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RELIABILITY PROGRAM PLAN
FOR THE
ISOTOPE BRAYTON GROUND
DEMONSTRATION SYSTEM
(PHASE I)

75-311360

September 30, 1975

MASTER

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

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RELIABILITY PROGRAM PLAN
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(PHASE I)

1.0 GENERAL

1.1 Introduction

The AiResearch Reliability Program Plan, presented herein, is applicable to the Ground Demonstration System (GDS) and the preliminary Brayton Isotope Power System Flight System (BIPS FS) design. This plan, in response to the Energy Research and Development Administration (ERDA) Contract E(04-3)-1123, is submitted to assure ERDA that AiResearch Manufacturing Company has the organization, the technical capability, and the intent to conduct a comprehensive reliability and quality assurance program.

1.2 Scope and Purpose

This plan describes the reliability and quality assurance organizational relationships, the methods to be used, the tasks to be completed, and the documentation to be published. The total program is intended to provide the necessary reliability and quality assurance associated with the design, fabrication, and testing of the GDS. It is consistent with the general objectives of the ERDA Quality Assurance (QA) program requirements document "SNS-1" dated April 1972 and reliability program requirements document "SNS-2" dated 17 June 1974 but has been specifically modified for the GDS with the intent of establishing background data for the subsequent Phase II effort.

1.3 Application and Implementation

This plan applies to all AiResearch activities supporting the Brayton Isotope Power System (BIPS) development program. The plan will be implemented when approved by ERDA and will continue through the

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life of the program. Reliability program requirements shall be imposed on the subcontractors by AiResearch procurement contracts and specifications. The plan will be updated periodically as the need arises.

1.4 Applicable Documents

ERDA

SNS-1, Quality Assurance Program Requirements for Space Nuclear Systems, AEC-SNS, April, 1972

SNS-2, Reliability Engineering Program Requirements Publication, AEC-SNS, 17 June 1974

Military

MIL-HDBK-217A, Reliability Stress and Failure Rate Data for Electronic Equipment, 1 December 1965

MIL-HDBK-217B, Reliability Prediction of Electronic Equipment, 20 September 1974

Garrett Corporation - Corporate Policy

Production 1-3 Reliability Data Reporting System

Production 1-4 Reliability Requirements for Designs

Production 4-1 Product Quality, Reliability, and Safety

Production 4-2 Quality Control System and Functions

AiResearch, Phoenix

Operational Procedure 4.96 Reliability Program

Operational Procedure 4.99 Trouble Reporting and Correction System (TRAC)

QC-048 General Quality Program Plan, Revision 4, 1 October 1974

2.0 RELIABILITY ORGANIZATION, AUTHORITY, AND RESPONSIBILITIES

2.1 Organization

The AiResearch, Phoenix (AIRPHX) reliability organization, with its access to the Division Manager for ultimate authority, provides the talent and direction for performing those specific tasks necessary to provide assurance that the required quantitative reliability is achieved in service. This organization is depicted in Figure 2-1. Responsibility for overall guidance, policy, and coordination of the reliability program for the AIRPHX Division is assigned to the Director of Engineering and administered by the Supervisor of Reliability Engineering. Since reliability is inherent in design, prime responsibility for establishing reliability design objectives is assigned to the cognizant project design team. This includes the continuous monitoring and control of those activities necessary to ensure and demonstrate full achievement of the reliability objectives. For the BIPS, this responsibility has been assigned to the GDS/FS Program Manager and will be administered by his Reliability and Quality Assurance Manager. Organizational relationships are depicted in Figure 2-2.

2.2 Authority

Reliability policies, in the form of Corporate Directives and Division Operational Procedures, constitute the fundamental charter of the established Reliability Engineering Department and outline the disciplines to be followed in the orderly pursuit of reliability matters through the total organization.

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Note: Dashed lines indicate Technical Authority.

AIRPHX RELIABILITY ORGANIZATION
FIGURE 2-1

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AIRPHX RELIABILITY PROGRAM ORGANIZATION

FIGURE 2-2

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The documents applicable to AIRPHX reliability program follow and will be made available to the ERDA:

(a) Garrett Corporation Procedures

1-3 Reliability Data Reporting System

1-4 Reliability Requirements for Designs

4-1 Product Quality, Reliability, and Safety

(b) AiResearch, Phoenix, Operating Procedures

4.96 Reliability Program

4.99 Trouble Reporting and Correction System (TRAC)

2.3 AIRPHX Reliability Functions

2.3.1 Reliability Engineering Supervisor

Responsibility for the overall guidance and coordination required for establishing and monitoring the reliability program for the AIRPHX Division is assigned to Engineering and administered through the Assistant Director of Engineering, Engineering Sciences, and his designated Supervisor of Reliability Engineering. The Supervisor of Reliability Engineering is the single focal point for reliability activities and is specifically charged with performing the following tasks:

- (a) Initiate and submit for Management approval (through established channels) recommendations on Division reliability organization, operating procedures, and department responsibilities as required for conformance to Corporate and Divisional reliability policies.
- (b) Coordinate Divisional reliability training and indoctrination programs with Personnel Training Department, as required.

- (c) Monitor the Division reliability program on a continuing basis and act as a consultant to the Engineering Projects and to other departments for the resolution of contractual, administrative, and technical reliability problems.
- (d) Direct the actions of the Reliability Coordinators (Engineers) who are assigned within the Engineering Projects and other Departments.

2.3.2 Reliability Coordinators

Each major department (e.g., Sales, Quality Control, Manufacturing) and the Engineering Project within the division has at least one Reliability Coordinator (Engineer) whose functions include:

- (a) Acting in liaison capacity between the department and the Reliability Engineering Supervisor in matters involving reliability policies, procedures, and organization.
- (b) As directed by the department head, serving as focal point for the resolution of interdepartmental administrative or technical problems related to reliability requirements.

2.4 Reliability Manager

As noted on the Reliability Organization Chart (Figure 2-2), a Reliability Manager has been designated to discharge reliability program responsibilities for the BIPS. This designee will also coordinate the quality assurance activities relative to the BIPS. He will report directly to the BIPS GDS/FS Project Director. The Supervisor of Reliability Engineering will assist as necessary to assure that the Reliability Manager has direct unimpeded access to Division Management for the resolution of any problem that is not readily solvable through normal channels.

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2.5 Department Responsibilities

The basic Reliability Organization for the AiResearch, Phoenix Division is an in-line function within the established Project system. Primary responsibilities for product reliability in design, manufacturing, quality control, and other associated areas are vested in the operating departments as shown below:

- (a) Engineering - The BIPS Program Manager is responsible for:
 - (1) Inherent reliability of design, and when required, attainment of specified quantitative levels
 - (2) Establishment of test parameters (development qualification, production acceptance, reliability demonstration) commensurate with the need to obtain data for predicting, controlling, and demonstrating reliability
 - (3) Preparation of formal reliability documentation required for submittal to customer; e.g., Reliability Program Plans, Status Reports, and Failure Mode and Effects Analyses
 - (4) The economical coordination of Human Engineering, Safety Engineering, Maintainability, and similar efforts to avoid discipline conflicts and duplication of effort
- (b) Reliability Engineering (Within Engineering Sciences) - Reliability Engineering is responsible for:
 - (1) Reliability analyses required for the prediction and evaluation of product reliability, including the establishment of component reliability, effect of variability, confidence level, statistical design of experiments, and quantitative determinations

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- (2) Reliability analyses (for Change Control) required to assist in Change Board determinations
 - (3) Technical assistance to Engineering Projects and other departments on matters relating to reliability
- (c) Quality Control - Quality Control is responsible for the following functions:
- (1) Control of quality in accordance with MIL-Q-9858 (regular practice) to assure the manufacture, test, and delivery of products at specified reliability levels
 - (2) Maintaining a Reliability Data Center that complies with the failure reporting system requirements of MIL-STD-785 (this applies specifically to the closed-loop Trouble Reporting and Correction System - TRAC)
 - (3) Circulating copies of the Trouble reports to the department affected
 - (4) Taking corrective action when a failure involves product quality. Establish, in coordination with the Engineering Project, the scheduling and criteria for corrective action
 - (5) Establishing criteria for classifying or reclassifying a vendor as an approved source
 - (6) Preparing or completing a general Reliability Survey form to be used for vendor surveys

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- (d) Purchasing - Purchasing is responsible for maintaining a supplier selection program based upon review of suppliers' reliability programs, quality-control systems, facilities, and past performance to assure that suppliers are capable of meeting reliability requirements in accordance with applicable Government and AiResearch specifications.
- (e) Field Service - Field Service is responsible for the following:
 - (1) Collecting, recording, and analyzing field operational experience
 - (2) Training field maintenance personnel
 - (3) Coordinating with Engineering, Quality Control, and other departments to assure timely solution to field problems
- (f) Other Departments - Although other departments are involved in performance of the reliability function, the related primary responsibilities fall entirely within the scope of established departmental responsibilities and are not separately defined herein.

2.6 Supplier and Subcontractor Reliability Programs

AiResearch Purchasing Department is charged with maintaining a supplier selection program based upon review of suppliers' reliability programs, quality control systems, facilities, and past performance to assure that suppliers are capable of meeting the reliability requirements in accordance with applicable Government and AiResearch specifications. The Purchasing Department has a reliability coordinator as a part of the established AiResearch reliability functional team. Vendor-

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generated trouble reports are transmitted through the Purchasing Department, as are AiResearch-initiated requests concerning vendor reliability efforts.

A comprehensive system exists for the survey, evaluation, and selection of suppliers to ensure maximum reliability*. Prospective suppliers are evaluated on their capability to supply equipment meeting the required standards in accordance with technical requirements. Specific areas of supplier activity monitored by reliability include supplier reliability organization structure, receiving inspection, shop control (with emphasis on the control of parts in process), trouble reporting and corrective action, and reliability testing when required. Physical surveys are not always mandatory in supplier selection. When AiResearch has a history of procurement from a particular supplier who has continuously proven his reliability and quality capabilities, an approval for a purchased item may be given without a new physical survey. Such an approval, however, will be substantiated by documented evidence of previous survey. It is the responsibility of the project reliability engineer to ensure that all applicable reliability requirements are in turn imposed on lower-tier vendors to AiResearch. Suppliers of commercial or off-the-shelf items are not subjected to a physical survey as a general rule; however, adequate inspections and tests are performed on such items to assure AiResearch that the items meet all applicable requirements.

2.7 Reliability Indoctrination and Training

A reliability awareness program was inaugurated at AIRPHX several years ago utilizing lectures, pamphlets, posters, and films. This program has proven effective in making each person more aware of the impact his efforts have on reliability and has been credited with bringing about an increase in achieved reliability.

*AiResearch documents PSC-5980 entitled, "Reliability Program Requirements for AiResearch Vendors." and GT-8314-R entitled, "Reliability Survey of AiResearch Vendors."

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The qualifications required of personnel for reliability assignments include additional training (company-sponsored) in reliability, probability theory, and statistical analysis. All engineers assigned to reliability tasks have had extensive hardware experience (design, development, or testing) in one or more specialized product areas.

2.8 Interface Relationships

The reliability liaison and working channels for the BIPS are depicted in Figure 2-3. Direct communication is authorized and indeed encouraged between the BIPS Project Reliability and Quality Assurance Manager and all agencies, subcontractors, and elements having a responsibility for contributing to the overall reliability effort. Daily contact will be maintained with engineers assigned to the BIPS projects. Communications will be established and maintained with subcontractors and vendors through visits and exchange of correspondence and reports. The Supervisor of Reliability Engineering will monitor the adequacy of the reliability program and its implementation and will provide an independent audit of its effectiveness.

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RELIABILITY LIAISON AND WORKING CHANNELS

FIGURE 2-3

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3.0 DESIGN RELIABILITY ELEMENTS

3.1 Design Specification

The AIRPHX prepared and maintained Configuration Control Document (CCD) for the Mini Brayton - Ground Demonstration System (MB-GDS) will address the functional, environmental, physical, reliability, and performance requirements of the GDS and the FS. The CCD will be periodically reviewed by the Reliability Manager to assure that it is compatible with all reliability requirements.

3.2 Reliability Design

Various accepted techniques will be used by the GDS/FS design team to eliminate or minimize critical failure modes. Stress derating and redundancy are techniques routinely used by the design engineers and will, in this program, be especially applicable to the refinement of the existing baseline design of the electrical control system. Stress/strength analyses, materials analyses, tolerance studies, and design tradeoff studies are techniques which have already been used in the design of the GFE (Mini-BRU, Recuperator, and Heat Source Assembly) and will continue to be applied during the design of the GDS and FS. The Reliability Manager, as a working member of the GDS/FS team, will be able to assure that the appropriate techniques are being used to design reliability into the hardware and software. He will monitor the activities of the design engineers, participate in all design reviews, provide such assistance as design check lists, and initial all drawing changes.

3.3 Expected Environments

A Manufacturer to Use Sequence (MUS) is a flow diagram which identifies the logistical and operational environments to be encountered from the time the item is accepted until the item is functioning in its

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intended role. Preparation of an MUS will definitely be a requirement for the FS and may also be required for the GDS. In any event an Environments Table which defines the magnitudes of all expected environmental inputs to the FS will be prepared to guide the design effort. This Environments Table will become a part of the CCD.

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4.0 RELIABILITY ENGINEERING PROGRAM ELEMENTS

4.1 Reliability Goal

A reliability and confidence level goal or requirement considered achievable will be established by the Division of Space Nuclear Systems (SNS) of ERDA. Factors such as use environment and duty cycle which affect the goal shall be defined.

4.2 Demonstrated Reliability

SNS establishes a minimum acceptable level of reliability for programs extending beyond development. While it would be desirable to be able to demonstrate the attained reliability of the system by means of a long endurance test, it is not economically feasible to do so. Therefore, the endurance test must be viewed as but one of many data sources which combine to make an assessment possible. An analytical assessment utilizing all available data (test program results, materials, design, and stress/strength analyses, and historical experience with similar components and materials) will be used to provide reasonable assurance that the minimum acceptable level of reliability has been met or exceeded.

4.3 Failure Mode, Effects and Criticality Analysis (FMECA)

A Failure Mode, Effects and Criticality Analysis will be performed on each major subsystem. The worksheet shown in Figure 4-1 will be used in compiling the data. Hazard categories as defined in MIL-STD-882 will be used in the FMECA.

In order to conform to the requirements of the ERDA Reliability Specification, SNS-2, the FMECA worksheet will contain three columns not routinely used in such analyses. These columns, headed A, B, and C, will be used to calculate a relative measure of failure mode and

SYSTEM _____
SUBSYSTEM _____

COMPLETED BY _____
DATE _____

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS

*A MODE LIKELIHOOD (1 TO 100) – *B EFFECTS IMPACT (1 TO 100) – *C CRITICALITY (A x B)

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effects criticality in the following manner: (a) The failure mode will be ranked on a relative scale of likelihood from 1 to 100 (with 100 being the most likely) and this number will be placed in column "A", (b) The effect of the failure will be ranked on a scale of 1 to 100 (with 100 being the most severe) and this number will be placed in column "B", (c) Numbers in columns A and B will be multiplied together to produce a criticality ranking, and this number will be placed in column C. Failure modes having a high ranking shall be given special emphasis for elimination. Those that cannot be eliminated shall be highlighted and appropriate testing and analysis shall be performed to verify an acceptably low probability of occurrence.

A preliminary FMECA will be performed on the preliminary IBFS very early in Phase I. It will be completed six months after receipt of order (ARO) and will of necessity be a very preliminary analysis. An FMECA of the GDS will receive concurrent attention with the objective being to complete a preliminary FMECA 12 months ARO in order to have it available for the Preliminary Design Review. The final FMECA for the GDS will be completed 18 months ARO.

Each FMECA will be published in report format to include summary sheets highlighting failure modes having a high relative criticality ranking. In addition, consolidated lists of critical components and processes will be generated as a direct output of the FMECA. These check lists will be utilized not only as guidance for the project engineers responsible for GDS and FS design but also to alert quality assurance personnel to the critical components and processes and their critical parameters. Thus, the reliability program analyses relative to the system hardware will serve to influence the quality assurance activities which follow.

4.4 Logic Diagrams

System logic block diagram(s) will be developed to accurately depict the logical association between various modes of failure that individually or in combination can cause a failure. The system logic block diagram will generally follow the functional logic of the system and must be capable of describing synergistic and dependent modes of failure as well as multiple modes of failure from the same component or components. Logical symbols such as AND, OR, NOR gates, etc., shall be used as required. Unique and uncommon symbols shall be clearly defined.

4.5 Probability Equations

System failure (or success) equations will be developed to describe the association between the failure modes and their impact on the system. The probability equation is a mathematical representation of the system logic, is compatible with the system logic diagram, and is used to allocate probabilities of failure modes and assess system reliabilities. All assumptions conditioning the probability equations and assessments shall be stated.

4.6 Allocations

The probability equation will be used to perform a study early in the design phase to allocate failure probabilities to components based on the requirements of Paragraphs 4.1 or 4.2.

4.7 Assessment

The reliability equation will be used to assess system reliability by combining all available information to ascertain the adequacy of the system and data and to provide direction for the test program. Periodic assessments shall be made throughout the contract

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and the results compared with the reliability goals. All available test data will be used, however, heavy reliance must be placed on engineering judgments in estimating the long term endurance capabilities of the equipment.

4.8 Computer Aid to Reliability Assessment and Improvement

AIRPHX has recently subscribed to a computer program and service "PREDICTOR" which provides a valuable tool in calculating and improving design reliability. This program is especially adaptable to electronic circuits such as those used in the electrical control system for the GDS and the IBFS.

The reliability parameters of electronic components have been well documented and compiled into such volumes as MIL-HDBK-217A, MIL-HDBK-217B, and RADC notebook. These documents contain tables and methods which allow the calculation of electronic and electrical component reliability for parameter variations such as voltage stress, current stress, semiconductor junction temperatures, ambient variations, and environment modes.

The computer program used by AIRPHX has stored therein all of the MIL-HDBK-217A, MIL-HDBK-217B, and RADC information, thus enabling a determination of component reliabilities for a large number of components. Changes in environment (e.g., missile launch versus satellite orbital and ambient temperatures) are easily varied and their effect determined. The program has the capability of analyzing redundant circuitry so that reliability can be enhanced in an optimum manner. A parts lists can be generated from the reliability input data giving part number, vendor, price, and quantity. Maintainability studies are an option in the computer program and allow estimation of such factors as down times and repair times, should ground or maintained missions be contemplated.

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Failure modes and effects analysis capability is being incorporated into the program and should provide a means of synergistically evaluating the impact on the mission of various failure modes.

4.9 Program Reviews

Periodic reliability program reviews will be held in conjunction with the preliminary and final design reviews of the GDS. The purpose of these reviews is to inform SNS of progress, problems, recommendations, and significant accomplishments in the area of reliability.

4.10 Maintainability and Human Factors

The BIPS will be required to operate free of maintenance during space operation. However, maintainability will be an important consideration for certain ground operations. For example, the system must be capable of being fueled in minimum time in order to reduce personnel exposure to nuclear radiation. Potential human-induced errors must be identified and eliminated in order to (a) prevent incorrect assembly of components (b) preclude inadvertent shut down or start up or improper operation of the GDS during tests, and (c) to facilitate check out of the FS prior to launch. For these and other reasons, maintainability and human factors will be treated as integral parts of the BIPS reliability program. As a part of the design effort, a study will be made of the requirements for test, checkout, component replacement, assembly, disassembly, and monitoring of the GDS and FS. Based upon this study, access and other design features will be provided to enhance system maintainability. Similarly, a concerted and systematic effort will be undertaken to minimize the potential for human-error. This effort will cover not only the design of the BIPS but will also apply to operational and instructional material and training associated with its handling, storage, transportation, checkout, and use. Maintainability and human factors will be among the subjects covered at each system design review.

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4.11 Progress Reports

Progress reports shall be provided to SNS on the schedule required by the contract. These reports will address those areas of the reliability program required by Paragraph 3.2.4.1 of SNS-2.

5.0 TEST PROGRAM

5.1 GDS Testing

AIRPHX will prepare a test plan for performance and endurance testing of the GDS. This plan will be prepared as a part of Task 3 and will be updated and revised to accommodate program changes as well as contributions from other task activities. After ERDA approval is obtained, the final test plan will be implemented in Task 6 (Test and Evaluation). The Reliability Manager will be an active participant in the preparation of the test plan and in the analysis of the results.

5.2 Data Sources

Test data will be obtained from the results of developmental tests performed on components and MB-GDS subsystems. All available data from the development programs resulting in the Government Furnished Equipment (GFE) will be utilized. GFE will include the Mini-BRU, Recuperator, and Heat Source Assembly (HSA). For example, the many tests run on the bearings, turbine, and compressor of the Mini-BRU during design and development will provide data required to support or to reasonably contradict the defined failure modes and their estimated probability assessments.

5.3 Reliability Demonstrations

The limitations of the GDS performance tests and the relatively short term endurance test (to demonstrate long mission life capability with statistical confidence) are generally recognized. Therefore, many supplemental tests are planned to aid in validating the long mission life being designed into the BIPS. Tests thus far identified are described in the initial draft of the BIPS Phase I Integrated Program Plan (IPP) dated 28 August 1975. (This IPP has been prepared and will be kept current by AIRPHX at the direction of ERDA. The IPP is

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intended to formally document coordinated government and contractor effort on the BIPS program. A primary goal of the IPP is to develop confidence in the end product.) The IPP currently identifies numerous tests designed to provide confidence that:

- (a) Designs are sound and delivered equipment meets established acceptance criteria
- (b) Materials selected and fabrication techniques employed will result in meeting design objectives
- (c) The BIPS will satisfy the requirements of reliable operation over extended periods of unattended operation in space

Wherever possible, accelerated testing techniques will be utilized to demonstrate component longevity. The IPP already provides for a number of accelerated cyclic fatigue and materials aging tests (both "in program" and "recommended"). More will be added as the need is identified. While accelerated test techniques are easily adapted to cyclic failure phenomena (e.g., low cycle fatigue), accelerated aging of materials has its limitations. For example, data from which long term creep predictions are made has, to a great extent, been developed by techniques which permit the use of accelerating the test by increasing the temperature by a small amount to simulate a large increase in time. Metallurgists feel that this approach, although considered to be conservative in nature, can be misleading because of the fact that accelerated tests performed at elevated temperatures can result in fundamental changes in the failure mechanisms. Therefore, long term tests (30,000 to 50,000 hours) at design operating temperatures will be required for certain materials in order to confirm or modify existing data.

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5.4 Additional Tests

Additional tests required to confirm the validity of the design approach and the credibility of the reliability predictions will be identified as the program progresses and will be made a part of the IPP.

5.5 Failures and Corrective Action

A system will be established to record and analyze all failures occurring during design, manufacturing, assembly, and test. The system will be implemented after completion of the Preliminary Design Review of the GDS. AIRPHX has an established, functioning closed-loop corrective action system called TRAC (for Trouble Reporting and Correction System) which will be proposed to be utilized during Phase II of the IBS program. Whether TRAC will be utilized for the GDS or a more streamlined procedure adopted awaits review of the definitive contractual requirements.

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6.0 RELIABILITY PROGRAM MILESTONES

Reliability program milestones for the Phase I BIPS program are shown in Figure 6-1.

RELIABILITY PROGRAM SCHEDULE -PHASE I ACTIVITIES

FIGURE 6-1