SELENIDE ISOTOPE GENERATOR

for the

GALILEO MISSION

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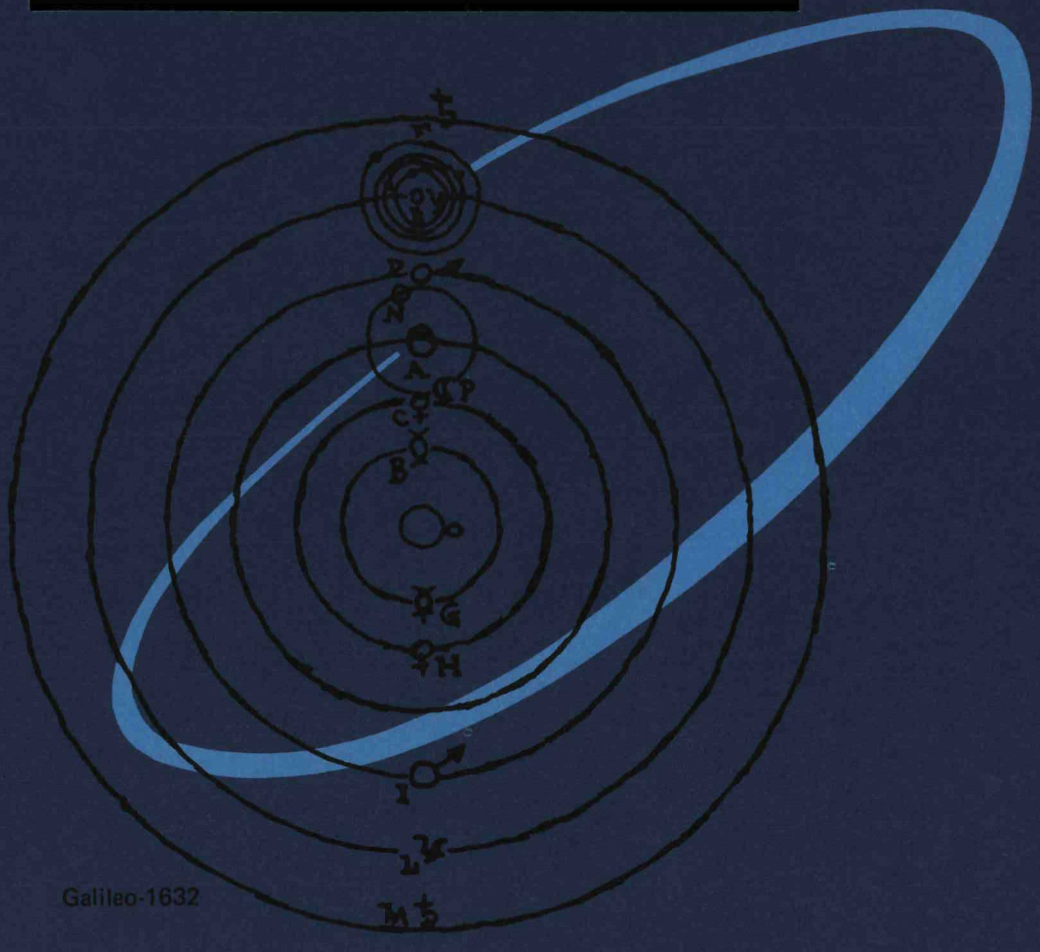
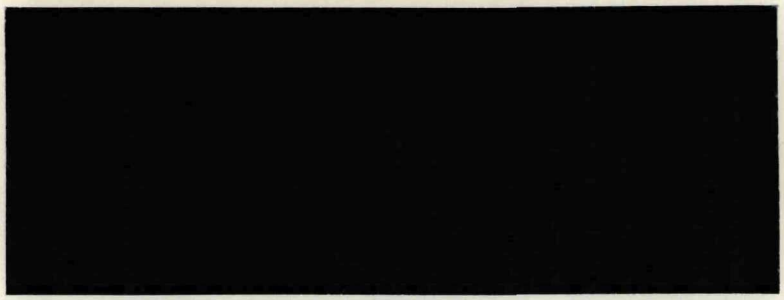


Galileo-1632

TELEDYNE ENERGY SYSTEMS

DISCLAIMER

Pictured on the cover is Galileo's drawing of the solar system, which includes the four satellites of Jupiter he discovered in the 1600's. A Renaissance professor, inventor and astronomer, Galileo perfected the telescope with which he made his Jupiter discoveries. The 1982 NASA mission to Jupiter is named in his honor. Like Galileo and his telescope, the NASA mission to the far reaches of outer space will be contributing to Mankind's never ending quest for knowledge.



SELENIDE ISOTOPE GENERATOR

for the

GALILEO MISSION

RELIABILITY PROGRAM PLAN

TES-2865-06

October 1978

Appd by ASTAP on Nov 3, '78 (Browns) for SAIV

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Prepared for the U.S. Department of Energy
under Contract ET-78-C-01-2865

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REVISIONS

Revision Number	Page	Date	Description

The margins of the Revised Pages are marked by a vertical bar and the revision (Rev. X) to indicate where changes (additions, modifications, corrections, deletions) from the previous issue were made.

FOREWORD

This report constitutes the Reliability Program Plan (RPP) for the Selenide Isotope Generator (SIG) program. It delineates the specific tasks that will be accomplished by Teledyne Energy Systems and its suppliers during design, development, fabrication and test of deliverable Radioisotopic Thermoelectric Generators (RTG), Electrical Heated Thermoelectric Generators (ETG) and associated Ground Support Equipment (GSE).

The Plan is formulated in general accordance with procedures specified in DOE Reliability Engineering Program Requirements Publication No. SNS-2, dated June 17, 1974. The Reliability Program Plan presented herein defines the total reliability effort without further reference to Government Specifications. The reliability tasks to be accomplished are delineated herein and become the basis for contract compliance to the extent specified in the SIG contract Statement of Work.

NOTICE

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

INTRODUCTION

This document defines the reliability effort for the SIG Galileo Isotope Generator program. It is an integral part of the SIG Program Plan, TES-2865-09, and is identified in that Plan as Task 10.0. It delineates the specific reliability engineering tasks that are to be accomplished by Teledyne Energy Systems and its suppliers during the design, development, fabrication and testing of RTG's, ETG's and GSE.

This Reliability Program Plan (RPP) is formulated utilizing the procedures specified in DOE Reliability Engineering Program Requirements Publication SNS-2, dated June 17, 1974 to the extent specified herein. This plan, in conjunction with requirements specified in Task 10.0 of the SIG Program Plan, defines the total reliability effort without further reference to Government Specifications.

The RPP is organized into four sections, in addition to the Introduction, with identity as follows:

- Reliability Organization and Documentation
- Design Analysis
- Testing Evaluation
- Reliability Assessment

An Appendix is included which provides a cross reference between the sections of this plan and the applicable paragraphs of the SNS-2 publication.

The scope of the four subtasks identified above are as follows:

10.1 Reliability Organization and Documentation

Subtask 10.1 of this RPP is directed to the administration of the Reliability Program Plan. It involves monitoring of the tasks, determining their current status

in regard to milestone time in the overall program, identifying and resolving problems, planning and reporting the results of the evaluation and analysis activities.

10.2 Design Analysis

Subtask 10.2 of this RPP is directed to the reliability analyses of the design. It involves the establishment of mission and system goals and criteria and formulates the criteria for assessment of the system reliability. Analyses of design are identified and models generated to predict and assess end-of-mission generator reliability-power characteristics.

10.3 Testing Evaluation

Subtask 10.3 of this RPP is directed to the establishment of test criteria and sample size, type of test and duration of testing. It also includes the collection and reduction of test data and evaluation of test data from a statistical viewpoint.

10.4 Reliability Assessment

Subtask 10.4 of this RPP is directed to the assessment of the component and generator capabilities for achieving the power requirements specified for RTG at Jupiter orbit.

10.1 Reliability Organization and Documentation

a. Reliability Organization and Management

1. The Reliability Manager (SIG Task Leader) reports directly to the Safety/Reliability Supervisor who in turn reports to the Manager of Central Engineering. The Reliability Manager reports to the SIG Program Manager for all reliability activities related to the Galileo Mission program and interfaces with the other SIG Task Leaders in the implementation of their respective task activities. Figure 10-1 shows the organizational interface of Reliability Engineering within Teledyne Energy Systems. It portrays the organizational independence of the reliability operations in its relationship to SIG program management.

2. Management of Teledyne Energy Systems will conduct audits of the reliability program activities at a minimum of once a year using personnel assigned from other than the SIG program. These audits will be conducted to monitor the progress and effectiveness of the program. A record of such audits will be reported in the Program Monthly Progress Reports.

3. The Reliability Manager has the authority and resources to plan, implement, and manage the reliability program described herein, and to ensure its effective execution.

4. The Reliability Manager has authority for direct liaison with technical and support groups within Teledyne Energy Systems and with DOE,

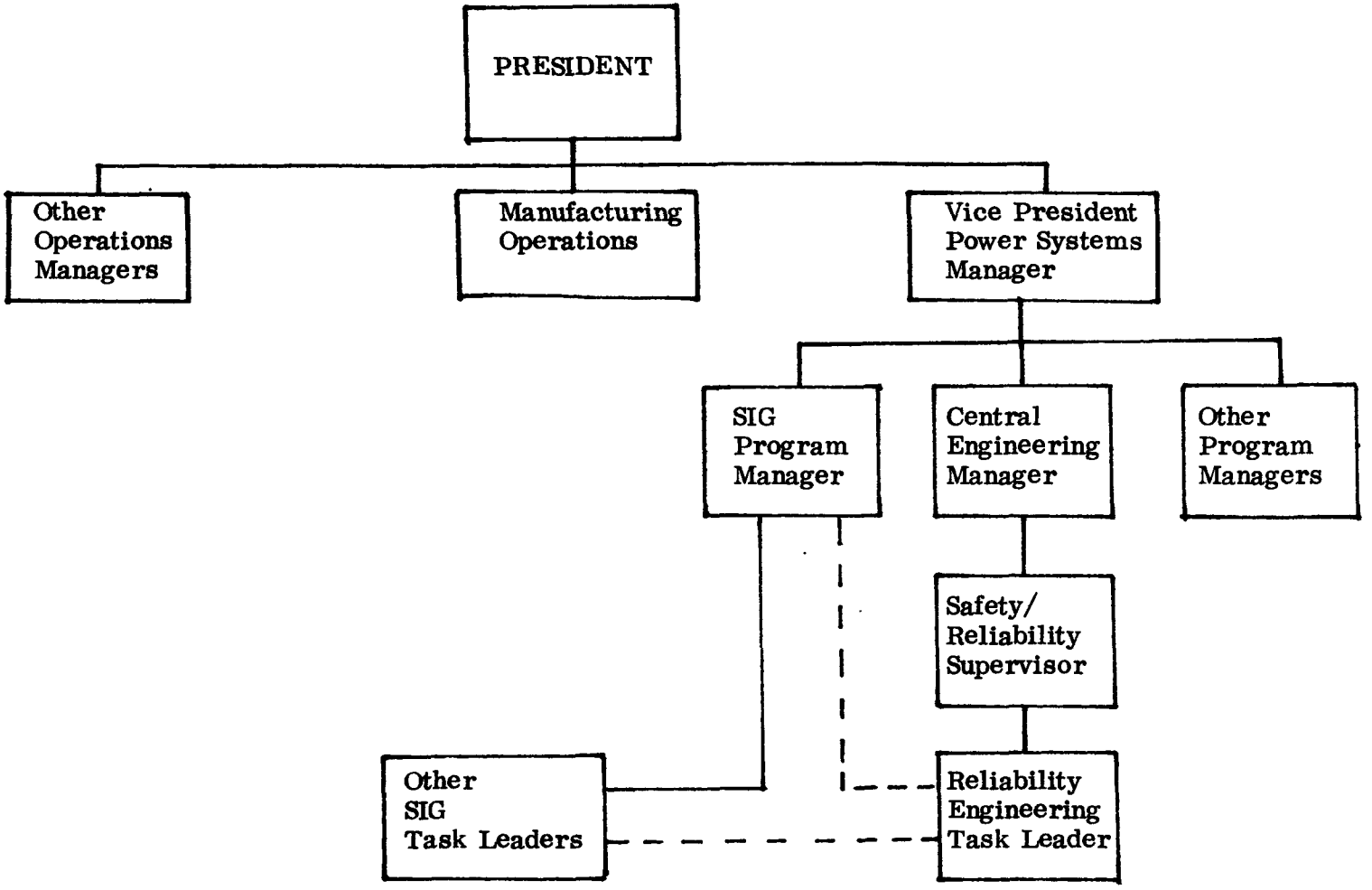

FIGURE 10-1: SIG PROGRAM ORGANIZATIONAL INTERFACE

associated contractors and other agencies as necessary to implement the reliability program. Direct liaison between the Reliability Manager and other TES technical and support task groups are authorized.

5. Trained and competent personnel will be used to implement the SIG reliability program. Indoctrination of appropriate program personnel in reliability disciplines, techniques and procedures will be performed on an "as needed" basis if required.

b. Program Documentation

1. Schedule for reliability subtasks activities and milestones will be presented as an integral part of the overall TES SIG program schedule shown in the SIG Program Plan TES-2865-09.

2. Formal and informal reliability reviews will be conducted at appropriate times during the SIG program. Formal reliability reviews will be conducted integral with SIG Design Review No. 1 and No. 2. Informal, overall reliability program reviews will be conducted a maximum of twice a year with each review limited to one day. Such reviews will be scheduled at DOE's request at a time related to significant accomplishments for the purpose of informing DOE of problems, recommendations and results of reliability activities. Detail reviews relating to specific areas will be conducted on an as required basis.

3. A review of the production facilities of Teledyne Energy Systems was conducted prior to contract agreement to evaluate the capabilities

for fabrication and assembly of SIG ETG's and RTG's and fueling of RTG's. The planning and organizational activities required to update the production facilities which were identified at that review are covered in Task 17.0 of the SIG Program Plan. Additional reviews related to facilities, if any, are identified in that task.

4. Written memorandum type reports will be generated to document the progress and results obtained during implementation of the reliability subtasks. The format of the memorandum reports will be consistent with that established for the overall SIG program. Accomplishments, planned activities, problems and copies of applicable memoranda will be reported in, and attached to, Top Summary and/or Program Monthly Progress Reports as applicable. Pertinent matters of reliability importance will be reported to DOE upon occurrence.

5. Memorandum type reports of minutes of DOE/TES reliability meetings will be prepared within ten (10) days and distributed to attendees as a minimum. DOE approval of such minutes prior to distribution will be obtained if so directed at the time of the meeting.

c. SIG Program Management Support

1. This document, The Reliability Program Plan (RPP), is prepared in compliance with SIG Statement of Work CRDL A11. This plan defines the reliability work to be accomplished during the SIG program between design and the end of the contract. The scope of the individual tasks as they apply to the various program hardware items of RTG, ETG

and GSE is identified or referenced in this document. The RPP will be revised or updated, as necessary, to accommodate changes in the SIG program.

2. Formal memorandum type reports will be prepared to document the progress and results obtained during performance of the reliability tasks. Identification of the availability of such reports, or copies of such reports, will be provided through the SIG Top Summary and Monthly Technical Progress Reports, as applicable.

3. Two formal design reviews will be conducted during the SIG program as identified in Task 1.0. Reliability will provide input to and participate in the reviews. The scope and contents for the reliability input will be established jointly with DOE.

4. A configuration control board will be established as identified in the Configuration Control Plan, TES-2865-12. Reliability will participate as a member of that board with the primary responsibility of assuring that the risk to mission reliability due to changes is adequately identified.

5. A final report will be prepared at the conclusion of the SIG program. Reliability will provide input to that report and cover areas such as reliability assessment of components and RTG power performance.

10.2 Design Analysis

a. Mission Analysis

A mission analysis subtask will be prepared to identify and define criteria for formulating reliability design analyses, developing and evaluating test plans and assessing the reliability-power characteristics of the RTG throughout the mission.

The subtask will be implemented through the preparation of three analyses as follows:

1. Requirements and Goals - A requirements and goals analysis will be prepared to identify the end-of-mission power limits, define the mission phases, identify the time frame for each mission phase and describe the environments associated with each mission phase.
2. Logistic Profile - A Manufacturing-to-Use (MUS) logistic profile analysis will be generated using information provided by DOE to describe the various possible logistic sequences (storage, handling and transportation operations) associated with the RTG between DOE acceptance and delivery to JPL. A logistic environmental analysis will be included to identify the magnitude of the expected environments seen by the RTG during the preflight logistic phase. Packaging configurations, which mitigate the effect of the environments or improper handling will be identified.
3. Safe Operating Limits - A safe operating limit analysis will be prepared to identify limits to which the RTG may be operated without impairing performance. These limits will be imposed in procedures relating to testing and post-delivery operations.

Reliability engineering will verify during the review and approval of engineering drawings, processes, procedures and acceptance specifications that the applicable requirements and criteria developed in this subtask are incorporated therein. The program for review and approval of the documentation is identified in Subtask 10.2e.

b. Systems Analysis

1. A System Logic Synthesis model will be prepared to provide the tool for allocating and assessing RTG system failure probability from failure mode probabilities. The model will:

   - Establish a numerical value for the inherent system catastrophic reliability.
   - Disclose critical areas of reliability upon which design improvement efforts may be directed.
   - Provide a basis for making reliability trade-offs among the various components of the system.

   The model will provide for the logical combination of failure modes leading to RTG failure as identified by the Failure Modes, Effects and Criticality Analysis (FMECA). Failure probabilities will be allocated to the system failure modes and a probability equation of the mathematical model will assess system catastrophic reliability.

   The System Logic Synthesis model will be continually updated as significant design changes are incorporated.

2. A power degradation and variability analysis will be prepared to analyze the thermoelectric performance as a function of time using data supplied by DOE on tests performed by 3M, JPL and other sources. Results of

this analysis will be integrated with degradation characteristics as obtained from GDS-1, ETG and RTG tests. The degradation analysis will be continually updated as applicable data becomes available and results used as an input to Task 10.4c2.

3. The results obtained from the system logic synthesis and the degradation analyses will be integrated and incorporated into the Mision Performance Prediction Report, Subtask 5.3 of the SIG Program Plan. Reliability will monitor the overall reliability-power prediction analysis to assure that the three subtasks are integrated in a manner to provide statistical confidence level within the available data base.

c. Generator Design Analysis

A generator design analysis subtask will be prepared to identify the failure events in the RTG, GSE and related systems which could result in loss of electrical power during the mission and justify the retention of such events by analysis or test. The subtasks will be implemented through the preparation of a FMECA. The elements of the FMECA are·

1. FMEA - A failure modes and effects analysis (FMEA) will be prepared for the following designs:

   - RTG when operating for the mission time and in the environments identified in subtask 10.2a - Mission Analysis. The GFE radio-isotope heat source and thermoelectric converter will be included in the FMEA if appropriate data are supplied by DOE to the Contractor.
   - ETG when operating for the test time and environments associated with the scheduled testing described in Task 6.0 of the SIG Program Plan.

- GSE operational equipment identified in subtask 10.2d. Here, the effort will be limited to identification of failure modes which could conceivably result in loss of ETG and RTG power output.

2. Criticality Analysis - A criticality analysis (CA) will be prepared for the RTG based on combining (multiplying) the failure effect consequence rank with the failure mode likelihood rank values. The ranking values are as follows:

Failure Effect Category	Failure Effect Consequence	Rank
I.	Results in catastrophic or imminent loss of power performance and mission.	100
II.	Results in a reduction in power resulting in a partial mission failure.	50
III.	Results in failure or out of specification condition not affecting power.	5

Failure Mode Likelihood	Rank
Most likely failure mode	100
Very likely failure mode	75
Likely failure mode	50
Minor failure mode	25
Unlikely failure mode	10
Highly unlikely failure mode	5
Improbable failure mode	1

3. Single Point Failures - A single point failure analysis (SPFA) will be prepared for failure effects Categories I & II. Single point failures which result in a loss of electrical power during the mission will be identified and justification for their retention in the design supported by analysis and/or tests.

4. Reporting - Reporting of the generator design analysis subtask activities will be through the Monthly Technical Reports and at Design Review No. 1 and No. 2.

d. Ground Support Equipment Analysis

1. A system level failure modes and effects analysis will be prepared for the RTG Shipping Container, ETG Power Supply Console, Readout Console and Portable RTG Vacuum Maintenance Unit. The purpose for this analysis is to identify failures in the GSE system setup, operator error and component failures which may result in failure or degradation of power output of the RTG and ETG.

2. Criteria to be used in the design of control panels will be established for the GSE identified in 10.2d(1). The criteria will be developed from information contained in DOD Specification MIL-STD-1472B, Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Verification of the achievement of the criteria will be accomplished through document review and sign-off, 10.2e, and by walk and talk through of procedures.

3. The GSE designs will incorporate tolerances that permit interchangeability of parts and capability for being maintained. No formal maintainability analysis will be implemented. However, the above requirements will be reviewed during document review and approval, 10.2e.

e. Specification Approval

RTG, ETG and GSE system, design and procurement specifications, engineering drawings, test procedures and processes will be reviewed and approved by reliability engineering. Documents relating to tooling, test fixtures, and GSE equipments other than those idenfified in 10.2d(1) will be reviewed and approved on a selected basis. The requirements for and procedures associated with the approval and signoff are described in SIG Documentation Plan TES-2865-01. Approval will signify that reliability considerations are adequately provided and that appropriate controls are included to enhance the delivered hardware reliability.

10.3 Testing Evaluation

a. Test Criteria

1. Test design - Reliability Engineering will provide input to the design of generator and component tests identified in Tasks 6.0 and 16.0, respectively. Input will include test matrix, sample size, test sequence for the purpose of identifying potential weaknesses, unknown modes of failure and providing verification of the design in the mission application and environments.

2. Test technique - Tests will be formulated to provide results in parametric form wherever practical. Likewise, generator and component characteristics will be developed using variables in lieu of attributes type data in order to increase the statistical significance of the tests. Life type tests will be used for those items which are identified in the FMECA subtask as having limited life or performance as a function of time. Accelerated life testing will be considered for items critical to mission where test time is limited.

b. Acceptance and In-process Tests

1. Acceptance tests - Receiving inspection and fabrication acceptance test programs will be generated for reliability critical mission components. Such programs may contain destructive or non-destructive tests and would be in addition to those imposed by Quality activities.

2. In-process tests - In-process test programs will be generated for components critical to mission reliability to identify potential reliability problems (failure modes) and performance changes resulting from fabrication and process operations.

c. Component Tests

Data obtained from conduction of the component tests identified in Task 16.0 will be reduced and analyzed to identify new or verify projected failure modes, develop statistically valid parameter distributions and establish parameter trend versus time characteristics. Applicable data from these tests, combined with analysis where required, will be used for projections of performance characteristics to end-of-mission of 60,000 hours. Tests to be evaluated include, as a minimum, those identified in Subtasks 16.2, 16.3, 16.4, 16.5, 16.7, 16.9 and 16.10.

d. Generator Tests

Data obtained from tests conducted on GDS-1, ETG's and RTG's are reduced and evaluated as specified in Task 5.0. Reliability will identify the type of data required to maximize the generator reliability-power assessment.

e. Associated Contractor Tests

1. Thermoelectric - Reliability will review, reduce and evaluate all data supplied to TES on Thermoelectric Performance Tests performed by 3M Company, JPL, etc. The information will be used to support the data base for the assessment of thermoelectric power output and degradation.

2. Other data - Reliability will review and evaluate all data supplied to TES on GFE electrical heat source and other contractor component and material analyses and tests to maximize the data base for assessment.

f. Failure Review and Corrective Action

Teledyne Energy Systems has a single reporting system for pre-delivery non-conforming and problem/failures which covers both hardware and software

discrepancies. A description of the methods used to report, investigate and dispose of all such discrepancies are described in SIG Quality Program Plan, TES-2865-13. The program as defined in the SIG Quality Program Plan conforms to paragraph 6.4.2.1 of SNS-2 except (1) time in service, environments at time of incidents and corrective action ranking will be applied only to failures in deliverable hardware.

Reliability Engineering will participate in the problem/reporting and correction activity to the extent specified below:

- Perform or assist in the performance of analyses to determine cause(s) of failure or non-conformance of an item.
- Participate as a member of the Corrective Action Board (CAB) to assure that disposition of non-conforming item is acceptable and that the corrective action recommended is acceptable from a reliability viewpoint.

Reliability Engineering will review DOE or User (JPL) supplied reports covering problems or failures which occur subsequent to hardware delivery. The review will identify the impact, if any, on power performance of the generator or mission. If power output is affected, appropriate evaluations and recommendations will be generated.

A Failure Review Board is established for the SIG program. Its purpose and scope is identified in the Quality Program Plan. Reliability Engineering will participate or contribute to the Board's activity on an "as requested" basis.

10.4 Reliability Assessment

a. Assessment Technique

1. Probability distributions - Variables type data will be used in preference to attributes or worst case in order to enhance the development of a given parameter versus probability as a function of various environment conditions. Attributes and worst case data may be used where quantity of data is restricted or not cost effective.

2. Regression fitting - Trend analyses will be generated using least squares curve fitting techniques. Linear and non-linear fitting functions, which consider one or more dependent parameter, will be used as applicable. Goodness-of-fit and appropriate statistical inferences will be obtained.

3. System distributions - Monte Carlo techniques will be used for combining the subsystem and component statistical characteristics to formulate the system statistical characteristics.

b. Component Assessment

Results of analyses and tests of each component identified in Task 16.0 will be collected and integrated into a single assessment report. The assessment would identify failure modes, experience with failures, prediction of performance to end-of-mission and performance characteristics estimated at a 50% confidence level. All in-house, past TES programs, associate contractor and government agency data would be considered.

c. Generator Assessment

1. Approach - A reliability-power assessment will be prepared in conjunction with Task 5.0 to assess the capability of the SIG RTG to meet the power requirements specified in Attachment 1 to Appendix A to the SIG Statement

of Work. The method for computing the probability will be based on procedures developed by TES and approved by DOE. These procedures will be established from procedures identified in Annex A and B to Attachment 1 of Appendix A to the Statement of Work.

2. Method - An RTG Mission Performance Prediction Model will be prepared (Subtask 5.3 of the SIG Program Plan) to integrate the allocated failure probabilities, thermoelectric performance and degradation characteristics, environmental effect and mission time profile. This integration will identify the probability of meeting the end-of-mission power output. Reliability will assist in the preparation of the model for this prediction and provide necessary assistance to apply Monte Carlo techniques.

APPENDIX

CROSS REFERENCE INDEX

Reliability Plan Versus DOE Specification SNS-2

Plan Section No.	Task Description	SNS-2 Para. No.
10.10	Reliability Organization and Documentation	
10.1A	Reliability Organization and Management	3.1.0
10.1A1	Reliability Organization	3.1.1
10.1A2	Reliability Audits	2.1.0
10.1A3	Reliability Manager	3.1.2
10.1A4	Organization Interface	3.1.3
10.1A5	Personnel and Training	3.1.4
10.1B	Program Documentation	3.2.0
10.1B1	Reliability Milestones	3.2.1
10.1B2	Reliability Reviews	3.2.2
10.1B3	Facilities Reviews	3.2.3
10.1B4	Progress Reports	3.2.4
10.1B5	Meeting Reports	3.2.5
10.1C	SIG Program Management Support	2.2.0
10.1C1	Reliability Program Plan	
10.1C2	Monthly Progress Reports	
10.1C3	Design Reviews	
10.1C4	Configuration Control Board	
10.1C5	Final Report	
10.20	Design Analysis	
10.2A	Mission Analysis	
10.2A1	Requirements and Goals	5.1.0
10.2A2	Logistics Profile	4.2.0
10.2A3	Safe Operating Criteria	5.1.0
10.2B	System Analysis	
10.2B1	System Logic Synthesis Analysis	5.5.0
10.2B2	Power Degradation and Variability Analysis	4.3.0
10.2B3	Mission Performance Prediction	
10.2C	Generator Design Analysis	
10.2C1	Failure Modes, and Effects Analysis (FMEA)	5.4.0
10.2C2	Criticality Analysis (CA)	5.4.0
10.2C3	Single Point Failure Analysis (SPFA)	5.4.0
10.2C4	Reporting	5.4.0

APPENDIX (Continued)

Plan Section No.	Task Description	SNS-2 Para. No.
10.2D	Ground Support Equipment Analysis	
10.2D1	System Failure Modes and Effects Analysis	5.4.0
10.2D2	Human Engineering Analysis	8.0.0
10.2D3	Maintainability Analysis	7.0.0
10.2E	Specification Approval	4.1.0
10.30	Testing Evaluation	
10.A	Test Criteria	6.1.0
10.A1	Test Design	6.2.0
10.A2	Test Techniques	6.3.0
10.3B	Acceptance and In-Process Test	6.3.0
10.3B1	Acceptance Tests	6.3.0
10.3B2	In-Process Tests	6.3.0
10.3C	Component Test	6.3.0
10.3D	Generator Test	6.3.0
10.3E	Associate Contractors Tests	6.3.0
10.3E1	Thermoelectric	6.3.0
10.3E2	Other Data	6.3.0
10.3F	Failure Review and Corrective Action	6.4.0
10.40	Reliability Assessment	
10.4A	Assessment Technique	6.3.0
10.4A1	Probability Distributions	6.3.0
10.4A2	Regression Fitting	6.3.0
10.4B	Component Assessment	6.3.0
10.4C	Generator Assessment	6.3.0
10.4C1	Approach	6.3.0
10.4C2	Method	6.3.0