of these related background programs is indicated by these legend symbols on the chart:

H - Hardware fabrication and test

D - Detailed design

C - Conceptual design

S - Study

5.1.1.1 USER INTEGRATION ACTIVITY

General Electric's Space Division has an aggressive marketing organization dedicated to mating the customer's requirements with Company capabilities to result in profitable business. The Marketing organization pursues business across a broad range of government customers including DoD and all NASA centers. DoD is of major interest to Space Division. As a space and energy systems contractor Space Division activity pursues DoD business in a wide range of opportunity areas -- from the solar heating of Army barracks to sophisticated military spacecraft.

A cadre of approximately twenty (20) headquarters professional marketing personnel are assigned to cover the DoD marketplace -- most focusing their efforts on the spacecraft systems and subsystems areas. These individuals, 90% of whom hold engineering degrees, have the responsibility to bring the government's requirements and GE's capabilities together to the satisfaction of both.

As a result we have a detailed knowledge of the military space-oriented community, particularly U.S. Air Force commands and centers -- their personnel, missions and programs. Some of the key USAF centers covered in-depth are:

1. Air Staff (Pentagon)
2. Systems Command Headquarters
3. Aeronautical Systems Division
4. Space and Missile Systems Organization
5. Electronic Systems Division
6. Air Force Weapons Laboratory

Related organizations are also given close attention by Marketing. These include DDR&E; Office of Telecommunications Command and Control; Lincoln Laboratory and companies like Mitre and Aerospace who are under government contract to provide critical engineering support to Air Force centers.

PROGRAM PHASE		Heat Source Programs										Nuclear Safety Programs					Heat Exchanger Programs					High Temperature Materials										Space Nuclear Power Systems				Spacecraft Integration			Thermal Control Insulations and Coatings							
																						Refractories					Superalloys			Ceramics																
I	Ground Demonstration	H	C	H	H	C	H	H	H	C	C	S	S	D	H	H	D	C	H	H	H	H	H	H	H	H	H	H	D	H	S	S	S	H	H	D	C	H	H	S	S	S	S	H	H	
II	Qualification Program	H	C	H	H	C	H	H	H	C	C	S	S	D	H	H	D	C	H	H	H	H	H	H	H	H	H	H	H	D	H	S	S	S	H	H	D	C	H	H	S	S	S	S	H	H
III	Flight Hardware Production	H	C	H	H	C	H	H	H	C	C	S	S	D	H	H	D	C	H	H	H	H	H	H	H	H	H	H	H	D	H	S	S	S	H	H	D	C	H	H	S	S	S	S	H	H
Data Location (Para. No.)		5.1.2.2.1	5.1.2.2.2	5.1.2.2.3	5.1.2.2.4	5.1.2.2.5	5.1.2.2.6	5.1.3.2.1	5.1.3.2.2	5.1.3.2.3	5.1.3.2.4	5.1.3.2.5	5.1.3.2.6	5.1.4.2.1	5.1.4.2.2	5.1.4.2.3	5.1.4.2.4	5.1.4.2.5	5.1.4.2.6	5.1.4.2.7	5.1.5.2.1	5.1.5.2.1	5.1.5.2.1	5.1.5.2.1	5.1.5.2.1	5.1.5.2.1	5.1.5.2.1	5.1.5.2.2	5.1.5.4.1	5.1.5.4.2	5.1.5.4.3	5.1.5.6.1	5.1.5.6.2	5.1.5.6.3	5.1.6.2.1	5.1.6.2.2	5.1.6.2.3	5.1.6.2.4	5.1.6.2.5	5.1.7.2.1	5.1.7.2.2	5.1.7.2.3	5.1.8.2.1	5.1.8.2.2	5.1.8.2.3	5.1.8.2.4

H - Hardware Fabrication and Test
D - Detail Design
C - Conceptual Design
S - Study

Table 5.1-2. General Electric Related Experience

BLANK

In addition to the headquarters marketing staff, a field marketing organization known as Aerospace Programs Relations Division (APRD) is in place on-site at key "customer" or user locations. This organization functions as an arm of headquarters marketing - keeping abreast on a daily basis of customer or user requirements, policies and needs. This intelligence is continuously fed to Space Division Headquarters to keep management constantly in tune with the changing customer environment.

This in-depth and up-to-date knowledge of the customer/user community and its collective requirements is a very fundamental and critical capability which GE brings to the Mini-Brayton Program.

As a result of this capability, we will be able to keep Garrett as well as the AEC abreast of current trends in user requirements and goals. This will not only permit keeping the IBGDS program on a course consistent with Air Force goals for SURVSATCOM but will facilitate user understanding of the IBS and how it will best fulfill mission requirements.

5.1.2 HEAT SOURCE DEVELOPMENT

5.1.2.1 Capabilities Summary

General Electric is a leader in isotope heat source design and development. We are fully capable of complete design, test and integration of isotope heat sources into flight power systems. GE's most recent background in the heat source area lies in its intensive effort on the AEC's Multi-Hundred Watt Program. With this background GE uniquely brings to the proposed program specific in-depth heat source capability necessary for success in this program. Extensive background in the heat source area has covered a wide range of power requirements for application to both dynamic and static systems. Much effort has gone into such considerations as weight, design alternates, fabricability, and safety.

Figure 5.1-1 presents a montage of some of GE's heat source design and development efforts applied to a variety of space missions. These programs and other heat source background are discussed in the following paragraphs.

Figure 5.1-1. SNAP-27 Deployment on Lunar Surface During Apollo 12 Mission
(Upper Left)

Reference Mini-Brayton Spacecraft Design (Lower Left)

MHW-RTG Integrated with DoD Communication Spacecraft (Upper Right)

MHW-RTG Integrated with NASA's Mariner/Jupiter/Saturn (M/J/S) Spacecraft
(Lower Right)

5.1.2.2 Related Background

5.1.2.2.1 Multi-Hundred-Watt Radio- Isotope Thermoelectric Generator (MHW-RTG) (AT(29-2)-2831)

The Multi-Hundred Watt Radioisotope Thermo-
electric Generator has been designed and
developed by General Electric for the AEC to
be used on both the DoD communication satel-
lites (LES 8/9) and NASA's Mariner Jupiter
Saturn satellites. The generator (Figure 5.1-2)
uses a 2400 watt Pu-238 heat source and has
been designed to produce 125 watts of elec-
trical power, at 30 volts, at the end of five
years of orbital operation. Initially, it will
produce 150 watts at 30 volts.

Figure 5.1-2. MHW Generator

The MHW converter consists of 312 silicon-germanium (SiGe) thermocouples and a multi-layer molybdenum foil astroquartz insulation system housed within a sealed beryllium outer shell which serves as the RTG primary structure and external waste heat radiator. The SiGe thermoelectric material was selected because of its high conversion efficiency and for its ability to operate in air or vacuum at high temperatures - a prime consideration for long duration missions. During normal operation, the nominal hot and cold junction temperatures are 1000° and 300° C, respectively. An inert cover gas is provided for ground operations to prevent exposure of the oxidizable foil insulation to air. This gas is vented to space after launch.

The MHW heat source contains twenty-four spheres of plutonium dioxide to make up the 2400 watt (thermal) inventory (Figure 5.1-3). Each sphere is encapsulated in an iridium post-impact containment shell and is provided with its own impact protection. This assembly is referred to as a Fuel Sphere Assembly (FSA). The FSA's are arrayed in six planes along the length of the heat source, four FSA's to a plane, with each plane rotated 45 degrees with respect to the planes adjacent to it. For reentry protection, the FSA array is contained within a POCO-graphite aeroshell which is also the basic structure of the heat source. The aeroshell is enclosed by an iridium outer clad which provides the mechanical and thermal interface to the heat source, pneumatic isolation of the heat source from its environment, protection during the multiple skip class of reentries, and gas management for the helium generated by the fuel.

Figure 5.1-3. MHW Heat Source

5.1.2.2.2 Mini-Brayton Heat Source Assembly Design Study (NAS3-16810)

The objective of this study was to develop feasible design definition of Heat Source Assemblies (HSA) for use in 500 W(e), 1200 W(e), and 2000 W(e) Mini-Brayton isotope power systems. The HSA is a self-contained unit that maintains both thermal and nuclear control of an isotope-fueled heat source. It is a completely independent package which supplies heat to the power conversion system. Principal components consist of the Multi-Hundred Watt Isotope Heat Source (HS), the Heat Source Heat Exchanger (HSHX), the Auxiliary Coolant Heat Exchanger (ACHX), the Emergency Cooling Device (ECD), heat source insulation, and fragmentation and radiation shields, if required.

This program was the predecessor to NASA's HSA development program, described in the following paragraph (5.1.2.2.3).

5.1.2.2.3 Mini-Brayton Heat Source Assembly Development Program (NAS3-18541)

General Electric's Advanced Energy Program is presently performing this program for NASA LeRC. Its objective is to complete the development of technology required for the design and fabrication of reliable, long-lived and safe radioisotope fueled Heat Source Assemblies (HSA) and to design, fabricate and deliver three HSAs, not including Heat Sources.

This program is being conducted in three phases: Preliminary Design and Technology Verification, which will be completed within the first nine months; Detail Design, which will be completed by month 14; and Fabrication, Assembly and Conformance Testing of three HSA units which will be completed by the end of the 21-month period. These three instrumented units will not include heat sources (electric or isotope). Ground Support Equipment required to support the HSA during the Mini-Brayton system tests will also be identified.

5.1.2.2.4 SNAP-27 Heat Source (AT(29-2)-2581)

Under the SNAP-27 Program, General Electric designed, developed, flight qualified, and delivered plutonium-238 fueled heat sources for the SNAP-27 RTG. This program, initiated in late 1965, was a major AEC undertaking to provide flight quality hardware on a short schedule to the Apollo Lunar Surface Experiment Package (ALSEP). The fuel capsule

assembly is a 1480 W(+) $\text{Pu}^{238}\text{O}_2$ fueled heat source, designed to fit within the generator assembly cavity and provide the heat and temperature distribution required for proper integrated power unit (generator assembly FCA) performance. The cylindrical generator is 18 inches high by 16 inches in diameter (including the heat radiating fins) and weighs approximately 28 pounds without the fuel capsule. The thermoelectric assembly consists of 442 pressure contacted 3N and 3P lead telluride thermoelectric couples connected in parallel with each couple electrically ladderred to prevent the loss of the string due to an open couple failure. The couples operate in a hermetically sealed container with a 25 psia argon gas atmosphere. The plutonium dioxide is contained in a super-alloy capsule which weighs about 15.5 pounds. The fuel is in the form of microspheres and is contained within two identical 20-mil thick Haynes-24 internal liners.

5.1.2.2.5 250-Watt Re-Entry RTG (AT(29-2)-2048)

In this AEC Contract, General Electric designed a 250-watt RTG using both Pu^{238} and Sr^{90} . The design life of this generator was five years and the weight goal was two watts per pound using SiGe thermoelectrics. It was also required that, upon completion of the mission, the fuel capsules must be capable of deorbiting for disposal into preselected areas of the earth. This system was designed to be compatible with the Titan IIC dynamic launch loads and launch complex. A ground handling system was developed to remotely load the Sr-90 fuel capsules to the conceptual stage. The Nimbus Satellite was used for integration purposes.

5.1.2.2.6 RITE Heat Source (AT(30-1)-4104)

General Electric is responsible for the design and development of the nuclear heat source known as the Radioisotope for Thermal Energy (RITE) Heat Source. This work was performed in support of the Integrated Waste Management-Water System Program for the AEC's Division of Isotopes Development. The 400-Watt Plutonium-238 RITE heat source supplied continuous thermal energy to the waste processor for the sterilization and decomposition of solids, and to the pyrolysis unit to kill bacteria, incinerate organic compounds and provide for the catalytic reduction of ammonia. General Electric was responsible for design of the electric heat source simulator (Figure 5.1-4), radioisotope handling tools, radiation shielding, thermal control, nuclear safety analysis, RITE heat source license application, and support of the test program.

5.1.3 NUCLEAR SAFETY

5.1.3.1 Capabilities Summary

The Space Division has, over the past few years, developed a skilled and comprehensive capability in analysis and evaluation of the nuclear safety of spacecraft and missions

using RTG power systems. This demonstrated capability is highlighted by extensive experience on MHW SNAP-27, and Nimbus/SNAP-19 flight hardware programs, all of which satisfy very strict safety criteria. Some of GE's safety programs are highlighted in the following paragraphs.

Figure 5.1-4. Electric Heat Source Simulator

5.1.3.2 Related Background

5.1.3.2.1 MHW-RTG Safety Program (AT(29-2)-2831)

Major emphasis has been placed on nuclear safety in the AEC's MHW-RTG Program, and GE has performed a very intensive effort to ensure success in this area. Detailed safety specifications were prepared, and an extensive heat source testing program was conducted using fuel simulant. Tests included explosion, liquid fire, solid fire, heat source impact, and pad abort. In addition, a program plan was prepared and hardware was fabricated for the AEC's use in their live fuel tests. Other considerations in the safety program included ground handling design and operations, normal mission design and performance, and radiological safety.

A Preliminary Safety Analysis Report was prepared (GESp-7075 (GEMS-407), Vol. I, Reference Design Document and GESp-7076 (GEMS-407), Vol. II, Accident Model Document). Subsequent to its publication, more detailed analyses were conducted to evaluate the safety capability of the isotopic heat source as related to the Air Force LES 8/9 mission. The results of this evaluation were presented as the Updated Safety Analysis Review. Effort is currently continuing in the analytical and test areas to update and further evaluate the heat source safety potential. A Final Safety Analysis Report will be issued to document these findings.

5.1.3.2.2 SNAP-27 Nuclear Safety Evaluation (AT(29-2)-2581)

The most comprehensive of all the nuclear aerospace safety programs ever undertaken was the SNAP-27. This program extended over a two and one-half year period of intensive effort and encompassed every facet of nuclear/aerospace safety activity, discipline, and technology. It also required close liaison and coordination with several government agencies, and a number of government laboratories, centers, and contractors.

General Electric made a complete nuclear safety evaluation of the SNAP-27 RTG power system with respect to its use on the Apollo Lunar Mission and prepared the Safety Report which provided the basis for review for adequacy of nuclear safety and recommendation of approval for flight by the AEC, NASA, and DOD.

The SNAP-27 Safety Evaluation included the following principal outputs:

1. Definition of mission, associated equipment, and RTG design to use as baseline for analytical program.
2. Identification of potential accidents and aborts involving the fuel capsule that could occur prior to or during mission execution.
3. Characterization of environments associated with accidents and aborts including sequential events.
4. Analysis of fuel capsule response to environments and characterization of fuel release where necessary, including probability of release.
5. Determination of radiological consequences on a probability basis for instances of fuel release.

5.1.3.2.3 Mini-Brayton Heat Source Assembly Design Study (NAS3-16810)

Task 1, which was the safety study, focused on the general safety problems associated with an isotope fueled Mini-Brayton system. The purpose was to develop safety design requirements and guidelines, consistent with a space shuttle launch, which must be factored into the HSA designs. The manned space shuttle was selected as the reference mission since it imposes the most stringent safety requirement and represents a likely launch vehicle for future missions. Emphasis was placed on thermal control, radiation protection and blast

and fragmentation protection. Space shuttle integration considerations, hazards, and potential accidents were identified. A preliminary function flow analysis for the baseline shuttle mission encompassing the time frame between fabrication and recovery of the Heat Source was generated to facilitate this. The output of this investigation was a set of safety design requirements and guidelines to ensure personnel safety through all mission phases; to minimize the potential for accidents; and to preclude release of nuclear fuel to the biosphere in the event of catastrophic accidents or failures.

5.1.3.2.4 Design Study and Safety Analysis of Large Isotope Heat Source (AT(30-1)-3526)

In the Large Isotope Heat Source Study, the preliminary design and development aspects of a heat source of 20 to 200 kWt were investigated. The isotopes studied were Po^{210} , Cm^{244} , and Pu^{238} in various fuel forms. The Isotope Heat Source was designed to be coupled as a source of thermal energy with various types of power conversion systems including PbTe and GeSi thermoelectrics with pumped coolants, Brayton cycle, Dowtherm Rankine, Mercury Rankine, and Potassium Rankine. Net electrical powers in the range from 1 to 10 kWe can be attained with such systems. The technology available for the development of the Large Isotope Heat Source was investigated and a program leading to the manufacture and testing of the device was defined. In a follow-on task, the integration aspects and mutual compatibility of the Large Isotope Heat Source coupled with the compact T/E converters were examined. This study showed that the design parameters of the compact converters under development for the AEC are very close to the optimum parameters for the isotope system and that such an isotope thermoelectric power system is attractive for power levels in the range of 500 watts to about 2 kWe.

5.1.3.2.5 Separately Launched, Multi-Use Space Electric Power System, Phase II Preliminary Nuclear Safety Review and Documentation (NAS9-9751)

This study was a detailed review of the safety aspects of the isotope Brayton power system. A preliminary safety analysis report was prepared. Major tasks included mission definition, failure environment and system response analyses, failure probability determinations, fuel release and source term identification, and a nuclear hazards analysis. Significant environments included fireball/explosion reentry and impact. Mission phases examined

were prelaunch, boost, orbit, rendezvous, docking, startup, operational reentry and recovery.

5.1.3.2.6 Space Base Nuclear Systems Safety Study (NAS8-26283)

The Space Base Nuclear Systems Safety Study provided an evaluation of the potential and inherent radiological hazards of the NASA Space Base Program and recommended approaches for hazard elimination or reduction to acceptable risk levels. The results of the study were presented in a series of documents including Preliminary Safety Analysis Reports for both the Space Base and Reactor Power System, Radiological System Safety Guidelines and Requirements, and a System Safety Plan.

The Space Base Nuclear Systems Safety Study:

1. Determined the implications of the radiological hazards of the Space Base program on the Space Base itself.
2. Determined the impact of the presence of the nuclear sources of the Space Base on the supporting facilities and operations.
3. Determined the constraints imposed by the Space Base program on the design and operation of the associated nuclear hardware.
4. Provided the preventative and remedial nuclear safety oriented operational procedures, design guidelines and requirements for application in future design and development phases of the Space Base Program.

5.1.4 HEAT EXCHANGER TECHNOLOGY

5.1.4.1 Capabilities Summary

Design and performance of efficient heat transfer components will be especially important to the reliable operation of the heat source assembly in the AEC's Brayton systems test program. The extensive background of General Electric's Space Division in designing and fabricating specialized heat exchangers which involve difficult operational environments, material fabrication and processes, and thermal and hydraulic performance will be brought to bear on the successful accomplishment of this program.

The current work of Advanced Energy Programs (AEP) in NASA's heat source assembly development (NAS3-18541) represents Space Division's continuing advancement in heat exchanger design and fabrication. Additionally, this effort provided AEP with the unique opportunity of already having proven capability to build the specific heat exchangers required for this AEC program.

General Electric's contract experience in thermal control systems covers a broad range of applications and temperature levels. These thermal control programs considered various heat transfer approaches (i.e., conduction fin and vapor chambers) and fabrication technologies over a wide temperature range. These programs illustrate GE's demonstrated capability in the analysis and hardware development of heat transmission systems including conduction fin radiators and vapor chamber fin (heat pipe) radiators employing unique passive control concepts. In addition, Company-sponsored heat exchanger programs have also contributed to the outstanding competence which GE presently has in this area. Some of these programs, both contracted and Company-sponsored, are described in the following paragraphs.

5.1.4.2 Related Background

5.1.4.2.1 Liquid Metal-to-Air Heat Exchanger Design Study (F-33615-73-C-2065)

GE-SD recently completed a program for the USAF Aero Propulsion Laboratory to accomplish the preliminary design of a wrap-around heat exchanger which would be integral with a large turbo-fan engine. Liquid metal from a nuclear heat source would be circulated through the heat exchanger to deliver thermal energy to the compressor discharge air. As such the heat exchanger would replace the chemical combustors which normally accomplish this function.

5.4.1.2.2 Methane/Hydrogen Heat Exchanger Program (NAS3-14319)

In 1971, GE-AEG subcontracted GE-ESP to design and fabricate three different heat exchangers required for demonstration of cryogenic fuels in turbojet engines. The heat exchangers were the key items requiring extension of existing state-of-the-art technology relative to the thermal hydraulic design in preventing the formation of ice.

The heat exchangers were required to pre-condition hydrogen or methane fuel at -200° to -400° F prior to combustion in the turbojet engine. The fuel which was contained inside base tubes, was heated using engine bleed air at temperatures as high as 1180° F.

5.1.4.2.3 Radiator Structural and Mechanical Requirements Study - NASw-1449

This study investigated the problems of integrating large conduction fin radiators with the spacecraft and launch vehicles with emphasis on the structural and mechanical aspects. The study began with a determination of the maximum radiator area available as determined by launch loads, launch facility limitations, and nuclear shielding requirements. The role of the radiator as primary load bearing structure was examined by making a detailed comparison between a load bearing and a non-load bearing radiator. A detailed design comparison was made between a direct condensing and an indirect condensing radiator.

5.1.4.2.4 Vapor Chamber Fin Brayton Cycle Radiator Program - NAS3-10615

The purpose of this 18-month program was to identify a promising Brayton cycle vapor chamber radiator capable of operating in zero gravity and of being tested in a one-g environment. To accomplish this, Advanced Energy Programs identified vapor chamber working fluids, verified (through test) their compatibility with the chamber wall materials, measured their thermal characteristics, and prepared preliminary radiator designs based on these characteristics. A representative panel was then detailed, fabricated, and tested. The results were analyzed for application to full-scale Brayton cycle vapor chamber radiators and the radiator, which was designed to dissipate heat at temperatures between 20° and 350° F, was found to be competitive with conduction fin radiators at these low temperatures. This effort was redirected to develop a vapor chamber fin radiator which would operate at higher temperature levels (900° to 1300° F).

5.1.4.2.5 Compact Perforated-Plate Heat Exchanger

General Electric Corporate Research and Development Center conducted an analysis of counter-flow cryogenic heat exchangers which led to an advanced heat-exchanger concept: the perforated-plate exchanger.

A set of five heat exchangers employing the "perforated-plate" concept were fabricated for the U.S. Air Force (F33615-68-C-7472). From the experimental results, exchanger thermal effectiveness values of 98.3 to 98.5 percent were predicted at actual operating temperatures, as compared to a design goal of 99.0 percent.

5.1.4.2.6 Flexible Heat Pipe Development Program

In many spacecraft thermal control situations, means of rejecting waste heat to space is required. When the size of the controlled region is insufficient, some form of radiator is required to augment the rejection capability. If large radiator areas are involved or if a restrictive space envelope exists, packaging difficulties may arise with respect to the satellite and booster. A completely passive heat rejection system can be achieved by the use of heat pipes, and the packaging problem can be alleviated by using a deployable system which would erect itself in space. AEP has developed such a concept for a "folding" heat pipe.

The demonstration unit (Figure 5.1-5) uses water as the working fluid; however, the fluid selection for an operational unit would depend on the application and the desired operating temperature. The photograph shows one of the heat pipes deployed and operating. Close inspection will reveal the swollen configuration resulting from the vapor pressure of the water. The second pipe, shown wrapped around a twelve-inch radius mandril in the stowed position, is self-erecting when energy is applied to the heat input end.

Figure 5.1-5. Flexible Heat Pipe Demonstration Unit

The heat pipe enclosure consists of two sheets of 0.005-inch thick stainless steel, electron-beam welded along the edges. The pipes are approximately 34 inches long and four inches wide with plugs in the ends. The stubs of the pinched-off filler and vent tubes are visible in the photograph. Five mesh stainless steel wicking is spot welded on the inside surfaces of the two sheets of stainless steel.

5.1.4.2.7 SNAP-8 Radiator Panel Thermal Vacuum Tests

The primary purpose of the radiator test was to demonstrate the feasibility of constructing a liquid metal space radiator and to demonstrate its operation under a variety of test conditions. In addition, it was hoped that the radiator performance would confirm the analytical results of the Spartan series computer codes. Aluminum to steel bonds were successfully achieved on six-foot-long tubes. Six of the tubes were E-beam welded to fin plates, and the resultant fin-tube elements were subsequently fabricated into a 24-square-foot radiator panel representative of a segment from a conical SNAP-8 flight weight radiator. During the program the panel was tested (Figure 5.1-6) in vacuum

and air. This test made use of the GE/NaK loop facilities and a ten by five foot vacuum chamber. Operation tests in air totaled 72 hours, at a maximum inlet temperature of 550° F and a maximum flow rate of 0.66 pounds per second. Tested in vacuum, the total test time was 550 hours, including 175 hours continuously at the nominal design condition at 650° F inlet. Maximum inlet temperature was 700° F. At all test conditions, the heat rejected closely matched that predicted by analysis. Fin efficiencies within one percent of calculated values over the entire temperature range indicated the soundness of the bond between the

Figure 5.1-6. SNAP-8 Radiator Panel

stainless steel lines and aluminum armor. In addition to the thermal testing, the feasibility of deployment was demonstrated by rotating the panel through 90 degrees for several cycles while the radiator was operating.

5.1.5 HIGH TEMPERATURE MATERIALS

5.1.5.1 Capabilities Summary - Refractories

General Electric's Advanced Energy Programs' (AEP) interest and experience in refractory alloy development and processing can be traced back to the early 1950's; the course of continuing concentration upon the development and application of the refractory alloys has resulted in the availability of a high degree of present technical competence. Contracted and Company-sponsored work in refractory metal technology and in the fabrication of refractory metal structures, many of which utilize bimetallic joints, assure successful development of such components as the heat exchanger, ducting and turbine scroll in the proposed Brayton Systems Program for the AEC.

Significant results have been achieved in the areas of alloy melting and processing, forming, fabrication, welding, diffusion bonding, and mechanical property evaluation. The technology has been applied to such advanced components as turbine blades, turbine disks, liquid metal containment system components such as tubing, valves, EM pumps, tanks, boilers, condensers, sensors, and to other types of heat exchangers such as the solar Brayton cycle heat receiver. AEP's extensive background in refractory metals assures a high level of success on this program.

5.1.5.2 Related Background - Refractories

5.1.5.2.1 Refractory Alloy EM Pump Fabrication and Test (NAS3-10928), T-111 Tensile and Bend Test Evaluation (NAS3-15565), Compatibility of Ta Alloys in Lithium (NAS3-15553), SNAP-8 Refractory Alloy Boiler Development (NAS3-10610), T-111 Single Tube Large Scale Boiler Development (NAS3-9426), High Temperature Alkali Metal Valve Test Program (NAS3-8514) Alkali Metal Boiling and Condensing Investigations (NAS3-2528).

Present AEP personnel have been involved in a broad range of refractory metal applications. These have included: the development of various refractory alloys such as Mo-0.5Zr

and TZC (1.25%Ti-0.15%Zr-0.15%C-Mo) molybdenum alloys and F48 (15%W-5%Mo-1%Zr-0.06%C-Cb), AS30 (20%W-1%Zr-0.1%C-Cb) and AS-55 (5%W-1%Zr-1%Y-0.06%C-Cb) columbium alloys; the forging of over 2000 turbine blades from Mo-0.5Ti alloy and the application of metallic and ceramic coatings for testing in high temperature aircraft jet engines for hundreds of hours; the development and engine testing of Mo-0.5%Zr alloys (with roll clad Nichrome-3% tungsten oxidation protection alloys attached) for evaluation as stator nozzles in aircraft engines; the refractory materials procurement, joining development, coating technology and mechanical property design data associated with a "hot-structure" fin-rudder component for a reentry vehicle which was the predecessor to the ASSET Reentry Program; very extensive work on refractory alloys for potassium vapor turbines and for containment of liquid metal boiling and condensing heat transfer media for space power application at temperatures to 2150° F; and a complex large scale Cb-1Zr fabrication of a 10 kWe Brayton Cycle Solar Heat Receiver for space power applications.

Over a twelve year period, AEP was intensively engaged in the application of refractory alloys as containment materials for alkali metal heat transfer systems and Rankine cycle power generation systems. The scope of this effort is documented by about \$24 million in contracted effort in the area of space power development, of which a large portion directly involved the evaluation and use of refractory alloys.

During the course of this effort, considerable expertise was developed. Precise specifications and quality assurance requirements were developed as indicated in Table 5.1-3 and are available for the procurement of refractory alloys. The physical metallurgy and practical processing limitations and controls for refractory alloys became well established. Forming and joining techniques were reliably developed (this included very close control of helium cover gas welding atmospheres to less than 1 ppm each of oxygen and water vapor). The mechanical properties and particularly the alkali metal corrosion characteristics of several refractory alloys (principally Cb-1Zr and T-111) were studied extensively. The cleaning, handling, heat treating, and processing of refractory alloys were routinely performed under careful control to well-established specifications. Quality assurance control methods were established to maintain traceability of parts back to their original heats and to

Table 5.1-3. Typical AEP Refractory Alloy Material, Processing and Nondestructive Testing Specifications

Title	Specification Number
Sheet, Strip, and Plate: Cb-1Zr Alloy	B50YA-329
Bar and Rod: Cb-1Zr Alloy	B50YA-328
Seamless Tubing and Pipe: Cb-1Zr Alloy	B50YA-327
Foil Cb-1Zr Alloy	B50YA-330
Wire: Cb-1Zr Alloy	B50YA-333
Method for Ultrasonic Inspection	P3AYA-15
Fluorescent Penetrant Inspection	P3CYA-17
Radiographic Inspection	P3AYA-14
Helium Leak Test	P3CYA-16
Cleaning Cb, Ta Alloys	P4AYA-20
Welding Cb, Ta Alloys	P8AYA-13

provide documented data covering all critical operations. The extent of the successful experience which GE AEP has enjoyed in the fabrication and test of refractory alloy, alkali metal heat transfer systems is indicated by several refractory alloy loops of which the 100 kWt Cb-1Zr loop, the 400 kWt T-111 potassium boiler loop, and the high temperature alkali metal valve test loop are typical. The Cb-1Zr 100 kWt loop was operated successfully at temperature up to 2100° F for over 5000 hours surviving even the severe thermal transients associated with reaching burnout condition in measuring superheated vapor heat transfer coefficients. The T-111 400 kWt loop operated at temperatures to 2200° F; the facility operated the first time it was started and ran for over 2500 hours of trouble-free experimentation.

Refractory alloy experience has been gained in the forming of tubing, machining of complex valve and EM pump duct components, shrink fitting of close tolerance pump parts, welding of components and quality control inspection of both welds and bimetallic joints; all of this prior experience will be of direct benefit to the development and the manufacture of deliverable parts for this program.

Bimetallic Joints

Brazed Joints — The General Electric Company has developed and demonstrated the reliability of brazed, tongue-and-groove bimetallic joints. Joints between refractory alloys, such as Cb-1Zr, T-111 or Mo-TZM and austenitic stainless steel such as Type 316 and Type 321 or superalloys such as HA 25 have been utilized in many applications requiring long time service. These included: (1) the joining of refractory alloys to HA-25 and AISI 300 series stainless steels in liquid metal loops operating in vacuum where the liquid metal transfer tubes, pressure taps, and other services were supplied to the hot refractory alloy components through the vacuum chamber wall by means of bimetallic joints, and (2) the joining of tantalum heat transfer tubes containing mercury to a stainless steel primary loop system containing liquid NaK in the SNAP-8 boiler. Such brazed tongue-and-groove joints have been fabricated in sizes up to 2.5 inches in diameter.

Diffusion Bonding — The technology of Hot Isostatic Pressing (HIP), or Hot Isostatic Gas Pressure Bonding, has been developed to a high level of excellence in the past fifteen years at AEP. The process has been used principally in the joining of dissimilar metals and in the forming and joining of complex shapes, for such purposes as preparation of unique clad fuel element configurations, the formation of clad dissimilar metal tubing, or the preparation of metal-ceramic seals.

A wide variety of applications have been investigated. The bonding of dissimilar metals such as tungsten, molybdenum and titanium and of titanium and iron base alloys has been demonstrated, particularly in the attachment of metal cladding to core materials. Tantalum alloy or tungsten alloy clad cermet nuclear fuel rods having complex shapes and internal cooling holes have been clad on all surfaces with refractory alloy sheet metal and tubing cladding material to effect complete containment of the nuclear fuel and its by-products. Metal-ceramic joints have been made between Kovar, columbium, molybdenum or titanium and either alumina or beryllia; graded expansion metal-ceramic joints between materials of different expansion characteristics have been developed using graded powder compositions. Complex shapes in stainless steel, tungsten and beryllium have been pressure formed and diffusion bonded together over acid-leachable, expendable form-tools.

The unique background and capability of AEP in the design and fabrication of dissimilar metal joints should assure rapid and immediate progress in the design and integration of the Mini-Brayton turbomachinery with HSA.

5.1.5.2.2 Design and Fabrication of Brayton Cycle Solar Heat Receiver (NAS3-10944)

Perhaps one of the most applicable achievements of GE-AEP in the design and manufacture of large refractory alloy structures was the 10 kWe Brayton Solar Heat Receiver shown in Figure 5.1-7. The heat receiver was constructed under NASA Contract NAS 3-10944 and was intended for use with a Brayton cycle power system in earth orbit; the heat receiver's function was to collect solar energy and store it in a molten lithium fluoride heat sink to deliver a continuous supply of hot inert gas to a closed cycle

Figure 5.1-7. Brayton Solar Heat Receiver

turbine at 1960° R. The centerline of the larger gas collector manifold was about 66 inches in diameter; the receiver had 48 heat storage tubes and the system weighed 1174 pounds when completed. The manufacture of this component demonstrated the planning, quality control, manufacturing capability and joining technology which is necessary to assure the development and production of similar refractory alloy Brayton cycle heat transfer such as the Brayton's HSHX and ducting.

While the Brayton Solar Heat Receiver was very much larger than the HSHX in the proposed Brayton Demonstration Test Program, the excellent experience gained in the forming, machining, and weld assembly of the earlier system is directly applicable to the currently proposed work.

5.1.5.3 Capabilities Summary - Superalloys

Prior programs have imposed an in-depth knowledge of materials characteristics and the ability to fabricate various superalloys to stringent requirements. The selection and successful application of these high temperature materials in the past provide the basis for GE's fulfilling similar requirements in the AEC's proposed Brayton Systems Test Program. Some programs representative of the Space Division's capability in this area are described in the following paragraphs.

5.1.5.4 Related Background - Superalloys

5.1.5.4.1 SNAP-27 Program (AT(29-2)-2581) - Materials

The SNAP-27 plutonium-fueled thermoelectric power supply developed by the General Electric Company to power the Apollo Lunar Surface Experiment Package (ALSEP) was designed to provide a minimum of 63.5 watts at a minimum of 16 volts, for a total fuel and generator weight of 42.7 pounds. In order to achieve the specific power, several design and material breakthroughs were required, as detailed below:

1. This was the first SNAP system to take advantage of the high thermal conductivity and low weight of beryllium in order to meet the ALSEP weight limitations.
2. In addition to being able to withstand impact at terminal velocity, the fuel capsule provides the highest ratio of fuel to capsule weight of any comparable system.
3. Through the development of an IN-102-to-beryllium brazing technique, the final closure of the thermopile is accomplished by a seal weld which eliminates the possibility of losing internal gas pressure through leakage.
4. The external magnetic field was reduced to very low levels by designing self cancelling internal circuitry, degaussing loops, and hot shoe arrangement that utilizes a minimum of permeable material.
5. The electrical and thermal analysis of the thermopile was substantiated by the performance of test generators (70 watts) and end-of-life power may now be predicted to be 65 watts versus a specification requirement of 56.6 watts.
6. All generator deliveries were accomplished in accordance with the initial schedule established in 1965.

5.1.5.4.2 SNAP-27 Fuel Cask (AT(29-2)2581)

When changes were made in fuel cask requirements to incorporate superorbital reentry capability without the aid of a lunar module cask separation mechanism, a new fuel cask design was required on an accelerated schedule. The superorbital reentry required the use of a pyrolyzed graphite material which had never been used before and hence entailed a high degree of risk. Because this new material had little background, a testing program was initiated to determine its design characteristics. The results of this design and test program is directly applicable in other space power systems.

5.1.5.4.3 Liquid Metal-to-Air Heat Exchanger Design Study (F-33615-73-C-2065)

GE-AEP has recently completed a paper to the USAF Aero Propulsion Laboratory for the preliminary design of a wrap-around heat exchanger, which would be integral with a large turbofan engine. Liquid metal from a nuclear heat source would be circulated through the turbine-module heat exchanger to deliver thermal energy to the compressor discharge air. As such the heat exchanger would replace the chemical combustors which normally accomplish this function. (See Section 5.1.4.2.1 also.)

One of the objectives of this heat exchanger program was the study of metallurgical problems associated with liquid metal compatibility and oxidation.

In each module liquid metal headers are located on the forward end of the heat exchanger and are connected to the appropriate toroidal manifold envircling the engine. The NaK flows through finned U-tube assemblies oriented parallel to the engine axis.

Haynes Alloy HA-188 is chosen as the primary material for the tubes, fins, headers and ducting because it appears to have the best balance of the required properties of strength, ductility, oxidation resistance, fabricability, thermal conductivity, and resistance both to alkali metal corrosion and mass transfer. The welded and back brazed type of tube-to-header joint is selected, based upon the effective alkali metal seal provided by the weld, the assurance back brazing provides in prevention of weld strain and cracking, and its demonstrated reliability and economy in the fabrication of prior NaK-to-air heat exchangers.

5.1.5.5 Capabilities Summary - Ceramics

The Space Division has extensive experience in ceramic technology research and development as illustrated by the programs reviewed in this section. The structural ceramic program is of particular interest since it demonstrates the Division's understanding and ability to design, develop and fabricate both simple and complex ceramic materials which may also be applied to the Brayton Ground Systems Test Program.

5.1.5.6 Related Background - Ceramics

5.1.5.6.1 Electric Heat Sources

Table 5.1-4 lists the electric heat sources and electric heat source simulators which have been designed and developed for use in the MHW program. These heaters are grouped according to description and usage.

Table 5.1-4. List of Electric Heaters by Groups

Electric Heat Source	Description
Group 1 EHS No. 1, 2, 4, 5	Tungsten element heater with smaller diameter and length to simulate the original IHS design. Serial No. 2 of this group had an Irridation can, this heater was used for SPC testing.
Group 2A GEHS No. 1 (Graphite Electric Heat Source)	First graphite element heater for static test purposes only. Also designed with small diameter and length.
Group 2B GEHS No. 2 (Graphite Electric Heat Source)	Second graphite static heater designed with larger diamter and length. Possibility of dynamic testing when filled with ceramic spheres.
Group 3 DEHS No. 1 (Dynamic Electric Heat Source)	Tungsten element heater of latest size diameter and length with improved fabrication techniques to eliminate the ceramic and cement core construction.
Group 4 GDEHS No. 20, 21, 22 (Graphite Dynamic Electric Heat Source)	Graphite element of latest size with close fitting parts to permit hot dynamic testing.
<u>Electric Heat Source Simulators</u>	<u>Description</u>
Group 5A EHS No. 3	This graphite shell and steel ballast heater simulator was used for vibration fixture surveys at ambient temperature. Small diameter and length with external accelerometers.
Group 5B EHS No. 2	Larger size simulator containing a graphite outer shell and steel ballast with internal accelerometers for vibration fixture surveys.

The Group 4 heater became the prime electric heat source for the MHW Program (see Figure 5.1-8). It uses a graphite heater element machined in a serpentine configuration. The element is supported by an internal ceramic cylinder and restrained by ceramic insulators at the forward, center, and aft locations. All parts are machined to very close tolerances allowing only minimum gaps at temperature of several mils. To achieve a nominal 46.5 pounds, the ballast is a central molybdenum rod which receives the column loads from the end caps. The heater element is made from POCO Graphite AXF and all other graphite components are AXF-5Q.

Figure 5.1-8. Graphite Dynamic Electric Heat Source
(Forward End Enclosure Assembly)

5.1.5.6.2 Development and Evaluation of a Procedure for Toughening Structural Alumina Ceramics (L-68-0039)

(Work Performed for Ordnance Research Laboratory, Pennsylvania State University, University Park, Pennsylvania, under subcontract L-68-0039 of Contract No. N0W-65-0123-d.)

The purpose of this program was to develop and evaluate a procedure for applying a compressive ceramic glaze or veneer to a smooth alumina cylinder with a view to improving the mechanical strength, the resistance to point loading, and the impact resistance of the cylinder.

A number of commercial glazes and glaze frits were evaluated according to their maturing temperatures and thermal expansion characteristics. Ten of the more promising of these materials were applied on the outer surface of 4-inch rings of impervious recrystallized alumina 1/2-inch-wide and 1/10-inch-thick, and fired. The rings were then cut with a diamond saw, and the amount of change in the width of the gap, due to compressive stresses in the glaze was noted. It was found in general, the lower the thermal expansion of the glaze relative to that of the alumina body, the greater was the amount of compression.

5.1.5.6.3 "Development of Composite Structural Materials for High Temperature Applications" (Contract No. N00019-69-C-0310)

The purpose of this program for the Naval Air System Command was the development of composite materials with strength-to-density ratios that are higher than currently available superalloys at temperatures in excess of 1100° C (2000° F). The composite should also be resistant to oxidation at these temperatures. To meet these goals, a strength-to-density ratio in excess of 200,000 inches above 1100° C was required.

Past work on this program had been concerned primarily with sapphire whiskers as reinforcing fibers in a variety of matrix materials. The feasibility of reinforcing metals with high-strength whiskers was demonstrated previously by a model system of α -Al₂O₃ whiskers embedded in a silver matrix. These composites exhibited strength-to-density ratios as high as 725,000 inches at room temperature with 25 volume percent whiskers, and 320,000 inches at 870° C (1600° F) with 45 v/o whiskers.

5.1.6 SPACE NUCLEAR POWER SYSTEMS

5.1.6.1 Capabilities Summary

General Electric's Advanced Energy Programs has performed numerous systems design and development contracts covering a wide range of technologies for a variety of applications. Some of these programs are described in the following paragraphs.

5.1.6.2 Related Background

5.1.6.2.1 Mini-Brayton Economic RTG Study (AEC SNSO-6)

This study was directed at evaluating the Mini-Brayton power system for a 400 W(e) synchronous orbit application. Emphasis was placed on designing a low-cost, light-weight (less than 205 pounds) system/ both Pu-238 and Cm-244 fuels were considered. A reference design using Cm-244 was prepared which had a total weight of 186 pounds and a cylindrical radiator envelope 3 feet in diameter and 5 feet high; system efficiency was 23 percent. This system is illustrated in Figure 5.1-9. Analyses performed at higher power levels indicated specific powers of 5 watts/pound and net system efficiencies of 35 percent.

Figure 5.1-9. Mini-Brayton ERTG Study Conceptual Spacecraft

5.1.6.2.2 Multi-Hundred Watt Radioisotope Thermoelectric Generator Program (AT(29-2)-2831)

General Electric-Advanced Energy Programs is developing the Multi-Hundred Watt RTG (Figure 5.1-10) under contract to the Atomic Energy Commission. This generator, through the use of modular units, will satisfy the projected need for electrical power in the range of

Figure 5.1-10. Cutaway View of MHW Generator

100 watts to over a kilowatt. It will be the basis of the next generation of high performance RTG's providing power at a level approaching two watts per pound. The first application will be for the LES 8/9 mission.

As part of the Multi-Hundred Watt RTG Program, the design of the heat source has been directed toward the development of a modular fuel subsystem that would satisfy the composite design considerations imposed by nuclear safety and the RTG power and integration requirements. The 2400 thermal watt plutonium-238 fueled MHW heat source contains 24 fuel spheres rated at 100 watts each. The heat source exterior surface which operates nominally at a surface temperature of about 2000°F is designed to survive abort situations and provide post impact containment. This program is described further in Paragraph 5.1.2.2.1.

5.1.6.2.3 SNAP-27 Program (AT(29-2)-2581)

The first SNAP-27 system was successfully deployed on the lunar surface by the Apollo 12 astronauts in November 1969 and has provided electrical power at remarkably constant level. The Apollo 12 ALSEP RTG has greatly extended the Apollo scientific investigations by operating well beyond its one-year design life; it continues to produce in excess of 60 watts. Other SNAP-27's were also placed on the moon in the Apollo 14, 15, 16, and 17 flights. The exemplary performance of all the generators can be seen in Table 5.1-5.

Table 5.1-5. SNAP-27 Performance (Nov. 1974 data)

Apollo Mission Number	Launch Date	Initial Power (watts)	Current Power (watts)	Time on Moon (years)	% of Initial Power
12	11/14/69	74.0	61.8	5.0	.835
14	1/31/69	72.5	64.4	3.76	.888
15	7/26/71	74.5	67.9	3.29	.911
16	4/16/72	71.0	68.0	2.57	.958
17	13/2/72	75.4	74.4	1.92	.987

SNAP-27 is described further in Paragraphs 5.1.2.2.4, 5.1.3.2.2, and 5.1.5.4.1.

5.1.6.2.4 Separately Launched, Multi-Use, Space Electrical Power System (NAS 9-7444)

The purpose of this program was to conduct a detailed design and applications study of a separately launched, modular, 5 kWe radioisotope Brayton-cycle power generating system (Figure 5.1-11), and then to evaluate the multi-use capability, the economic, operational, and safety advantages and disadvantages of this concept. The program provided structural

Figure 5.1-11. Separately Launched Multi-Use Space Electrical Power System

design and load analyses covering several launch vehicles for four different NASA manned spacecraft missions and included: a heat source design and integration study, a design and optimization study of the closed Brayton-cycle system, a power module design and launch vehicle integration study including definition of ground system requirements, an investigation of spacecraft rendezvous and docking techniques, procedures, mechanisms, and interfaces, a thermal analysis of the power module interactions with the various launch vehicles and manned spacecraft configurations, an investigation of radioisotope recovery and reuse, a study of in-orbit maintenance repair and replacement, and an analysis of the power module/spacecraft dynamics for each proposed mission.

5.1.6.2.5 Brayton Cycle Turboalternator Compressor (NAS3-13449)

AEP, under contract to NASA's Lewis Research Center, completed Phase I of the Brayton Cycle Turboalternator Compressor (TAC) Program. The work defined the turbine alternator and compressor capable of operating with an argon or helium xenon gas mixture, and developing 40 to 160 kWe of power utilizing the zirconium hydride and other reactors as a heat source. The study provided preliminary detail design data such as thermodynamic performance, configuration definitions, materials selection, life capability, stress analyses, and bearing and

rotor requirements necessary for the final design and hardware buildup of a development TAC. In addition to performing the initial study, AEP has independently studied, analyzed and designed Brayton cycle turbomachinery in other sizes. AEP has conducted analyses and tests of the heat exchangers necessary to incorporate a TAC in a nuclear space power plant.

5.1.7 SPACECRAFT INTEGRATION

5.1.7.1 Capabilities Summary

The competence established within General Electric's Space Division in the area of nuclear spacecraft integration is presented in this section. The work of Space Division's Advanced Energy Programs (AEP) in space nuclear power provides the AEC with a contractor that has a broad spectrum of activity in integration of power systems from tens of watts provided by the small RTG's. Space Division's Nimbus/SNAP-19 integration program represents one of GE's most significant power subsystem integration programs. This program included the electrical, structural, and thermal integration of SNAP-19 into the Nimbus spacecraft. In addition GE performed the flight qualification and acceptance testing of this nuclear-powered spacecraft.

5.1.7.2 Related Background

5.1.7.2.1 NIMBUS/SNAP-19 Vehicle Integration Program (NAS 5-978)

In the Nimbus Program for the NASA Goddard Space Flight Center, General Electric Space Systems has been responsible for systems integration and test of the entire Nimbus A, B, C, and D vehicles. In addition, under a number of other contracts, General Electric Space Systems has been responsible for a variety of operational engineering tasks including design and operation of data handling systems and operation of the Nimbus Technical Control Center at Goddard Space Flight Center. Both the integration and test and the operational engineering activities have involved close support of the NASA project organization and extensive interfaces with the many associated Nimbus prime contractors.

Under the Nimbus B Integration and Test Program, Space Systems has had responsibility for integration of the SNAP-19 RTG into the spacecraft design. Activities in this area have included electrical, structural, and thermal integration of the RTG into the spacecraft design.

As part of this activity, special RTG thermal vacuum tests were conducted to determine thermal inputs to the spacecraft and to verify the adequacy of those areas of the spacecraft thermal design related to the RTG. General Electric experience also includes close cooperation with NASA Technical Officers and the co-contractor supplier of the RTG in developing design documentation of RTG/Spacecraft interfaces and evaluation of RTG test data accumulated during spacecraft system testing.

General Electric's activities on the Nimbus Program have included performance of integrated space/launch vehicle shroud tests to establish the effects of an RTG on prelaunch test requirements.

In addition, each GFE item has been functionally tested at General Electric prior to assembly, and all system testing of the complete spacecraft has been accomplished here, using GE-supplied stimulators for the payload sensors.

General Electric makes effective use of its imposing array of space simulation facilities for testing in a simulated space environment, matching facility sizes and capabilities to the requirements of spacecraft ranging from small scientific probes to large complex vehicles up to 21 feet in diameter and weighing as much as 44,000 pounds.

5.1.7.2.2 SNAP-27 ALSEP Integration and Qualification Test Program - (PO S/C 0404)

General Electric Space Division, under contract to the Bendix Corporation Aerospace Systems Division, conducted an integration, qualification and acceptance test program for ALSEP cask assemblies comprised of the SNAP-27 graphite LM fuel cask (GLFC), the SNAP-27 fuel capsule assembly (FCA) and the Bendix cask mounting hardware. The test program was intended to ensure adequate proofing of the combined SNAP-27 ALSEP design, compliance with the thermal interface limits, and integrity of each flight system. The program consisted of the following:

1. Acceptance and qualification tests of one system of flight design
2. Acceptance tests of five flight systems
3. Acceptance and qualification tests of one mockup system of cold flight design

4. Acceptance test of one mockup cold flight system
5. Associated integration activity.

5.1.7.2.3 SURVSATCOM Electrical Power Subsystem (SEPS) Conceptual Design Study (F19628-74-C-0155)

Space Division's Military Communications System Section of the Military Programs Department completed a study in August 1974 for the AFSC's Electronic Systems Division for an electrical power system for a SURVSATCOM mission (SEPS). This SEPS study compared relative merits of:

1. All nuclear systems of economic radioisotope generators (ERTG) developed by the AEC using:
 - a. Static thermoelectric conversion
 - b. Dynamic organic Rankine conversion.
2. Hybrid systems of ERTG and solar arrays using:
 - a. Fixed panel arrays
 - b. Oriented panel arrays—rigid fold-out and flexible roll-out.

As part of this study, a set of candidate SEPS/vehicle configurations were defined to:

1. Illustrate alternative methods of interfacing SEPS with the SURVSAT space vehicle.
2. Illustrate the impact of the space envelope constraints on the definition of the size, location, orientation, and vehicle interface characteristics of the SEPS components.
3. Illustrate methods of interfacing the SURVSATCOM space vehicle with candidate launch vehicles.

5.1.8 THERMAL CONTROL INSULATION AND COATINGS

5.1.8.1 Capabilities Summary

Insulation - Through its participation in a broad range of space systems programs, the Space Division has gained valuable experience in the design and application of insulation systems. These programs have ranged from the development of design concepts to fabrication for flight hardware. Table 5.1-6 summarizes a representative cross section of

such programs and the thermal concepts employed. Table 5.1-7 presents an insulation contracts summary.

Table 5.1-6. Space Division Programs Summary

Program	Super Insulation	Coatings	Type of Thermal Control
Voyager (Tasks A, B, C, & D)	X	X	Semi-active
Nimbus	X	X	Semi-active
Advent	X	X	Semi-active
MACS	X	X	Passive
Solar Probe	X	X	Passive
OAO		X	Passive
ATS		X	Passive
GGTS		X	Passive
Classified Programs	X	X	Passive

Table 5.1.7. Insulation Technology Contracts Summary

Contract		Customer	Approx. Value	Duration
1.	NAS8-5207 Thermal Contact Conductance	NASA-MSFC	30K	1 year
	NAS8-11247 Follow-on	NASA-MSFC	45K	1 year
	NAS8-11247 Follow-on	NASA-MSFC	45K	15 months
2.	NAS9-3685 Measurement of Multi-layer Insulation Thermal Performance	NASA-MSFC	81K	1 year
	NAS9-3685 Follow-on	NASA-MSFC	67K	1 year
3.	NAS9-4516 Evaluation of Critical Apollo Joints	NASA-MSFC	59K	13 months
4.	NAS8-11372 Part I - Design Criteria for Planetary Spacecraft to be Sterilized by Heating	NASA-MSFC	190K	1 year
	Part II - Development of Manufacturing Procedures for Planetary Spacecraft to be Sterilized by Heating	NASA-MSFC	192K	1 year
	Part III - Design Criteria for Typical Mars Landing Capsules Requiring Sterilization	NASA-MSFC	200K	1 year
5.	JPL 951322 Insulation of a Surveyor Seismometer	JPL	7K	6 weeks
	JPL 951322 Follow-on	JPL	12K	12 weeks
6.	JPL 951375 Study Report and Development Proposal for Seismometer Insulation and Support System	JPL	5K	7 weeks
7.	JPL 951537 Planetary Vehicle Thermal Insulation Systems	JPL	325K	21 months

Coatings - Materials groups in the Space Division have many years of experience in developing and/or selecting thermal control coatings for many different vehicles and missions. Activities have ranged from coatings research through every operation necessary to ensure success of the coatings in flight. Therefore, broad experience can be brought to bear on coatings problems for a large number of long and short-lived satellites and re-entry vehicles. Some examples include Nimbus, OAO, BIOS and classified Air Force satellites in near-earth orbits, ATS and GGTS in synchronous orbit. Table 5.1-8 presents a summary of some of the Division's contract development work in this space technology area.

Table 5.1-8. Thermal Control Coatings Experience

Program	Contract Number	Agency
Nimbus	NAS5-978	NASA
Advent	AF04(647)-476	USAF
Air Force Space Program	AF04(647)-6	USAF
Air Force Space Program	AF04(645)-76	USAF
Air Force Space Program	AF04(695)-155	USAF
Air Force Space Program	AF04(695)-432	USAF
Phase Change Coatings	NAS-1-5330	NASA/Langley
SNAP-27	AT(29-2)2581	AEC
Infrared Camouflage Coatings	AT33(657)-14478	USAF

5.1.8.2 Related Background

5.1.8.2.1 Planetary Vehicle Thermal Insulation Systems Program (PVTIS) (JPL 951537)

The Space Division performed this study of insulation systems for planetary exploration vehicles under contract to the Jet Propulsion Laboratory. This program investigated such insulation system factors as thermo-optical absorptivity and emissivity, material out-gassing, thermal conductivity, dimensional stability, and compatibility with sterilization procedures for several high-performance vacuum-insulation materials.

5.1.8.2.2 Propellant Storability in Space (PSIS) (AF04(611)-9078)

The Space Division performed this program for the Rocket Propulsion Laboratory of the Air Force System Command. The purpose of the work was to investigate the long-term storage capability of cryogenic and earth storable propellants in an orbital environment. One of the propellant considerations in the study was $\text{OF}_2/\text{B}_2/\text{H}_6$. Insulated propellant tanks with simulated meteorite shields and suitable thermal coatings were tested in a large vacuum chamber.

5.1.8.2.3 SNAP-27 Thermal Control Coatings (AT(29-2)-2581)

In the SNAP-27 program, high-temperature and emissivity coatings were developed for both the fuel capsule and the radiator. Under test at operating conditions, these coatings demonstrated characteristics superior to those required by the original specification. Details as to materials and processes can be obtained from the Quarterly Reports on the program. The design of a passive thermal control coating relies on an accurate prediction of the radiative properties of the vehicle surface while in space. To accomplish this, the optical properties of the coatings at the time of launch must be accurately known and controlled. Furthermore, the effect of exposure to the space environment on these properties over the lifetime of the mission must be clearly understood.

5.1.8.2.4 Beryllium Coating for SNAP-27 GLFC (AT(29-2)-2581)

Through the utilization of extensive background experience in ceramic-metal composites and glass technology, it was possible to develop a high emittance coating of lead borosilicate glass bonded iron titanate, and to optimize application and firing techniques to produce an intimately bonded emissive coating. Bonding of the coating to rhodium involved heat treating in an argon atmosphere at 1375° F. This emissive coating (Radifrax RC165) exhibited excellent bond strength compatibility with the rhodium and beryllium of the heat shield and with the isotope fuel under all anticipated abort conditions.

5.2 RELATED FACILITIES - SUMMARY

This section describes some of the related facilities and capabilities which the General Electric Company brings to the AEC's Isotope Brayton Ground Demonstration Program. The facilities available for use cover the complete spectrum of manufacturing, assembly and test facilities required for the proposed program. The facilities are located at Evendale, Ohio and Valley Forge, Pennsylvania.

The Valley Forge Complex of the General Electric Space Division (VFSC), a 900,000 square foot installation, is equipped with extensive facilities for development, manufacturing and test. Total value of Company-owned facilities in the Valley Forge complex is \$66.4 million, and this total is augmented by Government facilities valued at approximately \$18 million, and leased buildings totaling 660,000 square feet.

General Electric's Evendale, Ohio facility is a large, well equipped manufacturing, assembly and test facility particularly well suited to the manufacture of refractory metal components because of both the expertise and experience of the personnel at Evendale and the nature of the machining facilities located there. The facility occupies approximately 300,000 square feet of laboratory, manufacturing, test and office area.

The facilities which General Electric's Space Division brings to this program are grouped into three basic categories:

1. Manufacturing and Assembly
2. Test and Quality Assurance
3. Computer

5.2.1 MANUFACTURING AND ASSEMBLY FACILITIES

Evendale Operations has a variety of equipment and general facilities that are able to perform a wide range of manufacturing and test operations. The versatility of the manufacturing capability has been demonstrated numerous times over the years on one-of-a-kind,

first-time-perfect jobs that development programs demand. The following is a general listing of categories of manufacturing equipment available at GE's Evendale facility for use on the isotype Brayton Ground Demonstration Program:

● Complete Sheet Metal Shop	● EDM Machining
● Tool Room, Engine and Turret Lathes	● Honing Machines
● Milling Machines	● Shapers
● Numerical Control Mill and Drill	● Lappers
● Drill Presses	● Surface, Cylindrical and Thread Grinders

Detailed lists of specific machines in each general category are available.

Welding Facilities

Evendale Operation's welding laboratory is equipped to perform the high quality welds required for the Brayton's heat source assembly components. The Electron Beam Welding equipment consists of a 6 kW (150,000 volts) Hamilton Standard unit with chamber dimensions of 149 inches long by 23 inches wide by 30 inches high. It is additionally equipped with a GE-designed beam and work manipulator for automatic positioning control.

Inert-gas-tungsten-arc (GTA) welding chambers capable of being evacuated to 10^{-6} torr and equipped with analytical instrumentation for the continuous analysis of oxygen, water vapor and other gaseous impurities in helium are used extensively for the welding of columbium and tantalum alloys. The GTA equipment, Figures 5.2-1 and 5.2-2, consist of a specially built 3 foot diameter by 6 foot long tank with suitable glove ports, windows and doors, work table and power pack with control for hand or fully automatic welding. The tank is serviced by a high-purity inert gas supply with an elaborate gas-purity monitoring system to assure compliance with the purity requirements of the process specifications. The 3-foot by 6-foot chamber has two 8-foot diameter extensions which add 8 feet to the overall chamber length.

Figure 5.2-1. Vacuum Purged Inert Gas Tungston Arc (GTA) Welding Chamber

Diffusion Bonding

Two autoclaves for high temperature, gas pressure diffusion bonding are available for the conduct of process development and hardware fabrication operations. The smaller facility has a 6-1/2-inch diameter by 20-inch long useful work space and can be heated to 3000° F under 10,000 psi helium pressure. It is used for conducting initial process evaluation work leading to the selection of hardware configurations, the checkout of tooling, the establishment of process parameters, the determination of bend strength, the metallographic evaluation of the diffusion bonded joints and the provision of initial samples for further process evaluation studies.

The larger facility, shown in Figure 5.2-3 has a 12-inch diameter by 36-inch long useful work space and is also capable of operating at temperatures to 3000° F under 10,000 psi helium pressure. Both facilities would be available for the fabrication of the heat source assembly components in the Brayton Systems Test Program.

Figure 5.2-2. 8-Foot Diameter Extension to GTA Welding Chamber (Showing Cb-1Zr Alloy Manifold Segment).

Figure 5.2-3. Hot Gas Isostatic Press.

Additional Facilities

To provide additional manufacturing, fabrication and assembly support for the isotope Brayton Program, the Space Division's Valley Forge complex has a modern manufacturing capability equipped and staffed to meet the quality and reliability standards essential to this program's success. These facilities are available to augment those of our Evendale operations. In general, the Valley Forge manufacturing facility has the following shop areas, among others:

- Controlled Environment Manufacturing Facility
- Machine Shop
- Sheet Metal Shop
- Parts Laboratory

Controlled Environment Manufacturing Facility

The Controlled Environment Manufacturing Facility is an "isolated" facility located in the main building of the Valley Forge Space Center. The facility is operated in a special, confined location for the assembly of supercritical components in a near-pure environment (currently Class 100,000 but with design capability of improvement to Class 10,000).

The facility is a multi-room complex containing 11,000 square feet of floor space and arranged in satellite fashion around a centrally located cleaning room. There are four separate rooms for the processing and assembly of components. The entire area is pressurized, including all assembly (electrical, mechanical, and optical) areas. In order to maintain maximum possible cleanliness for the most critical activities, the rooms are maintained at various planned atmospheric pressures.

Machine Shop

The range of work which can be accommodated in the Machine Shop provides the Division with the flexibility required for spacecraft component fabrication. The Machine Shop is a modern, well-equipped area containing 78 major pieces of machine tool equipment. Equipment includes various sizes and capabilities of lathes, drill presses, milling machines, jig borers, and grinders (internal, external and surface grinding).

Machine parts range in size from less than 1/2 inch to large rings up to 84 inches in diameter. Specific equipment includes:

1. 42-inch Vertical Boring Mill
2. 84-inch Vertical Boring Mill
3. 4-inch Spindle Horizontal Boring Mill
4. Pratt and Whitney No. 2E Precision Jig Borer
5. Tracer Mill Machine

Sheet Metal Shop

Sheet metal fabrication for spacecraft is efficiently performed in the highly diversified facilities and by the skilled workmen in this operation. This enables the Division to process prototype units and semi-production runs within the same area.

Efficiency and flexibility are further increased by the use of the most recent developments in low cost tooling in conjunction with metal working equipment of the latest type. The sheet metal shop operation includes equipment for welding, painting, chemical treating, and aluminum heat treating of spacecraft products. Metallic arc, inert arc, gas, and resistance welding of ferrous and non-ferrous materials can be performed in this shop.

The Sheet Metal Shop contains 44 major pieces of machine tool equipment with capabilities for shearing, bending, rolling, notching, punching, and forming all shapes and configurations required for hardware support of major vehicle contracts. Specific equipment includes:

1. Six-foot Roll Machine, 3/16-inch mild steel capacity capable of roll forming sheets in diameter configurations of 10 to 20 feet.
2. Ten-foot Squaring Shear, 3/8-inch mild steel capacity.
3. Six-foot and eight-foot Press Brakes, 3/16-inch and 1/8-inch mild steel capacity to form intricate shape configurations.
4. Type OA Angle Roll, 1/8-inch mild steel capacity to roll form support angles used in structures.

RTG Storage, Loading and Assembly Station (RTG-LAS)

The RTG Loading and Assembly Station's (Figure 5.2-4) 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 is predicated on the following requirements:

1. Removal of the Isotope Heat Source (IHS) from the Storage Protection 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

Figure 5.2-4. RTG Loading and Assembly Station

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 identified above is completely reversible.

5.2.2 TEST AND QUALITY ASSURANCE FACILITIES

The Space Division has an imposing array of test facilities for final proofing of spacecraft systems and subsystems. These highly sophisticated facilities represent a substantial corporate investment and are adaptable to the development of many test programs. These facilities are supported by the most modern instrumentation systems available to measure and record test results. These facilities include:

- Long Life RTG Test Laboratory
- Component Test Laboratory
- Thermal Laboratory
- Vibration Systems
- Acceleration Test Facilities
- Shock Test Facilities
- Space Simulation and Environmental Test Facilities
- RTG Storage Facility
- Radiographic Facility
- Mass Spectrometer
- Standards Laboratory

Long-Life RTG Test Laboratory

This laboratory is equipped with four-foot diameter by five-foot long thermal vacuum chambers specially designed for long life testing of RTG's. The initial installation consists of four chambers, one of which is in a shielded enclosure for testing of fueled radioisotope thermoelectric generators, with provisions made for expansion to eight chambers.

The vacuum system, which is capable of maintaining a vacuum of 10^{-9} torr in an empty chamber, consists of a common mechanical roughing pump and individual ion and titanium

sublimation pumps at each chamber. The chamber thermal shrouds are designed to hold all points on the shroud to 100° K or less under a 4 kW load using liquid nitrogen cooling. A special feature of this chamber is a secondary shroud cooling system for use in evaluating special sink temperature conditions. This system is capable of maintaining the shroud at any temperature in the range of -50° F to +175° F with an overall temperature uniformity of +5° F on the entire shroud with a 4 kW input.

The data acquisition system consists of a 1200 channel ATLAM scanner coupled to an IBM 1620 computer. Typical time for a complete cycle from start of scan to printed record is five minutes. This includes the processed results of the 1200 data channels, 350 averages, and 350 maximum differences within each average, 100 voltage and current channels plus the 50 associated wattages. This highly flexible system can be started on any desired channel, stopped on any preselected block of 10 channels, continuously read-out on any selected channel, and read-out both visually on digital voltmeters and on punched cards.

Component Test Laboratory

A Component Test Laboratory occupies 14,000 square feet and is located in the main building of the Valley Forge Space Center. It contains test equipment and facilities for the testing of components under both ambient and environmental conditions. This laboratory is utilized for the development and evaluation testing, as well as the acceptance testing, of components and subassemblies.

The environmental test facilities encompass the complete range of launch and orbit environments including vibration, acceleration, temperature, humidity, vacuum, cold black space, and solar radiation. Test equipments for the measurement of performance of electronic components are located in this laboratory in a section adjacent to the environmental facilities area. These equipments are utilized for functional ambient testing of spacecraft components and can also be re-located adjacent to an environmental test facility for measurement of component performance during certain tests such as long term thermal-vacuum. The following equipments are located in the component Test Laboratory:

4 - 5-foot x 5-foot Vacuum Chambers (Vacuum: 10^{-9} mm Hg.) (Radiant Heat)

- 1 - 8-foot x 10-foot Vacuum Chamber (Vacuum: 10^{-8} mm Hg.)
- 3 - Temperature Chambers (Range: -100° F to $+400^{\circ}$ F)
- 3 - Temperature-Humidity Chambers (Range: -100° F to $+350^{\circ}$ F Humidity: 20% to 95%)
- 2 - Ovens (Range: 35° C to 270° C)
- 1 - Rate of Turn Table (Genisco)
- 1 - MB C-10 Vibration Exciter System (Force: 1200 lb, Freq: 5 to 300 cps)
- 2 - MB C-25 Vibration Exciter Systems (Force: 2500 lb, Freq: 5 to 2000 cps)
- 1 - MB C-125 Vibration Exciter System (Force: 100,000 lb, Freq: 5 to 300 cps)
- 2 - Solar Sub-Module Test Stations
- 1 - Sun Sensor Tester
- 3 - 24-inch x 24-inch Vacuum Chambers (Vacuum: 10^{-6} mm Hg. Temp: -20° F to $+250^{\circ}$ F)
- 1 - 30-inch x 30-inch Vacuum Chamber (Vacuum: 10^{-6} mm Hg. Temp: -20° F to $+250^{\circ}$ F)
- 1 - IR Horizon Scanner Test Chamber (Vacuum: 5×10^{-7} mm Hg. - Cold Black Walls)

Thermal Laboratory

This laboratory occupies approximately 2200 square feet within the Valley Forge Space Center. Here, capability exists to perform heat transfer and thermal investigations ranging from the applied research stage to the hardware stage. Included are such functions as engineering analyses, test preparation, instrumentation and testing on energy transfer, storage, generation or conversion devices; evaluation of thermal control coatings; development of thermal control systems; thermal conductance studies and experimental determination of thermal radiation configuration factors. The equipment in the thermal laboratory includes:

- 3 - 18-diameter by 30-inch high, Bell jar vacuum system
- 1 - 22-inch diameter 30-inch high, Bell jar vacuum system

Thermal Joint Conductance apparatus, suitable for use in vacuum systems with variable contact pressure capability, -100° F to 200° F, joint pressures to 100 psi

Super Insulation Thermal Conductance apparatus capable of measuring 8-inch by 8-inch multi-layer evacuated insulation, -320°F to 200°F

Spray Booth equipment for application of thermal control coatings

Calorimeter emittance measurement devices

Vibration Systems

Static testing is accomplished by the use of specially built loading frames, strongbacks, bending and shear frames, radiant-heating ovens, and shaped heating elements designed and built especially for the test item at hand, which are complemented by the standard load jacks in the 10,000 to 125,000 pound range, pumps, pressure bags, and loading fixtures, and supplemented by the best of the standard and universal testing machines. The versatile, flexible group of vibration systems used by the Space Division are capable of performing sinusoidal, random, or combined sine/random noise testing of space vehicle systems and components in the various vibration modes in which they will operate. Figure 5.2-5 depicts one of the exciters positioned for vibration testing of the Nimbus Weather Satellite.

Figure 5.2-5. Vibration Test Facility (Nimbus Weather Satellite Shown on Test)

Acceleration Test Facilities

Acceleration testing involves duplicating the tremendous g-forces to which space vehicle parts and systems are subjected with force outputs ranging from 1200 to 30,000 g/pound. The accelerations are equipped with the most accurate speed control and measuring devices available. These machines have the power, instrumentation slip rings, and fluid lines for component operation during test. They are also adaptable, through the use of a variety of mounting arrangements using specially designed jigs and fixtures, to test missile components, subsystems and systems. High and low temperature ambients are available on some units for combined environment testing. Equipment is available to automatically program tests involving general g levels and controlled rates of application permitting realistic flight profile tests. Experienced technical personnel are available to carry out the various test programs.

Shock Test Facilities

The shock test equipment includes a free fall drop test facility and controlled-impact drop tested. These facilities are capable of reproducing the complete spectrum of wave shapes with controlled rise, hold, and delay times. These machines are also capable of imparting up to 100 g's shock to the heavy loads and 2,000 g's to a 10-pound load. The engineering staff and skilled technicians are qualified to create realistic test conditions. Also available is such specialized equipment as a HYGEE actuator and a 10,000-pound capacity lab package tested to simulate transportation conditions.

Space Simulation and Environmental Test Facilities

General Electric has installed, and has operated at its Valley Forge Space Center, the largest single complex of space environment simulation facilities in operation in this country. Designed specifically for use in ground testing advanced and production space vehicles, they represent a combination of over \$13 million of General Electric and government timely investments for known or anticipated space programs.

These facilities are reviewed in the following order:

- Space Simulation Laboratory
- Space Environmental Test Facility
- Data Management System for Thermal Testing

Space Simulation Laboratory. The Space Simulation Laboratory provides the capability for ground testing complete spacecraft in a simulated space atmosphere which includes full solar simulation. Simulation Chamber is housed in a separate building which also contains a preparation area, control room, engineering offices, and the vacuum pumping system. The chamber itself, a stainless steel cylinder with spherical ends, is 32 feet in diameter and 54 feet high. The upper dome is provided with a trolley and mechanical jacking system which allows it to be raised from the chamber and moved aside, permitting access for a vehicle up to 20 feet in diameter. The chamber has been designed to simulate the combination of vacuum, cold black space, and solar radiation similar to that which an orbiting space vehicle would experience.

Space Environmental Test Facility. The Space Environmental Test Facility consists of four large simulators for the testing of space systems and subsystems in high vacuum and simulated solar thermal environments. Three of the simulators are 39-foot spherical chambers for the testing of complete spacecraft systems. The fourth simulator is a cylindrical chamber twelve feet in diameter by 26 feet long for the testing of small spacecraft or spacecraft subsystems. The design features of the simulators are given in Table 5.2-1.

The chambers are housed in a building 2400 feet long, 99 feet wide and 80 feet high which has a total 28,000 square feet of floor space. In addition to the chamber test area, the building houses a control room area (6,000 square feet) and an area for auxiliary equipment (6,000 square feet). Two separate enclosed preparation areas are located in the building and each of the three large simulators has a separate control room area. Test vehicles are carried from the preparation areas to the chambers by a 25-ton capacity overhead crane.

Table 5.2-1. Thermal Vacuum Chambers Capabilities

	39 ft. diameter sphere	12" dia. cyl. 26' long
Chamber Material	304 ELC stainless steel 3/8-inch thickness	304 ELC stainless steel 1 - 2-inch thickness
Access	Removable cover - 30' opening 48" x 96" side hatch	Hinged door at end - 12' opening
Vacuum	10^{-5} to 10^{-9} mm Hg.	10^{-6} to 10^{-8} mm Hg.
Interior Walls (Cold Black Space)	-173°C liquid nitrogen -253°C helium	-173°C nitrogen
Wall Thermal Emissivity	0.9	0.95 (extended fin surface)
Pumping	(4) 50,000 liter/second diffusion pumps 4100 square feet of liquid nitrogen surface 1000 square feet of gaseous helium surface	(2) 50,000 liter/second diffusion pumps 900 square feet of extended liquid nitrogen surface

The system chambers have been on-line and operating since the summer of 1962. Liquid nitrogen and diffusion pumping afford vacuums down to 10^{-8} mm/Hg in less than eight hours. Cryogenic pumping utilizing -253° C gaseous helium and heat flux simulation capability are also available.

The 12' x 26' chamber is a combination thermal and altitude chamber with a normal range of -75° to +120° C. When the liquid nitrogen shroud is used, the wall temperature can be dropped to -173° C. In addition, there is a circulating fan within the chamber to ensure temperature uniformity when operating at low simulated altitudes. This entire chamber is mounted on a seismic mass providing vibration isolation from the surrounding area. This allows it to be used for testing when stable mechanical conditions are required while simulating space environmental effects.

5.2.3 COMPUTER FACILITIES

To support the analytical tasks of the Brayton Systems Test Program, General Electric offers one of the most versatile computer processing complexes in the United States. This operation supports the work of all programs as a centralized function, allowing the integration of diverse requirements and the development of a minimum of operational systems and programs to best meet the need of many users. Time share terminals provide rapid access to other computer centers within the General Electric Company. Some of the computing facilities located at General Electric's Space Division are listed in Table 5.2-2.

Table 5.2-2. General Electric Computer Facilities

Facility/Equipment Type	No. Each	Description
<ul style="list-style-type: none"> ● Digital Computing Facilities <ul style="list-style-type: none"> - IBM 7094 Digital Computer - GE 635 Computer - Burroughs E101 Computer - IBM 1620 Computer - IBM 700 Series Peripheral Equipment - IBM 1130 Computer ● Semiautomatic Recording Equipment <ul style="list-style-type: none"> - Oscillogram Readers - IBM Card Puncher - Mann Comparator - Coleman-Powered Comparator - IBM Card-Handling and Tabulating Equipment - Mosely Plotters ● Analog Computing Facility <ul style="list-style-type: none"> - Reeves 400-Series Computer Consoles - Six-channel Recorders - X-Y Plotters - Philbrick Repetitive Operation Computer - Electronic Associates 231-R Computer Console 	<ul style="list-style-type: none"> 2 1 2 1 1 6 1 1 3 2 2 6 1 7 	<ul style="list-style-type: none"> Each with 32,000-word core memory 128,000-word memory Including two 500 line per minute printers, magnetic tape-to-card and card-to-tape converters, four tape units Capable of digitizing 15,000 points per day Directly records output For reading and digitizing film records with repeatabilities of 2 microns For reading and digitizing film records with repeatabilities of 10 microns Plotting rate 50 points per minute Each containing: <ul style="list-style-type: none"> 46 operational amplifiers 4 servo multipliers 5 diode function generators 2 servo resolvers 1 DVM Each containing approximately: <ul style="list-style-type: none"> 100 operational amplifiers 5 diode function generators 5 electronic multipliers 4 servo multipliers 2 servo rate receivers EDVM

5.3 PROGRAM ORGANIZATION

5.3.1 POSITION WITHIN CORPORATE STRUCTURE

The MBFS program will be implemented in the Advanced Energy Programs (AEP) operation of General Electric's Space Systems Department. This Department is part of the Company's 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 5.3-1.

Figure 5.3-1. Position of Space Systems Department in Corporate Structure

5.3.2 ADVANCED ENERGY PROGRAMS OPERATION

As shown in Figure 5.3-2, 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.

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)

Figure 5.3-2. Advanced Energy Programs Organization

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.

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. Pickett will have access to higher General Electric Management through established management channels for any and all required support and resources.

5.3.3 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 5.3-3 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 by GE under Contract NAS 3-18541 is assigned to the Advanced Nuclear Programs function. This provides concentration of all GE Brayton activities to assure an integrated GE effort in support of the prime AIRPHX IBFS Program.

Figure 5.3-3. Key Program Relationships

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.

This assures complete technology exchange and utilization between the IBFS Program 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 and mission operation aspects of the MHW-RTG program applicable to the IBFS program.

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 5.3-3); 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.

5.3.4 GENERAL ELECTRIC ISOTOPE BRAYTON SYSTEM PROGRAM ORGANIZATION

The General Electric organization established to support AIRPHX in the Isotope Brayton program is shown in Figure 5.3.4. 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 performance measurements in the technical, cost and schedule areas, and which assists in the measurement and evaluation of performance versus measurements.

General Electric Space Division functional organizations are established and operating to support an interest in space nuclear power. Established outer planet and probable earth orbital mission requirements are recognized. Economics, competitive with solar power and related spacecraft

Figure 5.3-4. GE Isotope Brayton System Program Organization

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

A particular implementation 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.

5.4 PERSONNEL QUALIFICATIONS

The assigned responsibilities, their current security clearance status, and the approximate percentage of time to be devoted to the Isotope Brayton Program (by quarter) is summarized in Figure 5.4-1 for the key GE personnel previously shown on the GE program organization, Figure 5.3-4.

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 IBSF and GDM design, and the fabrication of GE supplied hardware, GSE, STE and its installation in and 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 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. 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.

			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	100	100	100	100	20	20	20	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 5.4-1. Key Personnel Responsibilities and Participation

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. McCarthy will have primary responsibility for the Heat Rejection Heat Exchanger (HRHX) design, and will support the development efforts directed toward the beryllium radiator when confirmed for the IBFS.

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.

5.5 RESUMES

Key personnel assigned to the GE Isotope Brayton Program are presented below.

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 AAAs, 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 - 3 years

San Jose State University, working toward degree - 1 year

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 NASA designed boiler 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).

SECTION 5B

TELEDYNE ISOTOPES CAPABILITIES AND EXPERIENCE SUMMARY

5.1 Teledyne Isotopes Related Background

Teledyne Isotopes, Energy Systems Division, was originally organized in 1956 as the Nuclear Division of the Martin Company. In 1968, Teledyne acquired the nuclear personnel and nuclear products from the Martin Company. As a result of more than sixteen years experience in the role of development and integrating contractor for the AEC, Teledyne Isotopes personnel have established management and technical capabilities directly suited for developing radioisotope heat sources and related technologies for aerospace application.

The Energy Systems Division of Teledyne Isotopes averages greater than seventeen years experience per key engineering man in the nuclear and aerospace fields, and twelve years per man within the current organization. This group has developed the hardware and safety reports for approval of space and terrestrial radioisotope generators, nuclear reactors, radioisotope chemical processing plants and shipment and handling of special nuclear materials.

System hardware and safety licensing reports and analyses have been generated for the following SNAP systems: 1A, 3A, 9A, 7A through 7F, 11, 13, 17A, 19, and 29.

Contracts such as the Strontium-90 Fuel Development Program, IMP, 250-watt Surveyor, Voyager, Dodge-M, Pioneer Viking and LCHP RTG space programs have yielded additional information and techniques for use in heat source development and nuclear safety analysis. Teledyne Isotopes has supplied SNAP 19 RTG systems for NASA's Pioneer and Viking Lander programs and has most recently prepared the primary safety documentation required for launch approval.

In addition to Teledyne Isotopes' nuclear power system engineering, manufacturing and safety capabilities, the Company provides health physics and decontamination teams (NASA's Plum Brook Test Facility),

radiochemistry analysis, low level counting, mass spectrometry and age determination.

The Company, through its Westwood Laboratories Division, has also contributed its expertise in the fields of nuclear weapons testing (Projects HASP, STARDUST, and TRITON), atmospheric fallout (High Altitude Sampling Program, STARDUST), space science (Apollo, Lunar Exploration, and Apollo Applications), peaceful use of nuclear explosions (Plowshare), geology, geochemistry, hydrology and oceanography.

All of the engineering and scientific talents, analytical techniques and computer programs to successfully support the nuclear aspects of the KIPS Development Program are available within Teledyne Isotopes. Basic disciplines which together comprise Teledyne Isotopes Energy Systems Division capability include:

- Nuclear Engineering
- Aerophysics
- Thermodynamics
- Atmospheric Science
- Physical Sciences
- Materials Engineering
- Mathematics
- Radiation Shielding and Effects
- Health Physics

During the past sixteen years, Teledyne Isotopes has worked with:

1. The United States Air Force, Navy, Army, and Coast Guard, supplying nuclear power products and associated safety analysis reports and licensing.
2. The Atomic Energy Commission as a prime contractor for their Isotopes, Fuels, Space Power, Safety, and Reactor Branches.

3. The Sandia Laboratories, a prime contractor representing the AEC's Aerospace Nuclear Safety interests. Coordinated safety testing between Teledyne Isotopes and Sandia include actual reentry flight tests, impact testing, high altitude drop testing at the Tonopah Test Site, plasma arc reentry simulation, fireball and heating tests (Project Pyro) and continuous computer program and analytical technique comparison liaison.
4. The National Aeronautics and Space Administration's Ames, Goddard, Langley, Huntsville, Lewis, and Houston Centers. Test and analysis programs include force and moment inertia tests in various NASA wind tunnels, heating distributions in shock and plasma arc facilities, magnetic moment testing, reactor fuel element tests, vibration and thermal vacuum environment testing, health physics monitoring and decontamination.
5. The Martin Marietta Aerospace Corporation, McDonnell-Douglas, General Electric, AVCO, Rockwell International AI Division, Jet Propulsion Laboratory, Plum Brook Test Facility, and Los Alamos Scientific Laboratory, NUS, and Johns Hopkins Applied Physics Laboratory in the areas of supplying nuclear power products and nuclear safety services.

Almost all of the Company's nuclear capability has been developed during the course of designing, manufacturing, and supplying the nuclear community with radioisotope generators and nuclear reactors.

Safety Analysis reports and license applications have been generated for all of the following Teledyne Isotopes products, facilities, and experimental test programs.

<u>Designation</u>	<u>Application</u>	<u>User</u>
<u>Aerospace RTG:</u>		
SNAP 1A	Prototype Radioisotope Thermoelectric Generator (RTG) for space	AEC
SNAP 3A	First flight-approved RTG, Navy Transit Satellite	USN/AEC
SNAP 9A	Second flight-approved RTG Navy Transit Satellite	USN
SNAP 11	Prototype RTG for lunar application	AEC
SNAP 13	Prototype thermionic radioisotope generator	AEC
SNAP 17A	Prototype Sr-90 fueled RTG for space	AEC
SNAP 19	Third flight-approved RTG, Nimbus Weather Satellite	NASA
	Pioneer Spacecraft (Jupiter Flyby)	NASA
	* Viking Mars Lander	NASA
SNAP 29	Prototype Po-210 fueled RTG	AEC
LCHP RTG	* Selenide RTG Development Program	AEC
*Current major programs under AEC contract.		
<u>Terrestrial RTG:</u>		
SNAP 7A	Light buoy power	USCG
SNAP 7B	Lighthouse and Oil Platform	USCG, Phillips Petroleum
SNAP 7C	Weather Station, Antarctica	USN
SNAP 7D	Weather buoy	USN
SNAP 7E	Undersea Acoustic Beacon	USN
SNAP 7F	Navigational Aid	Phillips Petroleum

Commercial RTG:

Axel Heiberg	Arctic Weather Station	US/Canadian Weather Bureau
Sentry	Weather Station	US Weather Bureau
SENTINEL 25A	Oceanography	USN
25B	Undersea	ESSO
3	Navy Use	USN
3	Wellhead Control	Sinclair
SENTINEL 25C-1	Oceanographic	USN
25A	Evaluation Testing	USAF
25D	NOMAD Weather Buoy	USN
25E	Oceanographic	USN
8	Weather Station	USN
25C-3	ESSA Experiment	NAVFAC/ESSA
25F	Marine/Terrestrial Use	NAVFAC/NAVAIR
100	Marine/Terrestrial Use	NAVFAC/NAVAIR

SPACE GENERATOR HISTORY

74-311015-1
Page 5-6-B

TERRESTRIAL GENERATOR HISTORY

5.2 Teledyne Isotopes Facilities

Our plant, located in Timonium, Maryland, includes engineering laboratories, manufacturing and quality control facilities, health physics equipment, and fuel storage facilities to perform development, fabrication and testing of isotopic space power systems. Floor space of 54,000 square feet is allocated as follows:

Manufacturing	25,000 sq. ft.
Engineering	8,500 sq. ft.
Laboratories	5,000 sq. ft.
Testing	1,500 sq. ft.
Warehouse	3,000 sq. ft.
Administration	11,000 sq. ft.

(a) Manufacturing Facilities

The Isotopes Manufacturing Machine Shop capability comprises the following disciplines:

- (1) Sheet metal
- (2) Welding: resistance, spot and seam, fusion, air, gas, prog. automatic
- (3) Precision machining
- (4) Heat treating, annealing, brazing with size limitations
- (5) Leak detection, mass spectrometer
- (6) Component assembly

The equipment available for use in the shop is listed below:

- 1 Pratt & Whitney Jig Bore 2A
- 1 Blohm Grinder, 22 x 48, Surface
- 1 Landis Universal Cyl. Grinder 12"
- 1 #6 Cincinnati Vertical Mill, Dial-Type
- 1 Bridgeport Mill
- 1 #3 Cincinnati Horizontal Mill
- 1 #3 Cincinnati Vertical Mill
- 1 Norton Surface Grinder, 12" x 24"
- 1 Cincinnati Cutter, Grinder #2
- 1 Sunnen Hone
- 1 Centerless Grinder #2
- 1 18" Springfield Lathe
- 2 20' Ikegai/Tracer Lathe (Mimak Tracer)
- 1 Monarch 10 EE Precision Lathe
- 1 South Bend Lathe
- 1 Monarch 14" Eng. Lathe
- 1 Warner Swasey Turret Lathe 2A
- 1 DoAll Contourmatic Band Saw 16"
- 1 DoAll Metal Master Band Saw 36"
- 1 200 Ton Wilson Press, 2 Post
- 1 Pacific Hydraulic Shear, 3/8 x 10', mild steel
- 1 Pacific Hydraulic Brake, 200 Ton, 10'
- 1 Clearing Punch Press, 75 Ton
- 1 Niagara Punch Press, 23 Ton
- 1 Sciaky Spotwelder
- 1 Numerically Controlled Vertical Mill
- 1 Programmed Automatic Welder
- 1 Taylor Winfield Seamwelder
- 1 Tube Draw Bench, 10' x 25,000#
- 1 Fenn 3F Swaging Machine
- 2 Welding Dry Boxes, Vacuum or Gas

- 1 Vickers Programmed Welder, 300 amp. DC
- 2 P & H 300A Welders, AC-DC
- 1 Hevi-Duty Heat Treat Furnace, 24" x 24" x 8'
- 1 Homo Heat Treat Draw Furnace
- 1 Vacuum Furnace Brew, 7-1/2" Hex x 11"
- 2 Hydrogen Atmosphere Furnaces Pereny 6" x 10" x 30" long
hot zone, Inconel Muffle 2200°F, "D" Shape
- 1 Harper 3" diameter Hydrogen Atmosphere, 3000°F
- 1 Geco 3 x 4 Hydrogen Atmosphere, 2200°F, "D" Inconel
- 1 Cincinnati Bickford Drill Press
- 2 Allen 2 spindle Drill Press
- 3 Delta Drill Press
- 1 Najet Ultrasensitive Drill Press
- 1 Westinghouse 400-Cycle, 25 KW, Induction Mill
- 1 Fenn 2 High, 4 High Rolling Mill, 2" x 8"
- 1 Levin Jewelers Lathe
- 1 Pratt & Whitney Vertical Shaper, 12" Stroke
- 1 4' x 8' DoAll Granite Surface Table
- 1 Eastman Kodak Comparator
- 1 250 KV x 15 MA Westinghouse X-Ray
- 1 Tube Bender

We are currently engaged in the fabrication of hydrogen/oxygen generators and terrestrial and space thermoelectric generators. We have extensive experience in the machining and welding of a wide variety of refractory and heat resistant type alloys such as Tungsten, Molybdenum, Haynes 25, Hastelloy C, TZM, Moly Rhenium, Tantalum Tungsten and many alloys of similar nature. We have a quality control section well equipped for all types of precision measurements and controls.

SUPPORT MANUFACTURING CAPABILITIES

1. Weldmatic Parallel Gap Welder
Weldmatic Stored Energy Poke Welder
Hughes Stored Energy Bench Model Welder

For welding thermocouples, voltage taps, electronic-type modules and miniature spot welding.

2. Pasadena Hydraulic Platen Press (12' x 12")

To bond laminates, heat seal, etc.

3. Pressure Blaster (small)
Pressure Blaster (large)
S. S. White Micro-Blaster

To sandblast parts prior to coating and/or plating

4. Sel-Rex Jet Plater

Set-up for plating of nickel. Can be used for other types of plating by changing the solution and anodes, if required.

5. Selectron Brush Plating Unit

Used for selective plating of any type where part cannot be immersed entirely in a plating tank.

6. Tanks for Chemical Cleaning

Used for acid or alkaline cleaning where required. Also for solvent cleaning.

7. (2) Vapor Degreasers

For solvent vapor cleaning.

8. Flame Spray Equipment
Mogul R-2 Gun

Wire-type gun for spraying copper, nickel, nickel aluminide, etc.

Mogul TJ2 Rokide Gun

Rod-type gun for spraying aluminum oxide, zirconium oxide and any other rod-type materials.

Thermal-Arc Plasma Spray Gun

Powder-fed gun operating at extremely high temperature for any type powdered metal, oxide, or ceramic.

9. Ball Mill

For mixing any type of material required for emissivity spray coating.

10. Spray Guns

For application of emissivity coatings.

11. Proto-Maka

To produce proto-type printed circuit boards when required.

12. Vacuum Oven

For curing epoxies and RTV compounds in vacuum.

We also have the knowledge of solders and flux for the ordinary soldering job as well as exotic equipment and knowledge for mixing, curing, and deairating of epoxies and RTV compounds. With the aforementioned equipment we have the capability for instrumentation such as the attachment of strain gauges by the Rokide or adhesive method, making and attaching thermocouples and wiring of equipment as required for the end product.

(b) Thermoelectric Laboratory Facilities

The Thermoelectric Lab has the capability of research, development and manufacture of thermoelectric materials, elements and couples. In addition to these capabilities, we also have equipment and experience to do furnace brazing, bonding, heat treating and alloying at various temperatures and atmospheres.

Equipment available:

- 1 Kanthal Furnace (stationary), maximum temperature 1400°C, muffel size 3" I.D. x 24" long
- 1 Kanthal Furnace (rocking) maximum temperature 1400°C, muffel size 3" I.D. x 24" long. Capable of providing rocking action along a horizontal axis of varying angles and speeds at temperature.
- 2 National Vacuum Dry Ovens, maximum temperature 125°C, internal size 7" x 7" x 12"
- 1 Blue M Drying Oven (air), maximum temperature 260°C, internal size 18" x 18" x 18"
- 1 Blue M Drying Oven (air), maximum temperature 260°C, internal size 12" x 12" x 12"
- 2 Hoskin Lab Furnaces, maximum temperature 1900°F
- 1 Fisher-Johns Melt Point Apparatus
- 1 S/S White Airabrasive Unit
- 2 Lindberg Lab Furnaces, maximum temperature 2600°F, internal size 6" x 6" x 12"
- 2 Marshall Furnaces, maximum temperature 2800°F, internal size 18" x 18" x 18"
- 1 Lepel High Frequency Induction Unit, 12.5 K.V.A.
- 1 Lepel High Frequency Induction Unit, 25.5 K.V.A.
- 1 Reid #612 Slicing/Wafering Machine
- 1 Farrel 50 Ton Lab Press

- 1 Humbolt Ro-Tap
- 1 Patterson-Kelly Twin Shell Blender
- 2 Fenn Jaw-Type Crushers
- 1 Controlled Atmosphere Alloy Casting Box
- 1 Controlled Atmosphere Alloy Mixing/Blending/Handling Glove Box
- 2 Mettler Precision Balances, maximum capacity 1 KG, .001 GRM accuracy

The laboratory in which this equipment is located is temperature and humidity controlled.

(c) Computer Facilities

Data processing at Teledyne Isotopes is done via remote job entry (RJE) and also time sharing (T/S). Hardware for RJE mode includes a CØPE 1201 processor with 8K words of memory and peripheral attachments: 300 line/min printer, 300 card/min reader, 20 card/min punch, and a 300 increment/sec 14 inch drum plotter. The on-line card punch, a modified UNIVAC VIP 1710, also doubles as an off-line Key punch machine. Modems are attached for teleprocessing at either 2000 band or 4800 band.

The RJE equipment is used routinely on-line with various host computers: CDC 6400 (Utility Network of America, McLean Virginia), CDC 7600 (Babcock and Wilcox, Lynchburg, Virginia) IBM 360/91 (JHU Applied Physics Laboratory, Columbia, Maryland, IBM 370/165 (Service Bureau Corp., Paramus, New Jersey), and UNIVAC 1108 (Sci-Tek, Inc., Wilmington, Delaware). The RJE equipment is also used off-line for EAM utility functions: card listing and card duplication.

For T/S operation, a 10 character/sec Model 33KSR teletype and 15 character/sec Datel Model 1031 are available. The TTY is used principally for data base management and N/C mill tape preparation, while the upper and lower case Datel is used principally for word processing input: specifications writing and engineering document updating.

Computer programs for engineering analysis are FORTRAN with few exceptions. PL/I is used for several accounting programs. Approximately 100 different engineering and accounting programs are used at least monthly at the various host computers listed above. New programs and modifications are under development continuously and appropriate skills and experience are always available as need arises.

(d) Quality Facilities

The facilities for inspection of material and products at the Energy Systems Division include equipment for dimensional inspection, such as hand and bench measurement tools, electronic gaging equipment and optical comparators. Test tools are available for precision measurement of the thermoelectric properties of elements and couples, such as resistivity, polarity, Seebeck voltage, conductivity, and power checks. Radiograph machines for X-ray examination of parts and materials are available to the Quality Department locally.

(e) Materials Engineering and Test Laboratory Facilities

(1) Thermal Vacuum Chamber

Pressures of the 1×10^{-9} torr range are obtainable in a horizontally mounted, 4 feet long, 3-1/2 foot diameter chamber which is equipped with a black shroud to provide the necessary heating and cooling effects of space. Heating to a maximum of +250°F is accomplished with heated nitrogen gas and cold conditions of space to a temperature of -280°F are achieved with liquid nitrogen. The chamber is equipped with sight, instrumentation, and electrical ports and an internal handling system which will accommodate a 500-pound specimen.

(2) Bell Jar Vacuum

A variety of bell jars ranging up to 36 inches in height and 18 inches in diameter are available with gas, electrical, and fluid penetrations. Pumping stations may be attached to provide low working pressures as well as helium leak detectors (frequently used in seal development programs).

(3) Sound and Vibration Analyzers

A General Radio sound and vibration analyzer with a graphic level recorder is used to analyze microphone and accelerometer inputs. The system is portable and is used to analyze data taken at local dynamic test facilities.

(4) Glove Box Test Chambers

Four chambers averaging 50 cubic feet each have penetrations for fluids, gas, and electrical connections. The atmosphere of each is maintained by systems capable of removing nitrogen, oxygen, and water vapor. Two chambers are evacuable.

5.3 Teledyne Isotopes Program Organization

Figure A is an organization chart of Teledyne Isotopes delineating the company operational and company staff responsibilities. Reporting directly to the office of the President, Dr. J. Laurence Kulp, is Mr. P. J. Vogelberger, Jr., Vice-President and General Manager of the Energy Systems Division. The organizational structure for this division is presented in Figure B.

The Isotopic Brayton Program organization under the direction of the Program Manager, Mr. Robert Buxbaum, who reports to Mr. G. F. Linkous, Power Systems Department Manager, is shown in Figures C and D. The Program Manager's responsibility includes direction of all program aspects and responsibility for all contractual obligations, including cost, schedule, and technical performance. To execute this responsibility, his authority traverses the complete organizational structure. He is supported by a program team representing all division functions, making available the expertise and resources of the entire organization, yet retaining direct control with short communications paths. Mr. Buxbaum brings to the program recognized ability and success demonstrated as Program Manager of SNAP 19 Pioneer and Viking power systems for Jupiter Fly-by and Mars Lander space missions.

Mr. Wayne Brittain, Project Engineer, will integrate program technical activities. He has participated in design and project engineering on space power systems for more than a decade.

Mr. Denton Anderson, Technical Director for Safety and Reliability, will be responsible for the nuclear safety and reliability aspects of the program. He has been a project engineer on all major nuclear safety studies for the past ten years, including SNAP 9A, SNAP 29, SNAP 19-Nimbus, Pioneer and Viking.

REPORTS TO J. HAMILTON, GROUP EXECUTIVE

FIGURE A. TELEDYNE ISOTOPES ORGANIZATION STRUCTURE

REPORTS TO PRESIDENT, J. L. KULP

FIGURE B. TELEDYNE ISOTOPES ENERGY SYSTEMS DIVISION ORGANIZATION STRUCTURE

REPORTS TO VICE PRESIDENT AND GENERAL MANAGER

FIG. C. TELEDYNE ISOTOPES ENERGY SYSTEMS DIVISION
POWER SYSTEM DEPARTMENT ORGANIZATION

REPORTS TO MANAGER, POWER SYSTEMS DEPARTMENT

FIG. D. TELEDYNE ISOTOPES ENERGY SYSTEMS DIVISION
ISOTOPIC BRAYTON POWER SYSTEM ORGANIZATION

Mr. Frank Russo, Technical Director of Systems Engineering, is responsible for Space Power Systems Engineering activities. Mr. Russo brings extensive experience in space power systems design, evaluation, and performance predictions to the Isotopic Brayton Program.

Mr. John McGrew, Manager of Materials Engineering and Test, will be responsible for all materials technology and component testing. His involvement in nuclear hardware materials applications and testing spans the last sixteen years and all Teledyne Isotopes space power programs.

The Isotopic Brayton Program will receive the full commitment of the Energy Systems Division (ESD) and high priority will be accorded the implementation of this program. Due to ESD organization structure and staffing, no conflict is foreseen with other ESD product line requirements nor with requirements of the priority SNAP 19 Viking flight program and Low Cost High Performance Generator program. Viking flight hardware delivery will be completed by April 1, 1975, when the Isotopic Brayton work is scheduled to begin. The intense effort on the Isotopic Brayton during the first three months will not interfere with Viking activities which culminate with launch during August and program completion by September 30, 1975.

5.4 Teledyne Isotopes Personnel Qualifications

Figure E identifies the key technical and management personnel who will be assigned to this program. Included is their security clearance, percent of time devoted to Phase I of the program and their planned contribution to the program.

5.5 Teledyne Isotopes Resumes

Resumes of the key management and technical personnel are included in the following pages.

SUMMARY OF KEY TELEDYNE ISOTOPES PERSONNEL

<u>Individual</u>	<u>Security Clearance</u>	<u>% of Time*</u>	<u>Area of Responsibility</u>
R.S. Buxbaum	AEC "Q"	50	Program Management
W.M. Brittain	AEC "Q"	20	Integration of Program Technical Activities
D.C. Anderson	AEC "Q"	10	Nuclear Safety and Reliability
F.A. Russo	AEC "Q"	20	Systems Engineering
J. McGrew	AEC "Q"	20	Materials and Testing

*During Phase I

FIGURE E

RESUME: Robert S. Buxbaum

POSITION: Program Manager - SNAP 19 Viking Program

EDUCATION: Johns Hopkins University
BSE, Mechanical Engineering, 1951
MSE, Applied Mechanics, 1953

EXPERIENCE:

(1973 to Present) Responsibility for all Technical and Programmatic aspects associated with the fabrication, testing, delivery and pre-flight coordination of Radioisotope Thermoelectric Generators to be used on the NASA Mars Lander Mission.

(1970 to 1973) Deputy Program Manager - SNAP 19 Pioneer
Responsibility for systems engineering and analysis for development, fabrication, testing, delivery, pre-flight liaison and post flight data evaluation for Pioneer Flights F and G. Also included Technical Responsibility for all associated Ground Support Equipment and software.

(1968-1970) TECHNICAL DIRECTOR, SNAP 19 Program - Teledyne Isotopes, Inc. Project management, SNAP 19 nuclear fueled space power system for Nimbus B-2 spacecraft and associated software.

(1966-1968) PROJECT SYSTEMS ENGINEER, Space Nuclear Power Systems. Responsibility for systems engineering and analysis on developmental, nuclear fueled space power system for Nimbus B spacecraft, its ground handling equipment, and engineering configuration control. Duties also included resolution of manufacturing and quality assurance problems, planning, customer liaison, and contract compliance activities.

(1965-1966) SENIOR ENGINEERING SPECIALIST, Space Exploration Group. Mars Voyager Spacecraft and Lander study program. Structural dynamics analysis and design criteria. Developed computer programs for Martian impact lander structural design optimization studies.

(1964-1965) SENIOR ENGINEERING SPECIALIST, Martin Nuclear Division. Supervised all structural design criteria and dynamics analysis for radioisotopic fueled power sources (SNAP 11, 17A, 19, 21A) and fuel capsule impact investigations.

(1960-1964)

STAFF ENGINEER, Aerospace Division. Dynamics analysis on Orbital Space Station, gravity gradient systems, space rendezvous and docking, Tital III, Apollo Lunar landing. Formulated loads prediction, developed analog and digital computer programs and data processing techniques.

1953-1960

BENDIX CORPORATION, Bendix Radio Division, Towson, Maryland

(1958-1960)

PRINCIPAL ENGINEER, Advanced Developments Department. Supervised all mechanical engineering and design. Directed electromechanical design and fabrication of speech security equipment, antennas, and various undersea, ground based, and airborne equipment.

(1953-1958)

PROJECT ENGINEER, Missile Engineering Department. Directed all phases of mechanical engineering and design on Talos missile control subsystem. Original concepts on guidance and control packaging for severe environments. Prototype fabrication and production.

NAME: BRITTAIN, Wayne Michael

POSITION: Project Engineer

EDUCATION: B.S., Nuclear Engineering, North Carolina State University, 1961
M.S., Drexel Institute of Technology, 1966

EXPERIENCE: Teledyne Isotopes, Nuclear Systems Division
(formerly Martin Marietta Corporation, Nuclear Division) 1961 to Present

1966 to Present

Responsible for advanced concept studies for SNAP 19 RTG system. Studies concentrated on improved thermoelectrics and extended mission requirements up to five years. Project Engineer on a detailed study to select an optimum radio-isotope thermoelectric generator design for the Viking Mars Surface Laboratory system. Primary considerations were integration with laboratory system and anticipated nuclear safety requirements. Was responsible for Isotopes' input to the Atomic Industrial Forum spacecraft designer's handbook for nuclear space power systems. Also, was responsible engineer for thermoelectric design and analysis on RTG studies performed for the NAVSAT and Pioneer missions.

1964 to 1966

Was Design Engineer and Project Engineer on SNAP 11. As Design Engineer developed a thermal control system to maintain generator design temperatures and performed system evaluation. As Project Engineer was concerned with final qualification testing, delivery and on-site test group of RTG's delivered to government facilities; wrote SNAP 11 final report. A final design generator was successfully fueled and completed a simulated lunar mission at ORNL. Also, wrote specifications for thermoelectric elements and thermoelectric performance specifications for SNAP 11 and SNAP 19.

1961 to 1964

Assignments were in reactor core mechanical design and associated handling and fueling equipment. Was responsible mechanical design engineer for advanced PM reactor cores, including generating detailed core fabrication drawings and writing fuel element, control rod and other component product specifications. Was responsible for checking out PM core fueling equipment and did analysis and design of PM fueled core shipping container.

PUBLICATIONS:

"SNAP 11 Radioisotope Thermoelectric Generator." Intersociety Energy Conversion Engineering Conference, August 1968.

"Radioisotope Thermoelectric Generator Design for Voyager Surface Lander." Intersociety Energy Conversion Engineering Conference, August 1968.

Brittain, W.M. and Christenbury, S.T. "SNAP 19 Viking RTG Flight Configuration and Integration Testing". Proceedings of 1974 Intersociety Energy Conversion Engineering Conference.

NAME: Anderson, Denton C.

POSITION: Technical Director, Nuclear Safety and Reliability Unit

EDUCATION: B.A. Physics, Columbia College, 1951
Physics, Rutgers University (part-time graduate work), 1952-1954
Physics, Carnegie Institute of Technology (part-time graduate work), 1957-1961.

EXPERIENCE: 1961 to Present - Teledyne Isotopes, Energy Systems Division

Technical Director, Nuclear Safety and Reliability Unit. Responsibilities include: shield design of reactor and radioisotopic energy sources, development of transport theoretic methods and their application to engineering shield design and safety analysis and design of radioisotopic systems for aerospace and terrestrial applications and reactor systems. Have developed reliability analysis techniques and their applications to nuclear generator programs.

Also served as Supervisor of the Nuclear Safety and Radiation Analysis Unit, responsible for safety and shielding responsibilities.

Prior to this, was supervisor of the Radiation Analysis Unit.

1957 to 1961 - Bettis Atomic Power Laboratory

Was a Senior Scientist in Reactor Development and Analysis. Functions included development of transport theoretic approximations for application to thermal neutron flux distributions in primary shields, and fast neutron and gamma fluxes from cylindrical source and shield configurations. Responsibilities also included development of more rigorous solutions of neutron equation with emphasis on the angular distribution.

1951 to 1955 - Johns-Manville Research Center

Worked in Acoustics Section as a Physicist. Functions included calculation and measurement of acoustical properties of discrete and continuous sound absorbing materials.

AFFILIATIONS:

American Nuclear Society
Health Physics Society

PUBLICATIONS:

"On the Temperature Dependence of the Thermal Flux Kernel." Transactions of the American Nuclear Society, Vol. 2, No. 2, November 1959.

Anderson, D.C. and Shure, K., "Thermal Flux Distributions in Metal-Hydrogenous Shield." Nuclear Science and Engineering, Vol. 8, No. 3, pp 260-269, 1960.

"Solution of the Transport Equation by the Method of Polynomial Expansion." Part II, Transactions of the American Nuclear Society, Vol. 3, December 1960.

"On the Temperature Dependence of the Thermal Neutron Flux Kernel." Nuclear Science and Engineering, Vol. 7, No. 5, pp 468-471, 1960.

"Comparison of Measured and Calculated Thermal Neutron Distributions in High Temperature Water Shielding." Transactions of the American Nuclear Society, Vol. 4, No. 1, June 1961.

Anderson, D.C. and Ruwe, D.M., "A Probabilistic Treatment for Evaluating Aerospace Nuclear Safety." Transactions of the American Nuclear Society, Vol. 9, No. 1, June 1966.

Anderson, D.C., Ruwe, D.M. and Spamer, A.M., "Evaluation of Internal Dose Probabilities by a Monte Carlo Technique." Transactions of the American Nuclear Society, Vol. 10, No. 1.

Anderson, D.C., Ruwe, D.M., "Safety Requirements for Isotope Space Power Systems." Transactions of the American Nuclear Society, Vol. 12, No. 2, December 1969 (Invited Paper)

NAME: Russo, Frank A.

POSITION: Technical Director, Systems Engineering

EDUCATION: M.S., Management Science, The Johns Hopkins University, 1968
M.S., Nuclear Engineering, Massachusetts Institute of Technology, 1958, AEC Fellowship
B.S., Engineering Science, New York University College of Engineering, 1957, Magna Cum Laude Honors Graduate, Second in Engineering

EXPERIENCE: 1961 to Present - Teledyne Isotopes, Energy Systems Division

Technical Director, Systems Engineering. Responsible for Space Power Systems Engineering activities. Includes existing programs as well as advanced project development for LCHP generator.

Project Engineer. Responsible for technical direction of the program for supplying Radio-isotope Thermoelectric Generators for the Pioneer-Jupiter spacecraft. Includes liaison with manufacturing and quality control activities as well as governmental agencies (NASA and AEC) and component suppliers.

Technical Supervisor. Was responsible for thermal, thermoelectric and aerothermal analyses of space nuclear power systems. Directed twelve engineers in the development and evaluation aspects of new system designs. Also led the formulation of improved calculational techniques.

Project Engineer. Was responsible for engineering of small nuclear reactor powerplants. Activities included planning, organizing and directing developmental design efforts of all system aspects. Specific efforts were directed toward use of a unique coolant (P_4S_3) and control mechanism (varied hydrogen content of fuel form.)

Group Engineer. Was responsible for leadership of the nuclear analysis group. Directed nuclear design and analysis of the MH-1A Low Enrichment Floating Nuclear Powerplant and the Tubular Core Development program. Position included supervisory and direct technical responsibilities.

1958 to 1961 - Westinghouse Electric Corporation,
Bettis Atomic Laboratory,
Pittsburg, Pennsylvania

Reactor Physicist. Responsible for advanced concept development and monitoring of performance of pressurized water nuclear reactors. Designed and analyzed tests for evaluating fuel assemblies in test reactors. Also devised refueling procedures to facilitate operations for minimum plant shutdown and safety.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

GENERAL

QUALITY PROGRAM PLAN

QC-048, Rev. 4

October 1, 1974

Prepared by:

J. E. Scott
Administrative Assistant
Quality Control

Approved by:

B. A. Kulb, Manager
Quality Control

REPORT NO QC-048, Rev. 4

TOTAL PAGES 27

This document is the property of The Garrett Corporation. It is furnished for evaluation purposes only and may not be duplicated, used, or disclosed in whole or in part for any other purpose without the prior written permission of The Garrett Corporation.

ATTACHMENTS:

REV	BY	APPROVED	DATE	PAGES AND/OR PARAGRAPHS AFFECTED
NC	JES	BAK	3-15-72	Original issue
1	JES	BAK	4-24-72	Paragraph 8.4, first sentence: "---provided such acceptance cannot be made by witnessing AiResearch's acceptance test and inspection". changed to "---- whenever the customer representative elects not to make such acceptance by witnessing AiResearch's acceptance test and inspection".
2	JES	BAK	3-18-74	Update Corporate Policies.
3	JES	BAK	7-1-74	Paragraphs revised: 9.1, 9.2.1, 9.2.2, 9.3, 9.5, Appendix revised Pages 1 and 2 and 9 thru 12.
4	JES	BAK	10-1-74	Revised Appendix, Page 2.

TABLE OF CONTENTS

	<u>Page</u>
1.0 GENERAL	1
2.0 ORGANIZATION	2
3.0 REVIEW OF CONTRACT REQUIREMENTS, INITIAL QUALITY PLANNING, AND WRITTEN PROCEDURES	5
4.0 WORK INSTRUCTIONS	7
5.0 RECORDS	7
6.0 QUALITY TREND ANALYSIS	8
7.0 DRAWINGS, DOCUMENTATION, AND CHANGES	8
8.0 MEASUREMENT AND TEST EQUIPMENT	9
9.0 CONTROL OF PURCHASES	11
10.0 IN-PROCESS QUALITY ASSURANCE & INSPECTION	12
11.0 COMPLETED ITEM INSPECTION & TESTING	13
12.0 HANDLING, STORAGE, AND SHIPPING	13
13.0 NONCONFORMING MATERIAL, MATERIAL REVIEW, AND CORRECTIVE ACTION	13
14.0 STATISTICAL SAMPLING	14
15.0 INDICATION OF INSPECTION STATUS; CONTROL OF INSPECTION STAMPS	14
16.0 CUSTOMER-FURNISHED PROPERTY	15
17.0 QUALITY AUDITS	15

APPENDIX

Page

ORGANIZATION CHART - PHOENIX DIVISION	1
ORGANIZATION CHART - QUALITY CONTROL	2
PRODUCT FLOW CHART - QUALITY CONTROL/INSPECTION TASKS	3
RAW MATERIALS - FLOW CHART OF INSPECTION STATIONS	4
CASTINGS & FORGINGS - FLOW CHART OF INSPECTION STATIONS	5
PURCHASED PARTS - FLOW CHART OF INSPECTION STATIONS	6
SPECIAL PROCESSES - FLOW CHART OF INSPECTION STATIONS	7
ASSEMBLY & TEST - FLOW CHART OF INSPECTION STATIONS	8
CORPORATE POLICY, PRODUCTION 4-1	9
CORPORATE POLICY, PRODUCTION 4-2	10
CORPORATE POLICY, PRODUCTION 4-3	11
CROSS REFERENCE MATRIX	12

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
GENERAL
QUALITY PROGRAM PLAN

1.0 GENERAL

- 1.1 This Quality Program Plan is based on Garrett Corporation policies, Production 4-1, 4-2, and 4-3 (see Appendix, pages 9 through 11), and describes the standard practices utilized to assure the manufacture of conforming products at this facility. These products are complex, functional end items for which AiResearch has design control and/or engineering responsibility.
- 1.2 In order that AiResearch customers may benefit from the lower unit-cost attendant with the procurement and production of larger lots of detail parts, it is management's policy to promote the use of every AiResearch-designed detail part in as many different end-item models as possible. This practice permits the pooling of orders from various customers for various models involving a given detail part in order to make up economic production lot sizes of that detail part. Thus, a production lot traveling through the detail-part manufacturing process probably contains parts destined for more than one customer.
 - 1.2.1 This commingling of detail parts for various customers, added to the fact that the Department of Defense is AiResearch's largest single customer, has made it necessary to establish and operate to a Single Standard Quality Control system (SSQC) as prescribed by DCAS Regulation DCRL No. 8200.10A, which states, "The primary purpose of Single Standard Quality Control is to cover the contractor's 'system' for control of the materials, components, subassemblies, etc., during the 'commingling' period when these supplies are commonly handled and not identifiable to a specific contract or order". Also, "Under this system, the contractor agrees to purchase and to manufacture government and commercial material to government requirements".
 - 1.2.2 The "government requirements" to which AiResearch operates during the commingling phase are MIL-Q-9858A for general program requirements, and DCAS-approved AiResearch procedures for Material Review. This system also meets Federal Aviation

1.0 GENERAL

1.2.2 (continued)

Administration requirements, and complies with the intent of the quality control specifications of all major commercial aerospace companies.

1.2.3 The "Cross-Reference Matrix", on page 12 of the appendix, correlates the paragraphs of MIL-Q-9858A with the sections of this Quality Program Plan .

1.3 This facility is under the continual surveillance of resident quality assurance representatives of DCAS and several major aerospace companies.

1.4 It is possible, at considerable extra cost, to comply with unusual customer requirements which deviate from AiResearch's SSQC system in the purchase and/or manufacture of AiResearch-designed detail parts. However, in order to give the customer the benefit of the lower attendant costs, AiResearch Quality Control management has elected, in the pricing and proposal phase, to estimate the cost of the quality control task on the basis of being able to use AiResearch-designed detail part numbers which are common to existing or future AiResearch end items, and the attendant utilization of our SSQC system.

2. ORGANIZATION

2.1 The AiResearch-Phoenix Division and Quality Control Department Organizational Charts are shown on pages 1 and 2 of the Appendix.

2.2 The Corporate Director of Quality Control reports to the Executive Vice-President and is responsible for the formulation and establishment of Corporate Quality Control policies aimed at improving current practices and achieving corporate consistency. Further, the Director assists the divisions in the areas of interdepartmental relations, organization, manpower selection and training, and budgets and operating expenses.

2.0 ORGANIZATION (cont.)

- 2.3 The Manager of Quality Control in each Division reports to the Division Manager. The Quality Control organization is equivalent in stature to other major departments of the Division. Within each operating Division, the Manager of Quality Control has full responsibility and jurisdiction in all matters involving standards of workmanship, quality of materials, conformance to Engineering standards, and the relationship with customer Quality Control personnel. Commensurate with these responsibilities and authority, the Manager of Quality Control implements the necessary Quality Control policies by means of control procedures designed to assure that the Division produces and delivers quality products. The Quality Control organization, operating in accordance with the established system, is responsible for assuring that the quality standards established for any given product are met and maintained. This responsibility is discharged by the physical measurement of product and by continuous assessment and correction of all other activities contributing to product quality.
- 2.4 The Quality Control organization includes two major functions: (1) Quality Control Engineering, and (2) Inspection. An explanation of these functions is noted in the following paragraphs. (Also, see Appendix, page 3.)

2.4.1 Quality Control Engineering

Quality Control Engineering is concerned with the implementation of control procedures including the collection, analysis, and reporting of data related to product quality. Additional functions include analytical studies and evaluation of processes, implementation of corrective action on problems affecting product quality, interdepartmental efficiency studies, and other functions as related to quality assurance.

A Quality Control Engineer or Representative is assigned the responsibility for the achievement of customer satisfaction on all end products. The assigned Quality Control Engineer is able to effect all necessary controls throughout the chain of Inspection, even though the

2.0 ORGANIZATION

2.4.1 (continued)

duties performed by Inspection groups are of a continuing and relatively routine nature and not normally identifiable with a given end product. Further, because of the diversity of products flowing through the various Inspection groups and the complex schedule problems which are attendant to a diversified product line, any major problem which arises in connection with the items of a given program receives immediate action by the Quality Control Engineer.

Quality Control Engineering is responsible for the items listed below.

- (1) Quality Control Engineering representation for all project groups.
- (2) Coordination between Quality Control and Reliability Engineering.

Inspection is responsible for the following items. (See Appendix, pages 4 through 8)

- (1) Receiving and Shipping Inspection.
- (2) Precision parts and Stores Inspection.
- (3) AiResearch Source Inspection.
- (4) Assembly and Overhaul Inspection.

2.5 Quality Control Participation in Reliability

One of the primary responsibilities of the Quality Control organization is the assurance of inherently designed reliability during the manufacturing cycle and the feedback of information to the Engineering design groups to facilitate assessment and improvement of inherent reliability. In fulfilling this

2.0 ORGANIZATION

2.5 (continued)

responsibility, Quality Control Engineers are active participants in contract and procurement specification reviews, drawing reviews, inspection planning, and in coordination meetings with cognizant Engineering personnel for interpretation of data collected, summarized, and reported by the integrated reliability data center within Quality Control.

Primary responsibility for implementing inherent reliability in AiResearch products has been placed in the existing Engineering line organizations (projects) where, basically, the responsibility for designing reliable hardware must reside. The Technical Reliability Staff has been placed in the Engineering Services Department, which participates in all proposal activity, so that this staff will have broad scope to affect design in its inception. Continuing liaison is maintained between the Project Reliability Engineer and Project Quality Control Engineer. This assures full coordination in meeting the product reliability requirements of any particular program.

The AiResearch Reliability Program involves the collection of product experience by Quality Control from all areas of product fabrication, assembly, inspection, and test, as well as all phases of operation, repair, and overhaul as defined in Quality Control Procedures. Reports to the data center cover operations in both in-house and suppliers' facilities, starting with the design and development phase and continuing through production and ultimate end use of the product.

3.0 REVIEW OF CONTRACT REQUIREMENTS, INITIAL QUALITY PLANNING, AND WRITTEN PROCEDURES

3.1 Quality Control Engineering reviews customer's quality control specification during the pricing and proposal phase. Unusual customer requirements which deviate from

3.0 REVIEW OF CONTRACT REQUIREMENTS, INITIAL QUALITY PLANNING, AND WRITTEN PROCEDURES

3.1 (continued)

the standard AiResearch system are identified, listed, and filed for reference in the event the contract award is received.

- 3.2 Upon receipt of the Sales Order which is initiated upon receipt of a contract, Quality Control Engineering reviews the Sales Order to determine the contractual requirements regarding quality control. These requirements are compared to those identified during the proposal stage, per Paragraph 3.1, and any differences are reconciled through Contract Administration.
- 3.3 All contractual quality requirements which deviate from AiResearch's standard system are listed in a Quality Control General Instruction (Q.C.G.I.) which is on controlled distribution to all Quality Control sections.
- 3.4 The following written procedures define the quality plan for a given program, with precedence in the order listed:
- (1) Quality Control General Instructions (Q.C.G.I.)
 - (2) Divisional Operational Procedures (O.P.'s)
 - (3) Divisional Operating Instructions (O.I.'s)
 - (4) Quality Control Procedures (Q.C.P.'s)
(which make up the Quality Control Manual)
 - (5) Written procedures of other departments.
- 3.4.1 Item 1 defines the unusual quality requirements for a given program. Items 2 through 5 define the standard AiResearch Quality Program, and are summarized briefly in Quality Program Plans such as this one.

3.0 REVIEW OF CONTRACT REQUIREMENTS, INITIAL QUALITY PLANNING, AND WRITTEN PROCEDURES (continued)

3.4.2 All written procedures are reviewed periodically and revised as required to maintain economic and technical control of quality.

3.5 Drawings are reviewed by Quality Control Engineering upon initial release and at each subsequent revision to determine the need for special controls, inspection fixtures and inspection tooling.

4.0 WORK INSTRUCTIONS

4.1 Inspection for conformance to stated requirements is assured by having suitable inspection call-outs on shop travelers, such as the Production Work Order (P.W.O.), Manufacturing Operations and Tooling (M.O.T.), or Assembly Inspection Traveler (A.I.T.).

4.2 When required, due to the complexity or criticality of the part, inspection instructions are issued showing the characteristics to be inspected, and the level of inspection and tools or gages to be used. Forms used for this purpose are the Detailed Inspection Plan (D.I.P.) for supplier produced parts, and the Detailed Inspection Instructions (D.I.I.) and Assembly Inspection Instruction (A.I.I.) for in-process inspection.

5.0 RECORDS

5.1 Complete and reliable records are kept of all acceptance inspections and tests. These records are retained for the varying lengths of time, depending on the nature of the record, as called out in the Record Retention and Disposal Schedule, which is reviewed and approved by the Corporate Legal Office. This schedule is incorporated into the Quality Control Manual as a Quality Control Procedure.

5.2 Records are made available for on-site review by designated customer representatives and/or copies are furnished if required by contract.

6.0 QUALITY TREND ANALYSIS

- 6.1 Source inspection records, in-house inspection and test records, and field reports are analyzed to indicate quality trends in all reporting areas.
- 6.2 Scrap and rework costs are summarized according to department responsibility and cause.

7.0 DRAWINGS, DOCUMENTATION, AND CHANGES

- 7.1 Written procedures assure the adequacy, completeness, and the currentness of drawings and the control of changes in design.
- 7.2 AiResearch utilizes a configuration management system which satisfies the requirements defined in MIL-STD-490, MIL-STD-480 and is adapted to the AiResearch drawing system which satisfies the requirements of MIL-STD-1000 and MIL-STD-100A. A specification and end item part number is used to identify each contracted end item.
- 7.3 The SCN (MIL-STD-490) procedure is used to obtain prior approval for a change to the specification. Revised specifications are identified by a change letter following the specification number. One or more SCN's may be incorporated in a single revision. A log sheet is maintained in the specification document to briefly define changes.
- 7.4 End item part numbers for Military procured equipment consist of a basic drawing number followed by a double dash number, i.e. 123456-1-1. All end items having the same basic drawing number and first dash number are physically and functionally interchangeable in the next higher application (usage). A change in the second dash number indicates internal part(s) differences which affect support and maintainability programs. Dash numbers are assigned in sequence starting with 1 and each subsequent addition includes all prior changes. End item part numbers for commercial equipment are identified in the same manner as Military equipment except that in lieu of advancing the second dash number to identify differences, a series number is used.

7.0 DRAWING, DOCUMENTATION, AND CHANGES (Continued)

- 7.5 Configuration control is implemented with the establishment of a baseline configuration. A complete Engineering parts list is prepared and identified as P/L 1. Change Requests are used to introduce subsequent changes. Each change prior to release is reviewed and classified as either a Class I or Class II change. ECP's are prepared for all Class I changes and submitted to the customer for approval prior to release. ECP's include sufficient data relative to the change and its effect on support and maintenance programs to permit complete evaluation.
- 7.6 Class II changes are submitted prior to release to the local DCAS representative or customer for concurrence with the change classification. Change letters and a change letter log are used on each drawing to maintain a change record history.
- 7.7 The Nameplate Data Configuration Index (NDC) is used to provide nameplate marking requirements for the equipment and record the production serial number effectivity for each Class I change. The NDC provides a permanent record for each configuration and an index for each document authorizing the change.
- 7.8 Each Class I change subsequent to the established baseline is coordinated with the Manufacturing Departments and a production serial number effectivity established. Serial numbers are recorded on the NDC and identified accordingly on the end item nameplate.
- 7.9 The AiResearch Quality Control system provides for verification of, and compliance with, requirements for incorporation of changes at the specified effectivity. The production effectivity and configuration specified on the NDC must agree with the end unit nameplate when the end unit is submitted to final inspection.

8.0 MEASUREMENT AND TEST EQUIPMENT

- 8.1 AiResearch provides and maintains gages and other measurement and test devices necessary to assure that products

8.0 MEASUREMENT AND TEST EQUIPMENT

8.1 (continued)

conform to technical requirements. These devices are calibrated against certified measurement standards which have known valid relationships to national standards at established periods to assure continued accuracy. The calibration of measurement and test equipment is in conformity with Military Specification MIL-C-45662.

- 8.2 Dimensional measurement devices and gages used for product acceptance are under the jurisdiction of the Linear Metrology Section of Quality Control and are controlled in accordance with Linear Metrology Procedures (LMP). Non-dimensional measurement devices used for product acceptance, such as pressure gages, manometers, voltmeters, scales, flow devices, etc., are under the jurisdiction of the Physical Metrology Section of Quality Control, and are controlled by Metrology Procedures (M.P.)
- 8.3 Production jigs, fixtures, tool masters, or other such devices used for measurement devices for product acceptance are checked or proved initially and thereafter at use by verifying the conformity of the first part by other means.
- 8.4 When required by contract, AiResearch's gages, measurement and test devices will be made available to designated customer representatives charged with the responsibility of performing product acceptance at source, whenever the customer representative elects not to make such acceptance by witnessing AiResearch's acceptance test and inspection. If conditions warrant, AiResearch personnel will be made available for operation of such devices and for verification of their accuracy and condition.
- 8.5 AiResearch procedures assure timely identification of any precision measurement requirement which exceeds the known state of the art.

9.0 CONTROL OF PURCHASES

- 9.1 Suppliers who have the required quality control and inspection capabilities, financial resources, and production capabilities are listed on the computerized Approved Procurement Source List, which is updated monthly. The initial determination of the supplier's capabilities is accomplished by on-site survey of the supplier's facilities or by evaluation of documentation of the supplier's capabilities.
- 9.2 A monthly and quarterly computerized Quality Performance Summary shows the quality level of the parts submitted by each supplier during that month or quarter.
 - 9.2.1 Any supplier who shows three consecutive periods of unsatisfactory quality is classified as "Restricted for Quality" and marked for removal from the Approved Procurement Source List.
 - 9.2.2 Only suppliers listed on the Approved Procurement Source List are eligible for purchase orders from AiResearch.
- 9.3 Upon release of requisitions for a part which will be procured from suppliers, Quality Control Engineering conducts a review to identify and specify the Quality Control Supplemental Purchase Order Conditions which must be included in any AiResearch Purchase Order for that part. Quality Control Engineering also furnishes the Purchasing Department a list of Supplemental Purchase Order Conditions which apply to specific categories of suppliers, such as suppliers covered by source inspection or source surveillance, etc.
- 9.4 Conformance of purchased raw material to the applicable specifications is evidenced by one of the following:
 - (1) A report of physical and chemical tests conducted by AiResearch Chemical and Metallurgical Laboratory,
or
 - (2) Physical and chemical reports supplied by the raw material supplier or other competent laboratory,
or

9.0 CONTROL OF PURCHASES

9.4 (continued)

- (3) A certificate from the raw material supplier to the effect that the raw material has been tested and conforms to applicable specifications, and that the test reports are on file and available for review upon request.

- 9.5 All parts received from suppliers, other than certified suppliers, are subjected to AiResearch inspection acceptance, either at source or in-house. In addition to checking dimensional and functional characteristics of the parts, the inspector verifies compliance with other requirements of the AiResearch Purchase Order, including the Quality Control Supplemental Purchase Order Conditions.

10.0 IN-PROCESS QUALITY ASSURANCE & INSPECTION

- 10.1 In-process control of manufacturing is accomplished by appropriate combinations of set-up approval, first piece inspection, patrol inspection, and inspection at inspection stations.
- 10.2 Quality control of special manufacturing processes, such as heat treat, plating, etc., is accomplished by physical examination, measurement, or tests of the product processed, or by monitoring the processes themselves (furnace temperatures, solution concentrations, immersion times, etc.). Government specifications or AiResearch specifications equal to or better than Government specifications, are used to control special processes. Sub-tier special process suppliers are qualified to these same specifications, and are listed in the computerized AiResearch Directory of Controlled Processes and Sources, which is updated monthly.
- 10.3 Special inspection processes, such as radiography, fluorescent penetrant, magnetic particle, etc., are controlled by special work instructions and by testing and certifying the operators at specified intervals.

11.0 COMPLETED ITEM INSPECTION AND TESTING

11.1 Every end unit is subjected to final inspection and acceptance (functional) test upon completion, in accordance with Test Instructions (T.I.'s) derived from Acceptance Test Procedures (ATP's). Customer approval of the ATP is obtained when required by contract. Acceptance tests are conducted by the Engineering Laboratory under Quality Control surveillance.

12.0 HANDLING, STORAGE, AND SHIPPING

12.1 Inspection personnel monitor the condition and cleanliness of crates, boxes, and containers used in material handling, to minimize damage and contamination.

12.2 Every controlled stores area is audited at three month intervals for deterioration, corrosion, expiration of shelf-life limits, maintenance of critical environments in special packages, etc.

12.3 Inspection personnel maintain surveillance over the shipping function to assure that the products shipped are as called out on the Sales Order, and that they are accompanied by the required shipping and technical documents.

13.0 NONCONFORMING MATERIAL, MATERIAL REVIEW, AND CORRECTIVE ACTION

13.1 The control of discrepant and nonconforming material is accomplished in accordance with DCAS approved AiResearch procedures which comply with USAF Bulletin NR 515, D.O.D. Handbook H57, and MIL-STD-480. End units which depart from end unit contractual requirements are dispositioned by the Material Review Board (MRB) if the nonconformance is minor (Type II), or submitted to the customer for disposition if it is major (Type I). Detail parts or sub-assemblies which depart from AiResearch's self-imposed requirements, but which would not cause the end unit incorporating that part to violate end unit contractual requirements, are dispositioned by the Discrepancy Review Committee (DRC). The DRC is composed of two AiResearch MRB members, and uses the same process of decision making,

13.0 NONCONFORMING MATERIAL, MATERIAL REVIEW, AND CORRECTIVE ACTION

13.1 (continued)

record keeping, dispositioning, corrective action, and controls on discrepant parts as is used by MRB on nonconforming parts.

- 13.2 Every rejection document is encoded to indicate the department responsible and the corrective action taken to preclude recurrences. Quality Control personnel evaluate the adequacy of the corrective action statement. Rejection documents are entered into a computer program which scans all reports entered during the quarter to pick up entries which may be recurrences of previous entries. These suspected recurrences are listed on a quarterly computer printout for investigation by Quality Control Engineering to determine what additional corrective action may be required.

14.0 STATISTICAL SAMPLING

- 14.1 Receiving inspection of procured parts and in-process and final inspection of detail parts manufactured in-house are accomplished by statistical sampling in accordance with AirResearch Report QC-051, "Sampling Plans." Parts from lots accepted by this method are subsequently subjected to the proofs of assembly into, and functional test as part of, end units. (Final inspection and acceptance tests are performed on 100% of the end units, and not on a sampling basis.)

15.0 INDICATION OF INSPECTION STATUS: CONTROL OF INSPECTION STAMPS

- 15.1 The in-process status of detail parts and subassemblies is indicated by placing an acceptance stamp impression on the "traveler" adjacent to those operations and processes which have been completed.
- 15.2 Final acceptance of detail parts or subassemblies is indicated by placing an acceptance stamp impression on the item, or, if this is impracticable because of size or shape of the item, the acceptance stamp is applied to an attached tag. Final acceptance of end units is

15.0 INDICATION OF INSPECTION STATUS; CONTROL OF INSPECTION STAMPS

15.2 (continued)

indicated by applying the acceptance stamp to the nameplate on the unit.

15.3 Acceptance stamps are uniquely numbered to identify the inspector who accepted the item. Issuance and recall of stamps is controlled by a Stamp Custodian who maintains a log of stamps issued, returned, or placed in inactive bond because of loss, improper use, etc.

15.4 Parts made by a supplier carry an acceptance stamp containing a unique five-digit code assigned to the supplier by AiResearch.

16.0 CUSTOMER-FURNISHED PROPERTY

16.1 Materials, tools, equipment, etc., furnished to AiResearch by the customer are inspected upon receipt to verify that the items received are the items desired. They are also inspected for damage that may have occurred in-transit. The customer is notified and disposition instructions are requested in the event of deficiency, malfunction, loss, or breakage of the items furnished.

17.0 QUALITY AUDITS

17.1 A continuous quality audit program is conducted consisting of procedures audits to determine the adequacy of procedures related to product quality, and the degree of compliance to those procedures; and product audits consisting of re-inspection and/or re-test of selected parts, assemblies, and end units previously accepted. Any deficiencies discovered by these audits generate a request for corrective action to the responsible department.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

GENERAL
QUALITY PROGRAM PLAN

APPENDIX

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

ORGANIZATION CHART

PHOENIX DIVISION

*FUNCTIONS RESPONSIBLE TO CORPORATE OFFICES

**REPORTS TO ASSISTANT DIRECTOR, PROPULSION ENGINES
AS CHIEF, FLIGHT ENGINEERING AND AIRWORTHINESS

EFFECTIVE 5-8-74

**AIRESEARCH MANUFACTURING COMPANY
OF ARIZONA**

ORGANIZATION CHART

QUALITY CONTROL

APPROVED B.A. Kulb
B.A. Kulb
Quality Control Manager

APPROVED W.G. Orr
W.G. Orr
Vice President and Manager

PRODUCT FLOW CHART

QUALITY CONTROL / INSPECTION TASKS

PRODUCT FLOW
CUSTOMER INQUIRY

QUALITY CONTROL
FUNCTIONS

RAW MATERIALS -
FLOW CHART OF INSPECTION STATIONS

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

CASTINGS AND FORGINGS - FLOW CHART OF INSPECTION STATIONS

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

PURCHASED PARTS - FLOW CHART OF INSPECTION STATIONS

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

SPECIAL PROCESSES - FLOW CHART OF INSPECTION STATIONS

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PAGE NO. 10-2004

ASSEMBLY AND TEST - FLOW CHART OF INSPECTION STATIONS

CORPORATE POLICY

PRODUCTION 4-1

**PRODUCT QUALITY
RELIABILITY & SAFETY**

DIVISIONAL RESPONSIBILITY:

All divisional and subsidiary departments are responsible for assuring optimum quality, reliability and safety of our products to the full extent and degree of their functional contribution.

DEFINITIONS:

1. Quality: Conformance to Design and Specifications.
2. Reliability: The probability of an item performing a given function for a definite period of time under specified conditions.
3. Safety: The precautions taken during design, manufacture, inspection, test and use cycle, to preclude injury to personnel or property resulting from a discrepancy or malfunction in a product, while it is operating in its contractual environment.

END

THE GARRETT CORPORATION

EFFECTIVE: 11/1/73

**QUALITY CONTROL
SYSTEM & FUNCTIONS**

CORPORATE POLICY

QUALITY CONTROL SYSTEM:

Divisional and subsidiary Quality Control Departments shall establish and maintain an effective quality control system which adequately satisfies all company requirements. The medium of communication and implementation shall be by a well-organized, clear and current quality control manual.

QUALITY CONTROL FUNCTIONS:

Manufacturing divisions or subsidiaries shall establish and maintain a Quality Control Department that has a functional and administrative relationship to management equal to that of other departments in order to provide adequate organizational freedom for accomplishment of quality objectives. The principal responsibilities of the Quality Control Department shall include the following:

1. Adequately appraising all procured material and products, in-plant fabrication, assembly and test of all products to be delivered to our customer or to other divisions or subsidiaries.
2. Maintaining a quality assurance function whose primary efforts, working with other departments, are directed toward defect prevention.
3. Auditing all divisional or subsidiary operations and procedures that affect product quality and quality costs.
4. Coordinating with other departments and/or divisions in the formulation and implementation of plans/programs to assure compliance with customer and company requirements.
5. Recognizing that a quality function, performed by a Garrett Corporation Division or Subsidiary, shall be considered as an extension of the Quality departments of the other divisions and subsidiaries.
6. Establishing and maintaining a quality assurance operation capable of proper disposition of non-conforming materials, achieving necessary corrective action and assuring optimum product quality.
7. Establishing and maintaining the means of collecting, analyzing and disseminating data pertinent to all phases of product manufacture for the measurement of product quality.
8. Establishing and maintaining a metrology function capable of achieving and maintaining the level of measurement technology required for each division's or subsidiary's products.

END

The direction and plans for achieving the Quality Control Requirements in each division or subsidiary shall conform with the guide-lines noted in the subsequent paragraphs.

SALES PROPOSAL INVOLVEMENT:

Provide to Sales and Contract Administration, upon request, information pertinent to

1. Evaluation as to acceptability of proposal's quality requirements.
2. Quality Control and Inspection manpower requirements.
3. The Quality facilities and equipment required by the proposal.

NEW CONTRACTS INVOLVEMENT:

1. Verify that all concerned departments are aware of special quality requirements that are not accomplished by our standard procedures.
2. Inform Inspection of these special requirements.

PROCUREMENT QUALITY CONTROL:

1. Provide controls and actions for source selection.
2. Inform supplier of all pertinent quality requirements.
3. Provide sufficient controls or adequate inspection and test of all procured product upon receipt, at source, or a combination of both.
4. Maintain records of all suppliers' quality performance.
5. Consider the availability of supplier survey and/or source inspection by another division or subsidiary of the corporation.

MANUFACTURING QUALITY CONTROL:

1. Provide the means for adequate and economical inspection of manufactured items, including assembly and test.
2. Record results of inspection of manufactured items and maintain records of inspection of manufacturing's quality performance.

CUSTOMER INVOLVEMENT:

Work with other departments to effect corrective actions on valid customer complaints that relate to part/product quality.

END

CROSS-REFERENCE MATRIX
MIL-Q-9858A and QUALITY PROGRAM PLAN QC-048

MIL-Q-9858A	QC-048
Para. 3.1	2.0 & Indentations
3.2	3.0 "
3.3	4.0, 17.0 "
3.4	5.0 "
3.5	13.2
3.6	6.0 & Indentations
4.1	7.0 "
4.2	8.0 "
4.3	8.3
4.4	8.4
4.5	8.5
5.1	9.0 & Indentations
5.2	9.0 "
6.1	9.4
6.2	10.0 & Indentations
6.3	11.0 "
6.4	12.0 "
6.5	13.0 "
6.6	14.0 "
6.7	15.0 "
7.1	3.0 "
7.2	16.0 "