JUN 1 1968

ANSE DOC. NO. 6300-014
APRIL 25, 1966

SNAP-27 RELIABILITY MEASUREMENT PLAN

ADVANCED NUCLEAR SYSTEMS ENGINEERING

GENERAL ELECTRIC

MISSILE AND SPACE DIVISION

Valley Forge Space Technology Center

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ANSE DOC. NO. 6300- 014
APRIL 25, 1966

SNAP-27 RELIABILITY MEASUREMENT PLAN

CONTRACT AT (30-1)- 3535
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SECTION 1.0

SUMMARY

This report establishes the methodology and the plans by which the reliability of the SNAP 27 Integrated Power Unit will be measured. The integrated test program, as defined by The Integrated Test Plan (ERNS 0080-05-01), is satisfactorily balanced in that an adequate quantity of equivalent test missions are being provided for each of the significant mission environments.

Utilizing test data from the integrated test program, the IPU reliability design goal of 0.9950 has the capability of being demonstrated at a confidence level of 60 percent by April 1968. In the event that data from AEC testing of generators 14-18 is provided to GE-MSD, then the IPU reliability design goal will be demonstrated at the 66 percent confidence level.

An Operation Time Control Plan will be implemented to evaluate the effects of thermal cycling/transients on the IPU reliability.

SECTION 2.0

INTRODUCTION

This document fulfills Section 4.2 of the SNAP-27 Reliability Plan, Reference 12.1. The purpose of the Reliability Measurement Plan is to provide the criteria for reliability measurement and to describe the reliability measurement activities which will take place during the course of the SNAP-27 program. It is anticipated that the plan will be updated annually as the program progresses.

The Reliability Measurement Plan has been divided into nine major sections. These sections are:

- 1) System Analysis - A definition of the system for which the integrated test program is evaluated.
- 2) Mission Analysis - A definition of the mission for which the integrated test program is evaluated.
- 3) Evaluation of the Integrated Test Program - The analysis of the test program itself, for the purpose of defining all test data which will be applicable to reliability measurement, for determining the balance of the program relative to the mission parameters, and for determining the degree of confidence with which the test program will allow the reliability design goal to be met.
- 4) Integrated Data System - A description of the mechanized system which handles, processes and integrates all data from testing, inspection, and failure and trouble reporting.
- 5) Failure Analysis - A description of the procedures which are used to analyze all reported failures, recommend corrective action, and assess reliability significance.
- 6) Reliability Status Report - A description of the periodically issued documents which will present current values of measured reliability as the test program progresses.

- 7) Statistical Analysis - A description of possible alternatives and supplements to the statistical methods which are presently included in the plans for reliability measurement.
- 8) Operational Time Control Plan for Time or Cycle Sensitive Items - A description of the plan for minimizing the occurrence of prime equipment wearout prior to or during the mission.
- 9) Conclusions and Recommendations.

SECTION 3.0

SYSTEM ANALYSIS

3.1 DESCRIPTION OF SYSTEM

The SNAP-27 Integrated Power Unit (IPU) System will supply 56 watts of power at end of life to various experiments on the lunar surface for one year. It is a radio-isotope-fueled thermoelectric generator which will be transported to the moon by the Apollo Lunar Excursion Module (LEM). The nuclear fuel will be transported separately during flight and will be inserted into the generator on the lunar surface by one of the astronauts.

The flight hardware for the IPU System consists of the following subassemblies:

- Integrated Power Unit (IPU) - The IPU consists of the GA and the FCA integrated to produce power.
- Generator Assembly (GA) - The GA consists of the heat rejection system, the thermopile, and all components necessary to contain the thermopile and produce electrical energy when integrated with a heat source.
- Fuel Capsule Assembly (FCA) - The FCA consists of a properly encapsulated nuclear heat source and the end plate assembly required for insertion into the generator assembly.

In addition, the LEM Fuel Cask (LFC) will be mounted on the LEM and will contain the FCA during the trip to the moon. The LFC is designed to maintain its structural integrity during the earth re-entry and impact environments which can accompany a mission abort situation.

3.2 RELIABILITY BLOCK DIAGRAM AND MATHEMATICAL MODEL

The following reliability block diagram and mathematical model for the integrated power unit are tailored to fit the test data which will be obtained.

The measured reliability of the thermopile will be based upon the data collected during the engineering development and qualification tests of the generator assembly and the testing of quarter scale power thermoelectric couple module assemblies. It will be assumed that by proper considerations (such as placing four modules in series) an equivalent thermopile is configured. The module test times in a given environment will be added and the result will be divided by four to obtain the duration of equivalent thermopile operation in that environment. The total number of module failures in a given environment equals the number of equivalent thermopile failures for that environment.

The data to be used in measuring the reliability of the generator assembly and heat source minus the thermopile will be obtained from the engineering development and qualification tests of the generator. It is assumed that the simulated and actual heat sources are identical from a reliability standpoint. However, three separate reliability values will be determined for the generator assembly based on the different heat sources—reliability of the generator with the simulated heat source, reliability of the generator with the actual heat source, and finally the reliability of the generator combining data

using both heat sources. It is believed that this approach will detect any statistical significant difference in the influence of the heat source on the generator reliability.

3.3 APPORTIONMENT OF RELIABILITY DESIGN GOAL AND FAILURE MODE AND EFFECTS ANALYSIS

The subject apportionment and analysis will be found in the Reliability Estimate Analysis of the Snap-27 Generator Assembly (Reference 12.2).

SECTION 4.0

MISSION ANALYSIS

4.1 SEQUENCE OF EVENTS

The sequence of events which follows is restricted to the portion of the mission which is considered for reliability measurement purposes. This portion of the mission is that which occurs after the last operation of the Generator Assembly (GA) prior to flight. It is assumed that any failures of the flight hardware which occur prior to this last operation will be detected before launch.

4.1.1 FIELD TRANSPORTATION

The Generator Assembly (GA), the Flight Handling Tool (FHT), the LEM Fuel Cask (LFC), and the Fuel Capsule Assembly (FCA) will be transported from the assembly building at the Eastern Test Range to the launch pad. The LFC and FCA will be transported separately from the other equipment.

4.1.2 PRELAUNCH

The prelaunch phase covers the installation of the GA, FHT, LFC, and FCA in the Apollo Lunar Excursion Module (LEM). The GA, and FHT will be installed separately from the LFC and FCA. The FCA will be installed in the LFC before launch.

4.1.3 LAUNCH

The launch phase begins with the ignition of the first stage launch vehicle engines and ends with earth orbit insertion.

4.1.4 EARTH ORBIT INSERTION

Earth orbit insertion begins after the Saturn IV engine's burning period and ends when acceleration, due to body rotations and atmospheric drag, are below required orbital levels.

4.1.5 EARTH ORBITAL FLIGHT

Earth orbital flight begins when accelerations, due to rotation and atmospheric drag, are initially below required orbital levels and ends with the signal to start the engines for translunar flight.

4.1.6 TRANSLUNAR FLIGHT

Translunar flight begins with the signal to start engine for translunar flight and ends when the vehicle assumes an orbital attitude about the moon.

4.1.7 LUNAR ORBIT

The lunar orbit phase begins when the vehicle assumes an orbital attitude about the moon and ends when the LEM begins to descend toward the lunar surface.

4.1.8 LUNAR DESCENT

Lunar descent is initiated by the signal to fire the retro rockets which take the LEM out of lunar orbit and ends with the successful landing of the LEM on the lunar surface.

4.1.9 LUNAR OPERATION

Lunar operation begins with the successful landing of the LEM on the lunar surface and ends after successful completion of the Integrated Power Unit (IPU) operating life.

The phase includes the opening of the LEM cargo hatch, removal of GA, and FHT from the LEM, installation of the GA on the lunar surface, removal of the FCA from the LFC with the FHT, and installation of the FCA in the GA. The Integrated Power Unit (IPU) consists of the GA, and FCA.

The reliability design goal of 0.995 for the IPU excludes the generator protective circuit portion of the PCU. In addition, this goal applies only to the lunar operation phase from insertion of the FCA in the GA to the termination of the one-year mission.

4.2 MISSION PROFILE AND ALPHA VALUES

From the mission analysis, a Mission Profile, Table 4.1, and Alpha Values, Table 4.2, are developed. The alpha table is prepared directly from the mission profile using the reciprocal of the environmental and operational exposure times.

The alpha table is a mathematical representation of the mission used as a basis for determining the number of equivalent missions that a particular test environment will provide (i.e., it is a table of conversion factors for normalizing test time into equivalent missions). In the absence of accelerated stress testing, the alpha value for a particular component or subsystem would be the reciprocal of the mission exposure time — either environmental or operational.

TABLE 4-1 - MISSION PROFILE

Mission Phase	Success Criteria	Operating Time	Environment	Environment Time
1-Flight	Structural integrity plus no subsequent operating failures which can be attributed to vibration.	non-operating	Vibration	1.6 hours
2-Transient (Start-up)	System provides design output.	one cycle	Thermal/ Vacuum	one cycle
3- Lunar Operation	System provides design output.	8,760 hours	Thermal/ Vacuum	8,760 hours

TABLE 4-2 ALPHA VALUES

Each Equipment	Equipment Identification	Environment and Code																							
		Vibration*				Thermal-Vacuum				Temperature				Pressure				Life							
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Generator Assy-Unfueled	Engrg. Model Nos. 1, 5 6, 7, & 8 and Qual. Unit Nos. 10, 11, & 12	1/1.6							1/8, 760												1/8, 760				
Start-Up								1/1																	
Generator Assy-Fueled	Qual. Unit #13	1/1.6							1/8, 760												1/8, 760				
Start-Up								1/1																	
Thermocouple Assemblies	Quarter Scale Power Modules	1/1.6							1/8, 760			1/8, 760				1/8, 760					1/8, 760				
Start-Up								1/1		1/1				1/1				1/1							

*The mission time indicated (1.6 hours) is the sum of the launch and lunar descent phases of the mission.

Note Each Alpha Value will be utilized in conjunction with the recorded test time or test cycles for each test environment in order to convert this time or number of cycles to the number of equivalent test missions

Each Alpha Value represents, for the specific equipment indicated, the reciprocal of either

- (a) the amount of time, in hours, that a piece of equipment is expected to be exposed to the conditions (Code and Environment) indicated by its position in Table, or
- (b) the number of cycles that a piece of equipment is expected to be exposed to the conditions (Code and Environment) during one flight.

SECTION 5.0

EVALUATION OF THE INTEGRATED TEST PLAN

In order to satisfactorily measure the reliability of the Generator Assembly, it is necessary that a test program be planned and conducted which will produce sufficient testing with equal emphasis on the mission critical environments so that a statistically sound reliability value may be generated. This is the basis on which the Integrated Test Plan (Reference 12.3) for the Integrated Power Unit System was evaluated.

5.1 APPLICABLE TESTS

The tests which are considered acceptable as sources of data for reliability measurement are the Development Tests which involve the testing of the quarter scale power generator modules, the Engineering Test of the Generator Models 5-8, and the Qualification Tests of the Generator Models 10-13. These tests have been analyzed and the expected number of equivalent missions of tests has been calculated. These results are shown in Table 5-1.

TABLE 5-1. NUMBER OF EQUIVALENT TEST MISSIONS

Applicable Tests	Total Duration of Test	Total Expected Number of Missions ⁽¹⁾
Life	130,500 Hours	14.9
Thermal Vacuum	106,000 Hours	12.1
Generator Initiation and Warm-up	$(4 + 4 + 15)5 = 115^{(2)}$ Cycles	115
Vibration	NA	19

- (1) The values in this column have been determined by dividing the Total Test Time or Cycles by the alpha value found in Table 4-2.
- (2) This number has been estimated upon an average of five initiations and warmups for each of the eight Generator Assemblies and the fifteen quarter scale power thermoelectric couple modules. This is felt to be a conservative estimate and will be revised as more data becomes available.

This amount of test data is expected to be accumulated by mid April of 1968. Figure 5-1 and 5-2 present the growth of Life and Thermal Vacuum Test data. Test data resulting from the tests of Generator Models 14-18 have not been included in the estimate since these tests are not under GE-MSD's cognizance; however, if this data is made available, the reliability design goal will be demonstrated at a 66 percent confidence level. Also, the data which will accrue from flight model testing has not been included in the estimate since these tests as yet are not defined, however this data will be included when definition is made.

5.2 BALANCE OF TESTING

From Table 5-1 it can be seen that the testing is well distributed among the critical environments, It may be of value here, to restate the fact that the IPU's mission, which has a reliability goal of 0.995, is to supply the required power in a lunar environment for one year. Thus vibration is not an environment that will influence the attainment of the reliability goal. Nevertheless, it has been included as a critical environment since past history on other aerospace equipment has indicated that this environment often produces failures. Generator initiation or "start up" has been included since there is a possibility that the failure rate of the Generator Assembly may increase as the number of "start up transients" increase. Summing up then, it can be said that the distribution of testing among the critical environments appears to be well balanced; but, if feasible, all AEC test data should be made available to GE-MSD in order to develop higher reliability and greater confidence in the IPU assembly.

5.3 MEASURED RELIABILITY AT END OF PROGRAM (APRIL 1968)

The measured reliability of the IPU at the end of the test program in April 1968, based upon the estimated quantity of test data which is expected to be gathered and using the statistical method presented in Section 8.0 is presented in Table 5-2.

Figure 5-1. Estimated Cumulative Thermal Vacuum Testing of Generator Assembly

Figure 5-2. Estimated Cumulative Life Test of Generator Assembly

TABLE 5-2 RELIABILITY OF IPU

	R _{50%} confidence	R _{80%} confidence
Assuming Zero Failures	0.9999	0.9474
Assuming Zero Failures (With AEC Test Data)	0.9999	0.9631
Estimated Failure Rate	0.9948 ⁽¹⁾	0.9179

(1) This value was taken from Reference 12.2 ANSE Document No 6300-012, Reliability Estimate Analysis of the SNAP 27 Generator Assembly, then using the statistical method of Section 8.0 the reliability at the 80 percent confidence level was calculated.

5.4 DEMONSTRATED CONFIDENCE

The integrated test program will demonstrate the reliability design goal of 0.9950 for the Integrated Power Unit at a confidence level of 60 percent if no failures are encountered in the test program. The design goal was obtained from Reference 12.2. The statistical technique described in Section 8.0 was applied to determine this confidence level.

SECTION 6.0

INTEGRATED DATA SYSTEM

GE-MSD has established and maintains an Integrated Data System which will be adapted to the specific needs of the SNAP-27 Program. This system handles, processes, and integrates all data obtained from testing, inspection, and failure and trouble reporting. Pertinent test data required for reliability measurement of the IPU is indicated in the Alpha Table (Table 4-2). Figure 6-1 shows the data flow from various phases of testing. The availability of the test data is maintained by a historic test results file which contains the information needed to fulfill the applicable requirements.

Figure 6-1. Data Flow for the Development of a Reliability Status Report

SECTION 7.0

FAILURE ANALYSIS AND CLASSIFICATION

The occurrence of an out-of-specification condition during, or as a result of reliability significant testing, that would result in a mission failure or a decrease in the probability of completing a successful mission is cause for a failure analysis. These failures will be analyzed by the SNAP-27 Failure Analysis Board to determine the cause and if possible to eliminate the possibility of a recurrence. Then the failure is analyzed by the Failure Analysis and the Reliability Analysis Groups to determine if the failure should influence the numerical reliability of the item.

This section presents a set of ground rules for the inclusion or exclusion of test failures and mission times in the reliability calculations. It must be realized that certain conditions may exist in a particular situation which may warrant a deviation from these ground rules. These ground rules are:

- a) In order to be used, data (time and/or failure) must be from an applicable valid test from which data was planned to be taken.
- b) Once a decision has been made that the data has come from an appropriate test based on the criteria set up in a), both of the following rules must be applied before it is decided to include the time and/or failures.
 - (1) If the failure would cause the component to exceed its specification, it will be counted.
 - (2) If the failure mode that caused the failure could exist under mission conditions, the failure will be counted.
- c) If as a result of a failure analysis, an item's design is altered to eliminate the possibility of the recurrence of such a failure, then the reliability analyst will eliminate the failure from the system. A decision must then be made as to whether the accompanying test time should also be eliminated. To effectively

implement this decision, an engineering analysis of the design change will be performed to determine if the test data is still valid. If another failure occurs of the same type which has been eliminated, the original and the new one will both be entered into the data system.

SECTION 8.0

RELIABILITY STATUS REPORT

The purpose of the Reliability Status Report is to present a quantitative index of the reliability of the Integrated Power Unit System and each equipment level for which test data is available. This report will:

- Compare reliability status with estimated growth.
- Report the confidence level at which the reliability design goal was demonstrated for the IPU system and equipment levels.
- Describe reliability problem areas in conjunction with the planned corrective action and the increase in reliability that will be achieved by such corrective action.

Each quantitative reliability index will be derived from test data in accordance with this measurement plan.

The Reliability Status Report will be issued bimonthly beginning at the end of July 1966. It will contain mission failure rates and reliability indices at the 50 percent and 80 percent confidence levels.

Each Reliability Status Report will include:

- 1) A brief description of the equipment operation and mission against which reliability is reported.
- 2) The reliability block diagram and reliability equation.
- 3) A summary of the test data sources.
- 4) A table relating the current measured reliability and reliability apportioned design goals for the system and the appropriate measured equipment.

- 5) Growth curves for the system and measured equipment showing measured reliability versus time with the reliability design goal as a fixed line.
The major changes affecting reliability will be indicated on these curves.
- 6) A discussion of potential reliability problem areas including cause, proposed corrective action, date or serial number effectivity, and anticipated effectiveness. Subsequent reports will show the effectiveness by growth curves indicating the introduction of significant changes in design or manufacturing.
- 7) A tabulation showing the failure rates and reliability indices for the system and equipments of the selected configuration (See Figure 8-1).

RELIABILITY STATUS REPORT				DATE _____	
NOMENCLATURE	DRAWING NUMBER	FAILURE RATE		RELIABILITY	
		λ_{C1}	λ_{C2}	R_{C1}	R_{C2}
INTEGRATED POWER UNIT GENERATOR ASSEMBLY THERMOPILE GENERATOR ASSY TESTS 1/4 SCALE POWER MODULE TESTS HEAT SOURCE ELECTRICAL NUCLEAR LEGEND C_1 = 50% CONFIDENCE C_2 = 80% CONFIDENCE					

Figure 8-1. Sample Format - Tabulation of Failure Rates and Reliability Indices

8.1 STATISTICAL TECHNIQUE

The primary statistical technique to be utilized in measuring reliability is described in paragraph 8.1.1. It is based upon the normal approximation to the Poisson distribution. The Bayesian method described in paragraph 8.1.2 will be used as a backup to the primary technique. The Bayesian method will use prior data to provide a more realistic assessment of reliability early in the program. It will also compensate for a lack of sufficient test data at the time of the first flight.

8.1.1 PRIMARY TECHNIQUE

The primary statistical technique was established at GE-RSD approximately eight years ago. It has been successfully used to measure the reliability of a variety of re-entry and recovery vehicles for the Air Force and was recently accepted by the Navy for use in naval ballistic missile programs.

Test data are accumulated and reliability indices are calculated from these data and reported periodically in the Reliability Status Report (RSR). The reliability calculations are performed in accordance with the mathematical model which presents the system reliability as a function of the equipment reliabilities.

Reliability indices are computed at the 50 percent and 80 percent confidence levels for each item of equipment listed in the RSR. These values establish a measure of the mean value of the failure rate (λ_{50}) and the variance.

The following formula is used in the required calculations.

$$\lambda_{ij} = \frac{2N_{ij}}{2N_{ij} + 1} \frac{X_{ij}}{t_{ij}} \quad (1)$$

(specific environment and test code)

Formula (1) gives the failure rate for the i th environment and the j th test code where:

- λ is the failure rate, in failures per mission.
- t is the number of equivalent mission representing a specific number of cycles or amount of test time applicable to one mission.
- X is the number of failures.
- N is the number of serialized equipments tested.
- i is a subscript used to denote environment.
- j is a subscript used to denote test code.

Formula (1) gives the best estimate (50 percent confidence) of the reliability of an item of equipment for a specific test code and environment. A summation over j is required to obtain a failure rate over all test codes for a given environment. Thus

$$\lambda_i = \sum_j \lambda_{ij} \quad (2)$$

Similarly, the best estimate for the over-all equipment failure rate is given by:

$$\lambda = \sum_i \lambda_i = \sum_i \sum_j \lambda_{ij} \quad (3)$$

(over-all test codes and environments for a single item of equipment)

The formula for calculating the upper-bound failure rate at the 80 percent confidence level for a specific environment in which no failures have occurred is:

$$\lambda_{80i} = \frac{K_{80}^2}{t_i} \sum_j \frac{1}{t_{ij}} \quad (4)$$

where $K_{80} = 0.842$

ℓ_i = the number of items in the summation of i for
which $t_{ij} \neq 0$.

If a failure has been recorded in the test data, the following equation must be used to calculate the upper-bound failure rate for a specific environment at the 80 per cent confidence level:

$$\lambda_{80i} = 2\lambda_i + K_{80}^2 C_i + \left[4\lambda_i K_{80}^2 C_i + K_{80}^4 C_i^2 \right]^{1/2} \quad * \quad (5)$$

where

λ_i is defined by Equation (2)

$$C_i = \frac{\sum_j (\lambda_{ij} C_{ij})}{\lambda_i}$$

λ_{ij} is defined by Equation (1)

$$C_{ij} = \frac{1}{t_{ij}}$$

The upper-bound failure rate at 80 per cent confidence for all environments with no failures is

$$\lambda_{80} = \frac{K_{80}^2}{M} \sum_i \sum_j \frac{1}{t_{ij}} \quad (6)$$

(no failures, all environments)

where M represents the number of terms in the double summation for which $t_{ij} \neq 0$.

*See Reference 12.4

The upper-bound failure rate at the 80 percent confidence level for all environments with failure is expressed by the equation:

$$2\lambda_{80} = 2\lambda + K_{80}^2 C + \left[4\lambda K_{80}^2 C + K_{80}^4 C^2 \right]^{1/2} \quad (7)$$

(with failures, all environments)

where

λ is defined by equation (3)

$$C = \frac{\sum_i \sum_j (\lambda_{ij} C_{ij})}{\lambda}$$

A lower-bound reliability index may be calculated from any of the preceding failure-rate equations as follows:

$$R_x = e^{-\lambda x} \text{ where } x = \text{any of the subscripts used with } \lambda \text{ in the preceding equations.}$$

The statistical best estimate and the upper-bound failure rate at the 50 percent confidence level are equal.

8.1.2 BAYESIAN TECHNIQUE

In a reliability measurement program where there is a long period between the beginning of testing and the time when sufficient empirical data is available to develop with confidence anticipated or required reliability levels, the Bayesian approach to reliability measurement has often proven to be an effective statistical method of providing an early quantitative reliability value. This early input often can serve as an important factor when critical program decisions are required. Basically, the Bayesian techniques permit the combining of prior knowledge, as represented by the analytical reliability prediction, with the test data so that all sources of information are used to determine reliability. The analytical reliability prediction is examined for validity by the criteria listed in Table 8-1 and is adjusted accordingly. This prior estimate is now

TABLE 8-1. DEGREE OF CERTAINTY IN PRIOR INFORMATION

τ	Applicability of Available Information
1	1. Informed Qualitative Judgment
3	2. Based Primarily upon Generic Part Handbook Data
5	3. Partly based upon Generic Part Handbook Data; partly upon Similar Part Handbook Data
10	4. Based primarily upon Similar Part Handbook Data
20	5. Partly based upon Similar Part Handbook Data, Partly upon Frequency Data
.1x(f, t)	6. Frequency Data Solely: Similar Parts, Similar Applications
.3x(f, t)	7. Frequency Data Solely: Identical Parts, Similar Applications
.5x(f, t)	8. Frequency Data Solely: Identical Parts, Similar Applications
1x(f, t)	9. Frequency Data Solely: Identical Parts, Identical Applications.

Notes:

1. If a given set of data is "mixed", choose the principal category in the mixture which is weakest (most conservative) in the above list.
2. If there are other factors operative which are not covered explicitly in the above categories, but which it is believed will further reduce the "degree of belief" in the Reliability Prediction Analysis, it will be permissible to choose next lower (next weaker) category. The converse, (upgrading in the presence of additional "positive" factors) will not be permitted.

converted into a number of pseudo-equivalent missions and pseudo-failures which are combined with the actual equivalent missions and failures. The use of Bayes' Theorem in measuring the reliability of the IPU is particularly applicable, since due to the long mission requirement, there will be few equivalent missions of test data available early in the program or, for that matter, even at the end of the program. Thus, the application of Bayes' Theorem should help in realistically determining the IPU reliability. The approach that will be taken will be to provide two sets of reliability figures — the first one will be developed from the classical statistical methods described

in paragraph 8.1.1; the second number will use the Bayesian approach. A discussion of the way Bayes' Theorem will be applied to the SNAP 27 Program and its integration into the previously discussed statistics follows.

8.1.2.1 Bayes' Theorem

For reliability purposes, Bayes' Theorem is

$$P(\lambda/B) = P(\lambda) \frac{P(B/\lambda)}{P(B)} \quad (8)$$

that is, the probability of the event λ , given that the event B has already occurred (left side of the equation) is equal to the probability of λ with no knowledge about B; times the probability of the event B given the occurrence of λ , divided by the probability of B in the absence of any other information. $P(B)$ is often hard to directly define; however, it can be written for the continuous case as

$$P(B) = \int_{\lambda} P(B/\lambda) f_p(\lambda) d\lambda \quad (9)$$

Now, in order to be able to combine the prior estimate with the statistical method previously presented, the following tack is taken:

$$P(\lambda) = \frac{(e^{-\lambda \tau}) (\lambda \tau)^{\phi - 1} d\lambda}{(\phi - 1)!} \quad (\text{Gamma Prior Distribution}) \quad (10)$$

$$P(B/\lambda) = \frac{e^{-\lambda} t (\lambda t)^f}{f!} \quad (\text{Poisson Likelihood Distribution}) \quad (11)$$

Making the appropriate substitutions (8) becomes

$$P(\lambda/B) = \frac{(t + \tau)^{\phi + f} \left[e^{-\lambda (t + \tau)} \lambda^{\phi + f - 1} d\lambda \right]}{\phi + f - 1!} \quad (\text{Gamma Posterior Distribution}) \quad (12)$$

where:

t = accumulated test time (equivalent missions)

τ = pseudo test time (equivalent missions)

f = actual failures

ϕ = pseudo failures

Comparing the posterior probability (equation 12) with the prior probability (equation 10) we see that they are of the same form (gamma function) but t has been added to λ and f has been added to ϕ . The mean and variance of these compare as follows:

	Prior Distribution	Posterior Distribution
Mean	$\frac{\phi}{\tau}$	$\frac{\phi + f}{\tau + t}$
Variance	$\frac{\phi}{\tau^2}$	$\frac{\phi + f}{(\tau + t)^2}$

The estimated means and variances of the individual distributions can be summed to determine the estimated system mean and variance. With these parameters as input, the system failure can be computed as follows:

$$\hat{\lambda} = \hat{\lambda} = \sum \frac{\phi + f}{\tau + t}$$

$$\lambda_u = \hat{\lambda} + K^2 C + (4\lambda K^2 C + K^4 C^2)^{1/2} \div 2$$

where:

$$C = \frac{\hat{\sigma}^2}{\hat{\lambda}} = \frac{\sum \hat{\sigma}_i^2}{\sum \hat{\lambda}_i} = \frac{\sum \left[\frac{\phi + f}{(\tau + t)^2} \right]}{\sum \left(\frac{\phi + f}{\tau + t} \right)}$$

K = Normal deviate for desired confidence level

Thus, we are now able to combine the prior reliability estimate with the empirical data. A comparison of the measured reliability, which was presented in paragraph 8.1.1, using classical statistics and the above Bayesian method is presented in

Table 8-2. It should be pointed out that the prior estimate will be evaluated each time the reliability is calculated and if not in agreement within preset statistical limits with the test data, the prior will be eliminated.

TABLE 8-2. MEASURED RELIABILITY COMPARISON OF THE IPU

	Classical Statistics		Bayesian Statistics	
	R ₅₀	R ₈₀	R ₅₀	R ₈₀
Assuming Zero Failures	0.9999	0.9474	0.9999	0.9654
Assuming Estimated Failure Rate	0.9948	0.9179	0.9948	0.9556

It should be pointed out that the prior estimate will be evaluated each time the reliability is calculated and if not in agreement within preset statistical limits with the test data. The prior will be eliminated.

SECTION 9.0

STATISTICAL ANALYSIS

Statistical analysis will be performed on variable test data to supplement the reliability analysis of attribute and failure rate data and to provide additional insight into problems requiring statistical evaluation. A brief outline of areas of the SNAP-27 Program that may require statistical analysis and the methods which would be applied are presented in this section.

9.1 RELIABILITY MEASUREMENT

Variable statistical methods possess, in some instances, greater efficiency when applied to performance data, as contrasted with attribute or failure rate data; therefore, appropriate statistical methods will be used as back up for the failure rate approach described in Section 8.0. When the amount of data is limited, failure rate estimation methods can not always provide statistical estimates which indicate that the hardware has met required reliability/confidence goals. In this instance, the variables estimates will be used. These analyses will include distribution tests to confirm the probability distributions used.

The principal statistical methods to be used include: Analysis of Variance, Regression/Correlation Analyses, Statistical Tolerance Limits, and Error Propagation.

9.2 ANALYSIS OF SNAP 27 PROGRAM TESTS

Reduction of test data into a statistical format is an excellent method for meeting the criterion of validity of Section 3.0, Reference 12.3. Furthermore when used in conjunction with the design of experiments, the amount of observations may be pooled for the experimental error factor which cannot be done on a subjective basis.

To meet the criterion of timeliness, computer programs are available for reducing the analysis time; included are regression, both simple and multiple; and simple frequency distribution analysis which is combined with moment tests of normality.

9.3 INSTRUMENTATION VARIATION

The error due to this variation will be estimated. From a statistical viewpoint the elimination of instrumentation variation must lead to higher reliability/confidence estimate.

9.4 APPARENT 'MAVERICK DATA'

These data may be eliminated with statistical extreme value tests provided of course operational tests or strong engineering judgments parallel the statistical results.

SECTION 10.0

OPERATIONAL TIME CONTROL PLAN FOR TIME OR CYCLE SENSITIVE ITEMS

Time sensitive components may be operated for an excessive duration or amount of times during all phases of assembly, test and pre-flight checkout so that their useful life is expended prior to completion of the mission; that is, "wearout" type failures rather than purely random failures may start to occur.

To prevent such occurrences during the mission of the SNAP 27, an Operating Time Control System will be followed. This system requires that each time sensitive component have its operating time or number of cycles, whichever is critical, recorded during all phases of assembly, test and preflight checkout. To assist in accumulating this data, the Reliability Semi-monthly Data Report will be used. This standard computer run-off should provide the following information—component identification by drawing number and serial number, duration of test, type of test and the date of test.

There are two areas of the SNAP 27 Program where a time control system will be of value. The first is the number of "start ups" of the IPU — since there is a possibility that the reliability of the Generator Assembly will be decreased as the number of times the unit is started. This may be due to the repeated thermal cycling of the assembly. The second area is the amount of time and cycles that the individual thermocouples are operated. In this instance there is also a possibility of the reliability of the thermocouple being degraded.

When sufficient information is derived from the test program to set operating or cyclic limits, this limit will be apportioned among the various assembly, checkout, and operational phases that the Generator Assemblies will experience throughout their life. Then if prime equipment undergoes testing which exceeds these limits a thorough evaluation of the situation and the Generator Assembly will be performed by Engineering, Reliability, Quality Control, and the Program Office.

SECTION 11.0

CONCLUSIONS AND RECOMMENDATIONS

11.1 CONCLUSIONS

The integrated test program appears to be well balanced in that an adequate number of equivalent test missions will be provided for each of the significant test environments (See Table 5-1).

The integrated test program has the capability of demonstrating the reliability design goal of 0.995 for the generator assembly at a confidence level of 60 percent if zero failures are assumed. The design goal for the generator assembly was obtained from Reference 12.2. The statistical technique described in Section 8.0 was used to determine the demonstrated confidence value.

11.2 RECOMMENDATIONS

1) While the Integrated Test Program is well balanced in its emphasis on testing different environments, the number of equivalent missions of testing should be increased in order to gain increased confidence in the reliability of the IPU. This necessary increase in test data can be achieved if the AEC makes available to GE-MSD the results of their tests on Generator Assemblies Nos. 14, 15, 17, and 18.

2) Institute a time/cycle control plan which will monitor the cumulative operational time/cycles on sensitive items so that there will be no possibility of reliability deterioration prior to the beginning of the mission.

SECTION 12.0

REFERENCES

- 12.1 SNAP-27 Reliability Plan, General Electric ANSE Document No. 6300-013, dated 28 February 1966.
- 12.2 Reliability Estimate Analysis of SNAP-27 Generator Assembly, General Electric Document No. 6300-012, dated 18 February 1966.
- 12.3 Integrated Test Plan for the Integrated Power Unit (IPU) System for the Apollo Lunar Surface Experiment Package (ALSEP), General Electric Specification No. ERNS 0080-05-1, Revision A dated 11 February 1966.
- 12.4 Mathematical Techniques for Demonstrating System Reliability, General Electric Report No. 63SD327, dated 1 December 1963.

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