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ECONOMIC RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG) STUDY

FINAL REPORT

VOLUME II -

DEVELOPMENT PLAN

JH8

DISCLAIMER

FOREWORD

This is the final report for the project entitled, "Economic Radioisotope Thermoelectric Generator Study". The final report is presented in two volumes; Volume I - ERTG Design and Volume II - Development Plan. This study was performed for the Space Nuclear Systems (SNS) Division, U. S. Atomic Energy Commission, Germantown, Maryland, under Contract AT(04-3)-940. Mr. R. T. Carpenter was the ERTG Study Manager. Mr. Carpenter's efforts in providing technical direction and consultation during the performance of this study are gratefully acknowledged. Likewise, Mr. R. A. DuVal - AEC San Francisco Operations Office - is gratefully acknowledged for his participation in program reviews.

The work reported herein is the result of a team effort by personnel from the Westinghouse Astronuclear Laboratory, Westinghouse Research and Development Laboratory, Westinghouse Product Integrity Laboratory, AVCO Systems Division, Dynatherm Corporation and Oak Ridge National Laboratory. The Westinghouse Astronuclear Laboratory was responsible for the ERTG system design and integration as well as providing program direction to supporting laboratories and subcontractors. Mr. W. G. Parker was the Westinghouse Program Manager. The principal contributors and their specialties areas from the Westinghouse Astronuclear Laboratory were:

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R. E. Lowder, Manager, Product Assurance
J. W. Niestlie, Manager, Project Management
D. R. Roberts, Manager, Thermoelectric Programs
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J. W. H. Chi, Heat Pipes/Thermal Design

H. D. Coe, Jr., Mechanical Design
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J. E. Faulkner, Safety/Shield Analysis
E. H. Hemmerle, Safety Analysis

Support in the area of DC/DC converter design and analysis was received from the Westinghouse Research and Development Laboratory through the efforts of Dr. P. F. Pittman and Dr. R. J. Ravas and from the Westinghouse Product Integrity Laboratory through the efforts of Mr. C. Karr.

AVCO Systems Division, under subcontract to Westinghouse, provided the expertise in reentry body design and analysis. In addition, timely recommendations and guidance were provided with respect to system/spacecraft integration considerations. Mr. P. Levine was the Project Engineer from AVCO.

Dynatherm Corporation, under subcontract to Westinghouse, provided the expertise in low and high temperature heat pipe design and analysis, as well as guidance in heat rejection system design/integration. Mr. E. Kroliczek and Mr. W. Bienert were the Project Engineers from Dynatherm.

The efforts of personnel at the Oak Ridge National Laboratory for their contribution to the heat source design, heat source development program, and for providing shielding consultation are gratefully acknowledged. In particular, Mr. E. Lamb, Mr. K. W. Haff and Mr. C. L. Ottinger provided valuable guidance and consultation.

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1.0 INTRODUCTION

The Space Nuclear Systems Division (SNS), Atomic Energy Commission (AEC) is evaluating various electrical power system technologies for use in the development of an Economical Radioisotope Thermoelectric (or Thermodynamic) Generator (ERTG) that best fulfills the System Performance Objectives specified by the United States Air Force (USAF). This final report presents the results of the Economical Radioisotope Thermoelectric Generator (ERTG) Study utilizing the tubular thermoelectric module technology developed by Westinghouse under prior AEC contracts. The objectives of this study were:

- To develop and evaluate an ERTG design for a high power, Curium-244 fueled system based on the tubular thermoelectric module technology.
- To prepare a program plan for the development of a flight qualified ERTG.
- To estimate the costs associated with the production of one, ten and twenty flight qualified ERTG's.

The final report is presented in two volumes; Volume I - ERTG Design - presents the ERTG Design approach which best utilizes the attributes of the tubular thermoelectric module technology, and Volume II - Development Plan - presents the program plan for developing and producing flight qualified ERTG's based on the Second Generation ERTG Design.

This volume summarizes the program plan for developing and producing flight qualified ERTG's. The information presented explains what will be accomplished and when, in relation to the overall technical and management effort - defining a program geared to the design, development, qualification, and delivery within six years of ERTG hardware satisfying specified USAF performance objectives (see Section 1.2, Volume I). In addition, cost estimates are supplied for producing ten and twenty follow-on ERTG units based on the Second Generation ERTG Design.

The program has been divided into five phases; each phase encompassing a well-defined period in the evolution of the ERTG from concept to flight-qualified hardware. The program phases are:

- Phase 1 - ERTG Reference Design and Development Planning
- Phase 2 - Technology Development and/or Component Demonstration
- Phase 3 - System Development and Qualification
- Phase 4 - Flight System Fabrication
- Phase 5 - Follow-on Production

Phase 1 has been completed with the issuance of this final report.

Phase 2 is the cornerstone of the recommended development and production plan, since from this phase will evolve technology developments and component demonstrations which will be the basis for the ensuing system development and qualification effort. Therefore, greater detail in task definitions has been provided for the Phase 2 effort than for subsequent phases of the program. The total program has been evaluated in sufficient depth, however, to be assured that the Second Generation ERTG can meet all program objectives that have currently been defined and can be developed within the time schedule and cost estimate contained in this document. The development plan has been prepared in accordance with the program phase definition and program guidance provided by the SNS Design Study Program Manager. This guidance is included as Appendix A.

The planned effort will be performed at the Westinghouse Astronuclear Laboratory located 15 miles south of Pittsburgh, Pennsylvania, on Route 51. (The address is P. O. Box 10864, Pittsburgh, Pennsylvania 15236). The only exceptions will be:

- Technical support provided by government agencies.
- Technical support provided by subcontractors reporting to and directed by the Westinghouse Project Manager. Avco Systems Divisions (Avco Corporation, Wilmington, Massachusetts) and Dynatherm Corp. (Cockeysville, Maryland) are identified as subcontractors.

- Technical support provided, as required, from the Westinghouse Research Laboratories, the Manufacturing Development Laboratory, and the Product Cost Laboratory.

The Second Generation ERTG system proposed for development is described in Section 3.0, Volume I of this report. In addition, the Reference Design ERTG, based on state-of-the-art tubular thermoelectric technology, is described in Section 2.0, Volume I. The Reference Design ERTG is discussed in the context of the Development Plan as the "back-up" system.

Section 2.0 presents the Development Plan, while the production schedule is given in Section 3.0. The specific areas of government and contractor support identified above are described for the individual program phases discussed in the sections that follow. In addition, cost estimates are provided for each phase. The cost estimates are based on our current (1973) rates and include a 7.5% fee; no provision for adjustment of these rates over the duration of the ERTG development and production program has been included. In addition, Westinghouse burden has been applied to the AVCO and the Dynatherm cost estimates.

2.0 ERTG DEVELOPMENT PLAN

The recommended program for developing the ERTG has been planned in four major phases in accordance with the guidelines given in Appendix A. The principal phases, including production, are shown in Figure 2-1. The proposed program is predicated on prompt decisions at the completion of each phase to initiate the follow-on phase. With this continuity, the basic development program will be completed by mid-1975, permitting delivery of flight-qualified ERTG systems for an initial flight date of September 1979.

This development plan has been prepared with emphasis on utilizing technology developments from ongoing AEC sponsored programs and thus minimizing the development dollars required on the ERTG program. In particular, the FY-74 Compact Thermoelectric Converter Program and the previous Compact Thermoelectric Converter Systems Technology Program are illustrations.

Potential improvements in tubular module technology have been initiated as part of the FY-74 Compact Converter Program. In particular:

- Incorporation of "azimuthally segmented" thermoelectric washers into the tubular module design to increase the module output voltage to 30 volts, thus eliminating the need for DC-to-DC voltage conversion.
- Continued development of improved thermoelectric materials to replace the state-of-the-art lead tellurides used in the ERTG Reference Design.

Work performed during GFY-73 indicated that thin film electron beam vapor deposited (EBVD) tungsten on phlogopite mica is as effective a means for controlling tellurium transport, hence module degradation as the use of tungsten foil. The shunt heat losses associated with the use of the thin film barriers are low and allow the consideration of axially thinner washers and hence increased module voltage.

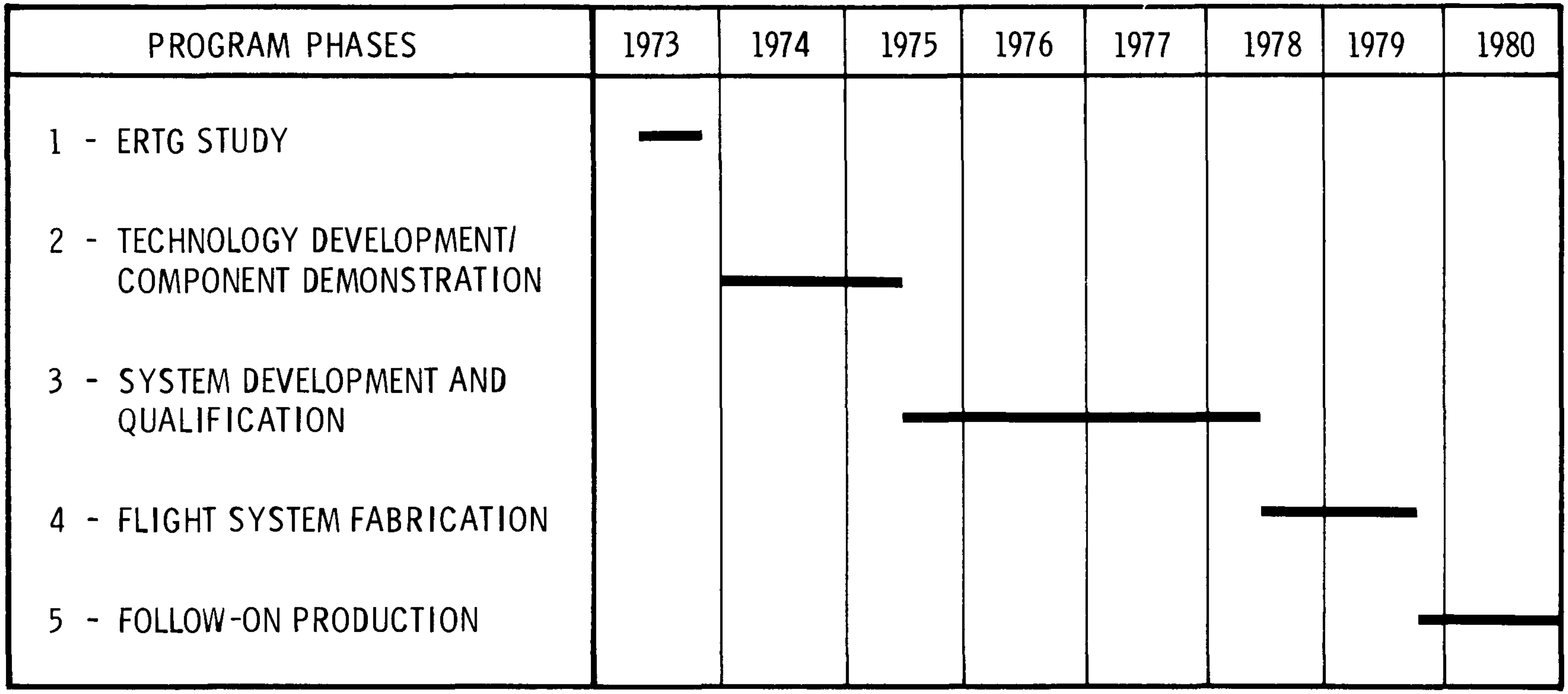

Figure 2-1. ERTG Program Schedule

Azimuthal segmentation of thermoelectric washers is a technique which can be used to produce substantially higher module voltages. In this configuration, the conventional thermoelectric washer is divided into a number of pie-shaped segments. The voltage, then, is increased by a factor equal to the number of segments. As part of the FY-74 program, the existing tubular module performance computer code, TEMOD, is being modified to allow analysis of the performance of a tubular module incorporating azimuthally segmented thermoelectric washers. A trade study is being performed to study the relationship between the number of axial sections per unit length and number of azimuthal segments per axial section on module performance. In addition, the design and fabrication implications associated with azimuthal segmentation is being investigated and a conceptual design of a generator incorporating azimuthally segmented washers is underway.

The FY-74 program includes specific tasks to continue evaluation of improved thermoelectric materials. The investigation of conversion efficiency improvements in tubular modules through the use of ternary thermoelectric materials is being continued. Installation and checkout of equipment required for ternary material preparation, p-type (APX-10) specimen fabrication and evaluation (Seebeck-resistivity measurements and Seebeck voltage probe measurements), capsule fabrication and testing, and data acquisition and reduction is underway. Material experiments are being conducted to allow a determination of the optimum p-type material heat treating procedures, APX-10/tungsten interaction and APX/molybdenum interactions. Similar experiments were completed during GFY-73 using n-type ternary material.

In addition, TEM-15P S/N-1 (a sublength technology module) heatup data are being analyzed to determine the in-module p-type ternary material thermal conductivity and electrical resistivity - temperature relationships.

A new class of high efficiency thermoelectric materials (designated TPM) is currently under development at 3M Company and preliminary evaluations are being conducted as part of the FY-74 program. A study is being performed to determine the feasibility of incorporating these materials into the tubular module. Problems associated with operation of the module in the high temperature range necessary to utilize the full potential of the TPM materials are being

identified. A mathematical model for determining the performance of a TPM/tubular module is being generated. The model will include the effects of dopant drift due to current flow on thermoelectric material properties. Westinghouse, as part of this effort, is working closely with the 3M Company relative to obtaining pertinent materials characterization and behavior data and to identifying areas of technology development required before serious consideration of incorporating the 3M material into a thermoelectric converter is warranted.

We have structured the Phase 2 - Technology Development - portion of the ERTG program to be complementary with the FY-74 Compact Converter Program discussed above. The schedular marriage of these two programs is indicated in Section 2.1. We are confident that a tubular module incorporating ternary thermoelectric materials, azimuthally segmented washers, and thin film diffusion barriers can be demonstrated during the eighteen months allotted for Phase 2. Phase 2, therefore, includes the necessary module development tasks.

We also believe that the TPM thermoelectric materials can be incorporated into a thermoelectric converter given adequate development dollars and time. A reassessment of a TPM/tubular module on the basis of the FY-74 compact converter program results, therefore, will be performed prior to committing to the full development of a ternary module. If these results are encouraging with respect to near term development of a TPM/module, then the development problem areas identified would be substituted, if desired, along with appropriate funding adjustments, for the task identified in Phase 2 for a ternary module.

The Phase 2 development plan has also been devised to increase confidence in those areas of the ERTG Design that can be considered component or processing demonstrations rather than technology developments. The intent has been to structure the minimum level program effort necessary to verify critical components and system interfaces in the ERTG Design.

Subsequent phases of the proposed program follow conventional phase-by-phase evolution to flight hardware through prototype design, testing, and qualification efforts. Summary descriptions of the major activities in each phase of the development program follow. A description of specific tasks for each phase is given including definition of subcontractor tasks and, where applicable, the requested government furnished support. A cost estimate for each task is presented.

2.1 PHASE 2 - TECHNOLOGY DEVELOPMENT AND COMPONENT DEMONSTRATION

The primary objective of this phase of the program is to develop and/or demonstrate the component technologies requiring emphasis prior to the time that a decision would be made to embark on an ERTG flight system development program. This phase of the program is therefore structured to provide the essential technical data relating to component development/component verification, system interface performance verification, and materials and subsystem processes development. Figure 2-2 shows the recommended program. This program phase, with respect to tubular module development, has been scheduled to complement and build on the FY-74 Compact Converter Program (CCP), as shown in Figure 2-3. For example, the development of a high voltage module through use of an azimuthally segmented washer design is scheduled to commence following completion of the mechanical and process design studies being performed on the FY-74 CCP. Likewise, initiating the development of the ternary tubular module is planned to start early in FY-75, thus utilizing the results of the FY-74 CCP. In addition, the development of a TPM tubular module for the ERTG program will be reassessed following completion of the FY-74 CCP.

The development of a fuel capsule/heat source for the ERTG is not contemplated during this phase. The heat source development program tasks proposed by ORNL have been reviewed and are adequate to accomplish the Phase 2 objectives relative to the ERTG. A task has been defined which will enable close follow of the ORNL program and provide technical assistance as may be required.

This phase of the program was planned to minimize the level of effort consistent with the guidelines included in Appendix A. Therefore, tasks which would update the system design on the basis of the results of the component/subsystem tests are not included; rather, incorporation of these results are planned during Phase 3.

Details of the Phase 2 Tasks are given below.

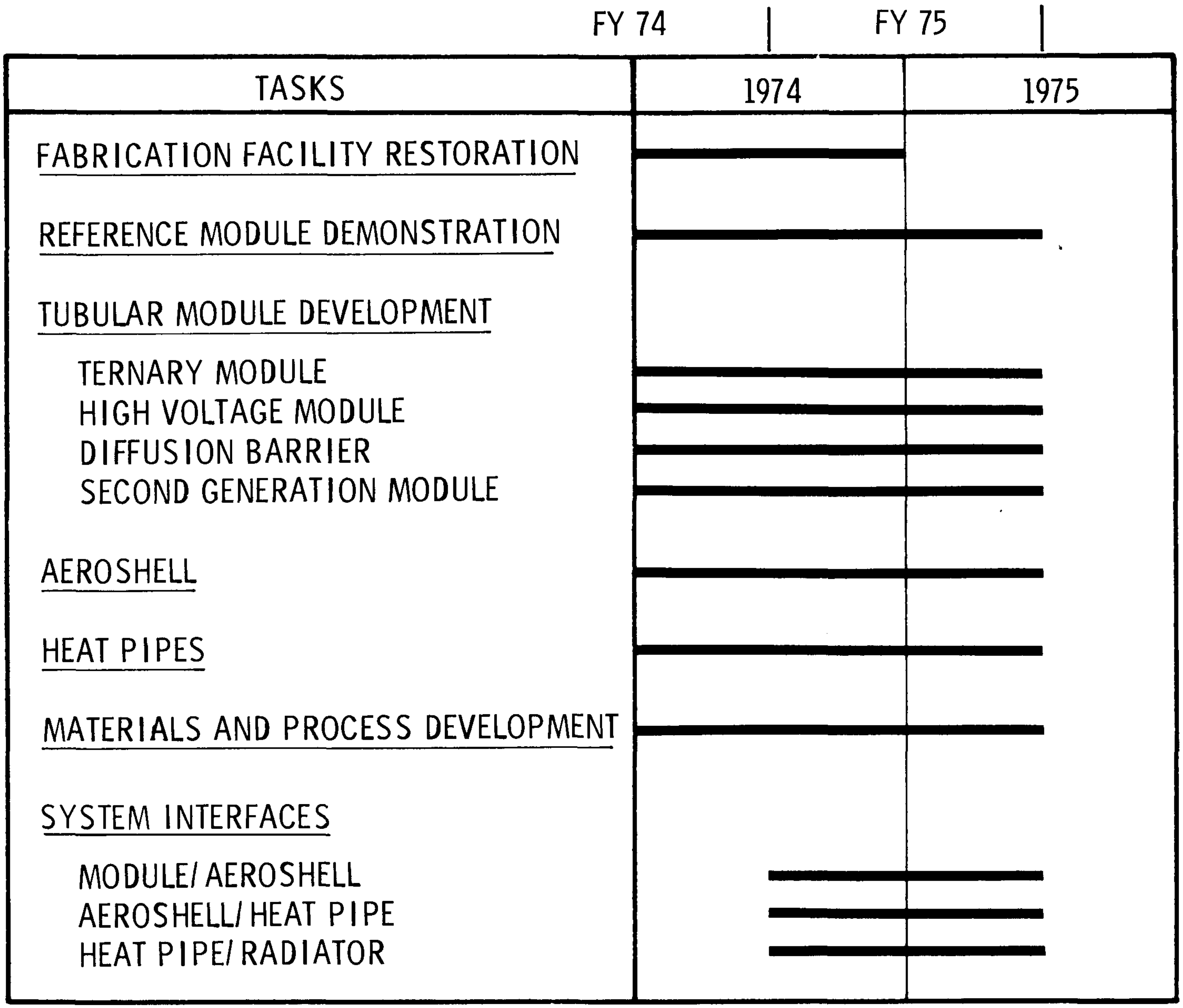

Figure 2-2. Phase 2 - Technology Development and Component Demonstration

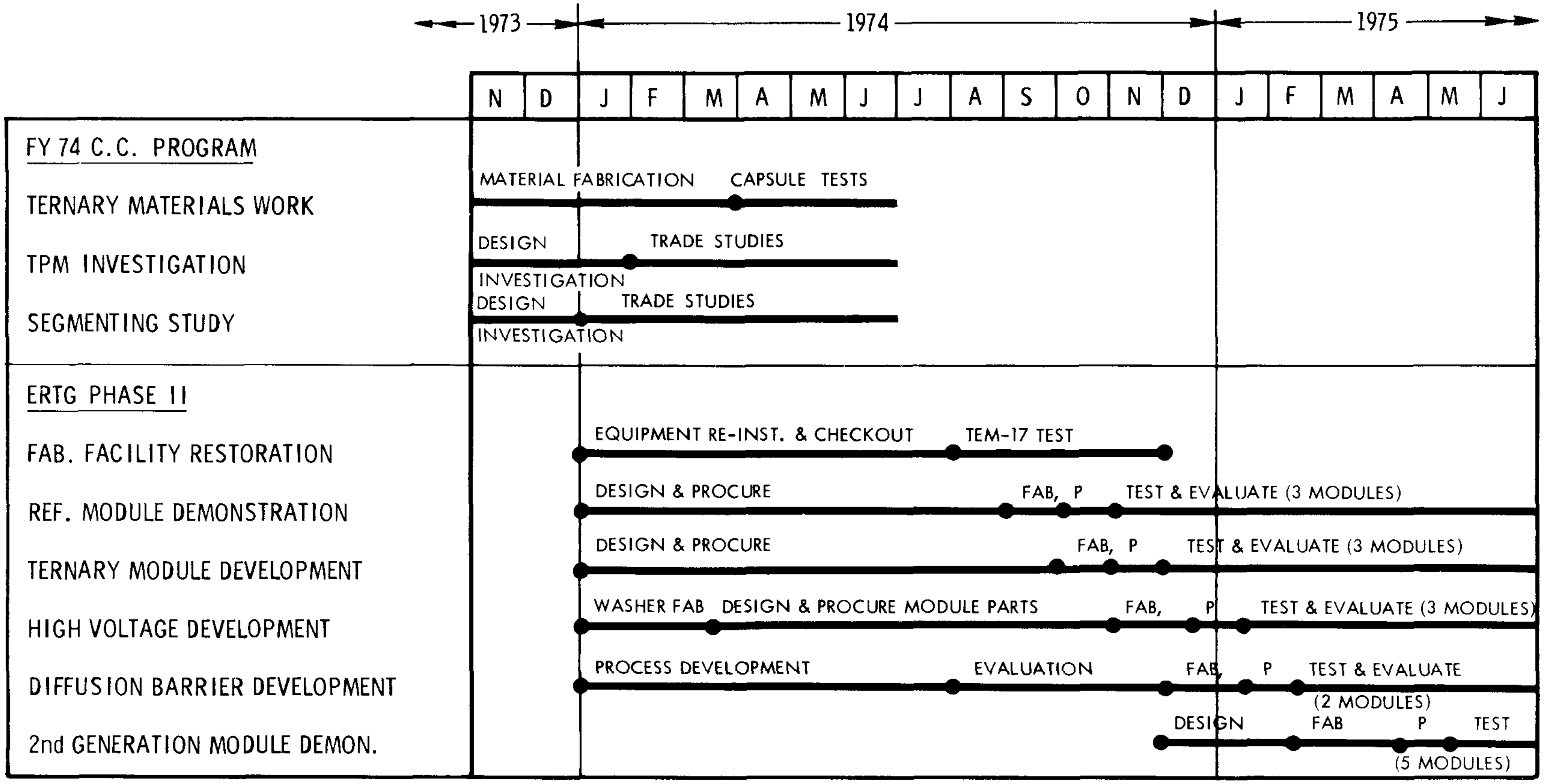

Figure 2-3. Compact Converter FY-74 and ERTG Phase 2 Module Development Schedules

2.1.1 *Westinghouse Task Statements*

TASK 2.1 - PROGRAM MANAGEMENT

This task will provide program direction, overall technical coordination, and general support for activities such as trips, briefings, reports, program planning, and budget control. Reporting will consist of monthly progress letters, a mid-term and final briefing, and a final report. This task also includes the programmatic and technical direction of subcontracts and interfacing with government agencies and laboratories. The measurement of the development of a TPM/tubular module on the basis of the results of FY-74 CCP will be performed as part of this task.

TASK 2.2 - HEAT SOURCE/FUELS DEVELOPMENT FOLLOW

A fuels/heat source development program is planned at ORNL. This program will be closely followed during Phase 2 so that the results of the ORNL studies can be included in a timely fashion into the ERTG heat source design. Test plans will be reviewed and recommendations made to enhance the applicability of the results to the ERTG design. Technical assistance, as required, will be provided.

TASK 2.3 - PRODUCT ASSURANCE

Quality Assurance participation during Phase 2 will consist only of those activities required to provide necessary inspection characterization of the test components. The identification of required characterization data will be the responsibility of the Program Manager, and the completion of inspections to obtain these data will be coordinated by the reliability engineer assigned to support the Phase 2 Program. Reliability engineering analysis will be an integral part of the design team effort to the extent deemed necessary by the Program Manager to maximize confidence in the demonstration program and resultant system design.

TASK 2.4 - RESTORATION OF THE TUBULAR MODULE FABRICATION FACILITY

Upon termination of the Compact Thermoelectric Converter System Technology Program, the Westinghouse Astronuclear Laboratory was forced to consolidate the ongoing programs. In particular the building housing all thermoelectric fabrication and testing activities was returned to the lessor. Subsequently, all Westinghouse-owned tubular module fabrication equipment was disassembled and/or placed in storage at the Laboratory. All government-owned equipment was returned by direction.

This task covers the efforts required to relocate, assemble, and checkout the equipment required prior to initiation of fabrication of the next tubular module.

This task also covers the efforts required to re-establish the static test capabilities. Instrumentation and Nak-fill equipment will be reactivated and the data acquisition system will be rewired in preparation for use in conjunction with static test stands which are defined under subsequent tasks.

A tubular module will be built, processed and tested as described in Subtask 2.4.2 to demonstrate that the objectives of this task have been met.

SUBTASK 2.4.1 - EQUIPMENT REINSTALLATION AND CHECKOUT

OBJECTIVES:

To restore all equipment required for tubular module fabrication and testing to proper working condition.

ASSUMPTIONS:

That no major equipment, such as the 100 ton washer press or the high temperature autoclave facility have been damaged and do not require substantial maintenance.

APPROACH:

All Westinghouse-owned module fabrication equipment (i.e., washer press, vacuum storage facilities, degassing equipment, glove boxes, ingot crusher, etc.) will be removed from storage, placed back into operation and checked out by laboratory personnel. All AEC capital equipment required for this operation (i.e., heat treating equipment, and electrical heater qualification system) will be replaced and checked out. In addition, equipment required for static testing of modules (i.e., Nak-fill system, R.F. brazing generator, etc.) will be reinstalled and checked out. The existing Hewlett-Packard data acquisition will be rewired to allow automatic scanning of static tested modules.

DATA TO BE OBTAINED: Not applicable

SUBTASK 2.4.2 - TUBULAR MODULE FABRICATION CONTINUITY DEMONSTRATION

OBJECTIVES:

To demonstrate capability to duplicate performance parameters of tubular modules after procurement of new equipment or reinstallation of existing equipment.

ASSUMPTIONS: None

APPROACH:

A tubular module, identical in design and processing to two previous TEM-17 series modules currently being tested as part of the Navy Isotope/Kilowatt Program, will be fabricated and tested using apparatus identical to that used to test the previous modules. The test will be conducted for approximately one month and data will be compared with similar data from the Navy modules to determine fabrication and processing capability continuity.

DATA TO BE OBTAINED:

Post processing dimensional measurements will be made on the module to determine the extent of compaction achieved during autoclaving.

Tubular module performance data generated during endurance testing (i.e., voltage, resistance, current, power output and power input) will be monitored, reduced and evaluated using rigorous techniques developed on previous module testing programs. A battery of data acquisition, reduction, plotting and analysis computer codes have been developed to assist in the evaluation of test data. These codes incorporate techniques for minimizing the effects of unavoidable random operating condition variations about the design operating point.

All data will be compared with similar data from the previous TEM-17 series modules.

TASK 2.5 - REFERENCE TUBULAR MODULE DEMONSTRATION

This task includes all design effort required to design, fabricate, and demonstrate successful operation of the reference module for the state-of-the-art, backup ERTG system described in Section 2.0, Volume I. Three modules of the reference design will be fabricated under this task. The first module will be destructively examined after fabrication and processing to verify proper component alignment. A second module will be tested under constant temperature conditions for a period of a year. A third module will be placed on static test, thermal cycled five times, and then life tested for one year to determine the post cycle performance stability. This effort also includes design work necessary to modify the static test equipment as required to allow testing of a module having an exposed single piece refractory inner clad extending beyond the stretch neck regions.

A description of the three module tests associated with this task are given in Subtasks 2.5.1, 2.5.2 and 2.5.3, respectively.

SUBTASK 2.5.1 - REFERENCE DESIGN MODULE PROCESSING EXPERIMENT

OBJECTIVES:

A reference ERTG design module will be fabricated and processed. Since this module will be the first 15 inch module with an inner diameter larger than 0.75 inch, the module will be destructively examined immediately after processing to verify proper component alignment.

ASSUMPTION:

That post destructive examination component measurements can be used to determine that successful compaction and circuit alignment has been achieved during processing of a tubular module.

APPROACH:

Immediately after processing the first reference design tubular module, axial and radial saw cuts will be performed to expose the circuit of the tubular module. Precise dimensional measurements will be performed to determine the extent of component shifting and deformation induced during hot and cold autoclaving processing.

DATA TO BE OBTAINED:

Immediately after processing, the ends of the module will be exposed to allow a room temperature circuit resistance check. A comparison of this data with theoretical calculations based on bulk component resistance contributions, is an indicator of the degree of compaction. After performing destructive examination saw cuts as discussed above, relative axial position of inner and outer conductor rings will be used to ascertain proper circuit alignment. Conductor ring and thermoelectric washer axial thickness measurements will be made to determine the extent of distortion. Acceptability limits have been determined by similar data from previously destructively examined modules.

SUBTASK 2.5.2 - REFERENCE DESIGN MODULE DEMONSTRATION TEST

OBJECTIVES:

- To demonstrate a reference design module for the ERTG system.
- To verify the accuracy of the performance calculations and degradation rate model used to determine the design of the reference module.

ASSUMPTIONS:

- That electrically heated test experiments can simulate performance of an isotope fueled ERTG.
- That the degradation rates can be accurately evaluated after one year of testing and extrapolated for a 5-year mission.

APPROACH:

A reference ERTG design module will be fabricated, processed and placed on electrically heated static test. The test will be conducted for a period of one year with the module operated under constant temperature conditions. Hot and cold clad temperatures will be held fixed at the reference system beginning-of-mission (BOM) levels. Performance data (i.e., heat input, temperatures, open circuit and load voltages, and load current) will be monitored on a regular basis to allow a determination of BOM performance as well as module degradation rates.

On a regular basis (approximately once per month) operating conditions in the test will be temporarily modified to simulate operation of the electrical load following device and decay of the ^{244}Cm fuel. After recording data at these revised conditions, the module will be returned to its initial temperature conditions for additional endurance testing.

DATA TO BE OBTAINED:

The same as those discussed in Subtask 2.4.2.

SUBTASK 2.5.3 - REFERENCE DESIGN MODULE CYCLING TEST

OBJECTIVES:

- To establish the degree of BOM performance reproducibility to be expected from identically designed, fabricated and processed modules.
- To establish the ability of the module to withstand a limited number of thermal cycles, thus permitting acceptance testing without affecting subsequent operation (performance stability) of the module.

ASSUMPTIONS:

Same as those given for Subtask 2.5.2

APPROACH:

A reference design module will be fabricated, processed and placed on electrically heated static test. Startup and beginning-of-life operating conditions will duplicate those of Subtask 2.5.2, above. Startup data in this test will be compared with that generated in Subtask 2.5.2 to establish the degree of performance reproducibility to be expected from identically fabricated modules.

After approximately one month of steady state operation, the module will be thermally cycled five times. After the thermal cycle tests, the module will be returned to steady state operating conditions identical to those of Subtask 2.5.2 above, and tested for a period of one year to determine the post cycle performance stability (degradation rate).

DATA TO BE OBTAINED:

The same as those discussed in Subtask 2.4.2.

TASK 2.6 - TERNARY MODULE DEVELOPMENT

Ternary lead telluride thermoelectric materials, with substantially improved conversion efficiency properties relative to standard lead tellurides incorporated in the reference design

modules have been fabricated and characterized on previous programs conducted at Westinghouse Astronuclear Laboratory. Thermoelectric material property data have been measured and basic compatibility of the materials with the other module conductor and insulating components has been established in die and capsule tests performed on other programs. This task involves all additional effort required to qualify the materials for subsequent incorporation into the Second Generation ERTG.

An accurate determination of in-module Seebeck coefficient, electrical resistivity, and thermal conductivity data for the p- and n-type ternary materials will be obtained by evaluation of data from materials study modules. It is anticipated that this data will differ somewhat from the laboratory measurements made on the material because of the effects of the additional material densification which occurs during the module processing cycle. The improved property data is required because the detailed design of the Second Generation Module will be determined by the thermoelectric material properties.

A discussion of the subtasks required to complete this task follows.

SUBTASK 2.6.1 - N-TYPE TERNARY MATERIAL TUBULAR MODULE TEST

OBJECTIVES:

- To provide data pertaining to in-module electrical resistivity and thermal conductivity data of n-type ternary thermoelectric material as functions of temperature.
- To provide n-type material module stability (degradation rate) data in an actual module environment to compare with capsule and die test data generated on a previous program.
- To perform destructive examination Seebeck and micro-probe tests to study possible component interactions upon completion of the test.

ASSUMPTIONS:

- That module electrical resistance and thermal heat input experimental data can accurately be used to back-calculate electrical resistivity and thermal conductivity data of the thermoelectric materials as functions of operating temperatures.

- That degradation rates can be accurately evaluated after one year of testing and extrapolated for a 5-year mission.

APPROACH:

A tubular module, identical to the reference design module, except that n-type ternary material will be used in both legs of each thermoelectric couple, will be fabricated and processed. The module will be placed on test in an electrically heated static test facility. The test will consist of a closely controlled heatup in which substantial electrical resistance and thermal heat throughput data will be generated. (The design of the module is such that no Seebeck voltage will be generated.) A steady state, constant temperature test of one-year's duration will then follow to allow a determination of performance stability of the n-type material in an actual module environment.

Upon completion of one year of testing, the module will be destructively examined for metallurgical investigation relative to materials compatibility.

DATA TO BE OBTAINED:

- Electrical resistance and thermal heat input will be monitored throughout the test.

- By assuming that electrical resistivity and thermal conductivity of the thermoelectric material can be accurately expressed as polynomial functions of temperature, the coefficients of polynomials can be determined from experimental resistance and thermal heat input data using least-squares curve fitting (regression) techniques. The in-module material properties will then be compared with direct measurements made on laboratory material samples to determine the effects of module processing on material properties.

- Steady state performance data will be evaluated to determine property changes as functions of testing time using techniques discussed in previous tests.
- After completion of the test, the module will be destructively examined to allow Seebeck and micro-probing of the thermoelectric elements. These data will provide insight into the mechanisms contributing to module degradation, if any is observed.

SUBTASK 2.6.2 - P-TYPE TERNARY MATERIAL TUBULAR MODULE TEST

OBJECTIVES:

The same as those discussed in Subtask 2.6.1, but for p-type ternary material.

ASSUMPTIONS:

The same as those discussed in Subtask 2.6.1.

APPROACH:

The same as discussed in Subtask 2.6.1.

DATA TO BE OBTAINED:

The same as discussed in Subtask 2.6.1.

SUBTASK 2.6.3 - TERNARY MATERIAL POWER MODULE TESTS

OBJECTIVES:

- To demonstrate improved performance characteristics of a power module designed with ternary thermoelectric materials.
- To identify and evaluate potential interactions between p- and n-type ternary material during module operation at typical temperature conditions.
- To perform a destructive examination of one of the modules to identify potential solutions to interactions, if they exist.

ASSUMPTIONS:

Same as those given for Subtask 2.5.2.

APPROACH:

Two tubular modules, identical in design to the reference system module except that ternary p- and n-type material will be substituted for TEGS-2 P and GE-NL material will be fabricated, processed, and placed on static test. Heatup data will be correlated with calculations to determine the correlation between calculated and experimental parameters in such a module over a wide range of temperatures. Steady state, constant temperature tests will be conducted for a one year period to allow a determination of degradation characteristics.

One of the two modules will be destructively examined at the end of the test phase.

DATA TO BE OBTAINED:

- Heatup data from these modules will allow a determination of ternary material Seebeck coefficient data as a function of temperature in a module. Using techniques similar to those used to determine resistivity and thermal conductivity data as discussed in Subtask 2.6.1, above, these data will allow a determination of the effects of module processing on Seebeck coefficient data.

- Tubular module performance data generated during the one year endurance test will be monitored and evaluated as discussed in Subtask 2.5.2 to determine degradation rates.

- Post destructive examination Seebeck and micro-probe data will be obtained and evaluated as discussed in Subtask 2.6.1.

TASK 2-7 - HIGH VOLTAGE (SEGMENTED WASHER) MODULE DEVELOPMENT

A 10 percent efficiency improvement in the Reference Design ERTG is available by modifying the conventional tubular module couple configuration design to allow the direct generation of 30 volts. Weight, simplicity, and reliability improvements are also obtained through the elimination of the DC/DC conversion device planned for use in the reference

design system. The generation of higher module voltages in the tubular module design is attainable by introducing an azimuthally segmented thermoelectric washer. Preliminary studies of this technique are currently underway on the FY-74 Compact Converter Program.

An azimuthally segmented module has the additional advantage of allowing both electrical access leads to be extended from a single end of the module. For the ERTG system, this modification will eliminate the complexity of the reference design inter-module buss connections. Joule electrical losses in the busses will also be reduced.

This task will cover the effort required to commit the segmented washer design to hardware and qualify the technique for incorporation into the Second Generation ERTG Module.

SUBTASK 2.7.1 - WASHER SEGMENTING TECHNIQUE INVESTIGATION

OBJECTIVES:

- To perform engineering trade studies to determine the optimum number of axial and azimuthal segments meeting the system voltage requirements.
- To identify segmented thermoelectric washer fabrication techniques.
- To identify inter-segment mica insulator fabrication techniques.
- To identify assembly techniques for modules incorporating azimuthally segmented thermoelectric washers.

ASSUMPTIONS: None

APPROACH:

The output voltage of a module incorporating azimuthally segmented thermoelectric washers is proportional to the product of the number of axial and azimuthal sections incorporated. An initial engineering trade study will be performed to determine the optimum ratio of the two types of sections. That is, should the thermoelectric washer be broken into a large number of pie-shaped segments to minimize the number of axial sections required or vice-versa.

After determining this ratio, and hence the physical dimensions of the thermoelectric washer segments, fabrication investigations will be conducted to determine optimum techniques for producing the pie-shaped thermoelectric washer segments. Washer sawing techniques and direct pie-shaped washer pressing experiments will be completed.

In addition, techniques for cutting thin mica sections to be used as inter-segment electrical insulators will be studied. These investigations will determine the minimum feasible dimensions for inter-segment insulators.

Finally, revised assembly techniques for fabricating modules incorporating azimuthally segmented thermoelectric washers will be devised. Although no major obstacles are foreseen, module assembly techniques will be complicated by the fact that the thermoelectric couples will not be pre-assembled prior to module assembly.

DATA TO BE OBTAINED: Not applicable.

SUBTASK 2.7.2 - HIGH VOLTAGE DESIGN PROCESSING EXPERIMENT

OBJECTIVES:

- To implement segmented couple fabrication and module assembly techniques identified in Subtask 2.7.1.
- To verify that proper component axial and azimuthal alignment can be maintained during processing operations in a high voltage design in which aximuthally segment thermoelectric washers and electrical conductor rings are utilized.

ASSUMPTIONS:

The same as those discussed in Subtask 2.5.1.

APPROACH:

An azimuthally segmented tubular thermoelectric module having component dimensions identified in a previous trade study, will be designed, fabricated and processed in the Westinghouse autoclave facility. Immediately after processing, axial and radial saw cuts will be performed to expose the thermoelectric circuit of the tubular module. Precise dimensional measurements will be made to determine the extent of component rotation, axial shifting, and deformation induced during the hot and cold autoclaving process.

DATA TO BE OBTAINED:

Same as Subtask 2.5.1.

SUBTASK 2.7.3 - HIGH VOLTAGE MODULE DEMONSTRATION TEST

OBJECTIVES:

- To verify the accuracy of the mathematical model developed to calculate performance of an azimuthally segmented module.
- To identify new degradation mechanisms introduced, if any, as a result of implementing azimuthally segmented thermoelectric washers.
- To qualify concept by steady state testing or identify additional design modifications required by destructive examination.

ASSUMPTIONS:

The same as listed for Subtask 2.5.2.

APPROACH:

An azimuthally segmented high voltage module, identical to the module discussed in Subtask 2.7.2 will be fabricated, processed, and instrumented for static test. The module will be tested for a period of one year at operating conditions identical to those discussed in Subtask 2.5.2.

If initial data indicates the existence of inter-couple shorting, the module will be removed from test to allow a destructive examination to identify the cause and solution.

DATA TO BE OBTAINED:

The same as those discussed in Subtask 2.4.2.

SUBTASK 2.7.4 - HIGH VOLTAGE MODULE CYCLIC TEST

OBJECTIVES:

- To establish the degree of BOM performance reproducibility to be expected from identically designed and fabricated high voltage (azimuthally segmented) tubular modules.
- To establish the ability of a high voltage module to withstand a limited number of thermal cycles, thus permitting acceptance testing without affecting subsequent operation (performance stability) of the module.

ASSUMPTIONS:

The same as listed for Subtask 2.5.2.

APPROACH:

An azimuthally segmented high voltage module, identical to the modules discussed in Subtasks 2.7.2 and 2.7.3 will be fabricated, processed, and placed on electrically heated static test. Startup and BOM operating conditions will duplicate those of Subtask 2.7.3 above. Startup data in this test will be compared with that generated in Subtask 2.7.3 to establish the degree of performance reproducibility to be expected from identically fabricated modules.

After approximately one month of steady state (constant temperature) operation, the module will be thermally cycled five times. After the thermal cycle tests, the module will be returned to steady state operating conditions identical to those of Subtask 2.7.3, above, and tested for an additional 11 months to determine the post cyclic performance stability (degradation rates).

DATA TO BE OBTAINED:

The same as those discussed in Subtask 2.4.2.

TASK 2.8 - TRANSPORT BARRIER DEVELOPMENT

A thin tungsten foil washer, sandwiched between two mica insulating washers, is used in the state-of-the-art TEM-17 and TEM-X S/N-3 designs as a barrier to axial transport of tellurium from the p-type to the n-type PbTe thermoelectric washers (which produces electrical property degradation in the n-type material). However, work performed during GFY 1973 indicated that thin tungsten film vapor deposited on the mica surfaces were just as effective as the foil in controlling tellurium transport, while offering the benefit of a substantial reduction in shunt heat losses. Accordingly, a thin film barrier will be developed for the Second Generation ERTG to take advantage of the reduced heat loss benefit.

Although the tungsten-film-on-mica approach is equivalent to the tungsten foil approach in controlling axial tellurium transport, neither approach is effective for totally eliminating transport of tellurium around the edges of the mica insulating washer, and an increment of degradation due to the latter still exists in the state-of-the-art TEM-17 and TEM-X S/N-3 designs. This task will thus be addressed not only to the development of thin film diffusion barriers, but to the implementation of these barriers in such a way that all tellurium transport degradation, regardless of the transport path, is eliminated.

Specifically then, this task covers a study to define the optimum technique for deposition of thin film barriers, with the serious candidates being sputtering, electron beam vapor deposition and ion plating; a decision on whether to establish an in-house deposition capability or an outside source; development of production deposition processes; evaluation and qualification of specimens produced by those processes; development of techniques (other than thin film) for controlling non-axial tellurium transport; and evaluation and qualification of overall barrier schemes.

SUBTASK 2.8.1 - DEPOSITION PROCESS SELECTION & FACILITY ESTABLISHMENT

OBJECTIVES:

- To select the optimum vapor deposition process for application of crystalline tungsten films to PbTe-type thermoelectric washer faces.
- To select the optimum vapor deposition process for application of crystalline tungsten and tellurium-reactive-metal films to phlogopite mica substrates.
- To establish an in-house facility, or identify and/or develop a vendor facility, for performing the above processes.

ASSUMPTIONS: None

APPROACH:

In the case of tungsten films deposited on PbTe washer faces, the ultimate goal or concept is suppression of tellurium transport at the tellurium source (i.e., the tellurium-rich p-type washer), thus rendering tellurium unavailable for transport by any path. Tungsten is specified as the film material because it is the only metal demonstrated to be completely compatible with both n- and p-type PbTe in the module processing/operating temperature range. The suppression mechanism for this approach is the apparent low diffusivity of tellurium in tungsten; but since this diffusivity is certainly non-zero, some tellurium will eventually become available for transport, and thus both the p- and n-type washers would be tungsten coated (with the former film serving as an "exit barrier" and the latter as an "entrance barrier").

For deposition of thin films on mica, the concept (as already discussed) is suppression of axial transport either through low tellurium diffusivity (tungsten) or through capture by direct chemical reaction (tellurium-reactive metals such as nickel or iron). It is desirable to investigate tellurium-reactive films because their effective barrier efficiency may be better than that of tungsten, particularly in films containing cracks and microscopic voids which would act as "short circuit" paths in the low diffusivity case. The overall barrier scheme in this case requires incorporation of a supplementary approach for suppressing non-axial

tellurium transport; the development of such an approach is the subject of Subtask 2.8.4. A study will be performed in which a review of recent developments and advances in thin film deposition technology, plus consultation with vendors and workers in the field, will be combined to define the optimum state-of-the-art approach to the above deposition cases. It is expected that the choice will be made among sputtering, ion plating and electron beam vapor deposition. Some screening experiments may be performed in vendor or Westinghouse Research and Development Center facilities to provide data in support of the choice. It will be determined whether an equipment facility to develop the chosen processes can be established in-house within the program schedule requirements, or whether an outside vendor must be developed. This determination will then be pursued through the procurement and setup of an in-house system or procurement of committed vendor equipment and services.

DATA TO BE OBTAINED:

- Identification of optimum tungsten-on-PbTe vapor deposition process.
- Identification of optimum tungsten (or tellurium-reactive metal) -on-mica vapor deposition process.
- Established in-house or vendor vapor deposition facility.

SUBTASK 2.8.2 - VAPOR DEPOSITION PROCESS DEVELOPMENT

OBJECTIVES:

- To develop an optimized production process for application of 5000 Å crystalline tungsten films to PbTe-type thermoelectric washer substrates.
- To develop an optimized production process for application of 5000 Å crystalline tungsten or tellurium-reactive metal films to phlogopite mica substrates.

ASSUMPTIONS:

That, if necessary, a vendor can be located who will designate, modify as required and reserve for use on this project an equipment system capable of performing the selected process.

APPROACH:

Using the vapor deposition technique and equipment facility developed in Subtask 2.8.1, a series of process experiments will be performed to develop the combination of material and process parameters required to deposit reproducible, high quality films. Parameters to be investigated and established include substrate pre-deposition processing; vapor source form and purity; deposition chamber atmosphere; in-situ substrate cleaning (glow discharge); substrate temperature during deposition; source-substrate distance and geometric relationship; cooling rates of deposited films; deposition of single layers versus multiple layers; and post-deposition processing of coated substrates.

DATA TO BE OBTAINED:

Complete process definition/specification for production vapor deposition procedures.

SUBTASK 2.8.3 - THIN FILM SPECIMEN EVALUATION

OBJECTIVES:

- To evaluate specimens produced by the optimum vapor deposition processes developed in Subtask 2.8.2.
- To develop a crystallographic atom position model of the phlogopite mica substrate surface to aid in theoretical consideration of deposition process variables and film/substrate bonding.

ASSUMPTIONS: None

APPROACH:

Evaluation of specimens will be made using the following techniques:

- Interferometric film thickness measurements.
- X-ray and/or electron diffraction determination of film crystallographic structure and orientation.

- Assessment of the epitaxial film/substrate relationship using the above crystallographic information plus an atom position model of the mica substrate surface which will be developed by the Westinghouse Research and Development Center.
- Metallographic (and possibly SEM) examination to identify physical/mechanical film defects.
- Measurement (probably qualitatively) of film adhesion/bond strength.
- Determination of the effects of heating and cooling to module processing and operating temperatures on film quality and adhesion.
- Determination of the effect of thermoelectric washer final densification on the structure of films deposited on the washer faces.

DATA TO BE OBTAINED:

- Crystallographic atom position model of phlogopite mica substrate surface.
- Crystallographic structure and orientation of deposited films.
- Film thickness
- Film defects
- Film adhesion/bond strength
- Effects of heating and cooling on film adhesion and quality.
- Effect of thermoelectric washer densification on film structure.

SUBTASK 2.8.4 - SUPPLEMENTARY NON-AXIAL BARRIER DEVELOPMENT

OBJECTIVES:

- To identify methods for suppressing non-axial tellurium transport, which can be used to supplement the metal-film-on-mica axial transport suppression scheme.
- To experimentally evaluate the methods identified and select the optimum methods for module utilization.

ASSUMPTIONS: None

APPROACH:

A study will be conducted to identify schemes for suppressing the transport of tellurium around the edges of the mica insulating washers in the module circuit. The most promising scheme proposed to date is the incorporation of inserts of tellurium-reactive metal into the inner conductor ring at the inner edge of the large mica washer and adjacent to the innermost part of the faces of the small mica washer.

Mockup assemblies of appropriate components will be built to approximate module circuit dimensions for each scheme developed, and these will be processed at module vacuum degassing and compaction conditions. Mockups will be tested by fitting them with internal heaters and external heat sinks, and exposing them to the module thermal gradient for 1000 and 3000 hours. The mockups will then be metallographically sectioned and examined by Seebeck voltage probe and electron beam microprobe techniques to evaluate the relative success of each scheme in suppressing non-axial transport of tellurium. The optimum scheme will then be selected and designated for in-module demonstration testing under Subtask 2.8.5.

DATA TO BE OBTAINED:

- Non-axial barrier designs.
- Seebeck voltage probe display of transport-degraded regions.
- Electron beam microprobe display of tellurium accumulations at barriers.
- Identification of optimum barrier design.

SUBTASK 2.8.5 - IN-MODULE DEMONSTRATION TESTING

OBJECTIVES:

- To demonstrate the effectiveness of the tellurium transport barrier schemes in the actual module environment.
- To select the optimum scheme for ERTG system utilization.

ASSUMPTIONS:

The same as listed for Subtask 2.5.2.

APPROACH:

A reference design module will be built incorporating tungsten-on-PbTe diffusion barriers, and a second module will be built using the optimum metal-film-on-mica axial barrier plus supplementary non-axial barrier design. These modules will be fabricated and tested under identical conditions to permit measurement of degradation rates (if any) attributable to both barrier schemes and selection of the optimum (lower degradation) scheme for ERTG system utilization. If both modules exhibit negligible degradation, the selection will be made on the basis of minimizing fabrication complexity and cost.

DATA TO BE OBTAINED:

- Module performance degradation rates for both barrier approaches.
- Identification of optimum barrier approach for ERTG system utilization.

TASK 2.9 - SECOND GENERATION MODULE DEMONSTRATION

Upon completion of the individual qualification tests associated with each of the development areas identified for incorporation into the Second Generation ERTG, a task will be performed to incorporate all of the improvements into a single module to be qualified for use in the ERTG system. This task includes all of the efforts required to demonstrate successful operation of the Second Generation ERTG.

The task consists of completing the reference design utilizing all information identified in earlier tasks (ternary material property data, effectiveness of diffusion barriers, etc.). Five identical modules will be fabricated and tested to demonstrated performance reproducibility, cyclic insensitivity, and temperature dependency of any residual degradation rates.

SUBTASK 2.9.1 - SECOND GENERATION ERTG MODULE DEMONSTRATION TESTS

OBJECTIVES

- To verify that the individual improvement design modifications developed in previous tasks can be successfully combined in a single module.
- To establish that the BOM performance level achieved by the module correlates well with calculations.
- To experimentally determine the performance stability characteristics of the reference module for the Second Generation ERTG.

ASSUMPTIONS:

The same as discussed for Subtask 2.5.2.

APPROACH:

A second generation module, incorporating all of the improvements identified and qualified in previous tasks, will be designed, fabricated, processed, and placed on static life test. Operating conditions in the test will be identical to those discussed in Subtask 2.5.2 except that module hot and cold clad temperatures will be held fixed at the BOM levels of the Second Generation ERTG. Thermal decay tests, as described in Subtask 2.5.2 will be conducted once per month.

Performance data described in Subtask 2.5.2 will be monitored on a regular basis to allow a determination of BOM performance as well as module degradation rate data.

DATA TO BE OBTAINED:

The same as discussed in Subtask 2.4.2.

SUBTASK 2.9.2 - SECOND GENERATION ERTG MODULE PERFORMANCE REPRODUCIBILITY TEST

OBJECTIVES:

- To establish the degree of performance reproducibility exhibited by a duplicate of the module discussed in Subtask 2.9.1.
- To separate effects of fuel decay from module degradation.

ASSUMPTIONS:

The same as discussed for Subtask 2.5.2.

APPROACH:

To duplicate the tests described in Subtask 2.9.1, however, operating the module at constant conditions would be continually varied to simulate operation of the electrical load following device and decay of the curium fuel. Test data would then be compared with the thermal decay test data from Subtask 2.9.1 to provide performance reproducibility information.

DATA TO BE OBTAINED:

The same as discussed in Subtask 2.4.2.

SUBTASK 2.9.3 - SECOND GENERATION MODULE CYCLIC TESTS

OBJECTIVES:

- To establish the ability of the Second Generation ERTG module to withstand a limited number of thermal cycles, thus permitting acceptance testing without affecting subsequent operation (performance stability) of the module.
- To provide additional BOM performance reproducibility data for the Second Generation ERTG module.

ASSUMPTIONS:

The same as those given for Subtask 2.5.2.

APPROACH:

A third module, identical to that described in Subtask 2.9.1 will be fabricated, processed, and placed on static test at conditions duplicating those of Subtask 2.9.1. Startup and BOM operating conditions will duplicate those of Subtask 2.9.1. Data from this test would be compared with that generated in Subtasks 2.9.1 to provide additional BOM performance reproducibility data.

After approximately one month of steady state (constant temperature) operation, the module will be thermally cycled five times. After thermal cycling, the module will be returned to operating conditions duplicating those of Subtask 2.9.1 to determine the post-cyclic performance stability (degradation rates).

DATA TO BE OBTAINED/EVALUATION TECHNIQUES:

The same as those discussed in Subtask 2.4.2.

SUBTASK 2.9.4 - SECOND GENERATION MODULE TEMPERATURE SENSITIVITY TESTS

OBJECTIVES:

- To obtain performance stability (degradation rate) data at two accelerated temperature levels to be used to evaluate the sensitivity of degradation rates to operating temperatures.
- To provide additional BOM performance reproducibility data for the Second Generation ERTG module.

ASSUMPTIONS:

The same as those given for Subtask 2.5.2.

APPROACH:

Two additional Second Generation ERTG modules will be fabricated and placed on static test. Startup and BOM operating conditions for both modules will duplicate those of Subtask 2.9.1, to provide additional performance reproducibility data.

After approximately one week of steady state data, operating temperatures of the two modules will be modified by increasing the average hot clad temperatures of the two modules 25°F and 50°F, respectively, above the reference design operating conditions. The modules would then be endurance tested under steady state (constant temperature) test conditions to provide stability data at accelerated temperatures.

DATA TO BE OBTAINED:

The same as those discussed in Subtask 2.4.2.

TASK 2.10 - MATERIALS AND PROCESS DEVELOPMENT AND EVALUATION

This task is concerned with all materials and process activity outside the tubular module structural envelope. It is principally involved with selection of optimum materials or processes from groups of attractive candidates in various system areas; evaluation of materials behavior in space vacuum, in space and system radiation environment, and at system operating temperatures; development and evaluation of assembly and joining techniques; and investigation of materials compatibility under specified system accident conditions.

SUBTASK 2.10.1 - THERMAL CONTROL COATING EVALUATION AND APPLICATION DEVELOPMENT

OBJECTIVES:

- Confirm the selection of the designated radiator thermal control coating.
- Measure the rate of increase of solar absorptance with exposure time ($d\alpha_s/dt$) in the radiator operating temperature range.
- Evaluate the coating resistance to neutron irradiation damage at the anticipated radiator surface dose rate.
- Develop a radiator surface preparation/coating application/coating curing process specification.

ASSUMPTIONS: None

APPROACH:

Additional consultation with NASA, IITRI, JPL, and other knowledgeable sources will be undertaken to ensure that the thermal coating selection - either Z-93 or IITRI zinc orthotitanate/trialkyl-terminated monomethyl silicone paint, the latter being preferred - is the best choice on a current state-of-the-art basis and that no unforeseen obstacles exist in utilizing the coating for the ERTG system radiator surfaces.

Thermal degradation of solar absorptance will be determined by making pre- and post-heating spectrophotometric measurements, in situ, on specimens heated for various time periods to the radiator operating temperature (200-300°F) in an ultrahigh vacuum work chamber. The operating temperature range noted will provide data for both Second Generation and Reference ERTG systems. This item will probably be subcontracted to a qualified outside laboratory, such as IITRI; however, this decision will depend on the consultation noted above which will initiate this task.

The effects of neutron irradiation at the radiator surface dose rate will be estimated from a combination of theoretical considerations and inferences made from the combined irradiation studies made by IITRI (and presently continuing under NASA Contract NAS 8-26791). It may also prove desirable to subcontract some proton-only damage studies to IITRI to establish upper damage limits.

A series of flat sheet specimens will be prepared to confirm that the state-of-the-art approach to, or existing data on, the following areas are adequate for ERTG system utilization.

- Optimum surface cleaning/treating procedure for 6061 aluminum alloy.
- Optimum paint application technique (spray, dip, brush, etc.).
- Optimum paint curing cycle (time, temperature, curing atmosphere).
- Optimum coating thickness.

Additional tests on these specimens will be made to yield data on the following areas at the particular conditions of interest to the ERTG system.

- Effect of sheet bending and stretching (both fabrication/assembly deformation and operational deformation) on coating adhesion.
- Effect on adhesion of exposure to a radiator operating temperature range (200-300°F) for various times.

DATA TO BE OBTAINED:

- $d\alpha_s/dt$ for the radiator operating temperature range (200-300°F).
- $\Delta\alpha_s$ estimate for 5 years of neutron irradiation.
- Material specification for coating procurement.
- Process specification for coating application and curing.

SUBTASK 2.10.2 - THERMAL CONTACT GREASE EVALUATION, PROCESSING AND APPLICATION DEVELOPMENT

OBJECTIVES:

- Selection of a thermal contact grease to promote maximum thermal conductance at the module copper compliant thermal clad/graphite aeroshell interface.
- Measure the effects of neutron irradiation on the relevant properties of the grease selected.
- Develop (if necessary) a process for conditioning the selected grease for space vacuum use.
- Develop a procedure for applying the grease at the subject interface prior to inserting the fueled module assembly into the aeroshell.
- Develop (if necessary) a sealing technique to ensure retention of the grease in the heat transfer annulus over the 5-year mission duration.

ASSUMPTIONS:

Pre/post-neutron irradiation measurements will be performed by ORNL as identified in Section 2.1.4.

APPROACH:

Consultations with suppliers and a literature survey will be used to identify candidate greases in addition to those already considered for the ERTG design presented in Volume I. Approximately six candidates will be selected for preliminary screening tests. These will be evaluated by making

comparative heat transfer measurements on flate plate copper/grease/graphite sandwich specimens while simulating the heat flux and temperature range of the actual system interface.

The two most promising candidates, as indicated by the screening measurements, will then be subjected to pre/post-neutron irradiation tests to determine the effects of the anticipated neutron dose on the thermal conductivity and physical characteristics (e.g., viscosity, consistency, etc.) of the materials.

Depending upon the materials selected, it may be necessary to develop a process (e.g., a vacuum heat treatment) to condition the material for use in the space vacuum environment (e.g., to pre-evaporate relatively volatile, low-molecular-weight polymer species so that such evaporation cannot subsequently occur during system operation). The effects of such processing on the relevant material properties would then be determined. A process would be developed for one or two materials, depending upon whether one candidate was disqualified on the basis of inadequate radiation resistance.

A procedure will then be developed for applying the grease to one or both of the mating surfaces such that, upon inserting the module into the aeroshell, an adequate bridge of grease is developed in the heat transfer annulus. (Alternately, consideration will be given to injecting the grease into the annulus after assembly has been performed). At this point, a final material selection will be made, if necessary.

Finally, if the creep/bleed characteristics of the grease are such that some flow out of the heat transfer annulus is possible over a 5-year period, a mechanical sealing arrangement will be developed for effectively retaining the grease in the annulus.

DATA TO BE OBTAINED:

- Relative thermal conductances of initial candidate greases.
- Changes in thermal conductances and consistencies of two final candidates due to neutron irradiation.
- Material specification for grease procurement.
- Process specification for space conditioning treatment (if required).
- Process specification for grease application at interface assembly.
- Heat transfer annulus end seal design (if required).

SUBTASK 2.10.3 - MODULE/AEROSHELL ASSEMBLY PROCEDURE DEVELOPMENT AND EVALUATION

OBJECTIVES:

- To develop a procedure and fixturing for loading the fueled module assembly into the graphite aeroshell.
- To determine the interface pressures resulting from various pre-assembly clearances.

ASSUMPTIONS:

That a stainless steel dummy module has the same thermal expansion characteristics as does an actual tubular module. This has been demonstrated in tests conducted under another tubular module program.

APPROACH:

The specimen configuration will be a graphite block of aeroshell thickness and bore diameter, a stainless steel dummy module with copper compliant thermal clad, and an electrical heater in the bore of the dummy module. Approximately three specimen sets will be made to provide a range of pre-assembly clearances.

Using one specimen set only, the heater will be operated at about 5000 watts (simulating fuel thermal power earliest installation time in the actual ERTG system) and the temperature and diameter of the compliant shell will be measured under various pre-installation cooling modes including still air, air blast, forced air in a loose-fitting duct, and liquid immersion. In each case, the surface temperature and diametral transients will be measured when cooling is discontinued. A pre-installation cooling mode will then be designated to become part of an optimized assembly procedure.

Using the above designated cooling mode, each specimen set will then be tested by operating the heater at about 5000 watts, cooling the module thermal clad and rapidly inserting the dummy module into the simulated aeroshell. As the module enters the aeroshell, the heater control mode will be switched from constant power input to constant thermal clad surface temperature, controlling the latter at about 300°F. As the thermal clad expands into contact with the aeroshell, stress developed in the compliant shell ribs will be monitored with bonded strain gages, and aeroshell temperatures will be monitored with implanted thermocouples, until an equilibrium condition is achieved. The thermal clad surface temperature will then be reduced stepwise to represent successively lower radioisotope fuel power levels, and the stress and aeroshell temperatures again monitored until equilibrium is regained after each step.

Evaluation of the results of the above tests will then lead to selection of pre-assembly clearance dimensions and cooling mode, and a loading fixture will be designed for use in the actual system assembly procedure.

DATA TO BE OBTAINED:

- Thermal clad surface temperature and diameter (at equilibrium) for various cooling modes at about 5000 watts power input.
- Temperature and diameter versus time from cooling shut-off.
- Compliant shell equilibrium strain and aeroshell temperatures for various preassembly clearances, at several thermal clad temperature levels.

- Optimum pre-assembly cooling mode designation.
- Optimum pre-assembly clearance designation.
- Module-into-aeroshell loading fixture design.
- Module-into-aeroshell preliminary loading procedure.

DATA EVALUATION:

Pre-assembly cooling mode and clearance will be selected on the basis of stress and thermal analysis calculations, the results of which will indicate the best balance between low stress levels for mechanical integrity and positive contact (both initially and throughout the mission duration) for enhanced heat conduction.

SUBTASK 2.10.4 - TUNGSTEN COATING PROCESS SELECTION FOR MODULE Ta-10W INNER CLAD

OBJECTIVES:

- To select a process for applying a thin (~.001 inch) coating of pure tungsten to the Ta-10W inner clad of the tubular module, to serve as a positive chemical reaction/diffusion barrier to molten thermoelectric material which may contact the clad during a launch pad or post-reentry-impact fire.
- To identify the facility requirement for implementing the above process.

ASSUMPTIONS: None

APPROACH:

A study will be made to select the optimum coating process for this particular coating/substrate combination; the leading candidates are chemical vapor deposition, sputtering, electron beam vapor desposition, and ion plating.

Having selected a process, it will then be decided whether a coating capability should be established in-house using existing or easily obtainable equipment, or whether an outside source should be developed. A cost estimate for facility development will be prepared for use in Phase 3 planning.

DATA TO BE OBTAINED:

- Coating process selection.
- Facility development cost estimate.

SUBTASK 2.10.5 - WELD AND BRAZE JOINT PROCESS DEVELOPMENT AND QUALIFICATION

OBJECTIVES:

- Develop welding and brazing procedures for all new joints in the tubular module reference design (excluding joints to be developed by ORNL as part of the module/fuel capsule assembly procedure).
- Design weld and braze fixturing for making these joints.
- Prepare welding and brazing specifications.
- Perform procedure, equipment, and operator qualification.

ASSUMPTIONS: None

APPROACH:

Welding parameters, filler metal selection, and weld pass configuration and sequencing will be established by making a series of process development welds on mockup specimens designed to accurately simulate the actual joints in every weld-related manner. The joints to be treated in this manner, based on the reference mechanical design, are the following:

- Module conductor pin (molybdenum) to external inner collector ring (molybdenum), fillet weld.
- External inner collector ring (molybdenum) to external outer collector ring (molybdenum), seam weld.
- External outer collector ring (molybdenum) to external conductor (molybdenum), fillet weld.
- Outer clad extension (Type 316 SS) to outer clad (Type 316 SS), butt weld.
- Weld neck (Ta-10W) to inner clad (Ta-10W), fillet weld.

Specimens will be evaluated by visual examination, liquid penetrant inspection, and destructive metallographic examination. A similar task will cover development of the braze joint between the Type 304 stainless steel retaining ring stretch neck and the Ta-10W weld neck.

A combination of weld joint sequence investigation and weld chill design will be performed to produce an overall assembly procedure in which weld heat from a given step cannot damage the existing assembly.

Specifications will then be prepared covering each individual weld and braze joint plus the overall assembly procedure from the joining viewpoint. Procedure, equipment, and operator qualification will then be performed in accordance with these specifications in anticipation of the hardware fabrication requirements of the Second Generation module.

DATA TO BE OBTAINED:

- Process specification for each weld and braze joint in the reference design tubular module.
- Fixture designs for each joint.
- Process specification for overall assembly/welding sequence.
- Procedure, equipment, and operator qualification data and records for each joint.

SUBTASK 2.10.6 - AEROSHELL/HEAT PIPE INTERFACE MATERIALS AND PROCESS DEVELOPMENT

OBJECTIVES:

- Develop a process for applying a high solderability metal coating to the graphite aeroshell.
- Develop a process for applying a high solderability metal coating to the aluminum thermal transition member.
- Select solder alloys for the aeroshell/transition member and transition member/heat pipe joints.
- Develop soldering processes and design fixturing for the above joints.
- Prepare assembly/soldering specifications.

ASSUMPTIONS: None

APPROACH:

A study will be performed to select optimum high-solderability metal coating materials and optimum coating processes for applying these to the graphite aeroshell and the aluminum thermal transition member. Nickel and copper appear to be the most attractive material candidates, and the application process will probably come from the family of vapor deposition techniques (sputtering, thermal evaporation/condensation, ion plating, and chemical vapor deposition). A decision will then be made whether to establish in-house or vendor capabilities for the coating processes; in particular, Avco has considerable expertise in applying coatings to graphite reentry bodies and this expertise is expected to enhance the results of and minimize the required effort for this area. This decision will be pursued through the development of acceptable processes, preparation of process specifications, and preparation of coated graphite plate and coated aluminum transition member segment specimens for use in soldering process development experiments.

Candidate solder alloys will then be selected for the aeroshell/transition member and transition member/heat pipe joints, and soldering processes will be developed for making these using the above specimens plus copper heat pipe segments. Variables to be investigated include solder alloy composition, flow temperature, mechanical properties, and evaporation rate and resistance to diffusional degradation at system operating temperatures; use of flux vs. fluxless techniques; pretinning or solder form and placement approach; and joint sequence.

Mechanical joint strength measurements will be made at room and operating temperature on specimens prepared by the optimum soldering processes; and when these indicate adequate in-system performance, process specifications will be prepared for the assembly/soldering procedures.

DATA TO BE OBTAINED:

- Material and process specifications for:
  1) Applying high solderability coating to graphite aeroshell.
  2) Applying high solderability coating to aluminum thermal transition member.
  3) Making aeroshell/transition member solder joints.
  4) Making transition member/heat pipe solder joints.
- Joint mechanical properties at room temperature and operating temperature.
- Solder evaporation and joint diffusional characteristics at operating temperature.

SUBTASK 2.10.7 - HEAT PIPE/RADIATOR INTERFACE MATERIALS AND PROCESS DEVELOPMENT

OBJECTIVES:

- To measure the mechanical properties and thermal expansion characteristics of copper heat pipe/Delta Bond epoxy adhesive/aluminum radiator joints at assembly and operating temperatures.

- To determine the effect of space vacuum exposure at system operating temperature on joint properties.
- To determine the effects of neutron and uv irradiation at mission dose levels and at system operating temperature, on joint properties

ASSUMPTIONS:

None

APPROACH:

The specimen configuration will be a 3-inch long copper heat pipe section bonded to a .030 inch thick sheet of 6061 aluminum alloy with Delta Bond, a high thermal conductivity aluminum-filled epoxy adhesive. Surface preparation procedures for the copper and aluminum will be developed to ensure that high quality epoxy/metal bonds are developed. The manufacturer's specification will be used for epoxy curing.

Bonded specimens will be tested to determine the mechanical and thermal expansion characteristics of the joint at room temperature (assembly and handling condition) and at 200 to 300°F.

A second group of bonded specimens will be exposed to $< 10^{-5}$ torr vacuum for 3000 hours at 200-300°F, and then tested to determine the effects of space vacuum exposure on joint mechanical and thermal expansion characteristics.

A third group of bonded specimens will be exposed to uv irradiation at 200 to 300°F and tested to determine the effects of solar radiation on joint properties. If further study indicates a potential problem, neutron irradiation and post-irradiation testing may also be performed.

A process specification will be prepared to cover metal surface preparation, epoxy placement, assembly, curing and subsequent handling.

DATA TO BE OBTAINED:

- Joint tensile and shear (or tear) strengths at room temperature and 200-300°F.
- Room temperature stress-strain relationship.
- Thermal expansion characteristics from room temperature to 200-300°F.
- Effect of vacuum exposure at 200-300°F on above properties.
- Effect of uv irradiation at 200-300°F on above properties.
- Process specification for joint fabrication.

SUBTASK 2.10.8 - MATERIALS COMPATIBILITY EVALUATIONS

OBJECTIVES:

- To confirm the ability of the fueled module assembly structure to maintain the Cm_2O_3 in an encapsulated condition through specified launch pad and post-reentry-impact accident (fire) conditions.
- To investigate the long-term diffusional interaction between Ta-10W and Haynes 188 at the module/fuel capsule interface operating temperature.

ASSUMPTIONS:

That surplus fabricated TEM-X S/N-3 modules with Ta-10W inner clads can be transferred to this program to provide specimens for this experiment.

APPROACH:

Sections of a fabricated tubular module will be combined with mocked-up fuel capsule sections and exposed to the time-temperature conditions specified for potential launch pad and post-reentry-impact fires. The specimens will then be subjected to metallographic examination, chemical analysis, and mechanical tests to ensure that release of ^{244}Cm could not have occurred as a result of the chemical reactions and diffusional interactions among the various components.

Haynes 188/Ta-10W diffusion couples will be annealed at the interface operating temperature for 1000 and 3000 hours in ultrahigh vacuum, and then examined by metallographic, electron beam microprobe and mechanical testing techniques to ensure that any interactions which may occur during the 5 year mission will not affect the structural integrity of the fuel encapsulation/ containment envelope.

DATA TO BE OBTAINED:

- Effects of fire conditions on intercompatibility of fuel containment members and their surrounding components.
- Effects of chemical reactions and diffusional interactions occurring during fire conditions on mechanical properties of fuel containment members.
- Effects of long-term diffusional interactions at operating temperature on structural integrity of fuel containment members.

TASK 2.11 - MODULE/AEROSHELL INTERFACE EVALUATION

The purposes of this task are to evaluate the results of the materials and process work concerned with this interface area (Subtasks 2.10.2 and 2.10.3), ensuring that the approaches developed therein are compatible with overall system assembly and operational requirements to measure the thermal conductance of this interface (under system operating conditions) for each of the proposed thermal contact schemes (direct thermal clad/aeroshell contact, thermal contact grease, gold foil), and select the best of these for system utilization.

SUBTASK 2.11.1 - EVALUATION OF MATERIALS AND PROCESS DEVELOPMENT WORK

OBJECTIVES:

- To ensure that the thermal contact grease, method of grease application, and heat transfer annulus end seal design (if any) developed in Subtask 2.10.2, are consistent with overall system assembly and operational considerations.
- To ensure that the module-into-aeroshell assembly procedure and fixturing design, developed in Subtask 2.10.3, are usable for all the candidate thermal contact schemes and are compatible with overall system assembly considerations.

APPROACH:

Work performed on the subject subtasks will be monitored and the developing results continually coordinated with those of the other related tasks and with Avco efforts to ensure that integrational problem areas and inconsistencies are identified and resolved at the earliest possible point in the program.

SUBTASK 2.11.2 - INTERFACE THERMAL CONDUCTANCE MEASUREMENTS

OBJECTIVES:

- To measure the module/aeroshell interface thermal conductance, at system operating conditions, for each of the candidate thermal contact schemes.
- To select the optimum thermal contact scheme for system utilization.

ASSUMPTIONS:

That a stainless steel dummy module has the same thermal expansion characteristics as does an actual tubular module. This has been demonstrated in tests conducted under another tubular module program.

APPROACH:

Two aeroshell/stainless steel dummy module with thermal clad/internal electrical heater specimen sets, similar to those used in Subtask 2.10.3, will be fabricated using the optimum pre-assembly clearance designated in that subtask. The components will be instrumented with thermocouples attached to the compliant thermal clad ribs and implanted in the graphite aeroshell near the bore. The sets will be assembled unheated, one with and one without the thermal contact grease selected in Subtask 2.10.2. The ends of the assemblies will be insulated and/or fitted with guard heaters to achieve near-adiabatic end surfaces. The remaining outer heat transfer surfaces will then be covered with an intermediate insulating material, selected and dimensioned to yield approximate system operating temperature levels at the thermal clad/aeroshell interface, and surrounded by a water cooling jacket.

Each set will be installed in a vacuum chamber, the internal heater raised to the BOM radioisotope power level of about 5000 watts, the equilibrium interface temperature drops measured, and the effective interface thermal conductance calculated. The specimen set using direct contact will then be disassembled, the thermal clad machined (if necessary) to provide clearance for placement of a gold foil liner in the aeroshell bore, the latter performed and the measurement repeated to obtain temperature drop data for this third thermal contact scheme.

DATA TO BE OBTAINED:

- Interface temperature drop at system operating conditions (BOM heat input level) for three thermal contact schemes.

DATA EVALUATION:

The optimum thermal contact scheme will be selected on the basis of a balance between minimum interface temperature drop and minimization of fabrication and assembly complexity. The thermal contact coefficient will be calculated for the optimum scheme for use in system thermal calculations.

TASK 2.12 - AEROSHELL/HEAT PIPE INTERFACE EVALUATION

This task is concerned with evaluation of the materials and process work relevant to this interface area (Subtask 2.10.6), to ensure that the approaches being developed are consistent with overall system assembly and operational requirements, and to measure the thermal conductance and temperature drops for the final interface configuration at system operating conditions.

SUBTASK 2.12.1 - EVALUATION OF MATERIALS & PROCESS DEVELOPMENT RESULTS

OBJECTIVE:

To ensure that the metal coating processes and assembly/soldering procedures for the aeroshell/transition member/heat pipe interface configuration, developed under Subtask 2.10.6, are compatible with overall system assembly and operational requirements.

ASSUMPTIONS: None

APPROACH:

Work performed on the above subtask will be monitored and the developing results continually coordinated with those of the other related tasks to ensure that problem areas and inconsistencies are identified and resolved at the earliest possible time in the program.

SUBTASK 2.12.2 - INTERFACE THERMAL CONDUCTANCE MEASUREMENT

OBJECTIVE:

To measure the effective overall thermal conductance of the aeroshell/transition member/heat pipe interface configuration under system operating conditions.

ASSUMPTIONS: None

APPROACH:

The specimen configuration will be a section of metal coated graphite aeroshell soldered to a metal coated aluminum transition member which in turn is soldered to the evaporator section of a copper wall heat pipe. Several specimens may be fabricated representing various combinations of the metal coatings, solder alloys and assembly/soldering procedures developed under Subtask 2.10.6. Specimens will be instrumented with thermocouples to measure temperatures in the aeroshell, transition member and heat pipe adiabatic zones, and the temperature drops across both solder joints.

The aeroshell section will be fitted with an electrical heater, and the specimen installed in a vacuum test chamber. The heat pipe condenser section will be contacted to a suitable heat sink which may be inside or outside the vacuum chamber. Thermal insulation will be applied to the heat pipe adiabatic zone.

The aeroshell section will be heated to system operating temperature and, with the heat pipe condenser section maintained at system radiator temperatures, all thermocouple readings will be recorded. The effective interface thermal conductance will then be calculated.

DATA TO BE OBTAINED:

- Heat input to aeroshell section at system operating temperature.
- Heat pipe adiabatic zone temperature.
- Solder joint temperature drops.

DATA EVALUATION:

An effective interface thermal conductance will be calculated from the heat input and temperature data and the specimen geometry. If several specimen variations are tested, a selection of the optimum configuration will be made on the bases of maximum conductance, minimum weight and minimum fabrication complexity.

TASK 2.13 - HEAT PIPE/RADIATOR INTERFACE EVALUATION

This task covers an evaluation of the relevant materials and process development work conducted under Subtask 2.10.7, to ensure that the information and approaches developed therein are consistent with overall system assembly and operational requirements, and the measurement of the heat pipe/radiator interface thermal conductance in the actual system configuration and at system operating conditions.

SUBTASK 2.13.1 - EVALUATION OF MATERIALS & PROCESS DEVELOPMENT RESULTS

OBJECTIVES:

- To ensure that epoxy joint fabrication procedure developed under Subtask 2.10.7 is consistent with overall system assembly considerations.
- To ensure that the effects of vacuum exposure and irradiation on joint properties have negligible impact on system operating characteristics.

ASSUMPTIONS: None

APPROACH:

Work performed on the above subtask will be monitored and the developing results continually coordinated with those of the other related tasks to ensure that problem areas and inconsistencies are identified and resolved at the earliest possible point in the program.

SUBTASK 2.13.2 - INTERFACE THERMAL CONDUCTANCE MEASUREMENTS

OBJECTIVES:

- To measure the heat pipe/radiator interface thermal conductance at operating temperature in a vacuum environment.
- To evaluate the effects of assembly and handling operations on the interface conductance.

ASSUMPTIONS: None

APPROACH:

The test specimen will consist of a 6061 aluminum sheet having the dimensions of a 1/24 sector of the system radiator, bonded to a single vertical heat pipe with Delta Bond epoxy adhesive in accordance with the process specification to be developed under Subtask 2.10.7. The heat pipe, of reference design material and dimensional configuration, will be bonded over a 30 inch length and will extend below the radiator sector with an adiabatic section about 12 inches long. After the radiator/epoxy/heat pipe assembly is processed through the epoxy curing cycle, the radiator and heat pipe will be instrumented with thermocouples and the thermal control coating will be applied to the radiator in accordance with the process specification to be developed under Subtask 2.10.1.

If it has been decided at this time that (for the actual system radiator) the thermal control coating will be applied to a flat radiator sheet which will then be formed into a cylindrical shell, the specimen radiator sector will be bent to a profile representing the system configuration diameter, and maintained at this profile and level of thermal control coating and epoxy joint stress throughout subsequent testing.

After curing the thermal control coating, the evaporator end of the heat pipe will be mounted in an electrical heater block, the heater block and heat pipe adiabatic section will be insulated, and the entire assembly installed in a vacuum test chamber. Approximately 180 watts will be applied to the heater block to bring the radiator sector to the 200°F temperature level representing BOM operation. Thermocouple readings will be recorded and used to calculate the interface

thermal conductance. The test will be continued for at least 3000 hours, with periodic conductance measurements being made, after which the assembly will be removed from the vacuum chamber and the epoxy interface (and thermal control coating) examined for cracks or other evidence of deterioration.

DATA TO BE OBTAINED:

- Heat input rate required to give 200°F radiator temperature level.
- Temperatures along heat pipe adiabatic and condenser sections.
- Condition of epoxy interface after 3000 hour operation.

DATA EVALUATION:

The overall thermal conductance of the condensor and interface will be calculated. The interface thermal conductance and temperature drop will be determined based on the predetermined heat pipe operating characteristics.

TASK 2.14 - HEAT REJECTION SYSTEM DEMONSTRATION

The purpose of this task is to experimentally demonstrate the mechanical and thermal characteristics of the heat rejection system for the ERTG Design. This task will consolidate the results of Tasks 2.11, 2.12, 2.13 and the work of AVCO and Dynatherm. A one quarter section of the heat rejection system will be assembled and evaluated.

OBJECTIVES:

- To demonstrate the structural adequacy of the bonded joints of the heat rejection system.
- To establish an overall temperature gradient for the heat rejection system.

ASSUMPTIONS:

None

APPROACH:

The test specimen will consist of an electrically heated dummy module or graphite aeroshell (fabricated as part of AVCO Tasks 2.4A and 2.5A), the aluminum transition block, six heat pipes (fabricated as part of Dynatherm Task 2.5D), and the radiator shell. The aeroshell will be full scale; a one quarter section of the radiator shell will be used. The test specimen will be assembled using the interface materials/processes resulting from Tasks 2.11, 2.12 and 2.13.

The electrically heated dummy module will be inserted into the graphite aeroshell under simulated launch pad conditions. The power input to the heater will be about 5000 watts at time of assembly. The transient response of the system in an ambient environment will be monitored. The assembly will then be subjected, while hot, to a representative launch environment typical of the Titan IIIC. The structural condition of the interfaces through monitoring of the interface temperature drops will be established. The assembly will then be tested statically and the results compared with those obtained prior to subjecting the heat rejection system to the launch environment.

The test specimen will be placed in a vacuum chamber and the thermal performance established. The system will remain on life test for about one year to establish degradation characteristics, if any exist. The heater power will be reduced at preselected times to simulate the ^{244}Cm decay.

DATA TO BE OBTAINED:

- Heat input.
- System temperatures.
- Demonstration of the structural adequacy of system interfaces.
- Stability in vacuum

2.1.2 Avco Task Statements

TASK 2.1A - PROGRAM MANAGEMENT

AVCO will maintain a project office to provide administrative and technical direction to all participating division organizations. The project office will also, in conjunction with the Material Department, prepare a subcontract plan covering major subcontracts. Two subcontracts are anticipated; 1) the fabrication of the graphite aeroshell billets and 2) the internal and external machining of graphite aeroshell parts.

The project office will:

- Prepare and issue a Project Directive document which provides administrative and technical direction to all participating Division organizations.
- Support subcontract negotiations through award, prepare and update the Subcontract Plan, and maintain technical management of the subcontracts.
- Insure maintenance of the desired program schedule, cost and performance.

TASK 2.2A - AERODYNAMICS DROP TEST

The reentry body design concept is a thick rectangular plate with curved edges having very different moments of inertia about each pitch axis. Drop tests to date have shown that flat plates can achieve high drag coefficients, but a viscous flow coupling occurs causing the plate to autorotate. Because of the markedly different aerodynamic and mass property characteristics of the design vis-a-vis the tested bodies, a limited drop test program is planned to demonstrate the descent and impact performance, to increase confidence in the design concept and/or to uncover problem areas.

OBJECTIVE:

To provide essential technical data on the terminal descent and impact velocity of the reentry body design concept.

APPROACH:

Six aerodynamic and mass-property simulated reentry bodies will be dropped from a helicopter and tracked via radar at the Wallop Island test facility. The models will be full scale and of low cost construction, such as fiberglass and weighted to achieve the correct β and moments of inertia. The test aircraft and radar range measurements are assumed to be government furnished; (similar testing was performed on the MHW program for cylinders).

The models will be used to assess the effect of the initial release attitude, viz, edge-on, side-on, tumbling, and to establish a sufficient reproducible data base.

DATA TO BE OBTAINED:

Radar tracking data, motion pictures and direct observation will be used to assess the terminal descent dynamics and impact velocity. A test report will be prepared which evaluates the impact velocity of the reference design concept based on the test data.

TASK 2.3A - HYPERSONIC PERFORMANCE DEMONSTRATION TEST

The reentry body concept is predicated on achieving a low β and low heating during reentry. The dimensions and weight of the aeroshell are directly related to aerodynamic performance, and hypersonic testing is deemed critical to prove out the design principles involved.

An analytical approach to the aerodynamic performance definition is only partially practicable because of the aerodynamic shape, angle-of-attack and yaw-angle range and Reynolds number range. The Reynolds number is of particular concern as by virtue of the aeroshell low β peak reentry heating occurs at very high altitudes, resulting in thick boundary layers, introducing the possibility of rotational flow effects aggravating the heating, i.e., does the edge act as a blunt or sharp edge for conditions downstream?

OBJECTIVE:

To provide essential hypersonic data to build confidence in the design, prove out the design concept, and/or to identify a critical problem area.

APPROACH:

A limited wind tunnel test approach will utilize a single facility with in-hand capability to produce a large amount of data at low cost. As a result of Shuttle program, new techniques have been developed which will be capitalized on.

AEDC Tunnel C can achieve Mach numbers of about 10. Force, moment, pressure and heat transfer data can be taken; thermal paints can be used to reduce cost of gathering heat transfer data.

A force and moment model would be used to obtain aerodynamic coefficients over the angle-of-attack and yaw angle range. A pressure model would similarly be used to obtain pressure distributions over the angle-of-attack and yaw angle range. Special heat transfer models are required for use of the thermal paint technique or for use of the thin-skin thermocouple technique.

The tunnel has a Reynold's number (pressure) range of about 10:1, which would be valuable to define Reynolds number effects. A preliminary estimate of the tunnel time is 3 to 10 days, depending on further operational considerations as balance changes. The model design would be worked out jointly with the facility.

DATA TO BE OBTAINED:

Aerodynamic force and moment coefficients covering the angle-of-attack and yaw angle and at two Reynold number conditions would be obtained. Automated data reduction techniques would be employed to reduce the manual data handling and to prepare tables and curves. The data would be compared with theory and used to compute revised reentry trajectories.

The pressure data would be obtained over the range of angle-of-attack, yaw and Reynolds numbers and reduced and summarized in a similar manner as the force data. The data will be used to support the interpretation of the coefficient and heat transfer data and assessed for any impact on the structural design.

The heat transfer data would be obtained over the range of angle-of-attack and yaw, and for two Reynolds numbers, and reduced and summarized as the other data. The data will be combined with trajectory data and the aerodynamic heating to the reentry body re-evaluated and compared with previous results.

A summary report will be prepared containing the data, comparing the aero-thermal performance based on test data with earlier predictions, evaluating the aerodynamic design concept, and identifying critical problem areas.

TASK 2.4A - MATERIALS FABRICATION DEMONSTRATION

Conceptual design studies indicate that a billet of graphite 5 x 15 x 24 inches is required for the aeroshell. A high-quality bulk-graphite is needed to implement the design. Discussions with graphite suppliers indicate that this size bulk plate has not been produced in POCO AXF or ATJ-S or other similar quality material. Both POCO AXF and ATJ-S have the scale-up potential, but because of the shorter processing time for POCO and current use of POCO on RTG programs it is recommended as the baseline material.

The POCO company has made a study of the scale-up problems and have concluded that by the use of external press facilities a block can be produced with a minimum density of 1.75 g/cc. The estimated lead time is 6 months.

OBJECTIVE:

To demonstrate fabrication of POCO AXF billets 5 x 15 x 24 inches in size.

APPROACH:

Two billets of POCO AXF in nominal sizes of 5 x 15 x 24 inches will be fabricated. The POCO company will use external press capability to form the billets and strive for the maximum density. Billet samples will be taken to compare the thermal and structural performance with POCO AXF including flexural and tensile ultimate stress and thermal conductivity. NDT testing will be performed to assess density variations and voids in the blocks. Structural testing will be performed to demonstrate AXF quality.

DATA TO BE OBTAINED:

Two 5 x 15 x 24 inch billets of POCO AXF will be obtained. NDT test data on density variations and voids will be obtained. Structural coupons cut from each billet will be used to obtain ultimate flexural and tensile stress and thermal conductivity data. The quality of the produced blocks will be compared with the standard AXF material being used in current RTG programs. Problem areas will be identified and process recommendations specified for Phase 3.

TASK 2.5A - AEROSHELL MACHINING DEMONSTRATION

The basic aeroshell concept of low β and low heating is contingent upon a light-weight aeroshell. In order to reduce the weight, pockets will be machined out of the graphite leaving sufficient material to satisfy the thermal-structural requirements. In addition, the centerline of the aeroshell will be machined to accommodate the tubular module and its electrical leads.

The machining approach is to use a 3-axis numerically controlled milling tool or a 3-D Tracer technique. The candidate source being considered is Ultra-Carbon Corporation.

OBJECTIVE:

To provide a machining demonstration that will prove out the aeroshell concept and provide a basis for cost estimates as well as potential cost reduction by design changes.

APPROACH:

One of the billets produced by POCO will be used to demonstrate the machining. Full scale simulation will be possible. The center hole, lead slots, pocket threads, end cap and aerodynamic fairing will be machined to demonstrate that the billets can be milled-out leaving thin walls. POCO will participate with Avco in formulating a machining plan.

DATA TO BE OBTAINED:

A recommended machining approach, design changes, and future machining cost estimates will be identified. All machining operations and problems encountered will be identified. There will be visual and NDT inspection including X-ray, acoustic and alcohol wipe, of the finished parts.

TASK 2.6A - COLD STRUCTURAL TESTS

The aeroshell design concept relies on its low weight to achieve low heating during reentry and a low impact velocity. The overall weight is critical to the system performance objectives as well. Weight reductions are accomplished by removing graphite in the interior of the shell leaving only enough mass to handle the structural loads and thermal requirements imposed by reentry. The resulting shell tends to consist of a thick center body and thin flat surfaces supported by ribs. Structural testing is recommended to prove out the aeroshell structural concept.

OBJECTIVE:

To prove out the aeroshell structural concept by testing sections of the aeroshell assembly.

APPROACH:

One of the 5 x 15 x 24 inch billets of POCO AXF will be used to machine parts to simulate the aeroshell structure. The structural models to be tested are:

- Beam Section. This model will simulate the action of the web, surface and center-body. Four part flexure tests will be carried to failure to establish strength limits and failure mode (3 models).

- Panel Section. This model will simulate the action of surface, web and center body under surface pressure loadings arising from SOS and SOT entry. Strength limits and failure modes will be determined (2 models).

- Edge Section. This model will simulate the action of edge pressure loadings and will establish strength limits and failure mode (2 models).

- Thread Section. This model will simulate the action of the endcap under axial load arising from thermal expansion of the tubular module and EOS loads (2 models).

- Shear Pin. This model will simulate the attachment of the edge panel. Strength and failure mechanisms will be determined by introducing shear loads into the pinned assembly (2 models).

- End Pads. End pad materials will be screened, including flexible graphite and felt metals to identify a candidate and end cap compliant interface material. Load-deflection data will be obtained on the candidates, the configuration will be a hemispherical pad (2 models).

Test planning for the above will include thermal and structural analyses, model design and special jig design.

DATA TO BE OBTAINED:

As the above tests are to be run cool (RT) they will be instrumented with strain gages. Data appropriate to each test will be taken, strain, load, deflection, temperature. The test results will be compared to the predicted data evolved in the test planning phase. Problem areas will be identified and recommendations made for design changes, if required.

TASK 2.7A - HOT STRUCTURAL TESTS

Although the aeroshell concept is designed to yield low heating, thermal stresses will be important due to the desire for light-weight resulting in thin wall sections interfacing with thick sections. To prove out the aeroshell structural concept, a limited thermal-stress test program is recommended. Avco experience on similar testing indicates that the quartz lamp thermal-structural test capability at Avco are adequate for the desired simulation.

OBJECTIVE:

To prove out the thermal-structural design concept of the aeroshell.

APPROACH:

The beam, panel and edge section model designs used in the cold structural tests (Task 2.6A) would be used to evaluate the significance of thermal stresses. Each model would be subjected to a simulated heat load imposed by quartz lamps in the Avco structural labs. Test planning will define the test setup and lamp programming. The thermal stress performance of each model will be predicted also (2 models per configuration).

The thermal-structural interface for the tubular module during reentry will be tested by heating the simulated tubular module (to be supplied by Westinghouse) and loading it to simulate reentry deceleration loads.

Test planning will include thermal and structural analyses, model and set-up design.

DATA TO BE OBTAINED:

Surface temperatures will be monitored. The resulting behaviour of each model will be compared with the analytical predictions evolved in the test planning phase. Problem areas will be identified and design changes recommended, if required.

2.1.3 Dynatherm Task Statements

A preliminary definition of heat pipes for the Economic RTG has been made as a result of the Phase I design study. The ERTG design utilizes 3/8" diameter axially grooved Cu-H_2O heat pipes to transport waste heat to the radiator. Details of the heat pipe geometries, performance specifications, interfaces with radiator and aeroshell, and qualification requirements remain to be established.

TASK 2.1D - PROGRAM MANAGEMENT

This task will provide the administrative and technical direction of the project. The monitoring of subcontracts and preparation of reports is included as part of this task.

TASK 2.2D - DEFINITION OF ERTG HEAT PIPE REQUIREMENTS

Dynatherm will provide assistance to Westinghouse in the finalization of the performance and interfacing requirements for ERTG heat pipes. The required heat pipe parameters will be established in terms of heat transport capability, heat transfer performance, assembly procedures, pressure retention, interfacing with the various generator components, and compatibility with processing procedures.

TASK 2.3D - ERTG HEAT PIPE DEVELOPMENT

- Conduct heat pipe design analysis to define the optimum axially grooved geometry for 3/8" diameter Cu-H_2O heat pipe to meet the heat transport and transfer requirements of the ERTG heat pipes. Give due consideration to existing fabrication technique.
- Generate specification for procurement of 3/8" diameter axially grooved tubing.
- Prepare development heat pipe design drawings.

TASK 2.4D - DEVELOPMENT OF AXIALLY-GROOVED Cu-H_2O HEAT PIPES

Axially grooved heat pipes have been used extensively in the past and have been flight qualified on several spacecraft. However, all axially grooved heat pipes that have been produced to date have been made of aluminum. Although the necessary technology for

fabricating axially grooved copper tubing is presently available, performance mapping of such a design will be required to substantiate its use in the ERTG heat pipes.

Currently the most practical method of manufacturing the axially grooved heat pipe tubes is by the cold forging process in which annealed predrawn tubing is passed over an internal mandrel, external rotating hammers simultaneously reduce the outer diameter and force the raw material to flow over the internal mandrel to produce the desired groove form. Since this process relies on cold working, ductile materials such as copper and aluminum are used. Internally grooved copper pipes for heat exchangers have been produced using this process; however, the internal grooves are not of the size and shape required for heat pipe operation. But, with some development effort, the desired size and shape can be produced.

Development of axially-grooved CuH_2O heat pipes will be conducted in two stages. In the first stage axially-grooved copper tubing will be procured per specifications developed in Task 2.3D. Breadboard heat pipes will be fabricated from this tubing and tested to establish basic performance characteristics including: heat transport versus charge, evaporator and condenser film coefficients, heat transport versus temperature, heat transport versus elevation and pressure retention capabilities of grooved tubing at elevated temperatures. This effort will be conducted in conjunction with the "Extension of Cu-H_2O Heat Pipe Technology to Higher Temperatures" in Task 2.5D which includes the development of basic processing techniques required for grooved heat pipes.

Based on the results of grooved design breadboard testing and CuH_2O heat pipe technology extension, the ERTG heat pipe design will be finalized including size, geometry and number of heat pipes. In the second stage of the Task 2.4D effort, prototype heat pipes which are representative of the heat transport requirements and geometry of the ERTG design will be fabricated and tested. The end result of this effort will be a fully developed reference design, whose performance parameters can be incorporated into subsequent qualification and flight hardware procurement specifications.

- Procure axially-grooved copper tubing per procurement specification developed in Task 2.3D. Tubing will be procured in sufficient quantity to fabricate all breadboards and prototype heat pipes required in this phase.
- Fabricate and test five (5) breadboard heat pipes. The breadboard heat pipes will be used to achieve the following:

  (1) Preliminary verification of processes developed under Task 2.5D.

  (2) Verification of design performance objectives.

  (3) Obtain basic engineering data including volumetric charge requirements, transport performance versus elevation in "One-G" and conductances.
- Fabricate and test five (5) prototype heat pipes of the exact size and geometry which will be used in the ERTG Design. The prototype heat pipes will be used to achieve the following:

  (1) Final verification of processes developed under Task 2.5D.

  (2) Perform complete performance mapping including gravity effect, bending, maximum/minimum operating temperatures and transient performance.

  (3) Establish conformance to leak tightness, pressure retention and other criteria not related directly to thermal performance.

  (4) Place the five prototype heat pipes on continuing life test at different temperatures.

TASK 2.5D - EXTENSION OF Cu-H_2O HEAT PIPE TECHNOLOGY TO HIGHER TEMPERATURES

The basic technology of Cu-H_2O heat pipes has been already developed under the Teledyne-Isotopes HPG program. But further effort is required to apply this technology to the axially grooved heat pipe design and to extend the operational temperature range from the current 150°C to approximately 180 - 200°C.

The internal surfaces of the HPG heat pipes were treated with a solution of Ebonol "C" to enhance the wetting of these surfaces by the water working fluid. This treatment produces a surface that is jet black, chemically stable, very adherent, and according to the compound manufacturer will withstand temperatures to about 200°C. At higher temperatures, slow

oxidation of the base copper occurs underneath the coating which may cause its destruction after prolonged exposure. Other surface treatments have been proposed and tested which promise a somewhat higher temperature capability. In addition to long-term operation, the heat pipes will probably be subjected during installation to short-term temperature cycles up to 300°C. Therefore the major effort of this task will be to expand the temperature range of Cu-H_2O heat pipes to at least 180°C and to develop processes which permit short-time processing cycles up to 300°C.

- Evaluate various processing techniques for axially grooved heat pipes including cleaning, outgassing, welding, and charging. Select and develop detailed processes for the production of the breadboards, prototypes and subsequent qualification and flight models. Establish leak tightness and pressure verification test.
- Obtain and review all available information and data on various passivation and surface wetting processes applicable to copper-water heat pipes such as steam oxidation, high concentration oxygen oxidation, super cleaning, and others.
- Select the five (5) most suitable techniques (Ebonol treatment plus four others) and fabricate 10—3/8" diameter axially grooved heat pipes for each of the selected processes.
- Performance test two heat pipes from each group to assess the wetting characteristics of each process.
- Subject three heat pipes from each group to short-term cycles at 300° C and evaluate the effects of this exposure.
- Place at least five heat pipes from each group on a development life test consisting of extended operation at different temperatures within the range of the ERTG application.
- Evaluate the test results to determine the process which will provide the best expected operational life of axially grooved Cu-H_2O heat pipes.

TASK 2.6D - HEAT PIPE/INTERFACES BREADBOARDING

The purpose of this task is to fabricate and test the axially grooved Cu-H_2O heat pipe for breadboarding with the ERTG aeroshell and radiator.

- Fabricate (8) heat pipes, performance map to establish characteristics and deliver to Westinghouse for bonding and breadboard testing.

2.1.4 Government Support

The specific areas of requested government support are

- Fuels/heat source development
- Neutron irradiation experiments
- Obtaining surplus tubular modules
- Material Survivability/Vulnerability Tests
- Reentry Body Testing

Each of these areas are discussed below.

FUELS/HEAT SOURCE DEVELOPMENT

ORNL has proposed a fuels/heat source development program for FY 1974, FY 1975 and FY 1976.

We have reviewed the intent of these tasks and recommend that the following tasks be included in the on-going AEC technology program in the areas of fuels production and development.

NONDESTRUCTIVE TEST DEVELOPMENT

This task is directed toward the development of new or improved non-destructive examination techniques that are required to assure the necessary quality of materials, components, and assembled capsules. The test methods will initially include ultrasonic, eddy-current, and other potential NDT methods for specific problems (i.e., radiography and/or penetrant examinations of certain welds or materials). The developmental effects include: selection and modification of existing techniques; establishment or reference standards; determination of technique sensitivity, reproducibility, and other parameters of performance; and the development of design criteria and hardware for both laboratory and remote inspection systems. For each method, changes in materials, thicknesses, and configurations will affect details of the examination techniques and/or equipment development.

DEVELOPMENT OF WELDING PROCEDURES

This task covers the development of welding procedures for joining capsules and includes work on the liner, strength member, oxidation barrier, and outer jacket for the module. In addition, a procedure for attaching a vent to the capsules must be developed. Although there is some degree of difficulty in anticipating the major problem areas which must be overcome in carrying out this task, there is one factor which is definitely known at this time which will have great influence on all phases of this task - the relatively high temperatures produced in the capsules by the fuel. It is roughly estimated that this temperature will be in the 600 to 800°C range. It will be necessary to simulate this thermal behavior in essentially all of our work from the initial development of welding parameters, to the making of welds on test coupons for mechanical property testing, and finally in all prototype capsule welds. This thermal requirement will obviously increase the time needed for all phases of this task and will influence the design of the various welding fixtures. In addition, our efforts will be constrained by the realization that all procedures must eventually be carried out in the hot cells.

PHYSICAL METALLURGY SUPPORT

This task provides a broad technology evaluation of materials for use in isotopic heat sources for advanced space power applications. Specifically, the effects of trace contaminants on the structural integrity of capsule component materials will be determined.

VENT EVALUATION

In cooperation with systems source designers, venting concepts will be examined with regard to their application to use with curium fuels. An experimental program using active curium fuel, which will augment the systems designer's tests and development program with inactive materials, will be performed on contractor-furnished vents. Tests will be performed at

temperature to determine plugging, compatibility, and helium flow characteristics under use conditions and anticipated accident conditions.

SOURCE CRITICALITY STUDIES

The criticality implications of the higher ^{245}Cm isotopic content of power reactor curium products (7.16% vs 0.729% in SRL material) need to be investigated. While it is true cursory examination of the source configuration does not indicate that a problem exists, it is believed that a detailed calculational examination is called for. This task is intended to provide those calculations.

FUEL SIMULANTS

In performing the series of safety tests, i.e., fire, impact, etc., it is required, from an economical standpoint, that preliminary tests be conducted using a relatively inexpensive fuel simulant in place of the relatively expensive curium fuels. This task is intended to examine potential fuel simulants that will closely approximate the physical characteristics of curium fuel materials and to provide an acceptable fuel simulant for use in the safety testing program.

LOADING AND HANDLING PROCEDURES, TOOLS AND EQUIPMENT

Tools, equipment, and procedures for loading and handling the ERTG source during its fabrication, loading with fuel, and subsequent handling must be developed for in-cell use. This task shall include the development and fabrication of these items to include cooling devices, calorimeters, tools for handling, and loading.

NEUTRON IRRADIATION EXPERIMENTS

Neutron irradiation of the two final thermal contact grease candidates will be performed at the total dosage estimated to apply to the module/aeroshell interface over a 5 year mission life. Pre-post-irradiation measurements of relative thermal conductivity, consistency or viscosity, and vacuum evaporation rates will also be provided.

SHIELD DESIGN STUDIES

Preliminary computations will be performed in order to assist user agency spacecraft systems design studies.

SURPLUS TUBULAR MODULES

One or more surplus fabricated-and-tested (as part of Compact Converter program) TEM-X S/N-3 series modules with Ta-10W inner clads to be transferred to this program for use as compatibility test specimens.

MATERIAL SURVIVABILITY/VULNERABILITY TESTS

It is requested that a facility such as AFWL perform calculations/experiments to assess the survivability/vulnerability of selected materials - coatings, adhesive bonds, etc., used for the ERTG Reference Design.

REENTRY BODY TESTING

Government furnished support is requested for performing The Aerodynamics Drop tests at Wallops Radar Range and the Hypersonic Performance Demonstration Test at the Arnold Engineering Development Center.

2.1.5 Cost Estimate

The preliminary cost estimates for performing the tasks previously identified are given in Tables 2-1, 2-2, and 2-3 for Westinghouse, Avco, and Dynatherm. The basis for the cost estimates is given below including a discussion of the uncertainties in the estimates. The cost estimates for the identified government support are given in Table 2-4. These estimates were provided by ORNL.

TABLE 2-1

Sheet 1 of 2

PHASE II - TECHNOLOGY DEVELOPMENT AND COMPONENT DEMONSTRATION (M&S, CAP, TOT is in $1000)		FY-74 MANPOWER (MM)						FY-75 MANPOWER (MM)						TOTAL MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
2.1	PROGRAM MANAGEMENT	12.0	3.0			56.5		24.0	6.0			113.0		36.0	9.0			169.5	
2.2	HEAT SOURCE/FUELS DEVELOPMENT FOLLOW	3.0				12.3		6.0				24.6		9.0				36.9	
2.3	PRODUCT ASSURANCE	3.0				12.3		6.0				24.6		9.0				36.9	
2.4	RESTORE TUBULAR MODULE FABRICATION FACILITY	4.0	12.5	1.5	15.0	70.4	54.0	1.0	4.0			13.9		5.0	16.5	1.5	15.0	84.3	54.0
2.5	REFERENCE TUBULAR MODULE DEMONSTRATION	9.5	16.5	5.0	46.6	152.9	20.0	9.0	15.0	5.0		89.2		18.5	31.5	10.0	46.6	242.1	20.0
2.6	TERNARY MODULE DEVELOPMENT	9.0	22.5	2.5	61.6	176.4	40.0	5.0	16.0	1.5		64.5		14.0	38.5	4.0	61.6	240.9	40.0
2.7	HIGH VOLTAGE MODULE DEVELOPMENT	17.5	22.5	7.5	30.7	188.4	20.0	15.0	23.5	6.0	30.7	175.9		32.5	46.0	13.5	61.4	364.3	20.0
2.8	DIFFUSION BARRIER DEVELOPMENT	7.5	25.0	1.5	41.0	147.8		28.5	47.5	2.0		239.7	95.0	36.0	72.5	3.5	41.0	387.5	95.0
2.9	SECOND GENERATION MODULE DEMONSTRATION							23.5	50.0	16.0	75.0	362.0	50.0	23.5	50.0	16.0	75.0	362.0	50.0
2.10	MATERIALS AND PROCESS DEVELOPMENT & EVALUATION																		
2.10.1	THERMAL CONTROL COATING	1.5	1.5		12.0	24.7		2.5	2.5		28.0	51.2		4.0	4.0		40.0	75.9	
2.10.2	THERMAL CONTACT GREASE	1.5	2.5		1.5	14.1		2.5	5.0	1.5	1.5	29.0		4.0	7.5	1.5	3.0	43.1	
2.10.3	MODULE/AEROSHELL ASSEMBLY	1.5	4.0		1.5	17.8		4.0	6.5	2.5	2.5	43.2		5.5	10.5	2.5	4.0	61.0	
2.10.4	TUNGSTEN COATING FOR Ta-10W							1.5				6.1		1.5				6.1	

Sheet 2 of 2

TABLE 2-1

PHASE II - TECHNOLOGY DEVELOPMENT AND COMPONENT DEMONSTRATION (M&S, CAP, TOT is in $1000)		FY-74 MANPOWER (MM)						FY-75 MANPOWER (MM)						TOTAL MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
2.10.5	WELD AND BRAZE JOINTS	2.5	5.0		3.0	26.3								2.5	5.0		3.0	26.3	
2.10.6	AEROSHELL/HEAT PIPE INTERFACE	2.0	3.5		4.0	21.8		2.0	3.5		4.0	21.8		4.0	7.0		8.0	43.6	
2.10.7	HEAT PIPE/RADIATOR INTERFACE	1.5	1.5		3.0	13.6		1.5	1.5		3.0	13.6		3.0	3.0		6.0	27.2	
2.10.8	MATERIALS COMPATABILITY							4.0	7.5		3.0	38.5		4.0	7.5		3.0	38.5	
2.11	MODULE/AEROSHELL INTERFACE EVALUATION																		
2.11.1	EVALUATE MATERIALS AND PROCESS RESULTS							1.5				6.1		1.5				6.1	
2.11.2	THERMAL CONDUCTANCE MEASUREMENT							4.0	7.5	1.5	3.0	43.2		4.0	7.5	1.5	3.0	43.2	
2.12	MODULE/HEAT PIPE INTERFACE EVALUATION																		
2.12.1	EVALUATE MATERIALS AND PROCESS RESULTS							2.5				10.2		2.5				10.2	
2.12.2	THERMAL CONDUCTANCE MEASUREMENT							2.5	5.0	1.5	5.0	33.4		2.5	5.0	1.5	5.0	33.4	
2.13	HEAT PIPE/RADIATOR INTERFACE EVALUATION																		
2.13.1	EVALUATE MATERIALS AND PROCESS RESULTS							1.5				6.1		1.5				6.1	
2.13.2	THERMAL CONDUCTANCE MEASUREMENT							2.5	2.5	1.5	3.0	24.8		2.5	2.5	1.5	3.0	24.8	
2.14	HEAT REJECTION SYSTEM DEMONSTRATION							10.0	11.0		2.0	70.5		10.0	11.0		2.0	70.5	

TABLE 2-2

AVCO PROGRAM TASKS PHASE 2 – TECHNOLOGY DEVELOPMENT (M&S, CAP, TOT IN $1000)		FY-74						FY-75						TOTAL					
		MANPOWER (MM)						MANPOWER (MM)						MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
2.1A	PROGRAM MANAGEMENT	2.6	0.7		1.7	25.3		3.9	1.2			38.2		6.5	1.9		1.7	63.5	
2.2A	AERODYNAMICS DROP TEST	0.6	4.6		2.1	27.7								0.6	4.6		2.1	27.7	
2.3A	HYPERSONIC PERFORMANCE DEMONSTRATION TEST	2.6			0.8	22.0		0.6				5.5		3.2			0.8	27.5	
2.4A	MATERIALS FABRICATION DEMONSTRATION				48.0	59.6											48.0	59.6	
2.5A	AEROSHELL MACHINING DEMONSTRATION										16.5	20.5						20.5	
2.6A	COLD STRUCTURAL TESTS	3.7	5.4		2.7	58.6		3.7	5.4			51.9		7.4	10.8		2.7	110.5	
2.7A	HOT STRUCTURAL TESTS	2.3	2.6			32.0		5.3	6.2		5.6	74.8		7.6	8.8		5.6	106.8	

TABLE 2-3

DYNATHERM PROGRAM TASKS

PHASE 2 - TECHNOLOGY DEVELOPMENT (M&S, TOT, CAP ARE IN $1000)

		FY-74						FY-75						TOTAL					
		MANPOWER (MM)						MANPOWER (MM)						MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
2.1D	PROGRAM MANAGEMENT	2.75				12.4		3.0		0.3		13.8		5.75	0	0.3		26.2	
2.2D	DEFINITION OF RTG REQUIREMENTS	1.1		0.4		6.0								1.1	0	0.4		6.0	
2.3D	PROTOTYPE HEAT PIPE DESIGN	1.1		0.4		6.0								1.1	0	0.4		6.0	
2.4D	HEAT PIPE DEVELOPMENT				3.6	5.6		1.5	3.8			17.5		1.5	3.8		3.6	23.1	
2.5D	TECHNOLOGY EXTENSION	1.2	3.5		1.4	17.1		1.2	3.6			14.7		2.4	7.1		1.4	31.8	
2.6D	HEAT PIPES FOR INTERFACE BREADBOARDING							.25	1.1		0.6	5.2		.25	1.1		0.6	5.2	

TABLE 2-4

PHASE 2 GOVERNMENT SUPPORT COSTS (Thousands of Dollars)

TASK	FY 74 Operating	FY 74 Capital	FY 75 Operating	FY 75 Capital
ORNL Liaison and Miscellaneous Hardware	5	10	13	50
Fuels/Heat Source Development				
Non-Destructive Test	6		86	80
Welding Procedures			106	40
Physical Metallurgy Support		20	20	
Vent Evaluation	3		20	30
Source Criticality Studies	2		6	
Fuel Simulants	3		10	
Loading and Handling Procedures				
Tools and Equipment			33	
Shield Design Studies			5	
Neutron Irradiation Measurements	0		2	
Surplus Tubular Module	*			
Material Survivability/Vulnerability Tests	*		*	
Reentry Body Testing	**		**	

* - Not available

** - See discussion of government costs

WESTINGHOUSE PROGRAM TASKS

TASK 2.1 - PROGRAM MANAGEMENT

Cost Basis - A full time Program Manager having technical and fiscal responsibility - including the programmatic and technical direction of subcontractors. The reporting requirements included in the estimate consist of monthly progress letters, a mid-term and final briefing and a final report; a full time engineer and a half-time technician to assist the Program Manager has been included.

Uncertainty - The principal uncertainty is in the reporting requirements which cannot be determined without additional AEC program guidance.

TASK 2.2 - HEAT SOURCE/FUELS DEVELOPMENT FOLLOW

Cost Basis - A design engineer on a quarter-time basis to follow the ORNL studies, review test plans, and provide technical assistance as required. A materials specialist on a quarter-time basis to assist in the interpretation of test data and how it relates to the ERTG Design; particularly in the areas of weld development and materials compatability/property data.

Uncertainty - A modest level of design effort as indicated has been included. It has been assumed that the Phase I ERTG design provides sufficient definition for the ORNL weld development studies. However, it is possible that once the preliminary experimental data are available, a design iteration on the end closure region may be required to enhance the results of subsequent tests. This design iteration would require about two months and consist of a full time mechanical engineer with half-time support from a thermal, thermoelectric, and materials engineer; comparable drafting effort (2 man-months) being required. In addition, a level of technical assistance has been assumed for costing purposes. This level may increase or decrease pending program results and the desirability of increased support from Westinghouse; neither of these can be determined at this time.

TASK 2.3 - PRODUCT ASSURANCE

Cost Basis - A Reliability engineer will be assigned on approximately a half time, but continuing, basis to provide reliability analysis support to the design engineering and test planning groups, and to coordinate any required quality control inspections.

Uncertainty - The level of Product Assurance manpower will be dependent directly on the quality assurance, reliability and program control specifications imposed by the contract for component development/demonstration hardware.

TASK 2.4 — RESTORATION OF THE TUBULAR MODULE FABRICATION FACILITY

Cost Basis — The capital equipment cost associated with the restoration of the tubular module fabrication facility at the Westinghouse Astronuclear Laboratory is based on a review of previous equipment purchase cost records. The labor cost associated with the equipment reinstallation and checkout is also based primarily on past records. The labor and M&S costs associated with the fabrication and subsequent testing of the tubular module associated with this task are based on much more recent cost information.

Uncertainty — Capital equipment cost uncertainties of approximately 15% exist because of the fact that a large portion of this equipment was originally purchased up to 5 years ago. It is assumed that the Bussman-Simetag 100 ton press used to fabricate thermoelectric washers can be put back into operation with no major overhauling or parts replacement. Module fabrication and testing (labor and M&S) costs are accurate to within 5 percent.

TASK 2.5 — DEVELOP REFERENCE DESIGN MODULE

Cost Basis — The cost of this task is based on a review of cost records related to the engineering and drafting efforts associated with the design and creation of a complete set

of drawings for a new module. Module fabrication costs,destructive examination costs and test evaluation and reporting costs have also been well documented on past programs; $20,000 has been allotted (capital equipment) for test stand hardware.

Uncertainty — Each of the individual effort costs is considered accurate to within 5 percent. The primary uncertainty is related to the number of modules assumed to be required to demonstrate successful operation of the reference design module. On this basis, a dollar level uncertainty of $40,000 is associated with this task assuming that an additional module may be required.

TASK 2.6 — TERNARY MATERIAL QUALIFICATION

Cost Basis — All bench-type qualification experiments (i.e., capsule and die tests) associated with the ternary materials will have been completed prior to initiating the Phase 2 portion of the ERTG program. The cost of this task, which involves only material preparation, acceptance testing and in-module experiments, have been generated by review of past cost records associated with similar efforts; $40,000 has been allotted (capital equipment) for test stand hardware.

Uncertainty — As in the previous task, the uncertainty level is established almost completely by the assumption that an additional module may be required to complete the task. On this basis, an uncertainty dollar level of $40,000 has been assigned to this task.

TASK 2.7 — HIGH VOLTAGE MODULE DESIGN

Cost Basis — The initial phase of this effort is related to washer pressing technique investigations, washer sawing technique investigations, intersegment electrical insulator development and couple assembly investigations. The task also includes engineering trade study and preliminary stress analysis efforts. Total costs of these initial phase efforts

represents about 25 percent of the total task cost. The remainder of the task involves module design, fabrication and testing efforts, the costs of which have been defined as above; $20,000 has been allotted (capital equipment) for test stand hardware and fabrication.

Uncertainty — An uncertainty of approximately ± 20 percent is associated with the initial efforts of this task. In addition, as in previous tasks, dollar level uncertainties are based on the assumption that an additional module will be required to successfully complete the test. The total cost uncertainty associated with items included in this task is $60,000.

TASK 2.8 — TRANSPORT BARRIER DEVELOPMENT

Cost Basis — The estimates for this task were based on experience obtained in identical activity conducted at WANL under the Compact Converter Thermoelectric Program. (This task largely represents a continuation of that work.) It has been assumed for estimating purposes that an in-house vapor deposition facility will be established. The level of effort is (approximately) one full-time and one half-time materials engineer, three full-time technicians, some drafting support and the necessary materials and outside services costs.

Uncertainty - A standard uncertainty of ± 15 percent is applicable to this task. If it is determined that the vendor facility approach can be satisfactorily pursued, the cost will be reduced by $40K, the cost of establishing an in-house facility less the cost of vendor services. If one of the demonstration test modules should be damaged or otherwise compromised during fabrication, the cost will be increased by $40K to provide an additional module.

TASK 2.9 — SECOND GENERATION REFERENCE MODULE DEMONSTRATION

Cost Basis — Manpower, M&S, and capital equipment cost estimates for this task are based on the cost records associated with the design and creation of a complete set of drawings for

a new module. The total cost includes provisions for a final set of engineering trade studies to determine module component dimensions required to meet system power and voltage objectives. The costs associated with the fabrication and testing of five identical second generation reference design modules have been factored into the total. Also included is $50,000 of capital equipment for test stand hardware and fabrication.

Uncertainty — An uncertainty of $40,000 in the total cost of this task is assigned to the possibility that an additional module may be required to complete the task.

TASK 2.10 — MATERIALS AND PROCESS DEVELOPMENT AND EVALUATION

Cost Basis — Most of the estimates prepared under this task were made on the basis of extensive experience obtained with very similar activities conducted at WANL for the Compact Converter Thermoelectric Program and the materials and process development portions of the recently-terminated NERVA Program. Items intended to be performed by outside vendors are costed (where possible) as if they were to be performed in-house, less the cost of equipment design, procurement and setup. The effort level is one three-quarter-time and one half-time materials engineer, two full time technicians, and some drafting support, plus the appropriate materials and outside services costs.

Uncertainty - A standard unertainty of $\pm$ 15 percent is applicable to all subtasks in this section, arising from lack of final detail in the definitions of the experiments to be performed, potential occurrence of unforeseen technical problems (or lack thereof), necessity for redirecting work as a result of changing system component integration requirements, and similar considerations. Specific additional uncertainty areas pertaining to individual subtasks are identified below:

SUBTASK 2. 10. 1 - It has been assumed that thermal degradation of solar absorptance can be measured in existing subcontractor equipment requiring only minor modifications for this experiment. Should this prove not to be the case, additional equipment-related cost of $10K will be incurred. On the other hand, if a surface preparation/coating application/curing process definable on the basis of existing data proves completely satisfactory for the RTG system radiator, then development costs in this area will be reduced by 10 percent.

SUBTASK 2. 10. 2 - If all greases investigated prove to have inadequate radiation resistance for this application, the work would be terminated with a cost savings of 45 percent.

SUBTASK 2. 10. 4 - If the results of materials compatability experiments (Subtask 2.10.8) indicate that an uncoated Ta-10W clad has adequate reaction/diffusion resistance, this work will be unnecessary and this subtask not performed.

SUBTASK 2. 10. 6 - This work was estimated on the assumption that a vendor can be identified who will designate, modify as required, and reserve for use on this project an equipment system (or systems) capable of performing the necessary coating processes. If such a vendor cannot be identified, an additional cost of $75K will be incurred for design, procurement and setup of an equipment facility. (Such a facility may overlap with the facility requirements of Subtask 2. 10. 4 and Task 2. 8).

SUBTASK 2. 10. 7 - If Delta Bond epoxy adhesive proves to be unsuitable for this application, due to excessive evaporation or inadequate radiation resistance, a second iteration of this subtask (using a new adhesive) would be required and the cost doubled.

SUBTASK 2. 10. 8 - If surplus Compact Converter Program tubular modules cannot be transferred to this program for use as specimens, then fabrication of a new module (or equivalent) will be required at a $35K cost not included in the estimate for this work.

TASK 2.11 - MODULE/AEROSHELL INTERFACE EVALUATION

Cost Basis - The estimates for this task were based on recent experience obtained in very similar activities conducted at WANL under the Compact Converter Thermoelectric Program and the recently terminated NERVA Program. The effort level is a one-third time engineer, eight man-months of technician support, one man-month of drafting support and the necessary materials and services costs.

Uncertainty - A standard uncertainty of ± 15 percent is applicable to this task. In addition, if the thermal contact grease approach should be abandoned due to inadequate radiation resistance (as discussed under Task 2.10, Subtask 2.10.2), the cost of this task will be reduced by 25 percent. Alternatively, if the module-into-aeroshell assembly procedure presents more formidable problems than currently anticipated, the cost of evaluation and integration of that procedure would be increased by 15 percent.

TASK 2.12 - AEROSHELL/HEAT PIPE INTERFACE EVALUATION

Cost Basis - The estimates for this task were based on recent experience obtained in very similar activities conducted at WANL under the Compact Converter Thermoelectric Program and the recently terminated NERVA Program. The effort level is four man-months of engineering labor, with a total of five man-months of technician and drafting support, plus the necessary materials and services costs.

Uncertainty - A standard uncertainty of ± 15 percent is applicable to this task. No additional uncertainty is visualized at this time.

TASK 2.13 - HEAT PIPE/RADIATOR INTERFACE EVALUATION

Cost Basis - The estimates for this task were based on recent experience obtained in very similar activities conducted at WANL under the Compact Converter Thermoelectric Program and the recently terminated NERVA Program. The effort level is three man-months of engineering labor, a total of three man-months of technician, machinist and drafting support, and the necessary materials and services costs.

Uncertainty - A standard uncertainty of $\pm$ 15 percent is applicable to this task. In addition, if Delta Bond epoxy adhesive proves to be unsuitable for this application due to excessive evaporation or inadequate radiation resistance, a second iteration of Subtask 2. 10. 7 would be required and the cost of this task would be increased by 50 percent.

TASK 2.14 - HEAT REJECTION SYSTEM DEMONSTRATION

Cost Basis - The estimates for this task are based on experience obtained on similar programs at WANL. A manufacturing engineer, a test engineer, and two technicians for three months has been allotted to assemble the heat rejection system and ready the system for testing. A test engineer and a technician has been provided in the estimate to perform the static and dynamic tests — assumed to require two months to perform.

Two man months of a test engineer and three man months of technician support has been allotted to perform the life tests (data point taken every week), reduce data, and prepare test reports; $2,000 has been allotted for miscellaneous hardware.

Uncertainty - A standard uncertainty of 20 percent is applicable to this task.

AVCO PROGRAM TASKS

TASK 2. 1A - PROGRAM MANAGEMENT

Cost Basis - Cost basis is on an average one-third time effort of senior project manager with related experience. The initial planning phases will be full time.

Uncertainty - Budgetary.

TASK 2. 2A - IMPACT VELOCITY DEMONSTRATION TESTS

Cost Basis - Previous Avco experience: Avco Model Shop - estimate on model fabrication and balance; Aerodynamicist for 3 weeks to design model, coordinate and monitor tests, and prepare test report. Helicopter and radar tracking to be GFE.

Uncertainty - Budgetary.

TASK 2.3A - HYPERSONIC PERFORMANCE DEMONSTRATION TEST

Cost Basis - Previous Avco experience: Aerodynamicist for 12 weeks to plan, coordinate and monitor tests and to prepare a final test report. The wind tunnel time and models will be GFE.

Uncertainty - Avco costs budgetary; wind tunnel test time depends on model-balance compatability, est. 3-5 days tunnel time.

TASK 2.4A - MATERIALS FABRICATION DEMONSTRATION

Cost Basis - Cost submission by POCO Graphite Co. based on large cylinder program to manufacture two billets of POCO AXF on a best efforts basis.

Uncertainty - If fabrication is not feasible, alternate segmented approach will be used and maximum cost to government is $8000.

TASK 2.5A - AEROSHELL MACHINING DEMONSTRATION

Cost Basis - Previous vendor experience, cost submissions by Ultra-Carbon Corp. with specialty machining experience, full scale POCO billets available. Cost reflects potential failure on first billet and success on second billet. Delivery of two aeroshells is planned.

Uncertainty - If successful on first billet, there will be a cost reduction of up to 30%.

TASK 2.6A - COLD STRUCTURAL DEMONSTRATION TESTS

Cost Basis - Avco Structures Lab testing and model fabrication estimates based on previous Avco experience. Duplicate models are costed to allow for redesign in the event of a model failure.

Uncertainty - Budgetary.

TASK 2.7A - HOT-STRUCTURE DEMONSTRATION TESTS

Cost Basis - Avco structures lab testing and model fabrication estimates based on previous Avco experience of thermal-structural testing of graphite. Duplicate models are costed to allow for redesign in the event of model failure. Tests will be supported by structural analysis; material purchased will have NDT screening to ensure quality.

Uncertainty - Budgetary.

DYNATHERM PROGRAM TASKS

Cost Basis - The basic heat pipe design is a 3/8" diameter axially grooved configuration. During Phase 2 it is assumed that this basic design will be developed in detail. On the basis of preliminary evaluations by the tubing manufacturer development of this configuration should not present any problem. Any major changes in ERTG geometry and performance requirements will, however, necessitate development of a new design. Also during Phase 2, an extension of existing copper/water technology will be required. This technology extension is required beyond what is available as a result of Isotopes HPG program to alleviate the uncertainties of long term operation in the 300-350°F range, to develop detailed procedures consistent with flight hardware requirements and to apply existing processes to the fabrication of the axially grooved heat pipe design. Finally, in order to maintain at least minimal program management functions, a program manager/program engineer devoting 25% of his time to the program has been assumed. A separate task has been added to reflect this effort.

Reporting has been limited to monthly progress letters and a final report during Phase 2.

GOVERNMENT SUPPORT TASKS

The cost basis for the government support tasks is given below. ORNL has identified the costs and cost basis for the fuels/heat source development program in addition ORNL has identified the liaison costs and miscellaneous capital equipment costs given in Table 3-4.

(a) Fuels/Heat Source Development

NON-DESTRUCTIVE TEST DEVELOPMENT

Cost Basis - Feasibility studies on the different materials and the capsule design to establish inspection methods, sensitivities, and reference standards will be made. Components to be used in fabrication studies will be inspected and documented to in-house-generated quality assurance requirements. Particular attention will be given to prototype procedures and equipment development for seal or closure weld inspections. These procedures along with destructive testing will be used to help establish welding parameters.

WELDING PROCEDURES

Cost Basis - During the first two or three quarters of FY 1975, ORNL would carry out weldability studies on the capsule materials to determine the effect of the procedural variables (such as pre-weld heat treatment, cleaning techniques, and welding process and parameters) on the weldability and mechanical properties (such as bend ductility and tensile strength) of the capsule materials. For example, the electron beam and gas tungsten-arc process will be compared to see if either has definite advantages over the other for a given material with respect to weldability and/or mechanical properties (including aging phenomena). Preliminary welding parameters would be developed at this time for the material thicknesses called for in the design.

During the latter part of this year fixturing for holding the various components during welding will be designed and fabricated and the development of procedures for welding full-size parts with geometries (including restraint) as close as possible to the actual parts will be initiated. The necessary data on weld shrinkage and the effect it has on dimensional tolerances will be acquired. Characterization of the welds would be continued during this period.

PHYSICAL METALLURGY SUPPORT

Cost Basis - Long-term aging stability and/or compatibility of these materials with oxygen and/or graphite will be determined. The mechanical properties of candidate alloys will be measured

under or after exposure to simulated heat source conditions to determine if environmental reactions or alloy instabilities lead to degradiation such as embrittlement or loss in strength.

VENT EVALUATION

Cost Basis - In FY 74 it is anticipated that an experimental plan will be designed and evaluated in which the contractor-designed vent concept will be incorporated into a test device. During FY 75 the vent test device will be fabricated and curium sources will be fabricated, and the devices will be experimentally tested under the stated conditions of use and anticipated accident conditions.

SOURCE CRITICALITY STUDIES

Cost Basis - In FY 74, a scanning type calculation using existing cross section data will be performed. This is intended to confirm that no serious problem of criticality exists. In FY 75, a detailed calculation, using "worst case" condition, will be made for the source design configuration. Verification of the "worst case" condition will be made by examining various conditions of reflection, geometry, and moderation. During this time it is anticipated that improved cross section data on curium isotopes will become available from other programs.

FUEL SIMULANTS

Cost Basis - In FY 74, literature will be searched to establish potential candidates as acceptable fuel simulants for curium fuels. It is anticipated that the materials can be narrowed down to four or less in the period. In FY 75, pellets of the candidate materials will be fabricated and a number of them tested in the fuel impact gun facility to compare their fines production similarity to the curium fuel form. (Impact testing of curium fuel will be performed in the base line curium development program). It is expected that one of the potential simulants will be selected as the simulant for use in the safety tests.

LOADING AND HANDLING PROCEDURES

Cost Basis - Basic procedures for loading fuel into the source and in-cell handling will be developed. Design of handling and loading tools, cooling devices, storage containers, etc., will be accomplished. Fabrication of some items, not of a capital expenditure classification, needed in other tasks will begin.

SHIELD DESIGN

Cost Basis - A cursory look at shielding required for the conceptual source design will be performed.

(b) Neutron Irradiation Measurements

A cost estimate is based on evaluation of six samples of greases, etc. Each sample would be loaded into an evacuated quartz tube, the tube placed in a "rabbit container", and irradiated in a reactor at ORNL. ORNL has estimated the cost at about $325 per sample.

(c) Surplus Tubular Modules

A cost estimate of the government support is not available at this time.

(d) Material Survivability/Vulnerability Tests

A cost estimate of the government support is not available at this time.

(e) Reentry Body Testing

An estimate for the aerodynamic drop tests is one day at Wallops Radar Range plus the use of a helicopter. The Hypersonic Performance Test will require three to five days at Tunnel C, AEDC plus about $30,000 for force/movement/pressure/heating models.

2.2 PHASE 3 - SYSTEM DEVELOPMENT AND QUALIFICATION

The primary objectives of Phase 3 of the program are prototype development and flight qualification of the Second Generation ERTG. The proposed schedule for accomplishing this objective is shown in Figure 2-4. This phase of the program is predicated on the assumption that a firm definition of system requirements and schedules, including the definition of the launch vehicle and spacecraft interfaces, will be provided by the AEC at the beginning of Phase 3.

The initial efforts in Phase 3 will be directed toward design of the flight prototype. The results from Phase 2 will be used to update the Phase 1 ERTG design. The design effort will be supplemented by the following areas:

- Preliminary Safety Analysis Report. A comprehensive review of the ability of the design to meet program safety requirements, including safety design criteria, a translation of mission requirements and constraints into specific safety and accident conditions and a summary of analyses performed. Also, a well-developed program defining all analyses and testing required to verify the ability of the developed system to meet safety requirements.

- Spacecraft Integration Evaluation. A user-oriented ERTG description which defines features and characteristics of the ERTG in terms of interfacing with spacecraft and experimental packages - discussing such areas as magnetic and electromagnetic field generation, radiation dose levels, various monitoring arrangements, thermal interface requirements and constraints, etc.

- Reliability Analysis. A thorough evaluation of the ERTG design in terms of its ability to meet program reliability objectives and the effect on reliability of alternate approaches to various elements of design. A definition of key areas which must be emphasized in assuring that the selected concept meets reliability objectives, and a defined design, test, reliability and quality assurance program which will assure that these objectives are in fact met.

- Ground Support Equipment Sequence. An evaluation of the requirements for special shipping, handling and launch-site test equipment, a preliminary definition of all shipping, inspection, installation and launch-pad test sequences; and conceptual design of special tooling and fixtures required along with

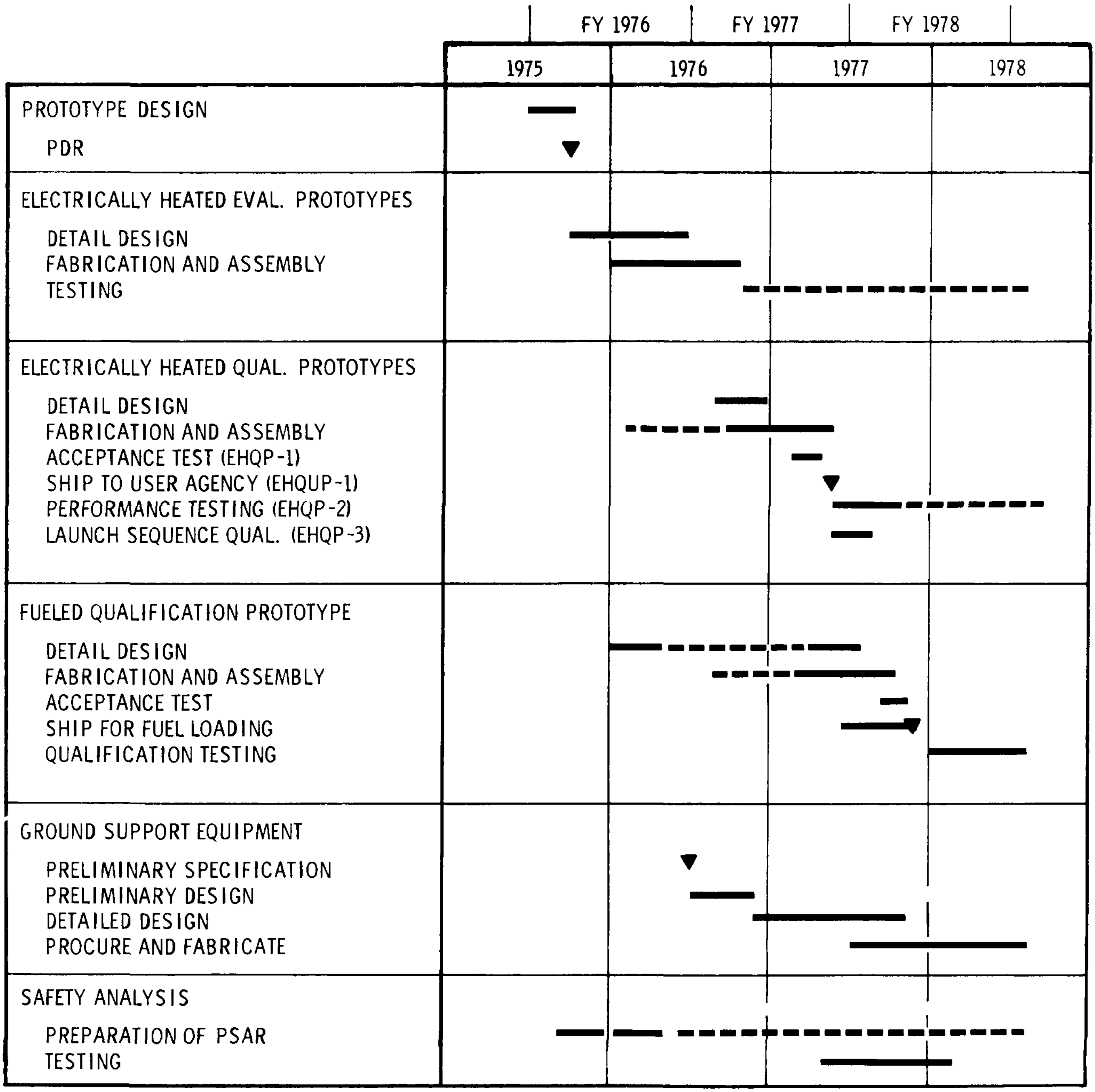

Figure 2-4. Phase 3 - System Development and Qualification

an updating of launch-site facilities. A defined GSE test plan covering the design, development and test of all special ERTG support equipment the qualification of this equipment, and its translation into operational use at launch-sites (including training program definitions).

The design of prototype test systems will be prepared in Phase 3, based on the results of the Phase 2 component design verifications. Hardware will be procured and, as shown in Figure 2-4, two Electrically Heated Evaluation Prototype (EHEP-1, -2) will be assembled. Product Assurance procedures will be implemented during this phase of the program as defined in Appendix B.

Both systems will be subjected to thorough performance testing and will be placed on life test. EHEP-1 will undergo performance mappings and evaluations in ambient and vacuum environment. The EHEP-2 test program will include several environmental tests representative of anticipated service conditions.

Three Electrically Heated Qualification Prototypes (EHQP-1, -2 and -3) will be assembled incorporating design modifications resulting from the EHEP-1, and -2 fabrication and testing. The first system (EHQP-1) will receive acceptance tests and will be shipped to a Using Agency. EHQP-2 will undergo performance testing and will be placed on long term test under design load in a vacuum environment. EHQP-3 will be performance tested and subjected to a series of environmental qualification tests. At the conclusion of these tests, the performance of the unit will be checked to confirm the capability of the ERTG design to meet mission requirements without suffering performance degradation.

Safety verification tests will be performed on the prototype heat source design to support the preparation of a final safety analysis report which is part of the Phase 4. Ground support equipment will be designed. The Fueled Qualification Prototype (FQP-1) will be tested at ORNL. The unfueled components will be acceptance tested prior to shipping to ORNL. The performance of the FQP-1 will be checked and the thermal, magnetic and radiation environment of the ERTG will be mapped prior to placing the unit on long term test.

2.2.1 Westinghouse Task Statements

TASK 3.1 — PROGRAM MANAGEMENT

This task provides the program direction and coordination, configuration control after appropriate design freezes have been effected, program planning and budgetary control, and reporting. This task serves as the focal point for incoming and outgoing contract correspondence assuring overall coordination and timely reaction to customer direction. In addition, technical and programmatic direction, including monitoring of configuration control programs of all subcontractors will be performed. Detailed requirements specifications for the ERTG will be prepared.

TASK 3.2 - PROTOTYPE DESIGN

This task will initiate Phase 3 and will provide a design of the prototype ERTG. By factoring in the results of the Phase 2 component development, this task will permit the Phase I Second Generation ERTG Design to be updated. The prototype design will be the precursor for detailed design of the actual prototype systems to be built during Phase 3. A complete performance description of the prototype design will be prepared. A preliminary test plan will also be prepared. The results of applicable AEC technology programs will be thoroughly reviewed at the outset of the design as well as being closely followed during this task and the remainder of the program. A PDR (Preliminary Design Review) will be held at the conclusion of this task.

TASK 3.3 - ELECTRICALLY HEATED PROTOTYPE SYSTEMS

Detailed design of the electrically heated evaluation prototype systems (EHEP-1 and EHEP-2) will be performed under this task following the PDR. Detailed drawings of each component and subassembly will be prepared along with an overall assembly drawing. A manufacturing plan will be prepared. The design effort will be supported by appropriate mechanical, thermal, thermoelectric, stress analyses, reliability and manufacturing personnel. This task will be supported by comparable design tasks assigned to Avco and Dynatherm for the reentry aeroshell and heat pipes respectively. Following the design freeze of the EHEP, two systems will be fabricated, assembled and readied for evaluation testing. The tubular module(s) will receive an electrical

acceptance test prior to assembly. After assembly, both systems, EHEP-1 and EHEP-2, will receive a brief evaluation of load-temperature performance. EHEP-1 will be subjected to a very thorough performance mapping to establish operating characteristics, while EHEP-2 will undergo extensive environmental operation.

The EHEP-1 tests will include performing ambient (simulating the launch vehicle environment) and vacuum evaluation of the system temperature profiles at no-load and design point conditions with various heater inputs which simulate the fuel capsule. The map created will form a basis for system verification as well as optimization for space conditions.

The tests on EHEP-2 will identify the effects of the significant individual environments as well as their accumulated result; i.e., launch environment superimposed on the thermal response of the electrically heated system. Several key parameters such as the load characteristics will be used as a measure of environmental effects and these results will be correlated with the EHEP-1 test data. At the conclusion of this test series, EHEP-1 will go on long-life tests in a vacuum environment which is expected to continue to the end of the program. EHEP-2 is potentially available for environmental tests such as the applicable parts of the MIL-STD-8108 series or full use, if required, as additional test hardware to support the safety evaluation program.

TASK 3.4 - ELECTRICALLY HEATED QUALIFICATION PROTOTYPE SYSTEMS

Final design of the electrically heated qualification prototype system (EHQP) will be performed under this task with as much feedback as possible from the experience gained in designing, fabricating and testing the evaluation prototypes. Detailed test specifications will be prepared.

Three EHQP systems will be built for subsequent qualification testing. Manufacturing procedures for these qualification systems will have been refined as a result of the earlier fabrication, assembly, and testing of the evaluation prototypes.

The first unit (EHQP-1) will receive a preliminary acceptance test similar to that intended for the fueled systems and shipped to the spacecraft contractor. This acceptance test will include electrical, thermal, and vibration tests. Sufficient information will be acquired to reinforce

and correlate with prior data obtained from the Evaluation Prototype Tests. It is intended that EHQP-2 will undergo a performance checkout and then be placed on steady-state life tests at design load in a vacuum environment, to demonstrate the overall service capability of the hardware.

The third unit (EHQP-3) will be static performance tested in a vacuum environment to establish initial data point and then tested in a series of environments typical of the launch sequence. At the conclusion, the unit will be operated in vacuum to (specification) required performance levels. This test will demonstrate the ability of the ERTG design to survive launch, orbit, and deployment as a functional operating unit. At completion, the simulated fueled module aeroshell will be impact tested as part of Task 3.7 to demonstrate the intact survival capability of the heat source design.

TASK 3.5 - FUELED QUALIFICATION PROTOTYPE SYSTEM

Detailed design of the fueled qualification prototype (FQP) will be performed with design feedback from the electrically heated prototype test results. Detailed design of the fuel capsule will be performed with close ORNL liaison. Detailed procedures for handling the fuel capsule and tubular module and for subsequent loading will be defined jointly with ORNL.

Fabrication of the FQP will be performed and most of the assembly done at WANL. Fuel loading into the capsule/tubular module unit will be performed at ORNL as will final assembly of the ERTG which consists of inserting the fuel capsule/tubular module assembly into the aeroshell and performing final electrical connections.

Following fueling of the FQP, qualification testing will be performed at ORNL to demonstrate the performance capability and flight readiness of the fueled design. Prior to testing, this task will also provide the test planning efforts needed to define the qualification procedures in detail. These procedures will be established jointly with the AEC with ORNL participation.

TASK 3.6 - SYSTEM AND SPACECRAFT INTEGRATION

This task will focus on ensuring that the ERTG design is compatible with the spacecraft and launch vehicle definitions specified by the AEC. Requirements, specifications and interface documents will be prepared at the beginning of Phase 3. These specifications will constitute a portion of the ERTG design criteria and GSE design criteria.

This task also will provide the definition for portions of the prototype ERTG qualification testing. Specifically, qualification tests that involve integration with a simulated spacecraft or space environment simulation will be defined under this task via liaison with the user agency and the spacecraft or integration contractor. This task also will include support, as needed, to the spacecraft contractor during testing of EHQP-1.

TASK 3.7 - SAFETY EVALUATION

This task will ensure that the prototype ERTG designs are continually monitored and that safety requirements are effectively incorporated into the designs. Conduct of safety verification tests will be a major activity during this phase and will require close coordination and liaison with the various organizations responsible for performing such tests. Tests crucial to the system design will be given schedular priority and results will be factored into the safety analyses. These tests will include subjecting a simulated heat source design to the anticipated earth impact environment, liquid and solid propellant fire environments. A fueled heat source safety environment test is not contemplated.

A preliminary safety analysis report (PSAR) will be prepared under this task. In addition, license application for the GSE (shipping casks) will be submitted. Appropriate system design and performance descriptions on a component and subsystem level will be incorporated. The results of analyses and tests related to the definition of accident environments will be prepared. The PSAR will contain the results of accident analyses, systems integration analyses, failure mode analyses, and fault-tree analyses. A quantitative assessment of the radiological hazards and risk associated with each phase of the specified mission will be developed. The fueled and unfueled prototype system tests will also be closely followed in order to promptly identify any performance anomalies that could have safety significance.

TASK 3.8 - GROUND SUPPORT EQUIPMENT (GSE) DESIGN

This task will be initiated during Phase 3 with an update of the Preliminary Utilization Analyses prepared in Phase 1. This update will permit firm GSE requirements to be specified after which preliminary and final GSE design will be performed; for example, the design of the shipping cask for the fueled module assembly. Requirement for checkout and use of the GSE will also be prepared as part of this task. The tool (head) for inserting the fueled module assembly into the aeroshell will be fabricated and supplied to ORNL for use during the FQP-1 assembly.

TASK 3.9 — PRODUCT ASSURANCE

A reasonable and adequate Product Assurance program will be pursued during Phase 3 consistent with those successfully applied at WANL during the developmental and qualification stages of previous programs for space and DOD applications. All of the provisions of the WANL Quality Assurance and Reliability Plans (Appendices B and C, respectively) are available for selective implementation during Phase 3. The extent to which the plans will be applied will depend on the sensitivity of the design, the number of reliability/safety critical components, and the process and systems controls designated by the contract. Based on these considerations, the Product Assurance program will be conducted so as to systematically apply appropriate configuration, fabrication, test and end item controls leading to the delivery of a fully documented ERTG for flight qualification.

2.2.2 Avco Task Statements

TASK 3. 1A- PROGRAM MANAGEMENT

Avco will maintain a project office to provide administrative and technical direction to all participating Division organizations. The project office will also, in conjunction with the Material Department, prepare a subcontract plan covering major subcontracts. Two subcontracts are anticipated; 1) the fabrication of the graphite aeroshell billets and 2) the internal and external machining of graphite aeroshell parts.

The project office will:

- Prepare and issue a Project Directive document which provides administrative and technical direction to all participating Division organizations.

- Support subcontract negotiations through award, prepare and update the Subcontract Plan, and maintain technical management of the subcontracts.
- Insure maintenance of the desired program schedule, cost and performance.
- Maintain liaison with Westinghouse, subcontractors and vendors, manage all configuration control and integration efforts.
- Provide administrative and technical documentation as required for the program and the PSAR.
- Participate in PDR and FDR.

TASK 3.2A- AERODYNAMICS

Sufficient aerodynamic studies and testing will be performed to derive the most advantageous reentry body design consistent with the programmatic performance objectives requirements and current technology. The Aerodynamics function will:

- Perform trajectory analyses in support of the reentry aero-thermal structural analysis, including direct, skip and spacecraft breakup.
- Perform preliminary design analyses on aerodynamic shape and size, including coefficients, heating and loads, factoring in further test data from Phase II. Design optimization shall consider thermal-structural, fabrication and TEM design requirements.
- Define, plan and carry out the aerodynamic tests necessary to the aerodynamic design, including force and moment coefficients, heating and pressures.
- Perform aerodynamic analyses of the final reentry body design using test data from Phases I and II; the results shall include the predicted aerodynamic performance, heating and loads for all abort modes.
- Perform reentry calculations for the spacecraft and predict the thermal environment through the breakup altitude.
- Prepare aerodynamics requirements regarding fabrication and mass-balance tolerances.

TASK 3.3A- THERMODYNAMICS

Sufficient thermodynamic studies and related testing will be performed to derive the most advantageous reentry body design consistent with the performance objectives and requirements

and current technology. Avco will make use of its multi-dimensional heat transfer computer programs to provide detailed thermal performance predictions during reentry. In particular, the thermodynamics organization will:

- Perform preliminary design analyses on reentry body thermal performance for direct-entry and skip abort modes as support of a joint aero-thermo-structural optimization study leading to a selected design.
- Support the thermal-structure test plan leading to the design of the test and evaluation of test results.
- Perform thermodynamic analyses of the final reentry body design. The results shall include reentry thermal performance and ablation.
- Prepare thermodynamics requirements regarding accuracy of the heating and material properties.
- Provide support to the reentry safety analysis to calculate the spacecraft breakup altitude.
- Prepare a preliminary safety analysis report on the reentry body thermodynamic performance.

TASK 3.4A- STRUCTURES

Sufficient structural studies and testing will be performed to derive the most advantageous reentry body design consistent with performance objectives and requirements and current technology. Avco will make use of industry standard programs such as NASTRAN to perform thermal-structural performance analysis during reentry. The structures organization will:

- Perform preliminary analysis on structural design in conjunction with aero-thermo-design leading to a selected reentry body design.
- Define, plan and conduct structural tests necessary to aeroshell design, including the engineering model testing under a thermal-stress simulation.
- Perform structural design analysis of the final aeroshell design, working in conjunction with manufacturing to evolve a low-cost lightweight aeroshell concept.

- Prepare a structure requirement regarding the material properties, manufacturing tolerances. Assess the sensitivity to the aero-thermal design including loads, heat rate and material properties.

- Prepare preliminary safety analysis report on the aeroshell in the structure area.

TASK 3.5 A- MECHANICAL DESIGN

The mechanical design studies will produce drawings of aeroshell approaches throughout the study. Each approach will be examined for weight, thermal-structural performance, fabricability and interface requirements. The mechanical design organization will:

- Perform preliminary mechanical design studies on the aeroshell in conjunction with aero-thermo-structure and with the graphite supplier and machine shop to evolve a low-cost lightweight design.

- Provide mechanical design support to aerodynamics and structures in test model design and fabrication including the engineering test model and mockup.

- Provide mechanical system interface support regarding the aeroshell interfaces including the TEM, heat pipes and launch support.

- Perform mechanical design analysis and prepare detailed drawings for the final design.

- Prepare design of aeroshell handling and shipping equipment.

- Perform mass properties studies to ensure the aeroshell meets the aerodynamic requirements.

- Prepare a preliminary safety analysis report on the aeroshell in the mechanical design area.

TASK 3.6 - QUALITY ASSURANCE

The Quality Assurance activity will provide the maximum assurance that the aeroshell conforms to the applicable specification and standards defined by Westinghouse. The QA organization will:

- Prepare a QA plan covering the manufacturing and machining of the aeroshell, including inspection and test procedures.

- Perform in-process and final inspections on all aeroshells produced in Phase III.
- Direct and monitor the aeroshell proof-testing and evolve the procedures for acceptance testing.
- Provide documentation of the QA effort for the PSAR.

TASK 3.7A- RELIABILITY

The reliability activity will ensure the aeroshell is designed, fabricated and tested to meet the operational reliability defined by Westinghouse. The reliability organization will:

- Prepare a reliability plan to insure the aeroshell will meet the operational reliability requirements.
- Monitor design and audit design specifications.
- Support all reentry mode safety analyses with a Failure Mode Analyses.
- Prepare a reliability analysis of the aeroshell factoring in test results, process and inspection data obtained on the aeroshells produced.
- Provide documentation of the reliability effort for the PSAR.

TASK 3.8A- MANUFACTURING AND ASSEMBLY

It is anticipated that fabrication of the aeroshell graphite billet and machining will be done externally; the assembly of the aeroshell parts will be done at Avco. The Project Office will direct the external manufacturing effort with consultation of the Avco manufacturing, materials and processes and QA personnel.

- Develop an assembly and packaging plan in coordination with the QA plan.
- Perform assembly and packaging of all completed aeroshells.
- Maintain logs concerning the assembly and packaging of each aeroshell.

TASK 3.9A - SYSTEM TESTING

The aeroshell will be flight qualified by subjecting to a series of tests simulating the time-sequence of flight environments from launch to reentry. Vibration, shock, noise, vacuum, reentry loads and thermal stress loads will be simulated. The Systems Test organization will support Westinghouse to:

- Prepare a Qualification Test Plan covering the sequence of tests, instrumentation and facility to be used.
- Initiate and direct the qualification test program and prepare final test reports.
- Prepare a Qualification Test record for the PSAR.

2.2.3 Dynatherm Task Statements

During this phase, the ERTG heat pipes will be designed, fabricated and flight qualified in accordance with the requirements of the ERTG Heat Pipe Prototype Specification developed early in Phase 3.

TASK 3.1D - PROGRAM MANAGEMENT

This task provides the program management to implement the administrative and technical direction of the project. The monitoring of subcontracts and the preparation of reports is included as part of this task.

TASK 3.2D - PREPARATION OF PROTOTYPE ERTG HEAT PIPE SPECIFICATIONS

Based on the results of the Phase 2 efforts, a prototype ERTG Heat Pipe Specification will be written by Westinghouse with support from Dynatherm. The specification will define the required operational performance characteristics, physical geometries and interfacing requirements, operating and non-operating environmental conditions, reliability requirements, and the quality assurance provisions for qualification and production prototype and flight qualified hardware.

TASK 3.3D — HEAT PIPE DESIGN & FABRICATION PROCEDURE DEVELOPMENT

Design drawings, supporting analysis, detailed fabrication procedures and test procedures will be required for the fabrication and testing of the prototype ERTG heat pipes.

- Develop the detailed design of the heat pipes to meet the functional and performance requirements of the prototype ERTG Heat Pipe Specification. This will include a complete set of drawings suitable for release to manufacturing for fabrication and assembly of all parts of these heat pipes. Supporting analysis will be generated and will cover thermal performance, lifetime prediction, stress analysis and weight.

- Develop the fabrication, assembly, welding, cleaning, surface treatment and charging procedures for producing the qualification and prototype ERTG heat pipes. This effort will include the processing of representative samples in order to qualify critical steps of the manufacturing process. A quality assurance log will be generated with check-off sheets for each step in the entire fabrication and testing process. In addition, all necessary tooling and fixtures will be designed and fabricated.

- Prepare plans and procedures for qualification testing the ERTG 3/8 in. diameter axially-grooved heat pipes. These tests will include:
  - Leak Tests
  - Pressure Tests
  - Thermal Performance Tests
  - Life Tests

  The thermal performance qualification tests will consist of two temperatures and burn-out vs. tilt tests.

TASK 3.4D — FABRICATION & TEST OF QUALIFICATION MODEL HEAT PIPES

During this phase, the 3/8-inch diameter axially grooved ERTG heat pipes will be qualified for use in the ERTG systems.

The qualification heat pipes per the design and procedure developed during Task 3.3D will be fabricated.

Qualification tests on twelve heat pipes per the test plans and procedures as developed under Task 3.3D during this effort will be performed. The object of these tests will be to qualify the axially grooved Cu-H_2O heat pipes for use in the ERTG systems. The heat pipes will be installed in a fixture which simulates the physical, functional and operational environment of the ERTG system. Data will be collected during burnout versus tilt tests at two temperatures. These data will be evaluated to verify that the heat pipe meet the qualification requirements defined in the ERTG Heat Pipe Specification. Testing will also include leak tightness and pressure cycling. Life tests will be conducted on the twelve heat pipes.

The tests will be conducted over a period of five years to verify operational life. At intervals of six months, one heat pipe will be removed from test, the internal surfaces examined, and an analysis of the working fluid performed.

TASK 3.5D — FABRICATION & TEST OF QUALIFICATION HEAT PIPE SETS

During this task, heat pipes for ERTG prototype testing will be fabricated, acceptance tested and delivered to Westinghouse as specified below:

- EHEP — 2 sets - 24 Heat Pipes per Set
- EHQP — 3 sets - 24 Heat Pipes per Set
- FQP — 1 set - 24 Heat Pipes per Set

Each heat pipe will be acceptance tested per the test plans and procedures developed during Task 3.3D. The object of these tests is to verify that each heat pipe meets the performance requirements of the ERTG System. These heat pipes will be tested at two temperatures and one tilt angle. Data will be collected and evaluated to verify that each heat pipe meets the minimum performance requirements.

Pressure cycling and leak tightness tests will also be performed on each heat pipe per procedures established in Task 3.3D.

2.2.4 Government Support

The specific areas of requested government support are:

- Fuels/Heat Source Development
- Performance of Fueled Prototype Test
- Safety Analysis and Test of Heat Source

Each of these areas are discussed below.

FUELS/HEAT SOURCE DEVELOPMENT

Continuation of the ORNL proposed fuels/heat source development program into Phase 3 is recommended. These tasks are of the same scope as identified for Phase 2 and therefore, the scope will not be repeated here. The following additional ORNL task is recommended during Phase 3:

SHIELDING DESIGN STUDIES

The contractor system and satellite shield will be designed utilizing programs developed for use in the SNAP-10 reactor program. The program will design shields for minimum weight for the desired dose. The neutron and gamma radiation spectra will be measured for the production grade fuel and this data will be used for the final shield design. Assistance will be provided to contractors in their work on ground handling requirements and to fabrication facility designers for shielding required for the fabrication facility.

PERFORMANCE OF FUELED PROTOTYPE TEST

This task would be performed by ORNL. The task definition was mutually formulated with ORNL. This task includes the fabrication and testing of a fueled full-up prototype ERTG unit. The task includes the fueling and loading of the source, loading the source into the ERTG unit, running approximately a one year operational test on the unit, and the destructive examination of the source and recovery of the fuel.

SAFETY ANALYSIS AND TEST OF HEAT SOURCE

The performance of impact tests, launch pad fire tests, and other government requested tests relating to the demonstration of the safety of the ERTG heat source design is assumed to be government furnished support. The hardware, such as an electrically heated module as defined in Section 2.2.1, will be furnished by Westinghouse. In addition, government support in related safety analyses areas such as population hazards (including analytical models) and assistance in obtaining shipping cask license is assumed.

2.2.5 Cost Estimate

The preliminary cost estimates for performing the tasks previously identified are given in Tables 2-5, 2-6 and 2-7 for Westinghouse, Avco, and Dynatherm, respectively. The cost estimates for the identified government support are given in Table 2-8 for those items where specific costs could be obtained. The basis for the cost estimates is given below.

TABLE 2-5

NO.	WESTINGHOUSE PROGRAM TASKS PHASE 3 - SYSTEM DEVELOPMENT AND QUALIFICATION (M&S, CAP, TOT are in $1000)	FY-76 MANPOWER (MM)						FY-77 MANPOWER (MM)						FY-78 MANPOWER (MM)						TOTAL MANPOWER (MM)					
	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
3.1	PROGRAM MANAGEMENT	48	36			284.9		48	36			284.9		48	36			284.9		144	108			854.7	
3.2	PROTOTYPE PRELIMINARY DESIGN	30	10	9	10	187.7														30	10	9	10	187.7	
3.3	ELECTRICALLY HEATED PROTOTYPE SYSTEMS	71	32	59	64	631.8	215	24	43		10	216.4								95	75	59	74	848.2	215
3.4	ELECTRICALLY HEATED QUALIFICATION PROTOTYPE SYSTEMS							51	49	30	74	512.9	70	14	27		5	129.9		65	76	30	79	642.8	70
3.5	FUELED QUALIFICATION PROTOTYPE SYSTEM	10	4	8		75.6		28	11	19	28	237		20	12			112.4		58	27	27	28	425	
3.6	SYSTEM AND SPACECRAFT INTEGRATION	6	6			39.3		12	6		5	70.1		12				49.1		30	12		5	158.5	
3.7	SAFETY EVALUATION	12				49.1		18	6		40	138.1		18	6		10	100.8		48	12		50	288	
3.8	GROUND SUPPORT EQUIPMENT DESIGN							42	6	15		233.7		36	6	17	5	220.4		78	12	32	5	454.1	
3.9	PRODUCT ASSURANCE	24	36			186.7		24	36			176.7		24	36			186.7		72	108			560.1	

TABLE 2-6

AVCO PROGRAM TASKS PHASE 3 - SYSTEM DEVELOPMENT & QUALIFICATION (M&S, CAP, TOT IN $1000)		FY-76						FY-77						FY-78						TOTAL					
		MANPOWER (MM)						MANPOWER (MM)						MANPOWER (MM)						MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
3.1A	PROGRAM MANAGEMENT	9.7	3.2		1.0	94.4		5.8	2.0		1.0	56.6		3.9	1.3			37.9		19.4	6.5		2.0	188.9	
3.2A	AERODYNAMICS	12.9	7.4		3.0	141.2														12.9	7.4		3.0	141.2	
3.3A	THERMODYNAMICS	7.8	3.0		1.5	77.7		1.9	0.7			19.4								9.7	3.7		1.5	97.1	
3.4A	STRUCTURES	9.0	14.2		23	154.9		3.9	6.1			66.3								12.9	20.3		23	221.2	
3.5A	MECHANICAL DESIGN	7.7		23.3		163.8		2.6		7.7		54.2		2.6		7.7		54.2		12.9		38.7		271.2	
3.6A	QUALITY ASSURANCE	2.7			2.0	25.2		3.3				28		2.0				17.2		8.0			2.0	70.4	
3.7A	RELIABILITY	9.0				74.1		3.9				31.8								12.9				105.9	
3.8A	MANUFACTURING AND ASSEMBLY		5.2		71	123			6.4		89	151			1.3		31	44			12.9		191	318	
3.9A	SYSTEMS TEST							12.9				105.9								12.9				105.9	

TABLE 2-7

DYNATHERM PROGRAM TASKS PHASE 3 - SYSTEM DEVELOPMENT AND QUALIFICATION (M&S, CAP, TOT ARE IN $1000)		FY-76 MANPOWER (MM)						FY-77 MANPOWER (MM)						TOTAL MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
3.1D	PROGRAM MANAGEMENT	6.75		0.12		30.7	6.75	0.13				31.2		13.5		0.25		61.9	
3.2D	PROTOTYPE RTG HEAT PIPE SPECIFICATION	0.6				2.5								0.6				2.5	
3.3D	HEAT PIPE FINAL DESIGN, FABRICATION AND TEST PROCEDURES	3.6	1.25	1.1	1.0	23.7								3.6	1.25	1.1	1.0	23.7	
3.4D	QUALIFICATION HEAT PIPES FABRICATION AND TEST	2.6	9.3		2.4	41.7								2.6	9.3		2.4	41.7	
3.5D	QUALIFICATION SETS FABRICATION AND TEST	1.0	5.0		9.0	32.6	2.5	12				45.4		3.5	17		9	78	

TABLE 2-8

PHASE 3 - GOVERNMENT SUPPORT COST ESTIMATES (THOUSANDS OF DOLLARS)

TASK	FY 76		FY 77		FY 78	
	Operating	Capital	Operating	Capital	Operating	Capital
Fuels/Heat Source Development						
Non Destructive Test Development	106	120	26	40		
Welding Procedures	115	60	15	20		
Physical Metallurgy Support	20		10			
Vent Evaluation	8	20				
Source Criticality Studies	6					
Fuel Simulants	5					
Loading & Handling Procedures	18	60				
Shield Design Studies	15		30			
Fueled Prototype Test	25		25	100	200	125
ORNL Liason & Miscellaneous Estimate	13	50	12	50	12	50
Safety Analyses & Tests of Heat Source*	0	0	180		105	

*Does not include effort for licensing GSE.

WESTINGHOUSE PROGRAM TASKS

TASK 3.1 - PROGRAM MANAGEMENT

Cost Basis - This estimate is based on establishing a Project Office to provide technical direction and maintain fiscal and configuration control. A full time Program Manager having technical and fiscal responsibility and providing the focal point for interfacing with government agencies. Three full time Project Managers reporting to the Program Manager have been included in the estimate; a design Project Manager, a Manufacturing and Assembly Project Manager, and an ERTG Systems Project Manager. The ERTG Systems Project Manager, in addition to planning and directing testing efforts, will provide technical direction to subcontractors and will be the focal point for interfacing with the spacecraft contractor. Provision for a full time Project Control Engineer with two assistants to provide technical and fiscal documentation, maintain project fiscal control and design configuration control, etc., has been included in the estimate.

Uncertainty - Cannot be established without further guidance from the AEC, particularly regarding reporting requirements.

TASK 3.2 - PROTOTYPE PRELIMINARY DESIGN

Cost Basis - The Prototype Preliminary Design effort for the ERTG assumes an update of the Phase 1 Second Generation ERTG Design to incorporate those developments accomplished during Phase 2 and to include minor design alterations based on detailed ERTG specifications being provided by the AEC. A four month design period is contemplated which will conclude with a PDR. The design effort consists of two full time mechanical engineers supported on a full time basis by a systems engineer, a thermoelectric design and analysis engineer, a thermal analyst and a materials scientist. Drafting and technician support have been included to the design effort as indicated in Table 2-5. Ten hours of computer time has been allotted to support the design effort. A systems engineer on a full time basis has been included in the estimate to prepare a complete performance description of the ERTG and to assist a half time test engineer in the preparation of a preliminary test plan.

Uncertainty - The principal uncertainty in the estimate is the degree of modification of the Phase 1 Second Generation ERTG Design required as a result of the user agency design and performance specifications assumed to be unknown until the start of Phase 3. The user agency specifications could potentially double or triple the design effort if little or no portions of the Phase 1 ERTG Design could be utilized. If it is assumed that the Phase 1 design requires only nominal modification, then the above estimates are good within -10 to +20%.

TASK 3.3 - ELECTRICALLY HEATED PROTOTYPE SYSTEMS

Cost Basis - The detailed design of the electrically heated prototypes (EHEP-1 and 2) of the ERTG will be prepared following the PDR. Detailed component subassembly and assembly drawings will be prepared including all interface control drawings. The design effort consists of two mechanical designers on a full time basis for eight months; full time support being provided by a thermoelectric designer and analyst, a thermal analyst, and a manufacturing engineer. In addition, effort is allotted for a half time systems engineer and a half time materials scientist. Comparable drafting and technician support has been included. Fifteen hours of computer time has been included to support the design effort. (It should be noted that detailed design of the fuel capsule is part of Task 3.5) The manufacturing engineer will, in addition to supporting the detailed design effort, prepare a detailed manufacturing plan for EHEP-1 and EHEP-2. Identical designs and manufacturing plans are assumed for EHEP-1 and EHEP-2. A full time systems engineer is included to provide the interface with Avco and Dynatherm design efforts. Long lead time materials will be ordered prior to completion of the design; effort has been included for a manufacturing engineer on a half time basis to follow material procurement.

Following the design, component fabrication and assembly will be completed. Two tubular modules will be fabricated, assembled and processed. On the basis of past experience, the cost per module is $40,000; $18,000 M&S, and the remainder engineering/technician labor. Each module will undergo a standard electrical checkout; the cost equivalent of a half engineer and a full technician man-month has been included in the estimate for each module.

The heat pipes (procured from Dynatherm) will be assembled to the radiators and aeroshells (procured from Avco); support components installed. Two manufacturing engineers and four technicians on a full time basis for four months has been assumed to accomplish the assembly and to assist in preparing the units for testing; $13, 000 has been allotted for hardware (radiator shell and supports) and tooling costs. The cost of the electrical heaters is included as part of the $18, 000, M&S costs for a module. A full time manufacturing engineer to follow both Dynatherm and Avco has been assumed.

The EHEP-1 system will be the first unit assembled for performance testing; it has been assumed that a full time test engineer plus two technicians for one month will be required to complete the test setup. Performance tests will be conducted (which will include, for example, thermal maps of the system at various electrical heater power inputs) for a period of three months; two test engineers and four technicians have been included to perform the tests, reduce data, and provide input to test reports. The unit would then be placed on life test in a vacuum environment; an estimate of five man-months of a test engineer and a technician has been included on the basis of a data point being taken each working day for five years. The capital equipment to support this test which would not be available for other tests include data acquisition, sensors, a vacuum chamber, control, etc., which is estimated to be $65, 000; $5000 of miscellaneous hardware has also been included. It has been assumed that the capital equipment would be purchased in FY-76.

The EHEP-2 unit will be the first unit assembled for environmental testing; therefore, a similar effort to EHEP-1 has been included in the estimate. The unit will first undergo a performance verification test, similar to EHEP-1, but for one month duration; a test engineer and two technicians have been assumed for this test. The unit will then undergo environmental testing such as launch load simulation for a period of two months with a comparable manpower loading as noted for performance test. The unit will then be placed on life test for six months and the results compared with EHEP-1; two test engineers and four technician man-months have been included to follow the life test plus remove the unit from test. The capital equipment required

to support the EHEP-2 tests and which would be available for subsequent tests includes a vacuum chamber, sensors, data acquisition, control, spectrum analyzer, etc., which is estimated to be $150, 000; $5, 000 has also been allotted for miscellaneous hardware. It has been assumed that the capital equipment would be purchased in FY-76.

Uncertainty - The estimate for preparing the detailed design is based on past programs of similar complexity; this estimate is most likely good within ±20%. The cost basis is the Second Generation ERTG Design with the assumption that only two full system units are required; naturally, if additional units would be necessary to satisfy specific government imposed requirements such as a performance reliability specification, then the estimate must be adjusted upward accordingly. The Reference Design ERTG, if used, would increase the number of tubular modules to four; an increase of about $75, 000 being required. A corresponding increase in assembly manpower/time/materials of about 50% would also be required; thus, about $60, 000. The cost estimate for testing of EHEP-1 and EHEP-2 is dependent on the test plan formulated as part of Task 3.2 and additional AEC program guidance; the estimate, based on our experience performing similar tests, is probably good within 30%.

TASK 3.4 - ELECTRICALLY HEATED QUALIFICATION PROTOTYPE SYSTEMS

Cost Basis - The detailed design of the EHQP-1, 2 and 3 will be prepared; it has been assumed that substantial design modifications will be required at component interfaces but that only modest design changes of basic components would be required over EHP-1 and 2. The design effort is initiated during fabrication and assembly of EHP-1 and 2 so that field modifications can be incorporated as early as possible. The design effort consists of a full time mechanical engineer and a manufacturing engineer for six months which are supported on a half time basis by a thermoelectric design and analyst engineer, a thermal analyst, and a materials scientist. Comparable drafting and technician support have been provided. Ten hours of computer time has been included to support the design effort.

The preliminary test plan will be updated. A systems engineer and a test engineer on a half time basis have been allotted to assist in the preparation of updated test plans and specifications.

Following the design, component fabrication and assembly will be completed for three units; EHQP-1, 2 and 3. Three tubular modules will be fabricated, assembled, and processed. On the basis of past experience, the cost per module is $40, 000; $18, 000 M&S, and remainder engineering/technician labor. Each module will undergo a standard electrical checkout; the cost equivalent of a half engineer and a full technician man-month has been included in the estimate for each module.

The heat pipes (procured from Dynatherm) will be assembled to the radiators and aeroshells (procured from Avco); support components installed. Two manufacturing engineers and four technicians on a full time basis for eight months has been assumed to accomplish the assembly, prepare the units, acceptance testing, and to package EHQP-1 for shipment; $10, 000 has been allotted for hardware (radiator shell and supports) and tooling costs. A full time manufacturing engineer to follow both Dynatherm and Avco has been assumed.

The EHQP-1 unit will be acceptance tested prior to shipment to the spacecraft contractor. The acceptance test will consist of performance testing plus subjecting the unit to the specified launch environment. The setup of the EHQP-1 unit for test is assumed to take two weeks and require one test engineer and two technicians to perform. This setup time is a 50% reduction compared with the EHEP units and is predicated on the basis that this unit represents the third time a system has been set up for test. Performance and launch environment tests are planned for two months duration with a requirement for two full time test engineers and two full time technicians. The capital equipment purchases for testing EHEP-2 would be used; $5, 000 of additional sensors, however, have been included in the estimate.

The EHQP-2 unit will be subjected to an initial electrical and thermal performance evaluation and then will be placed on life test in a vacuum environment. Prior to being subject to the vacuum environment, the performance of the unit will be evaluated under simulated launch

vehicle ambient environment. The steps in performing these series of tests are similar to the EHEP-1 unit tests; however, experience gained during performance of EHEP-1 is assumed to reduce the setup time to two weeks and reduce the test engineer follow requirement from two to one engineer. The technician effort, which is primarily a data reduction service, is assumed to be the same. The period of performance is reduced to two months prior to being put on life test; life test requirements are similar to EHEP-1 and a capital equipment investment of $65,000 would be required. The miscellaneous hardware requirement is assumed to be $2500.

The EHQP-3 unit will be performance tested and then subjected to a series of environments similar to the launch sequence. These series of tests would be nearly the same as the EHEP-2 unit series of evaluations and thus require similar manpower support. A life test of three months following launch environment evaluation will be performed instead of the six month EHEP-2 test. The test setup time is reduced to two weeks and capital equipment used for EHQP-1 and EHQP-2 would be available for use. A certain amount of miscellaneous test hardware would be required; $2,500 has been allocated. Upon completion of testing, the unit will be disassembled; the electrically heated modules packaged for shipment to Sandia. The effort required to remove the system from test has been included.

<u>Uncertainty</u> - The estimate for preparing the detailed design is based on past programs of similar complexity; this estimate is most likely good within ± 10%. The cost basis is the Second Generation ERTG Design; again with the assumption that only two units are required in addition to the unit to be supplied to the spacecraft contractor. If additional units are required as noted in Task 3.3, then the cost estimate would have to be appropriately adjusted. The Reference Design ERTG, if used, would increase the number of tubular modules to six; a cost increase of about $110,000 being required. A corresponding increase in assembly manpower/time/materials of about 50% would also be required; about $115,000. The cost estimate for testing is dependent on the test plan formulated as part of Task 3.2 and updated as part of this task. The estimate provided could vary by as much as 30%.

TASK 3.5 - FUELED QUALIFICATION PROTOTYPE SYSTEM

Cost Basis - The detailed design of the FQP-1 will be performed; it has been assumed that only modest design changes of EHQP-1, 2 and 3 would be required. The system design effort consists of a full time mechanical and a half time manufacturing engineer for four months supported on a half time basis by a systems engineer, a thermal analyst, a thermoelectric designer and analyst, and a materials scientist. The detailed design of the fuel capsule and the modifications to the module end closure region to convert from the electrically heated designs will be performed. The effort consists of a full time mechanical engineer for four months with half time support from a thermoelectric designer, and a thermal analyst; quarter time support from a manufacturing engineer and a materials scientist is included. Comparable drafting and technician effort have been included; five hours of computer time is also provided to support the design effort. In addition, close coordination with ORNL personnel is assumed during the design effort. A systems engineer on a full time basis for six months has been allotted to prepare in conjunction with ORNL detailed handling and assembly procedures for the fueled module assembly; likewise, a systems engineer for six months has been included to finalize test plans. Following the design, component fabrication and assembly for the FQP-1 will be completed.

One tubular module will be fabricated, assembled and processed. The module will undergo a standard electrical checkout; the cost equivalent of a half engineer and a full technician man-month has been included in the estimate for each module. On the basis of past experience, the cost per module is $40, 000; $18, 000 M&S, and remainder engineering/technician labor.

The heat pipes (procured from Dynatherm) will be assembled to the radiators and aeroshells (procured from Avco); support components installed. Two manufacturing engineers and two technicians on a full time basis for two months has been assumed to accomplish the assembly and to prepare the unit for shipment following acceptance testing; $5, 000 has been allotted for hardware (radiator shell and supports) and tooling costs. A full time manufacturing engineer to follow both Dynatherm and Avco has been assumed.

The acceptance test for the FQP-1 will be similar to the EHQP-1 and, therefore, comparable effort has been included. This test is planned such that the equipment used for EHQP-3 would be available. Following acceptance testing, the unit will be packaged and shipped to ORNL for testing. The fueling, assembly, and testing effort at ORNL, which will consist of both performance and vibration tests, is defined under government support. The test is assumed to last for one year with assembly and test setup requiring an additional six months. A one man year effort level has been included to support the test efforts at ORNL.

Uncertainty - The estimate for preparing the design is most likely good within ± 10%. The cost basis is the Second Generation ERTG Design. The Reference Design ERTG, if used, would increase the number of modules to two; an increase of about $30, 000. An increase in assembly manpower/time/materials of about 50% would be required; thus about $25, 000. The cost estimate for acceptance testing is as noted for the other tasks dependent on the test plan formulated but is probably good within 30%. A nominal support effort has been defined for testing support at ORNL; the uncertainty in this estimate requires further program definition.

TASK 3.6 - SYSTEM AND SPACECRAFT INTEGRATION

Cost Basis - A full time systems engineer will be assigned to assist in preparing design requirements, specifications, and interface documents which are compatible with the spacecraft and launch vehicle definitions specified by the AEC. This effort will parallel in time the preparation of the preliminary prototype design. In addition, the systems engineer will prepare specifications for testing of EHQP-1 through liaison with the spacecraft contractor. Technician support is provided to assist in the preparation of the specifications and interface documents. In addition, effort is included as part of this task to assist the spacecraft contractor during mating and evaluation testing of EHQP-1 with the spacecraft. This effort consists of, in addition to the systems engineer, a half time design engineer and a half-time thermal analyst plus a full time technician for a period of six months (assumed to be the test duration). Five hours of computer time has been included in the estimate.

Uncertainty - The degree of assistance required by the spacecraft contractor during assembly and testing of the EHQP-1 with the spacecraft which cannot be determined without further program definition.

TASK 3.7 - SAFETY EVALUATION

Cost Basis - A safety engineer assigned full time to the program with the prime responsibility for preparing the PSAR and providing support to ORNL (during prefueling, fueling, and testing of FPS-1) and to LASL (or Sandia) during planning, performance, and data analysis of safety related testing. A full time engineer and a full time technician during the testing phase has been provided in the estimate to assist in test planning, test design, and post test data evaluation. It is assumed that design input to the PSAR will be a product of specific Phase 3 design tasks.

The tests to be performed are:

- Impact test at temperature using a simulated fueled module assembly (2 units); hardware cost estimate of $10, 000/unit.
- Impact test of aeroshell/tubular module at temperature using simulated fuel capsule - electrical heater/tubular module/aeroshell provided from the EHEP-2 system; $5000 additional hardware cost assumed.
- Launch safety sequential test of simulated fuel capsule/module assembly (2 units) - hardware cost estimate of $5000/unit.
- Launch safety sequential test of aeroshell/tubular module using simulated fuel capsule - electrical heater/tubular module provided from the EHQP-3 system; $5000 additional hardware cost assumed.
- Fuel fines impact test using ^{244}Cm in a simulated small scale heat source/module container - assume $1000 per specimen - five specimens.

The costs of performing these tests are assumed to be GFE. Twenty hours of computer time has been assumed for preparing PSAR and doing post test data analysis.

Uncertainty - The design fabrication of the test pieces and the number of units for the impact and launch fire tests. These estimates vary considerably depending on safety requirements in terms of number of demonstrations required and confidence level specified imposed by the AEC which cannot be determined at this time.

TASK 3.8 - GROUND SUPPORT EQUIPMENT (GSE) DESIGN

Cost Basis - An engineering assessment based primarily on the design of shipping casks, handling tools, etc., in support of the SNAP-23A and Large Heat Source Development programs — A systems engineer for six months to update the Preliminary Utilization Analyses prepared in Phase I through liaison with government agencies, the spacecraft contractor, and the launch site personnel. Two full time mechanical engineers to prepare the preliminary design of the GSE which is assumed to last for one year. These engineers will be supported on a full time basis by a thermal engineer plus on a half time basis by a manufacturing and systems engineer. The preliminary design estimate includes preparation of procedures for checkout and use of the GSE. Appropriate drafting and technician manpower to support these efforts has been provided. Upon completion of the preliminary design, the final design of the GSE, including preparation of detailed fabrication drawings, will be prepared. The estimate includes two mechanical design engineers and a manufacturing engineer on a full time basis to finalize the GSE. These personnel are supported by a systems and thermal engineer on a a one-third time basis. Comparable drafting and technician time has been allocated. A procurement package will be prepared and orders let for procurement; a manufacturing engineer for six months has been included to perform this effort as well as follow fabrication of the handling tool for the fueled module assembly; $5000 has been allotted for two tool heads.

Uncertainty - These cost estimates are very speculative due to the many unknowns with respect to GSE and, at best, are no better than ± 50%. No provision has been allotted for designing facilities at the launch site or for designing remote control equipment for handling the fueled module assembly.

TASK 3.8 - PRODUCT ASSURANCE

Cost Basis - This estimate is based on contract application of top level space systems Quality Assurance and Reliability specifications, but with the various facets of such specifications programmed for implementation so as to achieve maximum benefit at critical stages of the prototype design with minimum expense. Approximately one Quality Assurance engineer, one

Reliability engineer, and two-three Inspection technicians will be assigned to judiciously implement the QA and Reliability Programs reflected by Appendices B and C.

Uncertainty - It is not clear, at this time, to what extent space system reliability, quality assurance, and project control specifications will be applied during the development and prototype qualification stage of the program.

AVCO PROGRAM TASKS

TASK 3.1A - PROGRAM MANAGEMENT

Cost Basis - A two man-year effort is assumed, consisting of a project manager, a systems integration engineer responsible for configuration control and a project business administrator.

Uncertainty - Budgetary

TASK 3.2A - AERODYNAMICS

Cost Basis - Avco reentry experience; computer program available. The cost assumes that the Phase 2 tests are funded and design effort is 1.5 man-years with a six-month duration. Intact reentry analysis only.

Uncertainty - Budgetary

TASK 3.3A - THERMODYNAMICS

Cost Basis - Avco reentry experience; computer programs in hand; effort of one man-year with a six-month design period and support to the thermal-structure testing. Intact reentry analysis only. Assumes Phase 2 tests are funded.

Uncertainty - Budgetary; if Phase 2 tests are not funded, costs must be adjusted.

TASK 3.4A - STRUCTURES

Cost Basis - Avco reentry experience; computer programs in hand; Phase 2 tests funded. Analytical effort is 1.5 man-years to support six-month design effort and structural test

effort; intact reentry analysis only. Structural test effort is one man-year effort with in-house cold structure tests and external thermal-structure testing. Assumes two aeroshells, one for backup, if required, with redesign.

Uncertainty: Budgetary; if Phase 2 tests are not funded, costs must be adjusted.

TASK 3.5A - MECHANICAL DESIGN

Cost Basis — Avco reentry experience; experienced graphite aeroshell designer from previous programs; total design effort is four man-years including aeroshell design, preparation of drawings, design maintenance for modifications continues until all aeroshells are delivered. Assumes Phase 2 tests are funded, i.e., no costs included for model design.

Uncertainty: Budgetary; if Phase 2 tests are not funded, costs must be adjusted.

TASK 3.6A - QUALITY ASSURANCE

Cost Basis - Avco reentry experience; available NDT specialists and equipment will comply with applicable Aerospace Nuclear Safety Policies.

Uncertainty - Increasing the number of aeroshells as would be required with the Reference Design ERTG will increase cost by about $38,000.

TASK 3.7A - RELIABILITY

Cost Basis — Avco reentry experience, available analyst with prior directly related experience; applicable Aerospace Nuclear Safety Policies; one man-year effort covering design and test period of all aeroshells.

Uncertainty: Budgetary

TASK 3.8A - MANUFACTURING AND ASSEMBLY

Cost Basis — Delivery of 8 aeroshells; Avco reentry experience, subcontracts for materials and machining; available skilled technicians in assembling graphite parts, one man-year effort covering delivery of all aeroshells.

Uncertainty - Increasing the number of aeroshells to 14, as required for the Reference Design ERTG will increase the cost by about $144,000.

TASK 3.9A - SYSTEMS TEST

Cost Basis — Avco reentry experience; available skilled personnel to define and carry out qualification tests. One man-year effort initiated after completion of structural development tests.

Uncertainty: Budgetary

DYNATHERM PROGRAM TASKS

Cost Basis — The major difficulty in Phase III will be the processing of the grooved tubing on time in order to meet specified delivery dates. Advanced procurement of materials during the very early stages of Phase 3 will be required. Since a substantial quantity of hardware is being produced during Phase 3 and since scheduling will be a major problem, a program manager/project engineer devoting 50% of his time to the program has been assumed.

A cost uncertainty exists in terms of the number of heat pipes required. The estimate is based on delivery of six sets of 24 heat pipes; the Reference Design ERTG will reduce the number to 12 sets with a cost increase of about $65,000.

GOVERNMENT SUPPORT TASKS

The costs basis for the government support tasks is given below. The tasks identified for FUEL/HEAT SOURCE DEVELOPMENT SUPPORT and for the FUELED PROTOTYPE TEST

SUPPORT were provided by ORNL on the basis indicated below. In addition, ORNL has identified the liaison and miscellaneous support estimates given in Table 2-8.

(a) Fuels Heat Source Development

NON-DESTRUCTIVE TEST DEVELOPMENT

Cost Basis - The development and use of prototype inspection techniques for correlation with destructive and welding studies will be continued. This will allow establishment of final procedures and remote inspection equipment as well as the evaluation of capsules to be fueled. Reference standards will be developed and appropriate inspection specifications drafted.

WELDING PROCEDURES

Cost Basis - The first quarter of FY-76 ORNL would refine both our welding procedures and fixturing, aiming toward a transfer of both to in-cell work. We would be welding on components as close to final configuration as possible and would use fuel simulants to mock up the necessary restraint and cleaning problems. The acquisition of dimensional data will continue. We will devote the last three quarters of the year to qualifying our procedures in-cell, making final fixturing design changes and to the fabrication of the capsules required for safety testing purposes.

PHYSICAL METALLURGY SUPPORT

Cost Basis - Long-term aging stability and/or compatibility of these materials with oxygen and/or graphite will be determined. The mechanical properties of candidate alloys will be measured under or after exposure to simulated heat source conditions to determine if environmental reactions or alloy instabilities lead to degradation such as embrittlement or loss in strength.

VENT EVALUATION

Cost Basis - During FY-76, tests begun in the latter part of FY-75 will be completed and examined. A final report will be written.

SOURCE CRITICALITY STUDIES

Cost Basis - In FY-76, final tupe calculations will be made on the "worst case" situation using improved cross section data.

FUEL SIMULANTS

Cost Basis - In FY-76, additional tests will be performed to determine effects of density and other parameters on the suitability of the selected simulant.

LOADING AND HANDLING PROCEDURES

Cost Basis - Fabrication of needed items will continue.

SHIELD DESIGN STUDIES

Cost Basis - In FY-76, a cursory look at the shielding required for the conceptual source design will be performed. This calculation will be made to determine a general shielding configuration and requirements. A detailed shielding analysis will be made for the source configuration and satellite using existing data. In FY-77, measurement will be made of the neutron and gamma radiation spectra and these data utilized to calculate the detailed shield configuration. Primary effort will be shield integration into the satellite design.

(b) Fueled Prototype Test

Cost Basis - The experiment will be designed during FY-76 and 77. Design will include the monitoring equipment required to monitor the electrical output and testing to be accomplished during the testing phase. During the first two quarters of FY-78, the source will be fabricated and loaded into the ERTG system and test assembly. During the last two quarters of the fiscal year, the system test would be initiated.

It should be noted that these costs may increase by about 25% if the Reference Design ERTG were used since two fueled module assemblies are required.

(c) Safety Analyses and Tests of Heat Source

Cost Basis - AEC/SNS has estimated cost of safety tests and model as follows:

Impact Test of Simulated Module	$30, 000
Launch Sequential Test	$75, 000
Fuel Fines Test	$ 5, 000
Computer Models	$20, 000

Costs are not available for government support required for licensing GSE.

2.3 PHASE 4 - FLIGHT SYSTEM FABRICATION

Two flight qualified systems (FQS-1, -2) will be assembled, tested, and shipped to the spacecraft contractor. The proposed schedule for accomplishing this objective is shown in Figure 3-5. This schedule assumes that the fabrication of FQS-1 and FQS-2 would commence prior to completion of FQP-1 testing at ORNL; once the initial test data has been obtained and a correlation established with the electrically heated units, design of FQS-1 and FQS-2 and fabrication of components would be initiated. The aeroshell, heat pipes, radiator, and support structure will be assembled at Westinghouse and shipped to the spacecraft contractor independent of the fueled module assembly. The assembly of these components will be initiated following completion of the FQP-1 tests at ORNL. The fuel capsule will be loaded into the tubular module at ORNL, the end caps installed, and checkout tests performed. This effort will commence once the results from the initial destructive examination of the fuel capsule for FQP-1 has been accomplished. The tubular module will, in addition, have been electrically tested and performance verified prior to shipping to ORNL. The fueled module assembly will be loaded into a shipping cask for delivery to either the spacecraft contractor or to the launch facility pending whether a fueled ERTG acceptance test at the spacecraft contractor facilities is required. This plan assumes a fueled acceptance test is not required. Since the tubular module forms an integral part of the heat source and the present design does not facilitate ease of insertion of an electrical heater in place of the fuel capsule, an electrically heated tubular module assembly will be delivered to the spacecraft contractor for mating and checkout of the ERTG with the flight spacecraft. This module will also be used during acceptance testing of the ERTG at Westinghouse. Technical assistance will be provided to the spacecraft contractor during acceptance testing of the ERTG and during pre-launch and launch activities at the launch site. Ground support equipment will also be delivered and close liaison maintained to qualify the site personnel for handling the system.

The final safety analysis report will be prepared; needed liaison and presentations undertaken to obtain approval from the cognizant and responsible agencies for the launch of the ERTG system will be provided. Planning support, and technical personnel, as required, will be

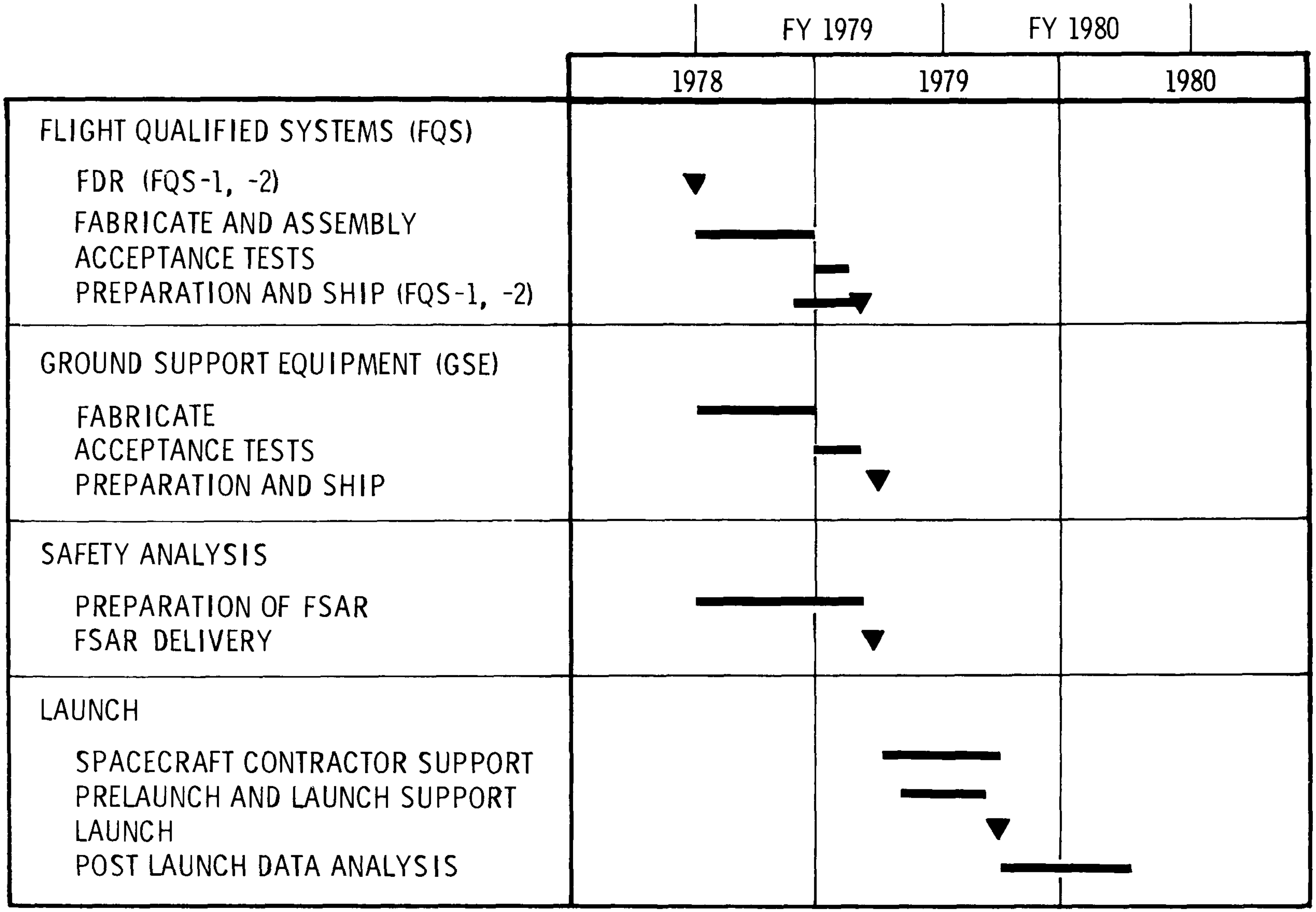

Figure 2-5 - Phase 4 - Flight System Fabrication Schedule

Astronuclear Laboratory

available for launch support. Post launch analysis of flight data will also be performed. The specific tasks to be performed to accomplish this phase of the program are outlined below.

2.3.1 Westinghouse Task Statements

TASK 4.1 - PROGRAM MANAGEMENT

This task provides the program direction and coordination, configuration control after appropriate design freezes have been effected, program planning and budgetary control, and reporting. This task serves as the focal point for incoming and outgoing contract correspondence assuring overall coordination and timely reaction to customer direction. In addition, technical and programmatic direction, including monitoring of configuration control programs of all subcontractors, will be performed.

TASK 4.2 - FLIGHT SYSTEM DESIGN

The tests of FQP-1, EHQP-1, EHQP-2 and EHQP-3 are part of Phase 3 and will establish the adequacy of the design (including continuous updating of the design as needed) to meet specific spacecraft interfacing and mission performance requirements. Significant design modifications, therefore, are not contemplated for FQS-1 and FQS-2. This task provides for incorporation of design modifications which are necessary to be responsive to changing spacecraft interfaces or mission requirements. Configuration control of the design will be maintained following the design freeze. Detailed engineering drawings for fabricating and assembling FQS-1 and FQS-2 will be prepared. A complete performance description for FQS-1 and FQS-2 including, for example, detailed thermal maps will be prepared by updating the performance description of FQP-1. In addition, if required, design modifications to an electrically heated tubular module assembly - which simulates the fuel capsule/tubular module assembly - for use in checkout of the power supply at the spacecraft contractor's facility will be made.

TASK 4.3 - FLIGHT SYSTEM MANUFACTURE AND ASSEMBLY OPERATIONS

Detailed schedules for procurement of components and fabrication of FQS-1, FQS-2, and an electrically heated tubular module will be prepared. Procurement of components, fabrication, and assembly of these units will be performed. Technical assistance will be provided as needed to component suppliers — monitoring of supplies, procedures, and processing, etc.

These units will be packaged and delivered to the spacecraft contractor; the tubular module and applicable end cap components will be delivered to ORNL for fueling and then subsequently delivered to the spacecraft contractor or launch site, as noted earlier.

TASK 4.4 - FLIGHT SYSTEM ACCEPTANCE TESTING

Flight system acceptance testing for FQS-1 and FQS-2 will be performed. These tests will be similar to those performed for FQP-1 and EHQP-1. Both environmental and performance acceptance tests will be performed on each unit. The electrically heated tubular module assembly will be used in lieu of using fueled modules. The tubular module(s), to be fueled at ORNL and the module for use in the electrically heated assembly(s) will undergo a standard set of electrical checkout tests, identical to FQP-1.

Prototype units will have been qualified during Phase 3 and, therefore, reduced levels for environment tests are planned since strict adherence to quality control has preserved the integrity of the design. A test package will be prepared and included with each unit shipment which will also document the "build records" so that a thorough record of the unit's history is available to the spacecraft contractor.

TASK 4.5 - SAFETY EVALUATION

With completion of all prototype design, development and test activities as part of Phase 3, as well as interagency review of the draft safety analysis report (SAR), the SAR will be expanded

into final form. Analyses will be upgraded when required, any special tests required to satisfy unresolved safety questions will be planned and executed, and close liaison will be maintained with the user agency and launch facility. Safety-related operational and emergency procedures found needed in addition to previously established procedures will be developed to guide the launch crew in performing the required pre-launch and launch tests, with minimum radiation exposures and radiological hazards. Support will be provided, as required, during the interagency safety review for flight approval.

TASK 4.6 - TECHNICAL ASSISTANCE TO SPACECRAFT CONTRACTOR

This task is designed to provide the continued technical support to the spacecraft contractor both during the checkout of the power supply at the contractor facilities and during pre-launch and launch activities at the launch site. The assistance will be in addition to the documentation resulting from Tasks 4.2, 4.3, 4.4, and 4.5, and is envisioned to include items such as interpretation of test results and guidance to perform field fitting of components; therefore, it is currently anticipated that a systems engineer and the lead mechanical design engineer would be required to support the spacecraft contractor.

TASK 4.7 - GROUND SUPPORT EQUIPMENT FABRICATION AND DELIVERY

The ground support equipment (GSE) specified and designed during Phase 3 will be fabricated, assembled, acceptance tested, and delivered to the spacecraft contractor and/or launch site as appropriate. In addition, training will be provided to appropriate personnel to insure proper/safe use of the GSE. It is also planned to provide engineering surveillance and consultation during GSE operations.

TASK 4.8 - POST FLIGHT DATA ANALYSIS

This task will provide effort to analyze telemetry data from the satellite and assess RTG performance. By judicious selection of instrumentation on the RTG (e.g., voltage and current measurements and key temperature measurements) a time-history performance map of the RTG performance on-orbit will be determined. These analyses will permit determination of degradation in performance, if any, along with determination of those changes that occur due to decay of the fuel.

Prior to launch, computer codes will be prepared to process the off-line telemetry data from tracking stations. These codes will permit mechanized handling of the data so that random errors from the transducers and FM communications links are minimized. Assuming that the telemetry system used for data transmission to Earth is a sampled data system (e.g., PCM/FM/FM) the data processing codes will be prepared to determine means and standard deviations for each transducer and each data acquisition set. These statistical compilations from the raw off-line data will be further used to determine time dependent trend effects and to compare with preflight performance predictions.

It should be emphasized that the mechanization of the data processing will supplement (rather than replace) the engineering assessment of the technical evaluation team. This approach will permit a more rapid and comprehensive analysis to be completed compared to a non-automated data processing plan.

TASK 4.9 - PRODUCT ASSURANCE

All provisions of the WANL Quality Assurance and Reliability Plans (Appendices I and II, respectively) will be applied for flight systems in a manner which will most economically and effectively assure compliance with all contract specifications.

2.3.2 AVCO Task Statement

TASK 4.1.A - PROGRAM MANAGEMENT

AVCO will maintain a project office to provide administrative and technical direction to all participating Division organizations. The project office will manage subcontractors, insure maintenance of the desired program schedule, cost and performance, maintain liaison with Westinghouse, and manage configuration control and integration.

TASK 4.2.A - QUALITY ASSURANCE

The Q.A. organization shall monitor the aeroshell fabrication, machining, assembly, and acceptance testing, perform in-process and final inspections on all aeroshells produced in Phase 4.

TASK 4.3.A - MANUFACTURING AND ASSEMBLY

The manufacturing and assembly organization will manufacture the necessary shipping containers for handling the assembled aeroshells, and package completed aeroshells.

TASK 4.4.A - FLIGHT TEST ANALYSIS

The flight test organization shall define flight data requirements and perform post launch data analysis.

TASK 4.5.A - MECHANICAL DESIGN

The mechanical design organization shall provide design maintenance of the aeroshell and GSE through the drawing release period.

TASK 4.6.A - PREPARE FSAR

All contributing organizations to the FSAR shall review and update the FSAR.

2.3.3 Dynatherm Task Statement

During Phase 4, two sets of axially grooved Cu-H_2O heat pipes (24 heat pipes per ERTG set) will be fabricated and acceptance tested in accordance with the procedure developed during Dynatherm Task 3.3D and delivered to Westinghouse. Acceptance tests will consist of leak test, pressure test, gas check and thermo-performance tests per the plans and procedures of Task 3.3D. A program manager will provide technical and administrative control during this phase of the program.

2.3.4 Government Support

The government support (in addition to providing detailed and timely coordination between the spacecraft contractor, launch site personnel, and Westinghouse), required for the flight qualified RTG's will primarily consist of the following:

- Continuation of the Fueled Prototype Test at ORNL.
- Assembling the fueled module assembly at ORNL and providing associated acceptance tests and loading the fueled module assembly into a Westinghouse provided shipping cask.
- Providing input to the preparation of the FSAR with respect to fuels data and related fuels tests such as fines determination.

2.3.5 Cost Estimate

The preliminary cost estimate for performing the tasks previously identified are given in Tables 2-9, 2-10, and 2-11 for Westinghouse, Avco and Dynatherm, respectively. The cost estimates for the identified government support are given below for those items where specific costs could be obtained. The basis for the cost estimates is given below including a discussion of the uncertainties in the estimates.

TABLE 2-9

WESTINGHOUSE PROGRAM TASKS
PHASE 4 - FLIGHT SYSTEM FABRICATION
(M&S, CAP, TOT is in $1000)

NO.	TASK	FY-79 MANPOWER (MM) E&S	FY-79 T	FY-79 D	FY-79 M&S	FY-79 TOT	FY-79 CAP	FY-80 MANPOWER (MM) E&S	FY-80 T	FY-80 D	FY-80 M&S	FY-80 TOT	FY-80 CAP	TOTAL MANPOWER (MM) E&S	TOTAL T	TOTAL D	TOTAL M&S	TOTAL TOT	TOTAL CAP
4.1	PROGRAM MANAGEMENT	33	24			194.0		18	18			117.9		51	42			311.9	
4.2	FLIGHT SYSTEM DESIGN	7	12	14	15	120.3								7	12	14	15	120.3	
4.3	FLIGHT SYSTEM MANUFACTURE AND ASSEMBLY	11	17	0	56	154								11	17	0	56	154	
4.4	FLIGHT SYSTEM ACCEPTANCE TESTING	13	18	0	6	104.9	150							13	18	0	6	104.9	150
4.5	SAFETY EVALUATION	21	9		10	120.5		3				12.3		24	9		10	132.8	
4.6	TECHNICAL ASSISTANCE TO SPACECRAFT CONTRACTOR	6				24.5		6				24.5		12				49.0	
4.7	GOVERNMENT SUPPORT EQUIPMENT FABRICATION AND DELIVERY	18	6		250	398.9		3				12.3		21	6		250	411.2	
4.8	POST FLIGHT DATA ANALYSIS	4	6		3	34.9		12	6		12	78.8		16	12		15	113.7	
4.9	PRODUCT ASSURANCE	23	45			204.8								23	45			204.8	

TABLE 2-10

AVCO PROGRAM TASKS PHASE 4 — FLIGHT SYSTEM FABRICATION (M&S, CAP, TOT IN $1000)		FY-79 MANPOWER (MM)						FY-80 MANPOWER (MM)						TOTAL MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
4.1A	PROGRAM MANAGEMENT	4.5	4.5		1.0	57.1		1.9	1.9			24.6		6.4	6.4			81.7	
4.2A	QUALITY ASSURANCE	2.0				16.2								2.0				16.2	
4.3A	MANUFACTURING AND ASSEMBLY		2.0		50	60.4									2.0		50	60.4	
4.4A	FLIGHT TEST ANALYSIS							3.2	3.3		.8	41.6		3.2	3.3		.8	41.6	
4.5A	MECHANICAL DESIGN	6.4		6.4		79.9								6.4	6.4			79.9	
4.6A	PREPARE FSAR	12.9				105.9								12.9				105.9	

TABLE 2-11

DYNATHERM PROGRAM TASKS PHASE 4 - FLIGHT SYSTEM FABRICATION (M&S, CAP, TOT is in $1000)		FY-79						FY-80						TOTAL					
		MANPOWER (MM)						MANPOWER (MM)						MANPOWER (MM)					
NO.	TASK	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP	E&S	T	D	M&S	TOT	CAP
4.2D	PROGRAM MANAGEMENT	2.6				11.9								2.6				11.9	
4.1D	FABRICATION AND ACCEPTANCE TEST	1.25	5.3		3.0	24								1.25	5.3		3.0	24	

WESTINGHOUSE PROGRAM TASKS

TASK 4.1 - PROGRAM MANAGEMENT

Cost Basis - This estimate is based on continuing the Project Office established during Phase 3. A full time Program Manager having technical and fiscal responsibility and providing the focal point for interfacing with government agencies. Two full time Project Managers; a design, manufacturing, and assembly Project Manager and an ERTG Systems Project Manager having responsibilities similar to those defined in Phase 3, directing the technical efforts up until delivery of FQS-1 and FQS-2. The Systems Project Manager will continue to assist the Program Manager until the completion of this phase. A Project Control Engineer and a technician will be assigned full time to the Program Manager to handle report preparation, cost analysis, etc.

Uncertainty - Cannot be determined without additional AEC program guidance with respect to reporting requirements.

TASK 4.2 - FLIGHT SYSTEM DESIGN

Cost Basis - The design of the FQS-1 and FQS-2 will include only modest design changes from FPS-1. The design effort consists of two full time mechanical engineers, a half time manufacturing engineer, and quarter-time support from thermal, systems, thermoelectric engineers, and a materials scientist for two months. Comparable drafting and technician support has been provided. In addition, effort has been included to permit updating performance reports and to provide input to the final safety analysis report; this effort consists of a full time systems engineer for nine months with support on a half time basis from a thermal and a thermoelectric engineer. Fifteen hours of computer time has been assumed.

Uncertainty - The principal uncertainty is the degree of design modification required by the spacecraft contractor. The design effort could be increased by as much as 50% or more pending changes required following the FQP-1 design. The uncertainty in the estimate performance for the report update and the safety support cannot be established at this time.

TASK 4.3 FLIGHT SYSTEM MANUFACTURING AND ASSEMBLY

Cost Basis - Three tubular modules will be fabricated, assembled, and processed. On the basis of past experience, the cost per module is $40,000; $18,000 M&S, and remainder engineering/ technician labor. Each module will undergo a standard electrical checkout; the cost equivalent of a half engineer and a full technician man month has been included in the estimate for each module.

The heat pipes (procured from Dynatherm) will be assembled to the radiators and aeroshells (procured from Avco); support components installed. Two manufacturing engineers and two technicians, on a full time basis for two months, have been assumed to accomplish the assembly and to prepare the units for shipment following acceptance testing; $5,000 has been alloted for hardware (radiator shell and supports) costs. A full time manufacturing engineer to follow both Dynatherm and Avco has been assumed.

Uncertainty - The cost basis is the Second Generation ERTG Design. The Reference Design ERTG, if used, would increase the number of tubular modules to three; a cost increase of about $110,000 being required. A corresponding increase in assembly manpower/time/materials of about 50% would also be required; thus, about $30,000.

TASK 4.4 - FLIGHT SYSTEM ACCEPTANCE TESTING

Cost Basis - The acceptance tests for the FQS-1 and FQS-2 will be similar to FQP-1 (Phase 3) and therefore comparable effort has been included. The test is scheduled such that the equipment used for FQP-1 is available for one of the units; however, to conserve schedular time, an additional capital investment of $150,000 to permit parallel testing of FQS-1 and FQS-2 is included. Miscellaneous hardware of $5,000 has been allotted. A detailed test report will be prepared; a full time test engineer has been included to assist in the report preparation.

Uncertainty - The test plan established during Phase 3 will determine the effort level required for acceptance testing; the above estimate on the basis of performing tests of similar complexity is probably within 30%.

TASK 4.5 - SAFETY EVALUATION

Cost Basis - A full time safety engineer to assist in updating the PSAR and interfacing with government agencies and subcontractors, publishing the FSAR and providing support to obtain interagency flight approval is planned. During the preparation of the FSAR, he will be assisted by an additional full time safety engineer, a technician, as well as receiving input from the design groups. Ten hours of computer time for analyses has been provided.

Uncertainty - The principal uncertainties are the need for additional testing beyond that planned during Phase 3 due to, for example, the interagency reviews for flight approval and the degree of support needed by the government during interagency reviews. It is impossible at this time to assess the magnitude of these uncertainties.

TASK 4.6 - TECHNICAL ASSISTANCE TO SPACECRAFT CONTRACTOR

Cost Basis - A systems engineer and a mechanical design engineer in addition to personnel from the Program Office has been assumed.

Uncertainty - Cannot be determined at this time.

TASK 4.7 - GROUND SUPPORT EQUIPMENT FABRICATION AND DELIVERY

Cost Basis - GSE is assumed to be fabricated by outside vendors; two shipping casks for the fueled module assembly at a cost of $50, 000 each; casks for the remaining system components have been fabricated during Phase 3. An additional $150, 000 has been allotted for other special tools such as a personnel shield at the launch pad. Two manufacturing engineers, full time for six months, to follow the fabrication and assembly has been assumed. The performance of acceptance tests for the shipping cask such as radiation field measurements and appropriate documentation of the GSE has been provided through alloting three man-months of engineering and six man-months of technician. In addition, support has been allotted to train personnel in using the equipment and to provide consultation of the launch site; six man-months of engineering effort has been allocated.

Uncertainty - These cost estimates have to be considered as very speculative at this point in time and, at best, are no better than $\pm$ 50%. No provision has been allotted for constructing a facility at the launch site or for fabricating remote control equipment for handling the fueled module assembly.

TASK 4.8 - POST FLIGHT DATA ANALYSIS

Cost Basis - Offline processed data from the RTG instrumentation would be provided by an appropriate government agency or the spacecraft contractor. A computer program for interpreting the data will be established; four man-months of systems engineering plus six technician man-months have been allotted. Two full time system engineers with technician support have been assumed to perform and document the data analysis for six months following launch. Fifteen hours of computer time has been allotted.

Uncertainty - Further guidance from the spacecraft contractor and/or AEC is required before a definitive estimate can be made.

TASK 4.9 - QUALITY ASSURANCE

Cost Basis - This estimate is based on contract application of top level NASA type Quality Assurance and Reliability specifications.

Approximately two full time Quality Assurance engineers and one half time Reliability engineer will be assigned to direct and implement the complete Product Assurance programs reflected by Appendices B and C. A total of approximately five Quality Assurance technicians will be assigned to perform all inspections and tests, and compile all data reports necessary for delivery of a flight system.

Uncertainty - Principle uncertainties concern how solidly the design freeze at the beginning of the Fabrication Phase is held. Every design change for flight system or ground support equipment will raise quality engineering review time, increase inspections, and add to configuration control data operations.

AVCO PROGRAM TASKS

TASK 4.1.A - PROJECT MANAGEMENT

Cost Basis - A one man year effort is assumed, including a project manager, systems integration engineer, and project business analyst. The systems engineer will support all external tests and operations.

Uncertainty - Budgetary.

TASK 4.2.A - QUALITY ASSURANCE

Cost Basis - Existing personnel and equipment capabilities. The total effort is four man months.

TASK 4.3.A - MANUFACTURING AND ASSEMBLY

Cost Basis - Delivery of two (2) aeroshells; subcontract to purchase materials and perform machining, with production at the rate of one per month. Assembly effort is four man months.

Uncertainty - Budgetary.

TASK 4.4.A - FLIGHT TEST ANALYSIS

Cost Basis - Previous flight test planning and analysis experience: a six (6) man month effort is allocated.

Uncertainty - Budgetary.

TASK 4.5.A - MECHANICAL DESIGN

Cost Basis - Previous experience indicates need for design maintenance through delivery of last aeroshell. A 12 man month effort is planned.

Uncertainty - Budgetary.

TASK 4.6.A - PREPARE FSAR

Cost Basis - Each contributing organization to the FSAR would be requested to review the FSAR and update the document. A total allocation of 12 man months is made for this finalization.

Uncertainty - Budgetary.

DYNATHERM PROGRAM TASKS

Cost Basis - Budgetary cost for Phase IV was based on similar programs conducted in the past. Basically, the cost basis was developed from both the HPG copper/water heat pipe and the ATS-F grooved heat pipe program. Program management required for both phases was assumed to be 20% during Phase 4.

Uncertainty - A cost uncertainty exists in the number of heat pipes required. The estimate is based on 48 heat pipes which is the Second Generation ERTG Design; the Reference Design ERTG would increase the number of heat pipes to 96 with a cost increase of about $24,000.

GOVERNMENT SUPPORT

The cost basis for the government support tasks is given below for those tasks where costs can be identified. ORNL provided the cost estimates for the fueled prototype test and for assembly of the fueled module assemblies for the flight system. In addition, ORNL has identified liaison costs of $12, 000 in FY 1979 and $12, 000 in FY 1980, plus $50, 000 of miscellaneous capital equipment for both fiscal years.

(a) Continuation of the Fueled Prototype Test at ORNL

Cost Basis - The system will be on test during the first two quarters of FY 1979. During this time the system would be monitored for electrical output, temperatures, and other pertinent information.

The ERG unit will be subjected to vibration testing over the range of ~5 to 2000 cycles per second utilizing alpha ~2500 force pound shaker table so that forces up to 10 g can be applied to the unit. The force table will be installed in a hot cell facility with monitoring and control equipment located outside.

The system would be disassembled during the last two quarters of FY 1979 and the heat source destructively examined. The electrical systems and generator would be returned to the contractor for examination.

Completion of the examination of the source will be accomplished and a final report will be written in FY 1980.

The cost of this support is estimated to be $150, 000 in FY 1979 and $30, 000 in FY 1980, with a capital equipment investment of $50, 000 in FY 1979.

(b) Fueled Module Assembly

Cost Basis - ORNL has estimated the cost for the fueled assemblies of the Second Generation ERTG to be $120,000. Two systems will be assembled at a cost of $240,000. This estimate would be increased by about 25% if the Reference Design ERTG were used.

(c) Input to FSAR

A cost estimate cannot be made at this time.

3.0 PHASE 5 - FOLLOW-ON PRODUCTION

Immediately following a successful development program and flight test of the first ERTG, follow-on production of ERTG units can be initiated. Assuming a total requirement of ten to twenty systems, sets of two to four units can be delivered at six month intervals following the initial delivery. Deliveries, therefore, could be spread out over a 4-1/2 year period following the initial delivery. There are two distinct ways to prepare to make these deliveries:

- Fabricate all components (except fuel) as early in the program as possible and hold them in storage until the operational program requires them.
- Fabricate all components only as needed to satisfy the delivery schedule.

In a production program, there is obviously the possibility of producing some components in each way. Both of these options are considered plausible approaches for producing the Second Generation ERTG Design. The major components and component assemblies were assessed independently in establishing a production schedule that best conserves costs while at the same time provides unit delivery consistent with available facilities, manpower, and the desired schedule. This evaluation resulted in a production schedule such that the initial unit (non-fueled hardware) can be delivered twelve months following receipt of a production order. An additional unit can be available for delivery every 1-1/2 months thereafter. This schedular rate is based on the following assumptions:

- Two months following receipt of order from the AEC to place orders for component hardware.
- Seven months to procure initial component hardware; additional hardware for each unit available at 1-1/2 month intervals.
- Three months to assemble, acceptance test and prepare the first unit for shipment; a unit can be shipped every 1-1/2 months thereafter, if needed.

The initial tubular module(s) would be delivered to ORNL nine months following receipt of a production order. A production facility for loading ^{244}Cm pellets into the Haynes 188 container and loading the fuel capsules into the tubular module, etc., does not exist. On the basis that

such a facility would be established, ORNL has reviewed the fueled module assembly and estimated that a unit could be fueled and available for shipment every 1-1/2 months following the initial unit delivery. The initial unit would be available for delivery twelve months following receipt of an order.

The availability of the twenty ERTG systems on the basis of the above analyses would be about 3-1/2 years. Table 3-1 identifies the cost estimate for ten and twenty production units. These estimates are based on the schedule presented above and the identified cost basis given below (which includes the uncertainties that can be identified at this time). These estimates assume the schedule for non-fueled hardware is independent of the number of units delivered; i.e., the schedule provides for four units to be available for delivery every six months months and, if only two units would be required, then the other two would be stored for subsequent delivery as needed. In this manner, full time manufacturing, assembly, product assurance, and testing personnel can be assigned to the program and the inherent problems and costs associated with personnel assigned intermittently to the program will be avoided. ORNL has assumed similar logic in their estimates. The cost estimates for ten or twenty ERTG's, therefore, are similar except for the decrease in time associated with producing ten ERTG's.

PROGRAM MANAGEMENT

Cost Basis - This estimate is based on continuing the Project Office established during Phase 3. A full time Program Manager having technical and fiscal responsibility and providing the focal point for interfacing with government agencies. A full time Project Manager responsible for manufacturing, assembly, and acceptance testing of the flight hardware, a Project Control Engineer, and a technician to handle report preparation, cost analysis, etc. will be assigned full time to the Program Manager. The cost estimate is based on four years for twenty units and three years for ten units; approximately six months beyond the time needed to produce ten and twenty units.

Uncertainty - Cannot be determined without additional AEC program guidance with respect to reporting requirements. If the delivery schedule is for two ERTG units every six months, since these personnel are assigned full time to the program the cost would most likely double.

TABLE 3-1

SECOND GENERATION ERTG PRODUCTION COST ESTIMATES
(THOUSANDS OF DOLLARS)

(Four ERTG's Delivered Every Six Months)

ITEM	TEN ERTG	TWENTY ERTG
PROGRAM MANAGEMENT	580	775
TECHNICAL ASSISTANCE TO SPACE-CRAFT CONTRACTOR	200	220
PRODUCT ASSURANCE	800	1100
COMPONENT COSTS		
Fuel Capsule Hardware	32	63
Tubular Module	475	945
Aeroshell	240	480
Heat Pipes	95	177
Radiator/Support Structure Hardware	74	148
AEROSHELL/HEAT REJECTION SYSTEM		
Assembly	95	190
Acceptance Test	180	360
FUELED MODULE ASSEMBLY AND ACCEPTANCE TEST	630	1260
FUEL COSTS	5160	10320
TOTAL	8561	16038

TECHNICAL ASSISTANCE TO SPACECRAFT CONTRACTOR

Cost Basis - A systems engineer on a full time basis in addition to personnel from the Program Office has been assumed.

Uncertainty - Cannot be determined without additional AEC program guidance.

PRODUCT ASSURANCE

Cost Basis - This estimate is based on contract application of top level NASA type Quality Assurance and Reliability specifications.

Approximately two full time Product Assurance engineers will be assigned to direct and implement the complete Product Assurance programs reflected by Appendices B and C. A total of approximately five Product Assurance technicians will be assigned to perform all inspections and tests, and compile all data reports necessary for delivery of a flight system.

Uncertainty - Principal uncertainties concern how solidly the design freeze at the beginning of the Production Phase is held. Every design change for flight system or ground support equipment will raise quality engineering review time, increase inspections, and add to configuration control data operations.

COMPONENT COSTS

The following gives the component costs for the principal hardware comprising the ERTG.

(a) Fuel Capsule Hardware

Fuel Capsule Tube	1
End Caps	2
Vent Tubes	1
Rupture Discs	1
Zirconia Spacers	2
Weld Verification Tubes	8
Weld Verification End Caps	8

Cost Basis - Each unit will require a fuel capsule assembly. The material for these assemblies is estimated to cost $400.00. To produce these components will require one machinist full time and one design/manufacturing engineer 20% of full time. For twenty units, one and one-half years is estimated while for ten units the time would be about half.

Cost Uncertainty - The greatest cost uncertainty results from the possible use of two 225 w(e) modules as in the Reference Design in place of the Second Generation Module. This would double the cost of the fuel capsule assembly.

(b) Tubular Module

Cost Basis - A tubular module will be fabricated, assembled, and processed for each unit. On the basis of past experience, the cost per module is $40,000; $18,000 M&S, and remainder engineering/technician labor. Each module will undergo a standard electrical checkout; the cost equivalent of a half engineer and a full technician man-month has been included in the estimate for each module.

Uncertainty - The cost basis is the Second Generation Design. The Reference Design ERTG, if required, would increase the number of tubular modules to two per ERTG; a cost increase savings of about $40,000/ERTG being required.

(c) Aeroshell

Cost Basis

- Billet Fabrication - An order will be placed for 10-20 billets with delivery to start 3 months after receipt of order and to proceed at one per month. This approach provides best incentive for cost reduction and provides schedule lead time.

- Machining - Place order to machine commencing upon receipt of first two billets and proceeding at rate of one every three weeks. This approach is compatible with machining requirements, provides continuity and achievement of low cost.

- Inspection and Assembly – Proceeds at one per month upon receipt of first machined billet. This approach trends to lower cost by virtue of steady continuing activity.

- Acceptance Testing – Proceeds at one billet every three weeks upon receipt of first assembled billet; continuity of testing will result in low cost.

- Delivery – The delivery of aeroshells for this first ERTG will be 7 months after initial order and will proceed at a rate of two aeroshells every one and one-half months thereafter. The cost per aeroshell is $24, 000. This cost includes Avco program management.

Uncertainty – The cost basis is the Second Generation ERTG Design. The Reference Design ERTG, if required, would increase the number of aeroshells required to two/ERTG with a corresponding cost increase.

(d) Heat Pipes

Cost Basis – The cost was based on similar programs conducted in the past by Dynatherm. Basically, the cost basis was developed from both the HPG copper/water heat pipe and the ATS-F grooved heat pipe program. Program management required was assumed to be 20%.

Uncertainty – A cost uncertainty exists in the number of heat pipes required. The estimate is based on 24 heat pipes per unit which is the Second Generation ERTG Design. The Reference Design ERTG would increase the number to 48 with a corresponding cost increase.

(e) Radiator/Support Structure Hardware

The radiator/support structure hardware for each ERTG system is:

Radiator Panels	4
Stiffening Ring Segments	12
Aeroshell Supports	4
Bus Bars	2
Heat Pipes (Cost for Bonding only)	24

Cost Basis - Each unit will require one radiator panel assembly, consisting of the number of components identified above. The assembly will be of two types, distinguished by having heat pipes for either the upper surface of the aeroshell or the lower surface. The material for these assemblies is estimated to cost $1,500. To produce these components will require a technician full time, and one design/manufacturing engineer 20% of full time. For twenty units, two and one-half years is estimated, while for ten systems, the time would be about half.

Cost Uncertainty - The cost basis is the Second Generation ERTG Design; the use of the Reference Design would about double the cost of the radiator assembly.

AEROSHELL/HEAT REJECTION SYSTEM

The following presents the basis for assembly and acceptance test costs for the non-fueled hardware.

(a) Assembly

Cost Basis - Each unit, complete except for the tubular module, will require one and one-half months to assemble. Two assembly technicians (one qualified for soldering) and one design/manufacturing engineer on a full time basis for two and one-half years has been included in the estimate for twenty systems; ten systems require half this effort. An allowance of $2,000 per ERTG has been included for miscellaneous hardware.

Uncertainty - The cost basis is the Second Generation ERTG Design; the use of the Reference Design would about double the assembly cost.

(b) Acceptance Tests

Cost Basis - The acceptance tests for the production units will be similar to FQS-1 and FQS-2 and, therefore, comparable effort has been included. The test is scheduled such that the equipment used for prior units is available for the production units. The cost basis is a test engineer and two technicians full time for one and one-half months per unit for setup, performing the tests and preparing test reports. Miscellaneous hardware of $1000 per unit has been allotted.

Uncertainty - The test plan established during Phase 3 will determine the effort level required for acceptance testing; the above estimate on the basis of performing tests of similar complexity is probably within 30%.

FUELED MODULE ASSEMBLY AND ACCEPTANCE TEST

Cost Basis - ORNL has reviewed the fueled module assembly and estimated on a production basis the cost to be $63,000 per ERTG system.

Uncertainty - The use of the Reference Design ERTG would increase the cost to about $83,000 per ERTG.

FUEL COSTS

Cost Basis - A cost of $100 per thermal watt based on guidance from the SNS Program Manager.

APPENDIX A

AEC GUIDANCE

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

Mr. W. G. Parker
Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

Dear Mr. Parker:

Subject: Project Development Plan and Cost Estimates for ERTG Program, Contract AT(04-3)-940

As a part of Contract AT(04-3)-940, you are required to prepare a development plan and associated cost estimates for the development of a power system similar to your reference design for use in an operational spacecraft, as well as for the follow-on production of an additional 10-20 power units for use in an operational space program.

Since the non-recurring costs, as well as the recurring unit costs for follow-on systems, and schedules for the development program are important factors in selecting a system(s) for further development by the AEC, it is necessary for the development plans and cost estimates for the various systems under consideration to be prepared on comparable bases. Therefore, you are requested to use the following guidance in preparing your development plans and cost estimates under the current contract.

Technology and/or Component Demonstration (Phase 2)

As the next step beyond the current design study, you should assume that the program will include a technology and/or component demonstration phase starting in the 3rd quarter of FY 1974 and continuing through FY 1975 (or longer, if necessary). This 18 month (or longer) phase 2 shall include the type of effort which you will have identified as requiring emphasis prior to the time the AEC could initiate a flight system development program in response to a firm

requirement from the DOD/Air Force, assumed to be no earlier than the 1st quarter of FY 1976. The objective of this phase 2 would be to provide essential technical data in identified problem areas in your system design and/or to demonstrate hardware components which are critical to the performance of the power system which may not have been adequately demonstrated heretofore or must be reduced to hardware for proof-of-principle, which are either impossible or, at best, very difficult to predict analytically. In other words, this phase of the program should be planned in a way to increase confidence in the system design prior to commitment to a larger development program required to meet a planned flight date. The level of effort for this phase of the program should be the minimum required consistent with the above directions.

The approach to be used for contracting for this next follow-on effort shall be to minimize the overall system contractor-type efforts and to maximize the use of available resources at the component or sub-system levels. In this regard, you should assume that the AEC will not duplicate similar technology areas at various contractors, but will place system peculiar efforts as well as more generally applicable efforts with the most appropriate contractor(s).

You can further assume that the on-going AEC technology programs in the areas of fuels production and development and safety which are relatively independent of system designs will be continued through Phase 2, even though the work content may be modified based on the results of the current system design efforts.

System Development and Qualification (Phase 3)

Assuming that at least one system option is pursued through Phase 2, the next phase of the program would include the development and qualification of one or more systems for use on a spacecraft with a planned flight date. This assumes that the AEC will have received a requirement from a user agency defining the system requirements and schedules, including the definition of launch vehicles and spacecraft so that the proper interfaces can be defined and the hardware deliveries to the user agency can be specified and properly

scheduled or that the AEC will be in a position to pursue such a development program on a technology development basis independent of a specific end-user requirement (e.g. in conjunction with the development of a standardized nuclear spacecraft).

You can assume that one, or more, system contractors will be selected by the AEC to pursue the Phase 3 program. All aspects of a system development program shall be included in the plan providing cost estimates for Program Management, Technical, Administrative, and Support-type personnel which you think is reasonable and adequate for the tasks to be performed. The development plan should include a definition of the tasks to be performed, the time and labor required, the facilities and equipment needed, and the division of responsibilities between the contractor and/or its sub-contractors and the Government and/or other Government contractors.

Phase 3 shall include the design, fabrication and test efforts required at the component and system levels to logically proceed as economically and as rapidly as practical from the end of Phase 2 to an electrically heated engineering prototype(s) and then to a qualification system (both electrically heated and fueled, if required) by the end of Phase 3. You should include an electrically heated prototype for delivery to the user program for mass, thermal, and electrical integration tests with a prototype spacecraft prior to the end of Phase 3. The duration of Phase 3 is system design dependent and shall be determined by the contractor. The equipment required to support the Phase 3 program shall be included, such as any special handling equipment or shipping casks needed for a fueled system test.

The contractor shall provide all test hardware and test facilities, except for unique type facilities which exist only at Government laboratories, e.g. arc-jet facilities and nuclear test facilities. The contractor shall be responsible for arranging for such unique Government facilities and including appropriate cost estimates where possible. Plans for testing of nuclear materials shall be

determined based on cost, safety, and other such considerations. Generally, all cold (non-nuclear) tests will be performed by the contractor and all hot (nuclear) tests will be performed by the AEC, with the possible exception of the fueled RTG system.

In the area of nuclear heat sources, you can assume that the AEC will perform fuels development and testing in support of the program and that the AEC fueling facility will load the fuel in contractor furnished hardware in accordance with previously agreed upon procedures. Any testing of fueled hardware shall be accomplished as specified above.

In the area of nuclear flight safety, Phase 3 will include those tests and analyses required to produce a preliminary safety analysis report during Phase 3. Feasibility reports or safety analyses will also be required to support tests involving nuclear materials.

In the area of quality control and reliability, the planned effort shall be design dependent and the contractor shall use his best judgement in determining the level of quality control and reliability effort required, at what point in the program, to assure a reproducible product which will meet the performance and reliability requirements specified for the flight program. Configuration control will be maintained after appropriate design freezes have been effected. By the end of Phase 3, a flight-qualified system design and associated fabrication procedures suitable for producing a flight system should be available.

Flight System Fabrication (Phase 4)

Assuming that at least one system has been successfully qualified in Phase 3, the flight system(s) will be fabricated, tested, delivered and launched in Phase 4. The program should provide one flight system and a back-up or spare system for delivery to the spacecraft contractor for mating with the flight spacecraft, assumed to be six months prior to launch. Flight systems should be interchangeable. If the system does not allow for substitution

of the nuclear heat source for an electrical heater, an electrically heated system shall be delivered in addition to the fueled systems. The contractor shall plan on conducting flight acceptance tests on the hardware prior to delivery. All necessary support equipment shall also be provided. The contractor shall plan on providing technical assistance to the spacecraft contractor during testing of the power system and during pre-launch and launch activities at the launch site. Post-launch analysis of data from orbit shall be included for a 6-month period.

A final safety analysis report shall be included for delivery approximately 6 months prior to launch. Contractor support shall be provided during the interagency safety review for flight approval.

Follow-on Production (Phase 5)

Immediately following a successful development program and flight test of the first flight system (Phase 4), you should assume that a follow-on order for 10-20 systems will be placed. The production schedule should be based on an optimum cost manufacturing plan, but you should also assume the need dates are for 2-4 flight systems every six-months after the initial delivery during Phase 5. The costs of manufacturing tooling, support equipment, etc. which are not available from the development program should be included in the manufacturing costs for Phase 5. The plan should provide for acceptance testing of each unit and contractor support of spacecraft testing and launch site activities involving the power supply.

In each of the phases identified above, you should attempt to identify the cost uncertainties associated with the cost estimates which you provide and to determine the effect of these cost uncertainties on the total estimated cost of the program.

If you have any questions concerning the above guidance, please contact me.

Sincerely,

Robert T Carpenter

Robert T. Carpenter
ERTG Study Manager
Space Nuclear Systems Division

cc: H. Rauch, SAN
R. DuVal, SAN

APPENDIX B

WANL QUALITY ASSURANCE PLAN

for

SPACE FLIGHT SYSTEMS

I. INTRODUCTION

Westinghouse recognizes that space flight systems require the achievement of carefully determined safety, reliability, and quality control goals. It is toward the successful and timely completion of these goals that the WANL Product Assurance Program is directed and implemented. The WANL Product Assurance Program consists of combined Reliability and Quality Assurance operations. This approach is used to assure a complete and consistent coverage of all applicable activities, from initial design to delivery of contract end items. This plan identifies the functions of WANL Quality Assurance in space flight systems.

II. QUALITY PROGRAM MANAGEMENT AND PLANNING

At WANL, the Product Assurance Manager has direct, unimpeded access to top management. He reports directly to the Division General Manager and is responsible for assuring that all quality and reliability requirements are being met in accordance with contractual commitments both in-house and at subcontractor locations. He is also responsible for reporting the status of the quality and reliability program.

The Product Assurance plan is supplemented by procedures which detail the responsibilities and methods for conducting the Product Assurance efforts. These procedures are Reliability Methods and Procedures (RMP's) and Quality Methods and Procedures (QMP's). The Product Assurance plan provides that all operations, from design through procurement, fabrication, assembly, testing, and shipment are controlled in a systematic manner to assure completeness without duplication of effort.

Formal Quality Assurance audits are conducted in all areas affecting product quality. Quality Assurance takes corrective action relative to any Quality Assurance deficiencies revealed as a result of audits. Quality Assurance or Reliability, as appropriate, will review deficiency areas to insure that corrective action has been taken. The provisions for internal corrective action are defined by WANL Quality Assurance procedures. Quality Assurance corrective action recommendations are directed to the supervisor most directly concerned.

The supervisor developes the plan to implement corrective action and communicates this to Quality Assurance. Quality Assurance insures appropriate corrective action follow-up is provided.

Quality Assurance conducts a training program to insure personnel proficiency in inspection operations. Performance of Inspection personnel is reviewed on a continuing basis to assess the need for additional training. In addition, Quality Assurance monitors and reports on the need for training in other areas which have an effect on product quality.

III. DESIGN AND DEVELOPMENT CONTROLS

All drawings and specifications for items assigned Surveillance/Drawing Code 1 or 2 are reviewed and approved by Quality Engineering. Drawings and specifications for items assigned Code 3 are reviewed and approved by Quality Engineering when the cognizant design group requests inspection. The review includes: determination of inspection and test methods; specified use of preferred and qualified parts; and, input of corrective action based on previous experience with similar or related items. Drawings and specifications for Code 4 items are not reviewed by Quality Engineering.

Drawing and specification change controls are defined in WANL Divisional Procedures. These procedures define the requirements for the initiation, review, approval, distribution, and control of all drawings, specifications, and subsequent changes. Quality Assurance will review Engineering Change Orders (ECO).

Quality Assurance reviews changes to design and process documents to assure adequate quality provisions, configuration control, appropriate effectivity, and prompt removal of obsolete documents. Procurement documents that implement changes are reviewed by Quality Assurance and new inspection plans are prepared as necessary.

Detail inspection and control plans will be established for all designs and subsequent changes. Various analytical techniques such as fault tree analysis will be utilized to identify areas where human error, basic inspection capability, etc., could introduce significant risks of poor quality. The quality assurance methods will be established so as to minimize such risks. Where necessary, changes to the design and/or processes will be recommended.

IV. IDENTIFICATION AND DATA RETRIEVAL

The basic identification system for component parts, subassemblies, and assemblies is defined by a Divisional Procedure. This procedure requires that each part, subassembly, and assembly shall be assigned a unique part number. In addition, unique serial and lot numbers are assigned independent of the part number, for the purpose of distinguishing between parts or groups of parts of the same part number. It is required that the drawing specify that serial or lot numbers shall be assigned to the parts when manufactured. The part number and serial or lot number identification is utilized on all record documents relating to the part and forms the basis for complete traceability of any part.

V. PROCUREMENT CONTROLS

A. Control of Contractor-Procured Material

Quality Assurance is assigned the responsibility for evaluating procured material to determine the extent to which it meets the specified requirements. This responsibility includes the detection and elimination of problems which might result in discrepant products. The Quality Assurance system for controlling procured material emphasizes the detection of material discrepancies at the earliest possible point in time.

B. Selection of Procurement Sources

Quality Assurance will evaluate and approve or disapprove procurement sources primarily on the basis of WANL survey results and WANL quality history records. Surveys performed at

the discretion of Quality Assurance include evaluation of the following:

- The supplier's quality control and/or inspection organization
- The supplier's inspection and test equipment
- The type of work with which the supplier is familiar

WANL Quality Assurance indicates each supplier's quality control and/or inspection capability by classifying the supplier as "approved" or "disapproved." This classification list will be transmitted to the Purchasing Department, in writing, and purchase orders shall normally be placed only with approved suppliers. Placement of an order with an unapproved supplier may be made only with the specific approval of Quality Assurance.

C. Procurement Documents

Prior to placement of a purchase order (P. O.), the purchase requisition (P. R.) is reviewed by the cognizant Quality Engineer as follows:

- A thorough review is made of the purchase requisition and referenced documents to assure that the order is complete and meaningful. This includes verifying that serial or lot numbers are assigned when required by the drawing.

- Procurement quality requirements are inserted in the order. This may, for example, simply consist of writing into the order that material certifications are required to be submitted by the supplier. When these requirements are more complex, a Procurement Quality Requirement (PQR) form is completed and attached to the order. This form will specify one or more of the following:

  - That the Quality Control Specification, WANL-QC-101, applies totally or in part.
  - That supplier submittals shall be made for inspection plans, nondestructive testing procedures, special processing procedures, etc. These submittals shall be made on Approval Request (AR) forms.
  - That source inspection is applicable and the extent to which it will be applied.
  - That source inspection data shall be submitted by the supplier.

- Inspection Instructions are prepared for WANL receiving inspection and/or source inspection. These instructions are normally prepared in detail in a standardized manner.
- If Government source inspection becomes a requirement, it will be placed in the PR by the cognizant Quality Engineer at the time that the PR is reviewed.
- Contractor source inspection is performed by Quality Assurance when required by the PQR and per the applicable Inspection Instructions prepared by Quality Engineering. Source inspection is utilized for the following reasons:
  - To verify that characteristics which may later be unmeasurable meet the design requirements.
  - To determine the acceptability, at the earliest point in time, of material that is on the critical path, schedule-wise.
  - To determine the acceptability of material in the most economical manner. Discrepancies discovered by source inspection are submitted by the supplier to WANL on a Variation Request (VR) form for disposition.

D. Receiving Inspection

Receiving inspection is performed by Quality Assurance in accordance with the instructions given by the cognizant Quality Engineer. The inspection includes, by a review of the paperwork, that source inspection has been performed, when required. All material is physically separated into the following categories, unless material size or similar restrictions prohibit:

- Material awaiting inspection or test
- Conforming material
- Nonconforming material

Full identity is maintained at all times prior to and during inspection. Stickers and tags are utilized to identify discrepant material and are a means of control, in addition to controlled segregation. In addition, the inspection status (awaiting inspection, conforming, nonconforming) is clearly noted. Processing of nonconforming materials is discussed in a later paragraph. All material leaving Inspection is identified by purchase order number, part number, serial number, or lot number, and inspection status.

E. Supplier Corrective Action

Quality Assurance will take prompt action to correct conditions at suppliers' plants which result, or might result, in substandard or defective materials, parts, assemblies, or services. Formal Quality Assurance procedures will be used when the quality problems are deemed critical by Quality Assurance. In all other cases where it is deemed necessary to take corrective action, a less formal procedure utilizing written and/or oral communications and Quality Assurance follow-up will be used.

VI. FABRICATION CONTROLS

A. Production Tooling and Fabrication Equipment

Production tooling, jigs, fixtures, and other fabrication equipment which control dimensions, contours, or location of fabrication operations on Surveillance Code 1 or 2 items are calibrated and controlled by Quality Assurance to insure initial and continuing accuracy. Code 3 items may be inspected by agreement between Engineering and Quality Assurance.

B. Control of Cleanliness of Fabrication and Test Areas

Stringent cleanliness is required for fabrication operations. Quality Assurance conducts periodic checks to assure that cleanliness requirements defined in process specifications are met and maintained. When it is determined that specified cleanliness requirements are not being met, Quality Assurance is authorized to put a "hold" on the affected operations until corrective action is completed and determined to be effective.

C. Process Control

Consistent control of fabrication processes is necessary to achieve the required reliability and quality. Quality Engineers will review process plans and define parameters to be monitored. Fabrication process operations will be monitored by Quality Assurance to the extent necessary to ascertain compliance to the Process Specification. Defect information generated by inspection will be fed back to the fabrication operation for correction of process deficiencies. Quality Engineering will provide follow-up action. Any changes to a qualified process will require that the process undergo a requalification to verify that the change does not affect the end product.

D. Certification of Fabrication and Inspection Personnel

Certification of personnel performing specialized operations (such as welding, soldering, radiography, dye penetrant) is accomplished per QMP's which provide for written, oral, and proficiency testing. Periodic evaluation of inspections, tests and quality audits establish the need for additional training and recertification. Records are maintained of all individuals certified with the dates of effectivity of the certification. These controls are extended to supplier personnel.

VII. INSPECTIONS AND TESTS

The Quality Assurance program utilized in the WANL fabrication and assembly areas is designed to provide maximum assurance that all applicable contract, drawing and specification requirements are obtained and maintained.

The criteria for determining conformance of all articles produced or assembled by WANL include drawings, specifications, and workmanship standards. The various WANL Divisional Procedures and QMP's specify that these documents are to be available at the time of inspection.

Inspection plans are prepared as two distinct types and can be considered as fabrication inspection plans, or assembly inspection plans.

Inspection plans to be utilized in evaluating products being fabricated at WANL are prepared by Quality Assurance as Quality Inspection Procedures (QIP's) or Inspection Instructions (II's) depending upon the complexity of the inspection required. The QIP is utilized for complex inspections and is a highly detailed, narrative type document specifying, as a minimum, the following:

- Identification of the article to be inspected or tested (e.g., part number, applicable specification, system involved, and nomenclature).
- Objectives of the inspection or test.
- Measuring and test equipment to be used - specifying range, accuracy, and type.
- Detailed operations to be performed by the test operator, including operational checks or calibration of the test equipment.
- Conditions that must be maintained during inspection and test, including ambient or environmental, and precautions to be observed to prevent damage to personnel, test items, instruments involved. Safety precautions are required if applicable.
- Criteria for passing or failing the test or for determining conformance or rejection of the article including reference to inspection standards.
- Sampling plans to be used, if applicable.
- The recording forms required and instructions for filling out the form. The Inspection Instruction (II) is utilized for simple, component-part types of inspection. This type of approach emphasizes defining the characteristics to be inspected, using standard gaging techniques. The cognizant Quality Engineer, at his option, may elect to write into the Work Order simple instructions such as "inspect to drawing," rather than using an Inspection Instruction.

Assembly inspection plans are written for assembly activities. The inspection requirements for such operations written by Quality Assurance are incorporated in an Assembly Plan. The Assembly Plan then becomes a combined assembly and inspection instructional document and is issued by the cognizant assembly activity with the concurrence of Quality Assurance. Each plan will include, as a minimum, the same content as noted above as the requirement for a QIP. Inspection plans for all other assembly operations will be written as QIP's.

Test plans are normally prepared in the form of WANL specifications. These plans are reviewed and approved by Quality Assurance. Inspection requirements are incorporated into these plans such that the document includes, as a minimum, the requirements applying to QIP content.

VIII. NONCONFORMING ARTICLE AND MATERIAL CONTROL

A. Nonconforming Material

Quality Assurance provides for the review, control, and disposition of nonconforming material in a standard, formalized manner. A preliminary review of all nonconforming material detected by inspection at WANL is conducted by a Preliminary Review (PR) action consisting of a Manufacturing Engineer and an Inspection Supervisor. Dispositions available to the PR action are:

- Rework to print
- Return to Inspection for additional information
- Submit to ERB or MRB
- Reject

Product nonconformances detected at a supplier's facility may be presented for review by WANL Engineering Review Board (ERB) on a Variation Request (VR) form.

B. Engineering Review Board (ERB)

ERB's are convened to act on all discrepant materials discovered by Inspection or reported by suppliers which require engineering decision for acceptance. As a minimum, the ERB consists

of the cognizant Design and Quality Engineers. Representatives of other departments may participate in the ERB as arranged by Reliability Management with advance notice to Quality Assurance. All "Accept," "Reject," and "Limited Usage" dispositions made by the ERB include a statement justifying the disposition made.

C. Material Review Board (MRB)

Nonconformance or repair procedures on components, subassemblies, and assemblies which, in the judgment of Quality Assurance, affect safety, function, procurement or required test data, schedule or interchangeability of the end item shall be brought to the attention of the contracting agency representatives for possible MRB action. In addition, the contracting office and prime contractor residents shall have the right to call for MRB action on discrepancies previously processed through ERB. This option must be exercised within two weeks after the transmittal to the residents by the Product Assurance office of the document which indicates ERB disposition. The MRB consists of the members of the ERB, and the representatives of Reliability and the contracting agency.

IX. METROLOGY CONTROLS

A. Inspection, Measuring, and Test Equipment

WANL Quality Assurance provides for the selection, evaluation, approval, maintenance, and control of all inspection standards, gages, measuring and test equipment necessary to determine conformance with specifications, drawing, and contract requirements. For the purpose of this Program Plan, tools, jigs, or fixtures which are used to obtain measurements that are criteria for acceptance or rejection by Quality Assurance shall be considered gages.

B. Initial Evaluation

Each piece of inspection, measuring and test equipment is initially evaluated to determine its accuracy and its suitability for performing the desired inspection or test. The results of this evaluation are documented and retained for future reference.

C. Periodic Calibration

All inspection, measuring, and test equipment used in product control or in critical engineering tests is periodically calibrated at established intervals to assure that the original accuracy is maintained. Each piece of equipment is identified by an identification number applied to the piece of equipment or the case. Each piece of equipment or its case is also tagged with a sticker showing the last date of calibration and the date of the next required calibration. A record system provides for the following, as a minimum:

- Identification of the piece of equipment.
- Results of initial evaluation and periodic calibration, including applicable dates and names of the individual performing the evaluation and calibration.
- A system for positive recall for calibration.
- A record of all repairs performed.

D. Calibration Facilities and Standards

Calibration facilities at WANL provide an environment that is sufficiently controlled to allow each piece of inspection, measuring, and test equipment to be evaluated and calibrated to its design accuracy. The dimensional gage laboratory is essentially dust-free and the temperature and humidity are maintained at 68 degrees ± 2 degrees F and maximum 50 percent relative humidity, respectively. Within state-of-the-art limitations, the standards used for calibration of inspection, measuring, and test equipment will have a tolerance no greater than 10 percent of the allowable tolerance for the equipment being calibrated. Approved commercial laboratories are utilized for calibrations when necessary.

E. Maintenance and Control

All inspection, measuring, and test equipment is maintained in a manner that will provide assurance that the original accuracy and capability of the equipment is not jeopardized. Any defective inspection, measuring, and test equipment is removed from service and not made

available for reuse until adequate repairs and re-evaluation assure that the equipment is again accurate and capable.

X. STAMP CONTROLS

The acceptability status of products is indicated by the use of tags, stickers, and copies of inspection documents attached to the product or the product container. Stamps (rubber and steel) are provided to each inspector for use on the tags, stickers, and inspection documents for identification purposes. The stamps are provided in several designs to clearly indicate status, and each stamp is numbered and traceable to an individual inspector. The design of the stamps is intended to be such that they cannot be confused with Government inspection stamps. A QMP provides a detailed description of the design, use, and control of the inspection stamps.

XI. HANDLING, STORAGE, PRESERVATION, MARKING, LABELLING, PACKAGING, PACKING AND SHIPPING

Design and manufacturing engineers are responsible for specifying preservation, packaging, handling, storage, and shipping procedures and designs. Quality Assurance reviews and approves such procedures and designs for adequacy and provides surveillance to verify compliance with the requirements. The Quality Control Release for shipping and other technical documents to accompany material or end items are described in a QMP. Any departures from specified handling, storage, preservation or shipping requirements are dispositioned in a manner identical to product deviations.

XII. SAMPLING PLANS, STATISTICAL PLANNING AND ANALYSIS

Quality Assurance will formulate inspection plans for hardware and raw material items which lend themselves to sample inspection. Where possible, these plans will be as defined in MIL-STD-105, MIL-STD-414, or handbooks H106, H107 and H108. Authorization of suppliers' sampling plans requires prior approval from Quality Assurance.

XIII. GOVERNMENT PROPERTY CONTROL

Quality Assurance will inspect Government-furnished property to detect damage in transit and completeness for its intended use. Control of Government-furnished property will be maintained to insure that damage does not occur.

Quality Assurance will advise and request disposition instructions from the resident or other Government-designated representatives as identified in the GFP agreement of such property found damaged, malfunctioning, or not suitable for its intended use.

APPENDIX C

WANL RELIABILITY PROGRAM

for

SPACE FLIGHT SYSTEMS

I. INTRODUCTION

The WANL Reliability Program for Space Flight Systems is designed to assure that all necessary functions affecting product reliability are accomplished in an effective, timely manner. Major elements of the reliability program include:

- Assurance, through analysis and review, that the necessary reliability to meet project objectives is inherently designed into systems and components.
- Evaluation of reliability status of various components and subsystems relative to reliability or qualification goals.
- Audit of all operations, from fabrication to end use, to prevent degradation of inherent reliability.
- Acquisition and reporting of all data pertinent to reliability evaluations or qualification determinations.

II. RELIABILITY PROGRAM MANAGEMENT

A. Reliability Program Control

The WANL reliability organization will be responsible for scheduling and assuring completion of the reliability tasks. Appropriate reliability functions, such as failure mode and effects analyses (FMEA's) and design reviews, will be shown on the project planning charts as required. Documented completion of such key functions will be required.

Priority of reliability effort will be highest for those functions recognized as most critical in achieving a high reliability. The status of progress toward applicable milestones will be reported regularly, concurrently with design progress reporting.

Reliability Procedures. This Plan is supplemented by WANL Reliability Methods and Procedures (RMP's) designed to provide specific operating instructions to the reliability and project personnel who participate in implementing the plan.

Reliability Program Reviews. Reviews of the Reliability Program Plan may be conducted at any time as required by the specific contract.

B. Reliability Indoctrination and Training

Reliability will recommend and assist in training and indoctrination programs to insure that all personnel are made aware ot the part they play in achieving reliability objectives. Also, recommendations will be made for training in potential reliability problem areas such as manufacturing and assembly. Informal education programs will be conducted as required by the Reliability organization.

C. Outside Procurements

Outside procurements involving a design function or functional testing on the part of the supplier will be reviewed by Reliability Engineering to evaluate the effect of the subcontracted item on overall system reliability. The supplier reliability program requirements will be determined in accordance with the criticality of the item. When deemed necessary, WANL-RS-201, "Reliability Program Requirements for Suppliers" will be made a part of the purchase order. The Reliability Department will provide appropriate surveillance to assure that the item(s) in question meet the same high standards of reliability called for in in-house-designed items.

D. Components Furnished by the Government

Reliability of Government-furnished property will be assured by consideration of the best available data, which would serve as a basis for an independent reliability evaluation. Appropriate supplementary testing will be performed if the need is specified.

III. RELIABILITY ENGINEERING

A. General

The Reliability Engineering effort will be documented by well defined tasks, which will be closely coordinated with the design effort. Such tasks may include systems reliability studies initiated early in a program and carried forth on a continuing basis. They may also include tasks related to procurement, fabrication, assembly, and maintenance, which will require more effort in the later phases of a program, such as disposition of non-conforming material, disposition of vendors' request for variations, and failure reporting and corrective action follow-up. These tasks are discussed below.

B. Design Checklists and Guidelines

To orient the design engineers toward reliability goals, Reliability will provide checklists developed from failure mode analyses. For example, the checklist will specifically include consideration of "material trasnport by sublimation at high temperatures and condensation on cooler surfaces under hard vacuum conditions." Quantitative assessments of the magnitude of this effect, both under anticipated operating conditions and during credible excursions from normal conditions, will be used in developing a reliable design. The checklists will include consideration that parts be adequately inspected and controlled.

Reliability will assure that the design engineers follow standard practices wherever possible and use handbook specifications and established design codes where applicable. In addition, reliability will provide guidelines with recommended margins based on variability of material strengths and on estimated loads.

C. Materials Review

At the earliest possible stage in the design of each major component, the design engineer, together with the Reliability engineer and a Materials engineer will review materials requirements and identify areas in which materials will have to be developed and/or tested.

Reliability Engineering will use the materials review meeting to obtain documentation of materials properties which will be needed in the detailed failure mode analysis and reliability predictions. Special materials tests will be recommended when results of failure mode and effects analyses indicate a need for additional information to assess the status of potential failure modes.

D. Review of Materials and Process Specifications

Detailed engineering drawings of components will specify the materials and processes to be used for fabrication, shipping, storage, etc. These specifications will be reviewed by Reliability Engineering to assure that the processing operations are effective and reproducible and that materials are adequately and realistically specified.

E. Reliability Apportionment and Prediction

Priority will be assigned to the reliability efforts associated with those parts of the program determined to be most critical in achieving overall high reliability. Priorities will be periodically reviewed to consider results of design and testing efforts. However, to be sure that critical areas do not escape timely recognition, a reliability apportionment study will be completed early in a program in order to determine the required contribution of each component to the overall reliability objectives of the system. The system objectives will be apportioned to the subsystems and to the components of the subsystems on which reliability can be assessed by testing or by analytical techniques. The apportioned reliability goals will serve as a guide for design and development efforts.

When the design features of a critical component are complete, reliability predictions; i.e., an estimate of the probability of the component's fulfilling its functional requirements for its projected life, will be made. Such prediction will be based on some combination of (a) available results of life tests, (b) analysis of previous experience and test results from comparable designs, (c) theoretical analysis of the design, and (d) results of FMEA's.

All available pertinent technical information, including that from the AEC and from NASA, will be used as an aid in analyzing the reliability of a design, and in defining possible problem areas.

Tests to be performed on components and assemblies will, insofar as possible, be designed to give information for reliability evaluation purposes.

F. Failure Mode and Effects Analyses

Failure mode and effects analyses (FMEA) will be conducted to study the possible causes and effects of failure of parts, components, subsystems, and systems. The preliminary failure mode and effects analysis will be used in the selection of design concepts and to identify uncertainties or weaknesses in the design concepts selected for development. It will provide a basis from which the relative reliabilities of competing designs can be evaluated. Detailed failure mode and effects analyses of a component will begin as soon as a sufficiently detailed design is available. Criticality ranking of failure modes will be utilized to apply efforts to the problem areas. The possible causes of failure will be identified and appropriate preventive or corrective actions will be recommended, based on FMEA results. Failure Mode and Effects Analysis will be conducted by Reliability Engineering and reviewed by Design Engineering. Operational procedures are detailed in RMP's. Failure Mode and Effects Analyses will be supplemented by fault tree analyses to evaluate system interactions. Results of the preliminary failure mode analysis will be discussed with the design engineers in continuing informal design reviews.

IV. TESTING AND RELIABILITY EVALUATION

A. Review of Test Plans

Test plans will be written for: (a) materials, components, or systems evaluation tests to provide necessary data for design calculations or reliability predictions, and (b) design verification tests to verify that components or systems behave according to design predictions under

specified conditions. All test plans will be reviewed by Reliability Engineering in accordance with detailed procedures contained in RMP's. Consideration will be given to the validity of the tests and whether they represent the actual conditions which will prevail under systems' operation. Tests plans will also be reviewed for their ability to uncover potential failure mechanisms. Test plans will include criteria on what constitutes an acceptable result and on what constitutes failure. Insofar as practicable, tests will be run in such a manner as to maximize the amount of data yielded for reliability evaluation, e.g., at higher temperatures and stresses than those anticipated in systems' operation.

B. Evaluation of Test Results

Test data will be evaluated to judge adequacy and suitability for its intended use. Recommendations for additional testing and/or design changes would be made in the event the data failed to confirm design reliability.

C. Informal Design Reviews

As design concepts become more firm, informal design reviews will be held to monitor the development of the design, to assess its reliability status, and to formally recommend any changes deemed necessary from reliability considerations. Reliability will prepare a summary of review results and send copies to the participants, to cognizant engineering management, and to project management.

D. Formal Design Review

A formal design review will be conducted upon design completion and prior to release of the design for manufacturing. The design will be reviewed for compatability with all specified requirements. The results of test programs and of failure mode analyses will be considered in the review. Personnel assigned to the design review will have the capabilities necessary to examine every aspect of the design to be sure that the best knowledge, techniques, and procedures are embodied in it consistent with overall system requirements and specifications. Detailed procedures are given in WANL RMP's.

E. Design or Specification Changes

Reliability will review any proposed design changes following the formal design review. Additional design reviews or tests will be recommended when the change may adversely affect the design reliability.

F. Failure Reporting and Corrective Action Follow-Up

Test failures and problems will be reported in accordance with existing WANL procedures. Reliability will assure that an adequate failure analysis is conducted and that corrective action is taken to prevent recurrences. The status of all corrective actions will be reported periodically to project management.