RELIABILITY PROGRAM REQUIREMENTS FOR SPACE AND TERRESTRIAL NUCLEAR POWER SYSTEMS

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OCTOBER 1982

U.S. DEPARTMENT OF ENERGY

**OFFICE OF SPACE NUCLEAR PROJECTS
WASHINGTON, D.C. 20545**

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FOREWORD

The provisions stated in this document shall apply to all programs within the Office of Space Nuclear Projects. The provision can be modified only by memorandum signed by the Office Director. This document supersedes SNS-2, "Reliability Engineering Program Requirements Publication", (June 17, 1974).

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RELIABILITY PROGRAM REQUIREMENTS

1 INTRODUCTION

The objectives of these program requirements are (1) to provide contractors with an outline of the reliability requirements established by the Department of Energy (DOE) in the areas of design, development, production, testing, and acceptance of space and terrestrial nuclear systems hardware, and (2) to guide the contractor in meeting these requirements.

This publication or particular portions of it is applicable as specified in the contract. Whether the contractors/subcontractors are subject to all the requirements or only to part of them will be specified by contract, program letter, or by the contract statement-of-work.

2. GENERAL PROGRAM REQUIREMENTS

2.1 Purpose

The contractor shall effectively plan, establish, implement, audit, document, and maintain control of a formal reliability program. The contractor's reliability organization will be subject to DOE review and approval.

2.2 Plan Preparation

The contractor shall prepare a Reliability Program Plan (RPP), which is subject to DOE approval, which will comply with policies, practices, and procedures outlined both in the contract with DOE and in the Request-for-Proposal (RFP) reliability requirements. The RPP format shall be readily identified with each reliability program requirement.

2.3 Elements To Be Included in the RPP

The RPP shall complement and support functions required by other contractual requirements. There is some overlapping and interfacing of requirements in the areas of quality and safety; however, these shall be identified in the RPP and shall not result in a duplication by the contractor.

The RPP shall include the following:

- o Identification of portions of the proposal that will use existing contractor documents and operations with no changes; identification of portions of the proposal that will use some form of existing documents and operations, an explanation of what changes will be needed to fulfill the requirements of the RPP, and a work and time schedule for making these changes.
- o A chart of the personnel and organizations that will be involved in planning and executing the RPP and the responsibilities and authority of each.
- o Appendices (when applicable) to describe hardware requirements for elements (such as Ground Support Equipment (GSE), modules, etc.) where the complete RPP may not be required.
- o References to applicable contractor policies and procedures.
- o Expected reliability-related interfaces between DOE, user, subcontractors, and suppliers and the responsibilities of each.
- o Identification of those reliability documents which are to be submitted to the Government for approval, review, or information.

2.4 Revisions

The RPP shall be updated as necessary if the work effort or contract is modified and any revisions shall be submitted to DOE for approval.

2.5 Implementation

The approved RPP is the standard DOE will use to evaluate the contractor's performance. The operations and documentation of the contractor and subcontractors are subject to inspection, review, and evaluation by the DOE and/or its designated representative at all times. Any inspection, review, or evaluation of a subcontractor's reliability program will be coordinated through the contractor.

The responsibilities and authority delegated to DOE representatives will be defined by the DOE Contracting Officer. Reliability functions required of the prime contractor shall be imposed on the subcontractor by the prime contractor's procurement contracts and specifications. The prime contractor is responsible for verifying that subcontractor products satisfy hardware reliability requirements.

3. ORGANIZATION AND DOCUMENTATION

3.1 Organization and Management

3.1.1 Reliability Organization

A clearly defined organization shall be responsible for the planning, implementation, and management of the RPP. Unless specifically stated otherwise in the RPP, this organization will monitor and ensure the accomplishment of all reliability tasks within the contractor's jurisdiction.

3.1.2 Reliability Manager

The Reliability Manager shall have the necessary authority and resources to discharge reliability program responsibilities. There will be direct liaison between DOE personnel and the Reliability Manager or his/her designee.

3.1.3 Interface With Other Organizations

The contractor shall identify and define in the RPP necessary technical and/or support groups and their responsibilities. Direct communication between the Reliability Manager and these groups shall be authorized.

3.1.4 Personnel and Training

Trained and competent reliability engineers shall be a part of the reliability program. Additional training, specific to the program, shall be given as necessary to ensure effective performance in satisfying requirements. The reliability organization shall aid and update program managers and personnel from technical and support groups on reliability matters.

3.2 Program Documentation

The contractor shall document that reliability engineering performance complies with program requirements to the satisfaction of DOE.

3.2.1 Reliability Milestones

The contractor shall indicate on a schedule of milestones when significant reliability efforts will be completed.

3.2.2 Program Reviews

Program design reviews require a formal reliability presentation. In addition, informal reviews and working meetings shall be held as necessary to

keep DOE informed on progress, problems, recommendations, and significant accomplishments.

The contractor shall submit the official minutes of each contractor/DOE reliability meeting within 10 days to DOE for approval. Copies of the minutes will be mailed to all attendees following DOE approval.

Program meetings/reviews (such as before and during construction of key facilities), preship reviews, or launch readiness reviews will be conducted as necessary.

3.2.3 Progress Reports

The contractor shall prepare a formal monthly report on the progress of the reliability program; this shall include subcontractor progress and a status of Action Items from joint contractor-DOE meetings. These monthly reports may be incorporated into the Monthly Program Progress Reports.

DOE will be notified by telecon of important pertinent matters which occur between reports.

3.2.4 Content of Progress Reports

Progress reports will include but are not necessarily limited to the following:

- o Progress of each reliability task including significant accomplishments and milestones during the reporting period.
- o Reliability problem areas and proposed corrective action.

- o Failures that occurred during the reporting period and the corrective action taken.
- o Unresolved failures requiring further action.
- o Decisions and actions during the reporting period having impact on the reliability effort and descriptions of their anticipated effect on reliability.
- o Anticipated reliability program slippages, their effects, and corrective action taken.
- o A description of formal or informal reliability recommendations, an evaluation of the recommendations effect on systems, and the action taken by the contractor.

4 DESIGN RELIABILITY ELEMENTS

4.1 Design Definition (Drawings and Specifications)

The contractor's design definition shall include a comprehensive evaluation of both the system and the subsystems (or units) defined in the Statement of Work. The evaluation shall consider the function, reliability, and performance of each system as well as its environmental and physical requirements.

If an item (or subsystem) called for in the contract is to be used in a larger system, the interfaces with the larger system must be included in the design and the reliability analysis of the design.

The Reliability Organization shall review the design definition to ensure its compatibility with reliability requirements.

4.2 Reliability in Design

Design activities shall employ: stress derating; tolerance studies; redundancy; stress/strength analysis; materials analysis; variables analysis; design trade-off studies; failure modes, effects and criticality analysis (FMECA); and similar techniques to eliminate critical failure modes and reduce the likelihood of early failure.

4.3 Environment

The contractor shall define a Manufacture-to-Use Sequence (MUS) based on information provided by DOE and by the design organization of the system in which the contracted item is to be used. All equipment used to mitigate or control the environment during the MUS shall be included in the reliability analyses. This MUS shall be used to define the expected environments and describe the various possible logistic sequences involved in moving a device from the time it is accepted to its end-use environment. Figure 1 is a simplified example of a MUS for a space application.

4.3.1 Environment Table

This table shall describe the magnitudes of all expected environmental inputs to the device during the MUS.

4.3.2 Packaging Configuration.

The packaging configuration shall be designed to mitigate the effects of the expected logistics environments and, where possible, the effects of improper handling. A description of the environments which will

Figure 1. Simplified Example of Manufacture-to-Use Sequence (MUS) for Space Application

be mitigated by the packaging and a brief description of the configuration will be included with the environment table.

4.4 System Variables Analyses

Each functional performance parameter shall be expressed by a well-defined, accurate mathematical model as a function of the factors which influence the output. These factors shall be established from measurements, tests, statistical distribution, or other sources. Analysis shall be updated in program milestone reports.

4.4.1 Variables Analyses Evaluations

Worst-case analyses or other statistical analyses should affirm the ability of the system to meet system requirements.

4.4.2 Variables Analyses Use

Results of these analyses (unless modified by system changes or contradicted by test data) shall be considered or included in the system reliability assessment.

Problems with a critical parameter can cause system failure; thus, sensitivity analyses, using the various mathematical models, shall be performed on all critical parameters.

The analysis models shall also be used in a nonduplicating manner to aid in assessing the effect of proposed design and parameter changes on system requirements.

5. RELIABILITY ENGINEERING PROGRAM ELEMENTS

5.1 Goals

A reliability goal or attainable requirements shall be established by DOE. All factors which affect the goal shall be clearly defined. This includes, but is not limited to, such factors as applicable use environments, interface with other elements of the system in which used, duty cycle, MUS, and system and component design.

5.2 Demonstrated Reliability

The contractor shall define a test program that will reasonably demonstrate the DOE goal specified above.

5.3 Reliability Participation and Analysis

The reliability organization will begin its involvement in the program with the RFP and shall continue participating through design, production, testing, and application (as defined in the contract).

5.4 Failure Modes, Effects, and Criticality Analyses (FMECA)

The FMECA shall provide a systematic, detailed, and continuous review of all system components and functions at the earliest possible phase of their design. The Analyses shall identify and define potential malfunctions and their effects on the performance of the system. The FMECA shall cover all DOE-contracted components and their interfaces, both with each other and with the larger system in which they may be used. The equipment necessary to test, maintain, or mitigate environments shall be included in the evaluation.

"Malfunctions" are those failures that can cause mission loss or deteriorated performance and are described as those incidents with the potential for causing harm to personnel or for damaging material either in the DOE or larger system operations.

To ensure design adequacy, the FMECA shall emphasize areas requiring redesign or additional detailed design, analysis, inspection, or testing.

5.4.1 Failure Modes and Ranking

All credible failure modes shall be identified to include relationships with single or multiple components including common cause or common mode failures. Worst-case environments will be assumed. Failure modes shall be ranked on a relative scale of likelihood from 1 to 100; 100 will represent the mode most likely to occur.

5.4.2 Failure Effects and Ranking

A systematic and detailed review shall be made of all possible effects resulting from identified modes of failure. The failure effect categories shall be clearly defined and ranked from 1 to 100; 100 will represent the worst case. A simplified example of failure effect categories and ranking is given below:

<u>Category</u>	<u>Failure Effect/Definition</u>	<u>Rank</u>
I	Results in catastrophic loss of the mission specified for the contracted item or loss of life or loss of mission for the larger system in which the item is used.	100

<u>Category</u>	<u>Failure Effect/Definition</u>	<u>Rank</u>
II	Results in reducing the performance (perhaps in power) of the contracted item or of the system in which it is used; it can also result in increased hazard to personnel or damage to equipment, thus causing schedular delays or decreased program capability.	50
III	Results in an "out of specification" condition; it does not affect system or mission performance.	5

5.4.3 Criticality

The rankings given in sections 5.4.1 and 5.4.2 above are multiplied to obtain a criticality ranking, which is then used in the failure mode elimination effort (see Section 5.4.4).

5.4.4 Failure Mode Elimination

The design goal shall be the elimination of single point failures and failure modes having a ranking of high criticality ranking or causing Category I or II effects. Those that cannot be eliminated shall be highlighted for appropriate testing and analysis to verify that an acceptably low probability of occurrence exists.

The contractor shall prepare a listing of Category I and II single point failures (SPF) which cannot be eliminated from the design. For each such SPF, the definition shall provide supporting analyses, acceptance tests, in-process inspection, and nondestructive testing applied during fabrication and assembly operations. Engineering, materials, safety, reliability, and quality assurance (QA) disciplines shall concur both in the listing and in

associated actions. The list should be completed no later than the final design review, and should be updated if the design changes or if new information becomes available.

5.4.5 FMECA Reporting

A FMECA report shall be prepared which includes the following: A thorough description of the hardware, functionality, design specification, expected environments, assumptions, and support documentation. Detailed FMECA worksheets will be provided and shall include the information required from sections 5.4.1 through 5.4.4 above. Summary sheets will be used to highlight failure modes having a high relative criticality ranking.

As a part of FMECA reporting, a list of critical parts, materials, and processes together with critical parameters shall be provided as a guide in generating lower tier specifications and in fabrication and processing operations.

5.5 Functional and Equipment Block Diagrams

In conjunction with the reliability prediction and FMECA efforts, the contractor shall use functional and/or equipment block diagrams of the entire system down to the component level. Each block shall indicate the current predicted reliability and the apportioned reliability goal for the system element represented.

5.5.1 Probability Equations

System failure (or success) equations shall 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 qualifying the probability equations and assessments shall be given.

5.5.1.1 Allocations

The probability equation shall be used to conduct an allocation study early in the design phase to allocate failure probabilities to components. This study shall be based on the requirements of sections 4.1 and 5.6.

5.5.1.2 Assessment

The reliability equation shall be used to assess system reliability by combining all available information to ascertain the adequacy of the system, adequacy of data, and provide direction for the test program. Periodic assessments shall be made throughout the contract and the results compared with reliability goals. Test data may be supplemented with engineering judgment and experience, particularly during the design stages.

5.5.1.3 Sensitivity Analysis

The reliability equation shall be used where necessary to determine the sensitivity of the system assessment to possible ranges of failure mode assessments.

5.6 Reliability Prediction

Starting in the conceptual design stage, the contractor shall develop reliability prediction models and predictions for the system. These models and predictions shall reflect applicable experience from previous space,

terrestrial fuel, and other related programs, and shall be revised as required by design evolution and as additional pertinent data become available. Predictions shall be performed in close coordination with FMECAs on the same system elements. The scale of effort and degree of precision in each prediction shall be appropriate to the phase of the project life in which the prediction is made and to the intended use of the results. Individual predictions shall be accomplished and results reported to users within the contractor's organization in time for the uses and decisions which each prediction is to support. Predictions are variously useful as a basis for:

- o Apportioning reliability goals within the system and planning a design capable of meeting end use or mission reliability goals.
- o Timely identification of potential reliability and safety problem areas and guiding design trade-offs.
- o End use or mission planning, test program planning, and reliability evaluation program planning.
- o Probability-of-occurrence determinations in FMECAs.
- o Redundancy studies.
- o Preliminary estimation of mean-time-between-failures (when used with FMECA) to support maintainability analysis and logistics planning.

6. TEST PROGRAM

6.1 Purpose

The purpose of the test program is to evaluate and verify the design of the hardware in its expected use and in selected extreme environments.

6.2 Requirements

The test program shall be designed to provide the necessary data to support the defined failure modes and their probability assessments. The program shall attempt to identify and eliminate potential weaknesses and unknown modes of failure. It shall also attempt to verify design adequacy.

6.3 Data Sources

In support of sections 6.1 and 6.2, all relevant data sources, including applicable data derived from previous DOE contracts, shall be evaluated and used. Except when necessary to clear up ambiguities or to assess statistics, previous data shall not be duplicated but rather added to so that a more complete data bank will be available.

6.3.1 Material Properties Test

Worst-case or statistical distributions of material properties such as high temperature mechanical properties, modulus of elasticity, Seebeck coefficient, emissivity, capacitance, compatibility with potentially interacting materials, shall be determined as a function of such factors as temperature, age, voltage, and stress. Tests need only be performed for those properties which are not well characterized and which are critical to work efforts specified in the RPP.

6.3.2 Variables and Attributes Tests

Adequate tests shall be conducted on components and systems to determine the characteristics of the selected item in the expected environments. Measurements shall be taken when necessary to determine how characteristics vary (variables data) as a function of another variable. Attributes tests, which are go-no go tests, shall be used if variables testing is not considered necessary or applicable. A statistical sampling procedure shall be used to determine the number of units needed for the tests.

6.3.3 Trend Data Tests

A trend data test program shall be established to determine the characteristics of the system or components as a function of age. Accelerated life testing or similar techniques may be necessary to provide information within the required time period. Such tests require DOE approval of a contractor-generated RPP.

6.3.4 Acceptance Tests

Hardware systems and computer programs shall be subjected to acceptance tests before they can be accepted by DOE. All units or programs are required to pass those tests specified in the performance section of their specification.

6.3.5 System Qualification/Demonstration and Lot Sample Tests

Additional tests shall be conducted on a selected sample from systems which have passed the acceptance test. These further measures are taken to reasonably assure DOE that the system meets the requirements of the specification. These requirements include years of operation in the expected

environments. These samples will be subjected to trend data tests (see section 6.3.3).

6.4 Failures and Corrective Action

6.4.1 Failure Reporting

When the preliminary design review is concluded, the contractor shall provide a system to record and analyze and report all failures.

Each Failure Report shall include, but not be restricted to, a description of the failure, time in service, environments to which exposed, cause, corrective action (or recommended corrective action), ranking (see sections 5.4.1 and 5.4.2), and recommendations.

6.4.2 Failure Review Board

The contractor shall establish a Failure Review Board (FRB) that shall review all failures and malfunctions occurring during or following qualification/acceptance tests of deliverable hardware or systems or module reliability/life tests. The FRB shall ensure that corrective measures are implemented, monitor the effectiveness of the corrective actions, and issue formal Failure Reports. Upon identification of a failure or malfunction, the DOE site representative shall be notified as soon as practicable. In the event that there is no assigned site representative, the DOE Program Manager shall be notified. Membership of the FRB shall consist of the following personnel or their designees as a minimum (FRB Chairperson is normally the QA manager; others require DOE approval):

- o Program Office Representative
- o Project Engineering Representative
- o QA Manager
- o Reliability Engineer
- o Design Engineer
- o DOE Representative, in observer capacity only

When a failure or malfunction is experienced, the responsible personnel will take the following actions:

- o Test Personnel will take whatever actions necessary for the protection of test personnel and hardware.
- o Test Engineering will place a hold on testing.
- o Project Engineer/QA Engineer will convene the FRB.
- o Failure Review Board will determine the root cause of the failure or malfunction. If not possible within a reasonable length of time, the FRB will collect all available evidence for determining the root cause of failure or malfunction at a later time.
- o Failure Review Board will determine disposition of the discrepant material.
- o Failure Review Board will determine corrective action necessary or will defer a decision until a later time if not practical before resuming the test.

- o Failure Review Board will obtain safety concurrence.
- o Only the Failure Review Board can release the hold on the test.

7. MAINTAINABILITY

7.1 Maintenance-Free Design

Maintenance-free equipment shall be the goal of the designer.

7.2 Tolerance Control

Tolerances should be controlled to ensure component interchangeability.

7.3 Maintenance and Operation Analyses

Operations requiring tests, checkout, inspection, assembly/disassembly, self monitoring, or related maintenance effort shall be analyzed to ensure that capabilities and procedures exist to adequately perform the functions. These functions include activities such as tests, checkouts, inspection, assembly or disassembly, self-monitoring, etc.

8 HUMAN FACTORS ANALYSIS

8.1 Human Factors Coverage

Human factors coverage shall begin with equipment design and continue through production to ultimate use. Coverage shall include analysis and elimination of potential human errors arising from (a) design considerations, maintainability, and equipment operations, (b) all operational and instructional material, (c) training associated with the equipment, and (d) responses to emergency or other stressful situations.

8.2 Reports

Analysis and recommendations shall be incorporated, where appropriate, with other reliability program reports.

APPENDIX A

LIST OF DEFINITIONS

APPENDIX A
DEFINITIONS

Common Cause Failure:

An event in which more than one system, subsystem, structure, component or feature are rendered incapable of performing their functions because of a single, more basic triggering condition.

Common Mode Failure:

The malfunctioning of more than one system, subsystem, structure, component or feature caused by the same physical phenomenon.

Contract:

The prime contract executed by the Government and the prime contractor which, in addition to the terms and conditions thereof, includes by reference or otherwise, specifications, procedures, drawings, exhibits, and other data necessary to its proper performance.

Contractor:

The individual(s) or concern(s) who enter into a prime contract with the Government.

DOE's Designated Representative:

A representative of the DOE stationed at the contractor's or supplier's plant or a representative of the inspection agency to whom QA functions have been delegated.

Derating:

The intentional reduction of stress/strength ratio in the application of an item, usually for the purpose of reducing the occurrence of stress related failures.

Failure:

The termination of the ability of an item to perform its required function.

Failure Analysis:

The logical, systematic examination of an item or its diagram(s) to identify and analyze the probability, causes, and consequences of potential and real failures.

Failure Mode:

A set of events for which the completion of the occurrence of each event simultaneously or in any order constitutes a specific kind (mode) of failure.

Failure Mode and Effects Criticality Analysis (FMECA):

FMECA is an FMEA with the added criticality calculation. Criticality is the product of the value of the probability of a failure mode occurring and an index number that weights the failure according to its seriousness in the performance of the mission.

Human Engineering:

The science of studying the human-machine relationships in order to minimize the effects of human error and fatigue and thereby provide a more reliable operating system.

Human Factors:

A body of scientific facts about human characteristics. The term covers biomedical and psychosocial considerations in the areas of human engineering, personnel selection, training, life support, job performance aid, and human performance evaluation.

Mean-Time-Between-Failures:

For a particular interval, the total functioning life of a population of an item divided by the total number of failures within the population during the measurement involved.

Reliability:

The probability that an item will perform a required function under stated conditions for a stated period of time.

Reliability Allocation:

The apportioning of a system level goal or requirement among the constituent components or subsystems.

Reliability Analysis:

The methods used by reliability engineers to evaluate the potential or actual reliability of a system. It includes mathematical modeling of the system and statistical evaluation of test data to derive numerical values for the terms in the model.

Reliability Assessment:

The appraisal of achieved reliability derived from statistically significant quantities of test data from relevant mission experience.

Reliability Assurance:

An effort established to audit an entire program to ensure that reliability goals are met. The audit may cover all design, production, test, and field activities.

Reliability Engineering:

An engineering evaluation effort independent of design, production, and test activities. Its elements include: evaluation of designs by use of mathematical modeling of systems and verification of proper utilization of parts; evaluation of test results; allocation of system reliability goals to the components of the system; participation in Failure Review Board disposition of problems.

Reliability Prediction:

The forecast of reliability based on analysis and test data obtained prior to actual mission experience.

Request for Proposal:

A formal request from DOE to prospective contractors to submit proposals or bids on a prospective contract.

Single Event Failure:

A failure mode requiring the occurrence of one and only one event that causes failure.

Single Point Failure:

Any failure which alone would cause loss of mission.

Stress Derating:

The design practice of stressing components at less than their rated values in order to increase reliability.

Subcontract:

An instrument or purchase order entered into under a Government prime contract with a supplier. It may include orders issued to activities or subdivisions within the supplier's organization.

Subcontractor:

The individual(s) or concern(s) who enter into a contract or purchase order under a Government prime contract.

Supplier:

A contractor or subcontractor actually performing the services or producing the contract articles.

APPENDIX B
LIST OF ACRONYMS

APPENDIX B

ACRONYMS

DOE	Department of Energy
FMECA	Failure Modes, Effects, and Criticality Analyses
FRB	Failure Review Board
GSE	Ground Support Equipment
MUS	Manufacture-to-Use Sequence
QA	Quality Assurance
RFP	Request for Proposal
RPP	Reliability Program Plan
SPF	Single Point Failure(s)