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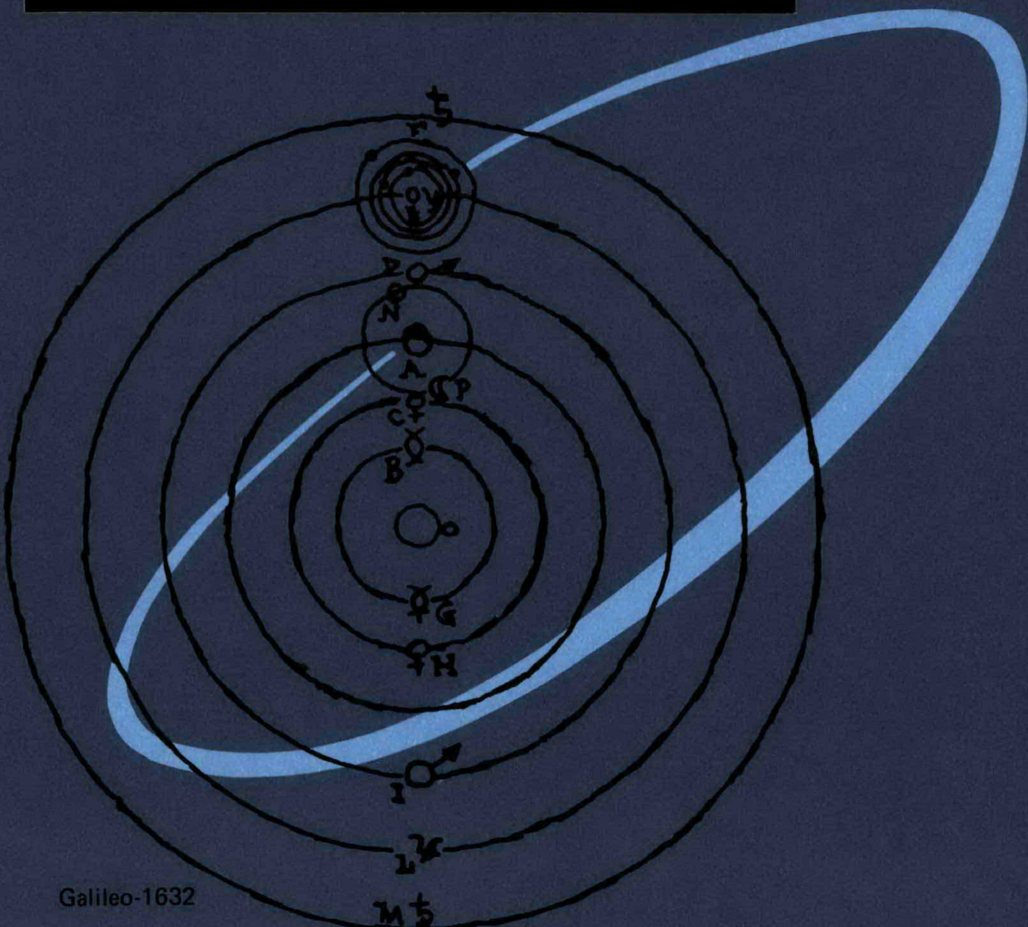
MASTER

SELENIDE ISOTOPE GENERATOR

for the

GALILEO MISSION



Galileo-1632

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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.

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SELENIDE ISOTOPE GENERATOR

for the

GALILEO MISSION

SIG/GALILEO CONTRACT COMPLIANCE
POWER PREDICTION TECHNIQUE

TES-2865-22

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Prepared by: T. E. Hammel
T. Hammel

V. Srinivas
V. Srinivas

Approved by: W. Brittain
W. Brittain

TELEDYNE ENERGY SYSTEMS
110 W. TIMONIUM RD., TIMONIUM, MD. 21093
PHONE: 301-252-8220 TELEX: 8-7780 CABLE: TELISES

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SIG/GALILEO CONTRACT COMPLIANCE POWER PREDICTION TECHNIQUE

Introduction: The technique for predicting the reliability-power mean and probability distribution function characteristics of the SIG RTG as a function of mission time is based on the combination of two models. The models are identified as the catastrophic model (probability that the RTG has not failed) and the degradation model (probability that a given power output is achieved for any time within the mission.) The method for obtaining the probability distribution function for either of the models and for combining the models is based on the Monte Carlo method.

In this first report related to the development of the prediction technique, only the degradation model is addressed. The emphasis is placed on this model since it requires extensive and early interaction with efforts to be generated by the 3M Co.

Objective: To formulate a procedure for predicting SIG/Galileo mean EOM power and its probability density function utilizing TES component test data and the thermoelectric degradation data generated during the 3M Company's module power degradation demonstration test program. This technique is prepared in compliance with CDRL Item No. B-11 (Attachment III to Appendix A of Contract ET-78-C-01-2865) and requires submittal to DOE with updates at six-month intervals throughout the program.

Conclusion: To predict the SIG EOM power, TES will utilize 3M-supplied data on the variations of total module heat flow (Q_{Module}) and the mean

T/E module output power degradation ($\gamma = P(t)/P_o$) as functions of mission time, and the hot junction (T_H) and the cold end hardware (T_{CEH}) frame base temperatures. Details of this data are described herein. The prediction technique utilizes a significant amount of data which will be generated by the 3M Co. Thus, early agreement on the model elements and the method of presenting the input data to the model are required.

Discussion: The SIG/Galileo statement-of-work calls for TES to prepare a prediction technique and predict RTG mean EOM power and its distribution. The thermoelectric module degradation data obtained during 3M's test program will be employed as key inputs to this prediction. The objective of this study is to formulate the degradation model, a portion of the overall power prediction technique. This initial definition of the power degradation prediction technique outlines a model whose current use is for mean EOM power calculations; the model will be expanded in the future to consider the reliability catastrophic model portion of the overall prediction technique.

Utilizing the data generated during their module power degradation demonstration test program, 3M will predict the variations of Q_{Module} and γ and their distributions with mission time. Since the module HJ and CEH temperatures are also affected by the degradation of RTG components other than the T/E modules, 3M should consider the HJ and the CEH frame base temperatures parametrically. TES will initially perform analyses to predict the variation with mission time of Q_{Module} due to degradation of all

RTG components except the T/E modules. TES will consider the HJ and the CEH frame base temperatures parametrically. The final phase, which will be performed by TES, is one of iterating between TES' and 3M's predictions of total module heat flow history, and determining, for the total system, the variations of total module heat flow, and the HJ and the CEH frame base temperatures as functions of mission time. Using the above HJ and CEH frame base temperature histories and 3M's parametric prediction of γ, the mean EOM power will be predicted.

A flow chart of the calculation procedure described above is shown in Figure 1.

3M's Module Test Program and Analysis

Fifteen modules will be tested at five different temperature levels to obtain an Arrhenius type relationship between the module power degradation and temperature (Reference 1). Utilizing the data obtained in the above test, the temperature and the duration of the accelerated life test will be determined. Twenty-four modules will then be placed on life test at the elevated temperature for the duration selected to determine the distribution of power about the mean.

Using the data generated during the accelerated life test and the Arrehenius type relationship between the power degradation and temperature, 3M will predict the variations of $\gamma(\gamma = P(t)/P_o$, where P(t) is the mean power at a given time and P_o is the mean BOL power) and Q_{Module} as functions of mission time. In order to perform the above calculations, 3M will require the HJ and CEH frame base temperature histories. Since these temperatures vary not only because of the thermoelectric module degradation but also due to degradation of the other RTG components (such as fuel decay, insulation degradation, emissive coating degradation, etc.), 3M will treat the HJ and CEH frame base temperatures parametrically. The ranges of these temperatures considered at any mission time should be large enough to encompass the corresponding temperatures expected for the total system. For example, T_H should range from 900°C to 800°C in 10°C increments, and T_{CEH} should cover a range corresponding to cold junction temperatures of 175°C to 135°C in 10°C increments. Data should be provided for a sufficiently large number of mission times so that system degradation can be realistically predicted as a continuous function of mission time. The above described data can be provided to TES in tabular form.

In calculating the variations of Q_{Module} and γ with mission time, 3M should consider including any relevant thermoelectric degradation data generated at JPL and General Atomics. Data obtained with individual elements, couples and modules should be included, if applicable.

TES Analyses

TES will initially predict the variation of Q_{Module} with mission time due to degradation of all RTG components except the thermoelectric modules (i.e., TES will determine the variation of all non-module heat losses with time). The analyses will consider the following effects:

(1) Fuel decay

(2) Insulation (non-module (side and end)) degradation

(3) Heat pipe performance degradation

(4) Emissive coating degradation

(5) Variations of solar and planetary IR fluxes due to:

(a) variations of sun-spacecraft and planet-spacecraft distances

(b) spacecraft/RTG orientation.

Here again, the HJ and CEH frame base temperatures, which are also affected by the T/E module degradation, will be considered parametrically.

The next step in the power prediction technique is to iterate between TE [illegible] and 3M predictions of the variation of Q_{Module} as a function of mission time, and the HJ and CEH frame base temperatures and to estimate for the total system the variations of Q_{Module} and the HJ and the CEH frame base temperatures as functions of mission time. The above iterative process is schematically illustrated in Figure 2. A unique point can be located on each plot for which total module heat flow, and the HJ and the CEH frame base temperatures are the same. Such a unique pair of points would represent the conditions for the total system. The iteration described above would be repeated at different mission times, and a plot showing the variation of Q_{Module}, and the HJ and CEH frame base temperatures with mission time would be made.

The last step would be to predict, for the total SIG system, the mean EOM power utilizing the HJ and the CEH frame base temperature histories obtained as described above and 3M's prediction of the variation of the mean normalized power (γ) as a function of mission time and the HJ and the CEH frame base temperatures. This step is illustrated in Figure 3 with an example of how the net power degradation over the entire Galileo mission is treated. The total time shown is 58,760 hours after fueling and the hot junction profile shown is the following:

BOL: $T_{HJ} = 860°C$

BOL → 1/2 year: $T_{HJ} = 860°C$

1/2 year → 1 year: $T_{HJ} = 850°C$

1 year → 1-1/2 years: $T_{HJ} = 840°C$

1-1/2 years → 5 years: $T_{HJ} = 830°C$

A realistic hot junction profile as derived in Figure 2 is treated via a computer solution which uses much finer T_{HJ} and time steps than shown on Figure 3. Using the Figure 3 approach, with a small enough step size, γ is determined as a function of mission time, so that SIG power is available as a function of mission time along with EOM power. Along with γ, the TES/3M BOL power prediction is used to generate these power data.

Reference: (1) Resser, L. L., "Selenide Thermoelectric Module Power Degradation Demonstration Test, Task 10.3 e, "SIG-LLP-1476, dated August 22, 1976.

FIGURE 1

FLOW CHART OF SIG/GLL POWER PREDICTION TECHNIQUE

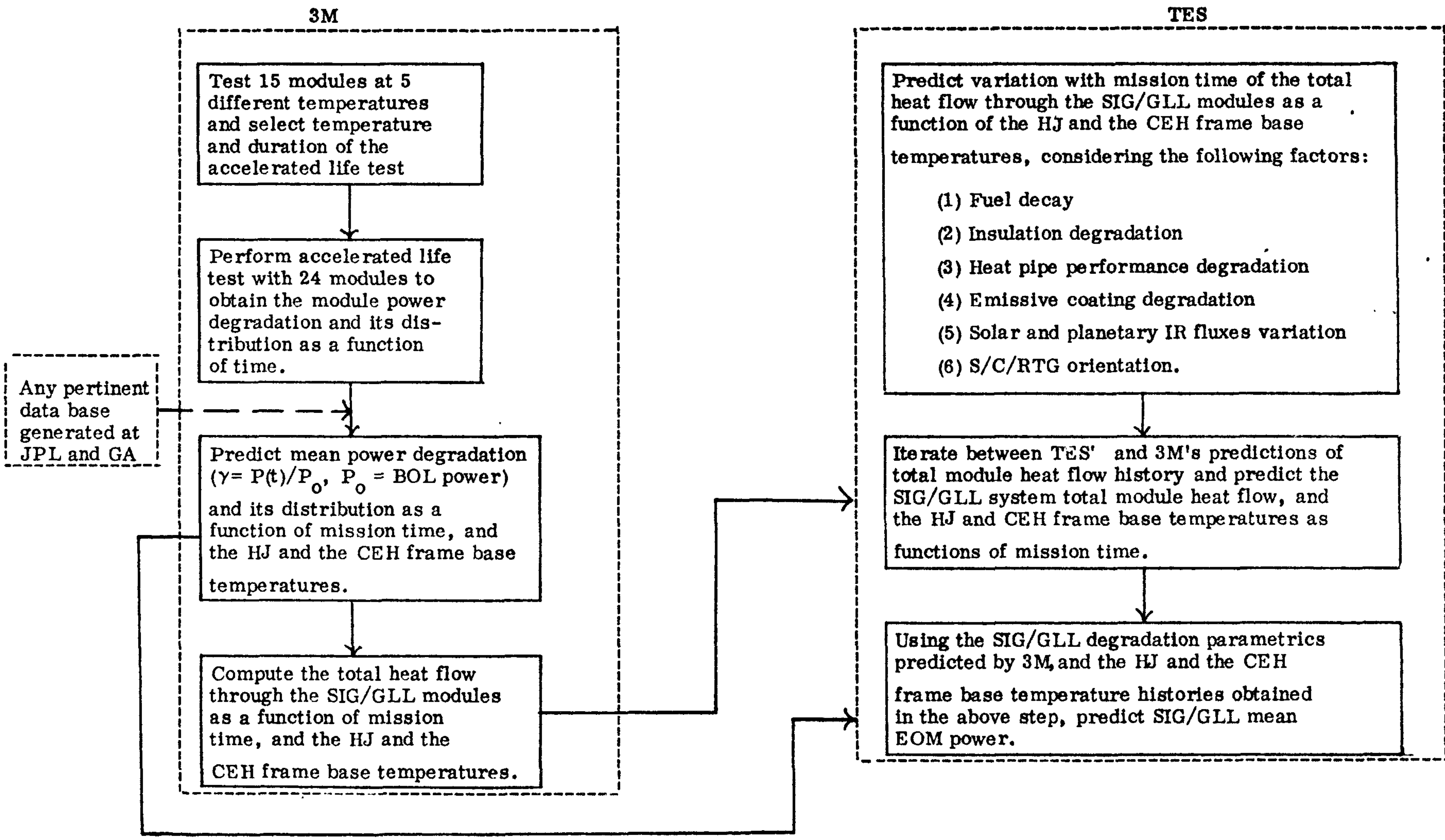

FIGURE — SCHEMATIC ILLUSTRATION OF ITERATION FOR Q_{Module}

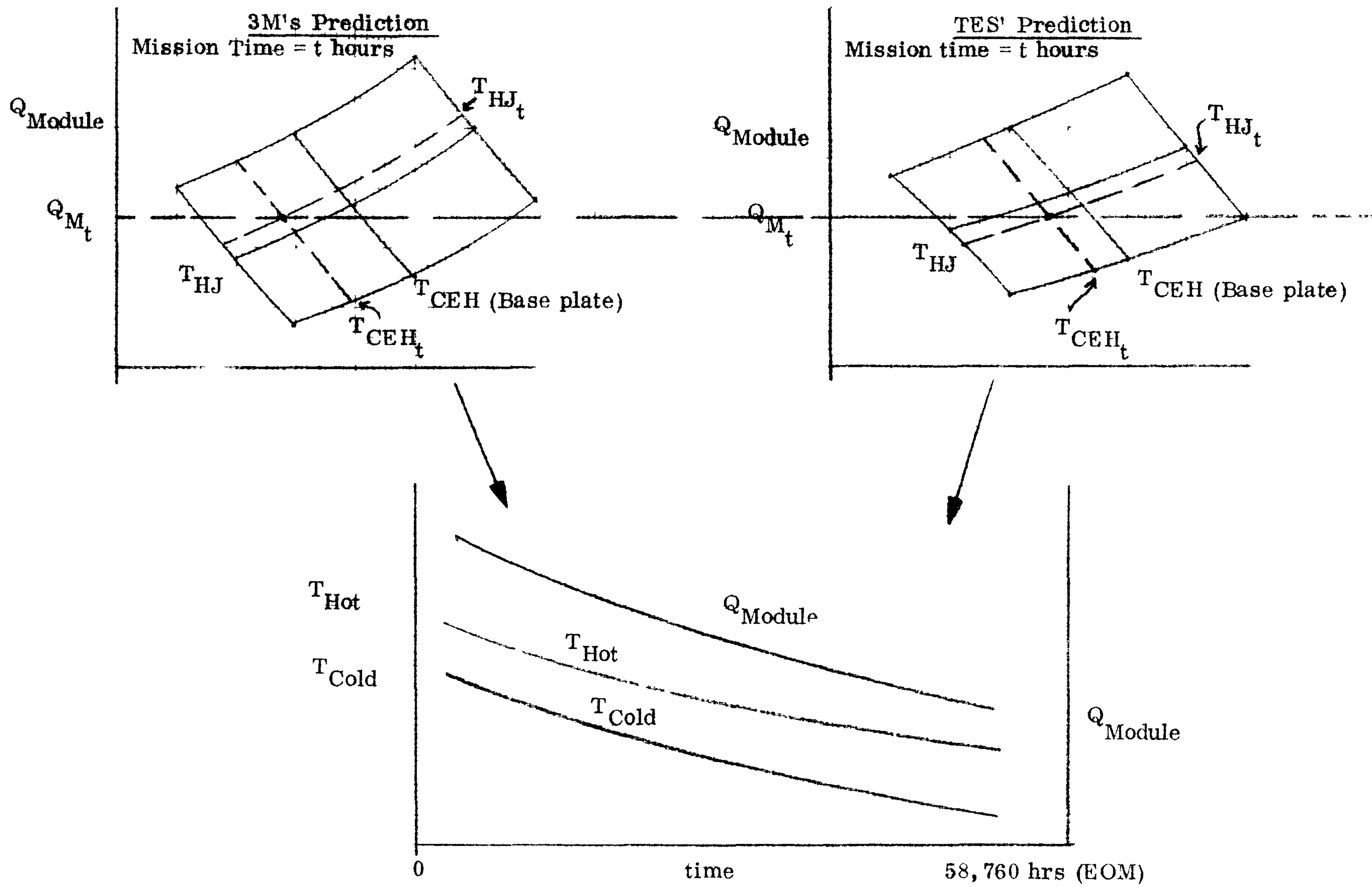

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FIGURE 3: SCHEMATIC ILLUSTRATION OF DETERMINATION OF MEAN [illegible] FROM 3M's DEGRADATION (γ) HISTORIES