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THERMIONIC REACTOR POWER SYSTEM DEVELOPMENT

VOLUME IV - REACTOR PLAN

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1. INTRODUCTION AND SUMMARY

This thermionic reactor plan is based on application of a thermionic reactor power system to nuclear electric propulsion (NEP) missions. The plan includes all development activities: design, analysis, experimental engineering, fabrication development, manufacturing, and testing for each reactor in the development program.

Scheduling of reactor development activities is based on an overall program plan leading to production of a flight reactor for 1983 launch. The major milestones proposed for the NEP power system development are shown in Figure 1. This schedule is based on a study performed to provide technical and cost data to the Advanced Propulsion Comparison Committee of NASA to be used as part of an evaluation of propulsion concepts for future interplanetary exploration.

For the purposes of this plan, the "reactor" includes: fuel elements, vessel, internals, reflectors, control drives, bus bars, reactor auxiliaries, and the control and instrumentation subsystem. The reactor auxiliaries includes cesium supply and fission product management subsystems. The control and instrumentation subsystem includes subsystems for: nuclear instrumentation, cesium pressure control, drum drive power, malfunction detection, and electrical output and miscellaneous monitoring instrumentation.

The summary specifications for the reactor are given in Table 1. A more complete specification is available in Reference 1. Reactor elevation and plan views are shown in Figure 2.

CY	72	73	74	75	76	77	78	79	80	81	82	83	
FY	72	73	74	75	76	77	78	79	80	81	82	83	84

Fig. 1. NUCLEAR ELECTRIC PROPULSION THERMIONIC POWER SYSTEM MILESTONES

TABLE 1
REACTOR SUMMARY SPECIFICATIONS

- Fast Reactor
- 162 Thermionic Fuel Elements (TFE)
- 150 kWe Gross Output (0.93 kWe per TFE)
- Approximately 24-Volt Reactor Output
- 1660 kW Thermal Power
- Launch Environment: Space Shuttle Cargo Bay
- 20% Redundancy in Electrical Power Capacity
- Eutectic NaK Coolant (980°K in, 1075°K out)
- Overall Size: 73.7 cm diameter, 92.5 cm length
- One Cesium Reservoir per TFE
- Complete Containment of Fission Products

Fig. 2 THERMIONIC REACTOR ELEVATION

Fig. 2 (cont'd.) Thermionic Reactor Plan View

1.1. SUMMARY STATUS OF REACTOR DEVELOPMENT

At the time of this writing, the emphasis in thermionic reactor power system development is fuel element development (Ref. 2). Work on the reactor, independent of the fuel element effort, is primarily conceptual design and analysis. Some experimental nuclear measurements have been performed and are reported in References 3 and 4.

The thermionic reactor development will make use, where appropriate, of technology and components developed in other programs. The nuclear data used in reactor analysis was largely obtained from work done in support of the Fast Breeder Program. The reactor control drive motors and bearings assumed in the conceptual designs are those developed in the zirconium hydride space reactor program. The niobium alloy reactor vessel technology base is taken from past work on the SNAP-50 program, as well as on subsequent liquid metal technology research supported by both USAEC and NASA.

Reactor development items may be divided into three categories: technology development, component development, and prototype tests according to the definitions in Table 2. The present status of reactor development items is assessed in Table 3 according to the categories designated in Table 2.

1.2. PROGRAM OBJECTIVES

The overall thermionic reactor development program is to provide the following information:

Thermal Power Distribution

Work is needed in this area due to uncertainties in nuclear cross-sections for materials in the reactor core - especially for neutrons in the resonance energy region. In addition, the analytical methods for calculating neutron flux distribution, especially at the core-reflector interface, are in need of further refinement.

TABLE 2
DEFINITION OF DEVELOPMENT CATEGORIES

Technology Development

- . Development of analytical tools for prediction of component performance over a range of parameter variations
- . Characterization of basic component materials properties under operating conditions
- . Development of fabrication processes

Component Development

- . Development of component for anticipated functional requirements of prototype device
- . The identification of major component failure mechanisms and the modification or redesign of components as necessary to eliminate or reduce effects to acceptable level
- . Demonstration of performance over range of possible operating conditions
- . Complete specification of materials and fabrication procedures

Prototype Tests (TA)

- . Complete specification of operating conditions
- . Complete fabrication drawings and specifications issued
- . Component qualification for range of anticipated parameter variations and full lifetime

TABLE 3

REACTOR DEVELOPMENT AREAS

Technology Development

- . Clean critical experiments to determine nuclear cross-sections and improve analytical techniques.

Component Development

- . Electrical bus joints
- . Neutron detector development
- . Control drum environmental test
- . TREX vessel hydraulic test
- . TFE-vessel joint development
- . Reactor C&I breadboard tests and irradiation tests
- . Liquid metal corrosion testing
- . Mechanical qualification testing
- . Mockup critical experiments
- . Cesium reservoir development

Prototype Tests

- . Reactor vessel joint fabrication
- . Control drive environmental test
- . Prototype vessel hydraulic tests
- . Instrumentation and controls
- . Electrical buses

Electrical Performance

Uncertainties in reactor power distribution and converter electrical properties result in an uncertainty of reactor electrical performance. This is to be measured in reactor tests over a range of reactor power levels and electrical loads.

Control Response

The prompt reactivity coefficients of a thermionic reactor are small and uncertain in magnitude at this time. Therefore, controllability, safety, and the response to load changes cannot be determined with sufficient accuracy.

Component Reliability

A component testing and evaluation program, plus analysis, is required to assure the reliability of the reactor assembly. The development program approach is that component testing is performed to establish reliability, while reactor tests are performed to measure integral performance.

The development program plan provides the information to answer these questions, along with accomplishing the development tasks associated with the items in Table 3.

A reactor development program plan is defined, leading to the fabrication of a flight reactor by 1981 for a 1983 launch. The plan provides for the development and fabrication of three reactors: Thermionic Reactor Experiment (TREX); Ground Prototype Reactor (GPR); and Flight Reactor (FR-1).

1.2.1. Thermionic Reactor Experiment

The thermionic reactor experiment is the ground operation of a near-prototypic thermionic reactor. The objectives of the experiment are:

- Measure the neutronic characteristics of a reactor assembly
- Determine the dynamic and control characteristics of a thermionic reactor
- Determine the thermal environment of reactor components
- Measure the electrical output of a large group of thermionic fuel elements (TFEs)
- Demonstrate startup, shutdown, and partial load (coast) operation

The objectives of TREX are met by performing the detailed activities described below in Section 2. It is estimated that these objectives can be accomplished in about 5,000 hours of equivalent full power operation of the reactor experiment. This establishes the lifetime development goal for the TREX reactor components.

The reactor for TREX is designed to best meet the above objectives and to embody certain features chosen for economy and program facilitation. The components of TREX that are selected to be as prototypic of the flight reactor as possible are:

- Thermionic Fuel Elements
- Reactor Vessel
- Reactor Internals
- Reflector Elements

This insures that the behavior of the core will result in valid measurements being obtained. It also will demonstrate adequacy of the TFE-vessel penetration design.

The reactor components that are non-prototypic include:

- Control Drive (motors and linkage)
- Bus Bars
- Controls and Instrumentation

The nuclear and control characteristics of the reactor can be measured sufficiently well with incorporation of the above non-prototypic components in place of the prototypic equivalents. At the same time cost savings result. The plan does not require that the flight control and instrumentation package be developed in time for TREX. Its appropriate functions are well simulated by use of digital computer control of the reactor and its electrical load. The TREX test facility is designed to facilitate replacement of the control drive units, if necessary, as well as replacement of the entire reactor for possible subsequent core tests.

The flow of the information obtained from performing TREX into the overall development program is described below in Section 1.2.4.

1.2.2. Ground Prototype Reactor Test

The GPR is a prototype of the flight reactor and is ground tested. The reactor design will contain improvements based upon the data from TREX. The components in GPR will be qualified for use in the flight reactor, including development for the mechanical environment of launch.

The objectives of the GPR test are:

- Confirm performance of the prototype reactor
- Confirm the thermal environmental parameters of the reactor components
- Demonstrate the integrated control of the reactor using a flight control and instrumentation package, including startup, shutdown, accelerated mission power profile, and thruster transients
- Measure the reactor electrical output for each TFE circuit over a range of power level

All of the components in GPR are prototypic including the control and instrumentation package. The test is to confirm the performance of an assembly of components that have been individually flight qualified. The electrical transmission lines are prototypic through, and including, the inverter section of the flight power conditioning modules which are incorporated in the test facility. The test facility is the same as that prepared for TREX with some modification between these two reactor tests. The heat rejection system used in GPR is designed and controlled to simulate the thermal time constants of the prototypic heat rejection system.

1.2.3. Flight Reactor

The flight reactor is manufactured and delivered to the power system integrator for incorporation into a deliverable flight system. The reactor is qualified to the specifications listed in Table 1.

1.2.4. Reactor Development Logic

The logic and information flow for development of the flight reactor is shown in Figure 3. The schematic shows how steps in the plan depend on information from the preceding steps.

Fig. 3. REACTOR DEVELOPMENT LOGIC AND INFORMATION FLOW SCHEMATIC (NOT TIME PHASED)

1.3. REACTOR PLAN SCOPE

A plan for each reactor in the development program will be presented including the Reactor Experiment, Ground Prototype Reactor, and Flight Reactor.

Component development work for each reactor is described under the plan for that reactor. The plan lists the number of test articles for each component and generally describes the type of apparatus or test facility required. Analytical tasks are listed with a brief work description given for each task.

The fabrication work items for each reactor are divided into tooling, special equipment, and manufacturing categories. Standard machine tools are not listed.

The test plan given for each reactor summarizes the operation sequence, measurements to be made, data analysis, and results expected from the test. Flight reactor testing is not planned.

Quality assurance and reliability plans are discussed in Volumes VI and VII of this series. A schedule for implementation of levels of QA and Reliability is included for each reactor.

The facility-related work items will be described in documents to be written.

The work schedule is detailed for each reactor. The time allotted for work items is based upon mean estimated time with successful accomplishment assumed. CPM or PERT-type network scheduling, including consideration for schedule slack time or slippage is beyond the present scope of this planning.

2. REACTOR EXPERIMENT PLAN

Activities in the thermionic reactor experiment are listed in Figure 4 with the time phasing shown. Associated major milestones are listed in Table 4. Descriptions of work in the various activities are presented next.

2.1. DESIGN AND ANALYSIS

2.1.1. Nuclear

2.1.1.1. Methods Development. Develop, maintain, and improve analytical methods for the nuclear design of thermionic reactors and for the evaluation of the results of nuclear experiments.

2.1.1.2. Cross-Section Development. Evaluate, correct, and improve basic neutron and gamma ray production cross-section data for the materials used in thermionic reactors and nuclear shields. Process the data and prepare in a form suitable for utilization by multi-group cross-section generation computer codes.

2.1.1.3. Analysis of Critical Experiments. Analyze the measurements performed under the critical experiment program described below with methods and cross-section data used in the design of thermionic reactors. Attempt to reconcile differences observed between analysis and experiment.

Provide pre-critical analyses as input to design licensing activities under the critical experiment program.

2.1.1.4. Reactor Design. Perform the nuclear analysis in support of the reactor experiment design and safety analysis. Complete the critical loading and fuel loading distribution to obtain the desired power distribution. Determine reactivity requirements and establish control element

Fig. 4. THERMIONIC REACTOR EXPERIMENT SCHEDULE

CALENDAR YEAR		72	73	74	75	76	77	78	79
ACTIVITY	FISCAL YEAR	73	74	75	76	77	78	79	
1. DESIGN AND ANALYSIS									
Nuclear									
Mechanical									
Electrical									
Thermal-Hydraulic									
Control and Instrumentation									
Materials and Processes									
Reliability									
2. COMPONENT DEVELOP. & EXPER. ENGR'G.									
Core Vessel Flow Test									
Control Drive Unit Test									
Control Drum Environmental Test									
TFE-Vessel Joint Development									
TFE Stem Thermal Test									
Reactor Assembly Mockup									
Vessel Joint Fabrication Development									
Liquid Metal Corrosion Testing									
Instrument. & Control Breadb'd. Tests									
3. CRITICAL EXPERIMENTS									
Clean Critical Experiment									
Mockup Critical Experiment									
4. FABRICATION									
Tooling									
Equipment									
Manufacturing									
5. QUALITY ASSURANCE									
6. TEST OPERATIONS									
Non-Nuclear Checkout									
Nuclear Tests									
Data Analysis									
7. FACILITY									
Conceptual Design									
Title I									
Title II									
Title III									
Construction									

TABLE 4

REACTOR EXPERIMENT SCHEDULE MILESTONES

1. Facility Construction Funds Authorized	January 1974
2. Initiate Full QA Controls	January 1974
3. Preliminary Reactor Design Complete	July 1974
4. Clean Critical Experiments Complete	July 1974
5. Complete Title I Facility Design	November 1974
6. Reactor Component Development Tests Complete	January 1975
7. Complete Title II Facility Design	April 1975
8. Final Reactor Design Complete	April 1975
9. Mockup Critical Experiments Complete	January 1976
10. Reactor Fabrication Complete	May 1976
11. Complete Facility Construction	January 1977
12. Complete Non-nuclear Checkout	May 1977
13. Initiate Nuclear Tests	May 1977
14. Reactor at Full Power	July 1977

design for adequate control and shutdown margins. Compute fuel burnup, fast damage fluxes, and fuel element reactivity worths. Calculate the reactor kinetics parameters and the temperature and power coefficients of reactivity. Study potential fuel melt-down configurations and fuel reactivity worth distributions for accident considerations. Provide neutron and gamma ray flux distributions as input to facility shielding design. Provide reactor material nuclear heating rates as input to reactor thermal analyses.

2.1.2. Mechanical

Mechanical design includes the preparation of engineering drawings and specifications for fabrication of reactor hardware excluding materials and process specifications and instrument and control engineering documentation.

Analyze the stresses in the reactor vessel and internals, the core, control drives and reactor auxiliaries. Calculate stresses and deformations due to internal pressure, thermal gradients, assembly alignment, and dynamic loads. Consider dynamic loads produced by normal and scram mode operation of control drives as well as by possible flow-induced excitation of the fuel elements.

Establish design values of deformation and stress for the reactor hardware materials accounting for variations in properties measured in physical testing.

Provide test requirement specifications for the development testing of reactor components and evaluate the test results for application in reactor design.

2.1.3. Electrical

The electrical design and analysis is concerned with the generation and transmission of the electrical output of the thermionic fuel elements.

Analyze the reactor to specify the reactor electrical output as a function of input thermal power accounting for power distribution, coolant temperature distribution, variations in performance between TFEs, variations in cesium pressure from optimum, and electrical losses in reactor buses.

Specify tests performed in the reactor experiment to evaluate the reactor's electrical performance.

2.1.4. Thermal-Hydraulic

The thermal-hydraulic design and analysis is concerned with the coolant flow distribution in the reactor vessel and the resulting temperature distribution in fuel elements, vessel, and core internals. Normal operation is considered as well as dissipation of afterheat following shutdown and certain accident situations such as flow blockage in a portion of the core.

Perform detailed hot spot analysis accounting for the effects on core temperatures of manufacturing tolerances and local power variations due to movement of control elements. Evaluate the possibility of significant vibration of the core as induced by the coolant flow.

Calculate detailed temperature maps of the core, vessel, and internals for use in mechanical, nuclear, and electrical design and analysis.

Provide a test specification requirement to the component development task for hydraulic testing of a reactor model.

Design flow channeling devices or orifices in the reactor vessel to effect a proper flow distribution. Provide a requirement specification for thermal or hydraulic measurements in the reactor experiment.

2.1.5. Control and Instrumentation

The control and instrumentation design and analysis is concerned with the stability and control of the reactor as well as the design and specification of hardware for reactor control and nuclear instrumentation.

Perform reactor control analysis to evaluate the reactor design in terms of its response to reactivity changes from various phenomena including coolant temperature changes, control element position changes, electrical load changes, and cesium pressure changes.

Devise control logic to insure that the reactor is safe and controllable overaall anticipated operating conditions.

Design the reactor nuclear instrumentation system and specify the location of neutron detectors.

Design the drum drive power control circuit and the cesium heater power control circuit.

Provide a test requirement specification as input to the test plan to obtain reactor stability and control data in the reactor experiment.

Specify the instrumentation required to measure temperatures, pressures, electrical voltage and current, flow rates, control element position, etc., so that the data from the reactor experiment on integral reactor behavior can be related to the design analyses.

2.1.6. Materials and Processes

Specify the proportion and composition of all materials used in reactor fabrication.

Specify fabrication processes and provide requirement specifications to the component development task for the development of process parameters.

Specify the chemical composition of the environment for operation of reactor hardware including coolant composition, impurity level in inert atmospheres, and vacuum levels as a function of operating temperatures and time at temperature.

2.1.7. Reliability and Maintenance

Evaluate the reactor design and operating plans to assure a reliability level commensurate with the reactor experiment as an engineering test to obtain basic performance data.

Evaluate the maintainability of the reactor design. Provide design input where appropriate so that the test schedule will not be compromised by a design not adequately providing for field maintenance of reactor hardware.

2.2. COMPONENT DEVELOPMENT AND EXPERIMENTAL ENGINEERING

Component development and experimental engineering includes all laboratory work to determine performance parameters for components, demonstrate the ability of critical components to function satisfactorily in the environment of the reactor experiment, and develop parameters for fabrication processes and tooling to be used in the manufacture of reactor hardware. Short term performance tests are performed before freezing the design for the reactor experiment. Long term component reliability testing is required before fabrication of the Ground Prototype Reactor and is described below in Section 3.2.

2.2.1. Core Vessel Flow Test

Experimentally determine the flow distribution and fluid pressure drop distribution in the reactor vessel. Construct a full-size model of the reactor vessel, core, and core internals. Circulate water through the vessel to simulate coolant flow. Measure flow distribution across the core. Use the model as a tool to evaluate orificing to achieve

proper flow distribution if required. Measure pressure drops through the model, from inlet nozzle to outlet nozzle. Measure separate contributions to pressure drop of plena, grid plates, friction through the core, and inlet and outlet losses.

2.2.2. Control Drive Unit Test

Fabricate a control drive unit including motor, linkages, position indicator, and support bearings. Simulate the mass and moment of inertia of the control element. Simulate the thermal environment in a furnace and operate for the number of cycles expected in the reactor experiment including both regulating and scram modes of operation.

Evaluate the durability and smoothness of operation of the assembly.

2.2.3. Control Element Environmental Test

Fabricate a section of a control drum and operate in the laboratory at design temperature and in the design chemical environment. Evaluate for materials compatibility both within the specimen and between the specimen and the environment. Operate the test for 5,000 hours.

2.2.4. TFE-Vessel Joint Development

Establish the design of the TFE-to-vessel joint including fabrication parameters and procedures for physical inspection.

Evaluate several concept joints for fabricability, inspectability, residual stress and resistance to tensile loads and thermal cycling. Perform additional measurements of joint quality by metallographic examination, x-ray, and mass spectrometer helium leak testing.

Select a reference design joint for the reactor experiment based upon the above results. Replicate and inspect the selected joint at least ten times to evaluate the reproducibility of the quality of the selected design.

2.2.5. TFE Stem Thermal Test

This test is to experimentally verify the normal operating temperature distribution in the TFE stem as well as demonstrate the ability of sensitive components to withstand thermal cycling.

Construct a full size replica of the stem - or portion of the TFE which extends outside of the reactor vessel. Attach a simulated electrical cable and mount thermocouples to be used to monitor the temperature distribution. Provide a d-c power supply to provide joint heating of the electrical conductors.

Simulate the thermal boundary conditions and heat inputs and measure the resulting temperature distribution. Evaluate the controllability of cesium pressure over the desired range and show that there are no "cold spots" in the cesium ducting.

Cycle the thermal conditions to simulate the expected number and kind of thermal cycles due to reactor startups over the duration of the reactor experiment.

Disassemble the test specimen and inspect the parts for leak tightness and electrical conductivity of high current carrying joints.

2.2.6. Reactor Assembly Mockup.

Construct a non-refractory metal, full size model of the reactor assembly. Demonstrate the effectiveness of tooling to be used for reactor assembly. Use the model for practice to establish the nuclear safety procedures employed to prevent criticality accidents during reactor assembly.

2.2.7. Vessel Joint Fabrication Development

This task is concerned with development of the fabrication parameters and joint design for the structural components of the reactor vessel.

Construct replica joints and evaluate by leak testing, tensile testing, and radiography for joint quality. Develop welding fixtures that may be required. Evaluate the non-destructive testing inspection methods versus results obtained by metallographic examination and tensile testing of the joint specimens.

2.2.8. Liquid Metal Corrosion Testing

Liquid metal corrosion testing is performed to evaluate the compatibility of the reactor materials exposed to coolant with the liquid metal coolant.

Establish the level of coolant purity required and demonstrate that acceptable corrosion rates are obtained if those purity levels are achieved.

Establish procedures for purifying and loading liquid metal into the coolant loop for the reactor experiment.

Establish the need for an on-line purification during loop operation, especially following opening of the system for repair.

Evaluate available instrumentation for measurement of oxygen concentration in the coolant at levels less than 1 ppm oxygen.

2.2.9. Instrumentation and Control Breadboard Tests

Instrumentation and control breadboard tests are electronic circuit tests in which the reactor control and instrument circuits are simulated, or actual hardware tested, with an analog computer simulating the kinetics of the reactor so that the dynamic behavior and stability of the reactor-control system can be studied.

Use these tests to evaluate the reactor-control circuit design.

2.2.10. Summary of Component Development Tests

The component development tests are listed in Table 5. The table also lists the number of test specimens of each kind in the program and indicates the need for special test facilities. The number of test specimens will change as reliability analyses are performed.

2.3. CRITICAL EXPERIMENTS

Critical experiments are performed to obtain basic nuclear reactor design data as well as to confirm the final nuclear design of first-of-a-kind reactor types. The critical experiments in the thermionic development program are divided into two categories: clean criticals and mockup criticals.

Clean critical experiments are conducted to check the cross section data and calculational methods to be used in the subsequent design work. They include operation of critical assemblies which are homogeneous and of a simple geometry so that the differences between calculated and experimental results can be interpreted in terms of the particular cross section data or analytical model being tested.

Mockup criticals are conducted to obtain final design data on assemblies that closely model the reactor being developed. They include as much as practicable of the inhomogeneities and geometrical complexities of the reactor that are difficult to model accurately in the calculations. They provide experimental data on power distribution, control worth, and reactivity from which the final fuel and control poison loading can be specified.

2.3.1. Clean Critical Experiment

Conduct a clean critical experiment program with the objective of comparing integral neutronic data with calculations to check analytical

TABLE 5
COMPONENT DEVELOPMENT FOR TREX

<u>Component</u>	TFE-					Instrument		
	<u>Reactor Vessel</u>	<u>Control Drive</u>	<u>Control Drive</u>	<u>Vessel Joint</u>	<u>TFE Stem</u>	<u>Reactor Assembly</u>	<u>Liquid Metal</u>	<u>and Control</u>
Prototypic of flight system	no	no	yes	yes	yes	no	yes	no
NU in TREX	1	9	18	162	162	1	1	1
NU in Dev. Program	1	1	6	15	1	1	2	1
							Loop tests	
Special Test Facility								
Required	yes	yes	no	no	yes	no	yes	yes

methods and cross-section data used in the design of thermionic reactors. Starting with the Thermionic Critical Experiment No. 1 fuel element, construct a homogeneous mixture of thermionic reactor core materials arranged in a simple geometry (approximately a cube). Reflect the assembly in one or more dimensions with various thicknesses of beryllium oxide. Measure critical masses, flux and power distributions, neutron spectra, and reactivity worths of core and reflector materials. Perform experiments in which the effects of poison (control) materials, alternative reflector materials, and simple heterogeneities are evaluated.

2.3.2. Mockup Critical Experiment

Design, construct, and license a zero-power mockup of the reactor for the reactor experiment. Include as many engineering complexities as practicable. Measure the critical mass, flux and power distributions, and isothermal temperature coefficient close to room temperature. Determine the reactivity worths of fuel elements and structural components, the worth of voids in the coolant, and differential worths at control elements. Experimentally evaluate the nuclear effects of omitted hardware as well as probable design modifications.

2.4. FABRICATION

Fabrication of the reactor includes provision for tooling and special equipment as well as for the actual manufacturing of the reactor hardware. Quality control of the hardware is included in the manufacturing task as distinct from quality assurance, which is a management function and is discussed in Ref. 5.

2.4.1. Tooling

Design and make the tooling required for reactor fabrication. This will consist mainly of welding fixtures. Evaluate the functioning of the tooling by trial setups using the reactor assembly mockup described above.

2.4.2. Equipment

Procure the equipment needed for reactor fabrication and quality control. Conduct a survey of local shops where this equipment may exist and its use can be hired. Plan using hired equipment where practicable.

2.4.3. Manufacturing

A detailed reactor manufacturing plan will be formulated at a later date.

2.5. QUALITY ASSURANCE PLAN

The quality assurance plan for reactor development will be written at a later date. The plan will include a schedule for implementation of the various controls specified by the plan and be included in Ref. 5.

2.6. TEST PLAN

The test plan specifies the steps comprising the experimental program and other operations at the test facility in performance of the thermionic reactor experiment.

2.6.1. Reactor System Checkout

A non-nuclear test of the reactor system is performed before bringing the reactor to criticality. It is assumed that the following operations are completed before beginning this plan:

2.6.1.1. All mechanical, electrical, structural, and instrument work related to reactor operation and facility safety.

2.6.1.2. All construction testing such as structural tests, operability checks, and functional tests.

2.6.1.3. Installation of the control drums, control drum drives and the reactor vessel with the electrical connectors in place according to the design.

2.6.1.4. Charging primary and secondary coolant system fill and drain tanks with NaK.

2.6.1.5. Preparation of facility operating procedures and manuals.

2.6.2. Test Sequence at Ambient Temperature

2.6.2.1. Control Element Operation. Operate each control element individually to verify the stepping rate, the scram time from several positions, the position indicator calibration, and the operation of the interlocks. Verify interlocks and sequencing, scram time, and loss of power scram by combined element operation to selected positions with subsequent scram.

2.6.2.2. Primary NaK Coolant. Fill the primary system with NaK from the fill and drain tank. Fill into evacuated loop, then set cover gas pressure at 30 psig. The recording of the drain tank level before and after filling the system provides a measure of the system volume. Start the main pump and vary the flow in steps up to full flow. Record the flow rate, pump discharge pressure, and the reactor differential pressure for each step.

2.6.2.3. Secondary NaK Coolant. Fill the secondary system with NaK from the fill and drain tank. Fill the evacuated loop then set the cover gas pressure at 35 psig. Record the drain tank level before and after filling the system to provide a measure of the system volume. Start the main pump and vary the flow in steps up to full flow. Record the flow rate and pump discharge pressure for each step.

2.6.2.4. NaK Purification. Determine the oxygen and carbon concentrations in the primary and secondary NaK by analytical methods. Purification is begun by the operation of the flow through cold traps in the primary and secondary systems. The oxygen level is expected to be between 50 to 100 wppm at this stage.

2.6.3. Test Sequence at Various Temperatures

2.6.3.1. System Heating. Examine the primary and secondary NaK piping systems visually and record the cold position. With the pumps of both systems operating, adjust the power to the primary loop heater until the maximum allowable heating rate has been attained. When the temperature reaches 400°F, reduce the power and main the temperature constant. Conduct a visual examination and record the piping position for comparison to predicted displacements.

2.6.3.2. NaK Purification. Maintain the NaK systems at 400°F until the oxygen concentration has been reduced by cold trapping to below 5 wppm. After 5 wppm oxygen is attained, place a carbon hot trap in operation. It is expected that the carbon concentration will be initially at the 30-50 wppm level. When the carbon concentration is reduced to 10-15 wppm and the oxygen concentration to < 2 wppm, the system temperature can be increased above 400°F.

2.6.3.3. System Heating. Adjust the power to the heater again so that the system temperature will increase. At 700°F reduce the power and hold the temperature constant. Conduct a visual examination and record the piping position. Increase the power input again, and at 1000°F reduce the power and hold the temperature constant. Repeat visual examination and position readings.

2.6.3.4. NaK Purification. At 1000°F isolate the cold trap and the carbon hot trap from the system when the oxygen concentration is < 2 wppm and the carbon concentration is < 5 wppm. The oxygen hot trap is not placed into operation. Reduce the oxygen concentration to < 0.3 wppm before raising system temperature above 1000°F.

2.6.3.5. System Heating. Adjust the heating rate until a temperature of 1300°F is achieved. Set the power input to maintain the system at a temperature of 1300°F. Repeat visual examination and piping system position reading.

2.6.3.6. Control Element Operation. Repeat the control drum tests conducted at ambient temperature.

2.6.3.7. Primary NaK Coolant. Vary the primary loop pump flow through the flow range in discrete steps. Record the flow rate, pump discharge pressure, and the reactor differential pressure for each step.

2.6.3.8. Secondary NaK Coolant. Vary the secondary loop pump flow over the flow range in discrete steps. Record the flow rate and pump discharge pressure for each step.

2.6.3.9. System Heat Loss. Maintain the system temperature at 1300°F and record the required power input.

2.6.3.10. Emergency Pump. Shut down both main pumps and start the emergency pump. Record the pump flow in the primary system and the natural circulation flow of the secondary system with the louvers of the air blast heat exchanger sequentially fully closed, one-half open, and fully open.

2.6.3.11. Natural Circulation. Shut down the emergency pump and record the natural circulation flow in both the primary and secondary systems.

2.6.3.12. System Cool-Down. Reduce the power input to the primary system heater and cool the systems within allowable rates. Record piping position at selected temperatures during the cool-down period. This step is complete when all temperature readings are ambient.

2.6.4. Preparation for Nuclear Tests

2.6.4.1. Drain Primary NaK Coolant. Drain the NaK coolant in the primary coolant loop into the fill and drain tank, bleeding cover gas into the loop to maintain a small positive pressure. When this is complete, set the cover gas pressure at 1 psig nominal.

Drain the core vessel.

2.6.4.2. Plant Protection System. Maintain or simulate the following conditions to test the control element rotation prohibit action:

- (1) Below minimum neutron count rate
- (2) High rate of neutron flux rise
- (3) High level of neutron flux
- (4) Multiple element rotation
- (5) Element rotation out of sequence
- (6) Low primary system pressure
- (7) Low NaK level
- (8) Low NaK flow
- (9) Shield plugs not in place
- (10) Reactor mode switch out of position
- (11) Low nitrogen flow in containment ventilation system

2.6.4.3. Plant Protection. Set up or simulate the following conditions to test the scram action:

- (1) Manual
- (2) High rate of neutron flux rise
- (3) High level of neutron flux
- (4) Electrical power system loss
- (5) Earthquake
- (6) Low NaK level in reactor vessel
- (7) High NaK temperature at air blast heat exchanger
- (8) High reactor exit NaK temperature
- (9) High reactor thermal power
- (10) NaK leak
- (11) Loss of voltage to neutron detectors
- (12) Low nitrogen flow in containment ventilation system

2.6.4.4. Nuclear Instrumentation System. The neutron detectors are located in the three wells around the reactor pressure vessel. Check and position the neutron detectors to attain the proper counting rate from the neutron detectors. Demonstrate the functioning of all system components and safety features.

2.6.4.5. Environmental Control System. Close and seal the radioactive NaK room and the containment. Exhaust air from the NaK room as nitrogen is introduced. Make one volume change before closing the air exhaust. Purge the containment of air by use of the vacuum pump and backfill with nitrogen. Continuously purify both the radioactive NaK room and the containment atmospheres by bleed-off to a hydrogenator and recombiner-dryer. When a purity of 1% oxygen by volume has been reached and maintained for eight hours, the facility is considered ready for nuclear testing.

2.6.5. Nuclear Testing

Upon completion of the non-nuclear checkout, the reactor system is ready for the nuclear test program.

2.6.5.1. Preliminary Control Element Worths. The reactor is brought critical with the core dry. Measure the negative reactivity worth of individual or groups of control elements by the rod drop and/or pulsed neutron methods.

2.6.5.2. Wet Critical. Shut down the reactor, fill the primary loop with NaK and bring the reactor to criticality at room temperature and zero-power.

2.6.5.3. Control Element Worths. Measure the shutdown reactivity with various numbers of control elements in the least reactive position using the pulsed neutron method. In addition to determining the shutdown margin, these measurements also give a value for the ratio of delayed neutron fraction to prompt generation time (β/ℓ).

2.6.5.4. Preliminary Isothermal Temperature Coefficient. In the first test to verify that the overall temperature coefficient is negative, heat the NaK electrically by increments at its design flow rate, and measure the subcriticality with the pulsed neutron method up to the highest temperature practicable. The coefficient measured is affected by the radial expansion of the grid plate and the resultant outward motion of the control drums as well as the expansion of the core.

2.6.5.5. Control Element Calibrations. Calibrate a control element by positive period measurements and with a reactivity computer. The primary objective of the first calibrations is to verify that the maximum reactivity addition rate possible is within safe limits. Calibrate the remaining control elements and report earlier calibrations as necessary. Precise control element calibrations are essential to measuring reactivity changes in most of the succeeding experiments.

2.6.5.6. Flow Coefficient. With the reactor critical at zero power and ambient temperature, vary the coolant flow rate over the full range. Reactivity changes are not expected, but if they occur they may be measured by the reactivity meter or by the change in control element positions required to hold the reactor critical. The most likely cause of reactivity variations with changing flow rate is flow-induced vibrations of the fuel elements or control elements. This would give "noisier" flux and reactivity signals which might be analyzed to determine the dominant vibration frequencies involved. Alternatively, if the forces exerted by the flowing coolant cause static deflections of core components, these would appear as a constant reactivity change proportional to flow.

2.6.5.7. Pressure Coefficient. With the reactor critical at zero power, vary the cover gas pressure and measure any reactivity change produced. No change is expected.

2.6.5.8. β_{eff}/ℓ Measurement. If the ratio β_{eff}/ℓ cannot be adequately measured by means of the pulsed neutron method employed for the shutdown margin measurements, it should be determined by an alternate method such as Rossi- α or noise analysis. The prompt generation time ℓ is useful in safety calculations.

2.6.5.9. Isothermal Temperature Coefficient. With the reactor shut down, circulate the NaK and heat electrically until the entire primary system is equilibrated at a higher temperature. The reactor is then made critical with a symmetric arrangement of control elements. Repeat the procedure at convenient intervals (perhaps 100°F) up to 1300°F coolant temperature.

Calculate the isothermal temperature coefficient from the successive critical control element positions and previously measured drum calibrations. Repeat the measurements while cooling down the system. Since thermal expansion effects are an important component of the temperature coefficient, it is important to verify that all parts return to their initial positions. The temperature coefficient is of basic importance to reactor safety and any anomalous behavior observed in the measurements must be understood before taking the reactor to power.

2.6.5.10. Control Element Calibrations in Hot Core. When 1300°F coolant temperature is reached, repeat some control element calibrations to determine the effect of temperature on the drum worth. The principal effect is expected to be the outward radial motion of the drums due to grid plate expansion. If the effect is large, additional calibrations may be done at lower temperatures. This data is needed for the analysis of the temperature coefficient measurements.

2.6.5.11. Flow Coefficient in Hot Core. Repeat the measurements of reactivity changes with flow rate at one or more of the temperature levels used in the temperature coefficient test, to determine whether flow-induced vibrations and deflections are increased or reduced by the effects of thermal expansion.

2.6.5.12. Pressure Coefficient in Hot Core. If any effect of cover gas pressure on reactivity is found in the room temperature measurements, repeat this test at the highest temperature level reached in the isothermal temperature coefficient experiment.

2.6.5.13. Stability Measurements. The stability of the reactor against perturbations in reactivity, temperature, flow, and electrical load at various power levels must not be assumed, but must be investigated experimentally in a safe manner as the power level is raised. Measurement techniques which may be employed are reactivity and flow oscillations, noise analysis, and simple transient experiments. Most of these techniques require a normalizing measurement at low power where no feedback

effects are present. These measurements are carried out at this point in the program after the static neutronic behavior is well understood from the initial experiments and before the power is raised beyond source level. The program of stability and transient measurements cannot be specified in detail at this time. One example of a simple transient experiment is given below.

2.6.5.14. Scram Transient Test in Hot Core. The purpose of this test is to separate the prompt part of the temperature coefficient from the overall isothermal coefficient. With the core at zero-power and 1300°F coolant temperature, scram one or more control elements and the flux transient recorded. From this data the reactivity variation with time can be determined. The identical test is repeated later at power levels where temperature feedback is significant. The difference in reactivity-time behavior is a measure of the temperature feedback with the initial portion of the response being dominated by the fuel Doppler and axial expansion effects.

2.6.5.15. Rise to Power. At this point a maximum of neutronic data has been obtained with a minimum of core and component activation. Any problems revealed by the measurements that require core modification can be resolved without the complications of high radioactivity levels. The test program will be reviewed and revised at this time to take account of the experience obtained with experimental techniques and the agreement of the results with predictions.

The reactor is then taken to power stepwise. At each intermediate power level some of the tests described above are repeated to confirm stability and safety criteria before proceeding to the next power level. The effects of electrical load changes on reactivity are measured as a function of the number of TFEs and their location. Load changes are selected to produce emitter temperature changes, and the resulting reactivity changes are measured as a function of emitter temperature. The procedure followed in increasing power is to first increase coolant flow rate and equilibrate at an overcooled conditions, and then adjust control

elements to raise the power level and restore the outlet temperature. Measurements of flow, temperature, and control element position taken in this sequence give values for the temperature coefficient and flow coefficient. The experiments specified for determining stability and transient response are repeated at each power level. Control element calibrations are rechecked at full power but are not expected to change significantly from the zero-power measurements made at maximum outlet temperature. The flux instrumentation is calibrated by heat balance at several power levels. Repeat the scram transient tests done at zero-power at full power. The radiation level in the facility is monitored closely during the rise to power to prevent unexpected high levels. At the conclusion of these measurements, the reactor is shut down in a stepwise manner, repeating a few tests at lower power levels to verify that no irreversible fuel deformations have occurred.

The sequence of experiments during the rise to power is planned to minimize the time spent at high power levels to reduce activation problems.

2.6.5.16. Thermionic. Monitor the electrical output of all TFEs at various reactor power levels up to that power level which gives the desired thermionic output. Increase the reactor power in discrete steps with cesium optimization curves taken on all TFEs and I-V curves recorded on selected TFEs at each step (20 to 40 total). All TFE parameters are routinely recorded during this operation.

Some special tests are also performed:

- (1) Measure effect of changes of NaK temperature on electrical output.
- (2) Operate with ganged cesium pressure control and load control to simulate possible modes of space power system operation.
- (3) Start up reactor and TFEs using NEP power-time profiles.

(4) Study reactivity changes due to cesium pressure changes.

(5) Measure effect of control element positions on TFE output.

2.6.5.17. Cesium Pressure Control Tests. The design for the flight prototype reactor incorporates a common cesium reservoir temperature for each of seven rings of elements in the reactor core. The cesium reservoirs of each ring are connected to a single control circuit with a previously calculated set point which provides a temperature sufficiently high to avoid cesium burnout. After connection of each ring, the following tests will be performed for that ring.

(1) Cesium optimization.

(2) Measurement of thermal efficiency compared to that for individual control of optimized cesium reservoir temperatures.

(3) Increase and decrease of 20% in reactor thermal power at constant cesium temperature and measurement of the thermal efficiency change.

These tests are repeated for each ring until all TFEs are controlled in this fashion.

If the feasibility of this method of cesium reservoir control is proven, the reactor thermal power will be corrected as required. All system dynamics tests may be performed with this method of control.

2.6.5.18. Automatic Reactor Control. Test the selected mode of automatic reactor control after completion of:

(1) Nuclear measurements specified above; specifically, all reactivity coefficients, stability, and control element worths are determined.

(2) Initial operation and measurements on TFEs.

- (3) Switch into automatic control mode using neutron flux and TFE voltage as control variables.
- (4) Operate in steady state condition for eight hours.
- (5) Tests to measure response of automatic control system to reactivity perturbations of ± 5 cents. (This may be changed as a result of imposition of safety limits).
- (6) Set reactor power at design power to load.
- (7) Repeat steps (2) through (5) above.

2.6.5.19. Electrical Load. Control the electrical loads connected to each set of fuel elements through the digital computer to simulate a spacecraft electrical load.

Test the response of the thermionic reactor power system to changes in spacecraft load. The perturbations sensed by the operating reactor due to either planned or accidental spacecraft load changes will depend upon the detailed design of the spacecraft power conditioning and control circuits which is not yet complete.

Tests include perturbations calculated to be caused by:

- (1) Step increase in power demand of 10%
- (2) Step decrease in power demand of 10%
- (3) Operation at 10% of design electrical power for one day

Perform at least one reactor shutdown and startup. The sequence of operations includes:

- (1) Shutdown reactor system

- (2) Adjust louvers and/or flow rate on the heat dump to provide system cooling rate corresponding to that provided by space radiator.
- (3) Hold liquid metal temperature in reactor core at equilibrium temperature specified for reactor startup. Time at this temperature should be long enough such that fission product after-heat is no greater than 3% of reactor design power.
- (4) Startup reactor and increase thermal power to raise TFE collector temperatures above saturation temperature of cesium at required cesium operating pressure.
- (5) Heat cesium reservoirs to provide required cesium pressure.
- (6) Close circuits to electrical load to draw current from the TFEs.
- (7) Adjust TFE loads in a ganged fashion to simulate spacecraft systems being turned on as power output from the reactor system becomes available. Adjust heat rejection to air as required.
- (8) The test is complete when stable operation delivering design power to the load is attained.

2.6.6. Data Analysis

Analyze the data measured in the reactor experiment - neutronic, control, thermal, and electrical. Attempt to reconcile discrepancies between experiment and calculation. Devise additional measurements, if necessary, to provide additional information required in the understanding of discrepancies.

Evaluate the data in a form to be most useful in the design of the prototype reactor.

3. GROUND PROTOTYPE TEST

Activities in the ground prototype test are listed in Figure 5 with the time phasing shown. Associated major milestones are listed in Table 6. Descriptions of work in the various activities are presented next.

3.1. DESIGN AND ANALYSIS

3.1.1. Nuclear

3.1.1.1. Methods and Cross-Section Development. The activities of Methods Development and Cross-Section Development continues as under the Reactor Experiment. New data and calculational methods are coordinated into the reactor analysis to improve the accuracy of prediction of nuclear design parameters.

3.1.1.2. Analysis of Critical Experiments. Analyze the critical experiments performed in the design of the GPR and reconcile differences between analysis and experiment.

3.1.1.3. Reactor Design. Perform nuclear analysis in support of the GPR design and safety analysis. The specific tasks are essentially the same as for the Reactor Experiment, except that the kinds of accidents considered are broadened to include postulated launch situations. This is required to design a reactor for a ground test that is prototypic of a flight reactor.

3.1.2. Mechanical

Expand the mechanical task described under the Reactor Experiment section to include design consideration for the dynamic loads induced by

Fig. 5. GROUND PROTOTYPE REACTOR TEST SCHEDULE

CALENDAR YEAR		74	75	76	77	78	79	80	81
ACTIVITY	FISCAL YEAR	75	76	77	78	79	80	81	
1. DESIGN AND ANALYSIS									
Nuclear									
Mechanical									
Electrical									
Thermal-Hydraulic									
Control and Instrumentation									
Materials and Processes									
Reliability Engineering									
Flight Safety Analysis									
2. COMPONENT DEVELOP. & EXPER. ENGINEER'G									
Core Vessel Flow Test									
Control Drive Unit Test									
Control Element Environmental Test									
TFE-Vessel Joint Development									
Reactor Assembly Mockup									
Instrument & Control Breadb'd. Tests									
Flight Electronics Package Qualif'c'n									
Vessel Joint Development									
Mech. Develop. & Environment. Testing									
3. CRITICAL EXPERIMENTS									
Mockup Critical Experiment									
4. FABRICATION									
Tooling									
Equipment									
Manufacturing									
5. QUALITY ASSURANCE									
6. TEST OPERATIONS									
Non-nuclear Tests									
Nuclear Tests									
Data Analysis									
7. FACILITY									
Modification									

TABLE 6
GROUND PROTOTYPE REACTOR TEST
SCHEDULE MILESTONES

1.	Conceptual Reactor Design Complete	March 1975
2.	Preliminary Reactor Design Complete	June 1976
3.	Final Reactor Design Complete	October 1977
4.	Complete Flight Safety Analysis	June 1978
5.	Complete Mockup Critical Experiments and Specify Fuel & Control Poison Loading	June 1978
6.	Complete Reactor Fabrication	October 1978
7.	Components Qualification Complete	December 1978
8.	Complete Facility Modification	April 1979
9.	Complete Non-Nuclear Tests	December 1979
10.	Initiate Nuclear Tests	January 1980
11.	Reactor at Full Power	April 1980

space flight in addition to thermal-mechanical loads on the reactor structure produced by mechanical integration with the power subsystem of the spacecraft. The reactor design will also account for features required for the power subsystem assembly sequence so that the GPR will be truly prototypic of the flight reactor.

3.1.3. Electrical

The reactor electrical design includes the same items listed for the Reactor Experiment. In addition, the Ground Prototype Test simulates the electrical transmission lines which connect the thermionic fuel elements to the spacecraft power conditioning equipment. Insure that this simulation is attained and specify measurements to be made in the test to evaluate the electrical characteristics of the total power grid.

3.1.4. Thermal-Hydraulic

This task is the same as for the Reactor Experiment.

3.1.5. Control and Instrumentation

This task is the same as for the Reactor Experiment, with the following exceptions.

The Ground Prototype Test includes design, fabrication, and test of a flight control and instrumentation package. This hardware is developed and flight-qualified prior to the Ground Prototype Test. The test is operated on the flight instrumentation package with the addition of additional safety interlocks that may be required for a ground test.

The GPR is operated with an electronic simulation of power and thrust subsystem equipment not included in the test hardware. Provide for this simulation in the design of the test facility and specify the operation of the test so that the effects of the simulation may be evaluated.

3.1.6. Materials and Processes

This task is the same as for the Reactor Experiment.

3.1.7. Reliability Engineering

Analyze and evaluate the reactor design and operating plans to assure a reliability level as required to achieve a power subsystem reliability level dictated by analysis of the entire spacecraft.

Implement with program management a program reliability plan to assure that all engineering activities are controlled to achieve the required reliability goals.

3.1.8. Flight Safety Analysis Input

Perform flight safety analyses for postulated accident conditions involving the reactor. Consider the events of fire, core compaction, core water immersion, and control malfunction in different environments where appropriate. Consider accidents in shipping, on the launch pad, sub-orbital flight, and orbital flight.

Provide reactor data to the overall flight safety analysis and perform liaison with this function in evaluation of overall flight safety questions.

Provide safety constraint requirements to the other reactor design activities in a timely manner so that safety requirements may be accounted for prior to finalizing hardware designs.

3.2. COMPONENT DEVELOPMENT AND EXPERIMENTAL ENGINEERING

Component development and experimental engineering includes all test work to determine performance and reliability parameters for components, demonstrate the ability of critical components to function satisfactorily in the environment of the Ground Prototype Test as well as in space, and

to develop parameters for fabrication processes, and tooling to be used in the manufacture of reactor hardware.

Long term component reliability testing is required before fabrication of the Ground Prototype Reactor and the Flight Reactor. This work is defined as Prototype Tests in Table 2.

3.2.1. Core Vessel Flow Test

Repeat the core vessel flow test performed for the Reactor Experiment only if the reactor core configuration has changed from the design of the Reactor Experiment to the design of the Prototype Reactor. Use the test equipment employed in developing the vessel hydraulics for the Reactor Experiment.

3.2.2. Control Drive Unit Test

Fabricate a control drive unit including motor, linkages, position indicator, and drum support bearings. Simulate the mass and moment of inertia of a control drum. Simulate the thermal environment with electric heaters and operate for the number of cycles expected in a space mission, including both regulating and scram modes.

Fabricate critical components of the linkages, especially wearing surfaces, and test in an appropriate irradiation environment in a test reactor to evaluate the effect of irradiation on the stability of the properties of friction surfaces.

3.2.3. Control Element Environmental Test

Irradiate representative sections of a control drum under simulated thermal conditions to evaluate the compatibility between drum and cladding material, as well as dimensional stability of the specimen.

3.2.4. TFE-Vessel Joint Development

Establish the reliability of the TFE-Vessel joint used in the Reactor Experiment through testing of identical specimens with imposed mechanical and thermal loading.

Further evaluate the fabrication processing parameters to produce joints of the required reliability and evaluate the efficacy of non-destructive testing methods used to measure joint quality.

3.2.5. Reactor Assembly Mockup

Construct a non-refractory metal, full size model of the reactor assembly. Demonstrate the effectiveness of tooling to be used for reactor assembly. Use the model to train manufacturing personnel and for practice to establish health physics procedures employed to prevent criticality accidents during reactor assembly.

3.2.6. Instrument and Control Breadboard Tests

Construct breadboard circuits for each of the subassemblies of the I&C package.

Experimentally evaluate the appropriate selection of circuit design parameters and input performance information to the final design of the flight electronics package.

3.2.7. Flight Electronics Package Qualification

Perform environmental qualification of the flight electronics (instrumentation and control) package.

Measure the performance of the package to be used in the Ground Prototype Test with an analog computer simulating the thermionic reactor.

3.2.8. Vessel Joint Development

Evaluate the ability of reactor vessel joints to resist vibration loading by fatigue testing of joint specimens.

Establish the reliability of non-destructive test methods in evaluating reactor vessel joints for leaktight service in the space application.

3.2.9. Reactor Mechanic Development and Environmental Testing

Perform tests to establish the ability of the reactor assembly to survive the dynamic loading imposed by shipping and by launch into space.

Perform individual component tests including tests of control drive assembly, transmission line and mounts, cesium reservoir and fission gas chambers and mounts, fuel elements and components, TFE-vessel joints, and reactor internals.

Perform a shock and vibration test of an assembly of the entire reactor. The test model will contain fewer than a full core loading of thermionic fuel elements with other core positions being occupied by mechanically-simulated fuel element models.

3.2.10. Component Development Summary

The numbers of each component to be tested for reliability will be specified following appropriate reliability analyses.

3.3. CRITICAL EXPERIMENTS

Perform mockup critical experiments of the GPR design to obtain data relative to fuel loading, control poison loading, power distribution, and reactivity worths. Perform the experiment in the facility used in the mockup experiments for design of TREX. These experiments model design changes that have occurred between specification of the TREX design and the GPR design.

3.4. FABRICATION

Fabrication of the reactor includes provision for tooling and special equipment as well as for the actual manufacturing of reactor hardware. For GPR, the reactor hardware includes the prototype flight electronics package for instrumentation and control. Quality assurance is discussed in Ref. 5.

3.4.1. Tooling

Design and make the tooling required for reactor fabrication.

3.4.2. Equipment

Procure the equipment needed for reactor fabrication and quality control.

3.4.3. Manufacturing

A detailed reactor manufacturing plan will be formulated at a later date for GPR.

3.5. QUALITY ASSURANCE PLAN

The Quality Assurance Plan for reactor development will be written at a later date. The plan will incorporate a schedule for implementation of the various controls specified by the plan and be contained in Ref. 5.

3.6. RELIABILITY PLAN

The Reliability Plan for reactor development will be written at a later date. The plan will incorporate a schedule for implementation of the various controls specified by the plan and be contained in Ref. 7.

3.7. TEST PLAN

3.7.1. Non-Nuclear Tests

The procedures followed here are essentially identical to those planned for TREX in accomplishment of the non-nuclear test phase (see Section 2.6.1.

3.7.2. Nuclear Tests

The procedures followed here are essentially identical to those planned for TREX in accomplishment of the nuclear test phase with the addition, in the case of GPR, of a test in which the reactor is controlled by the flight instrument and control package. Prior to this test, the reactor is controlled by conventional hardware to establish its performance characteristics relative to design to insure safe operation when controlled by the flight electronics package.

3.7.3. Data Analysis

Analyze the data measured in the GPR test - neutronic, control, thermal, and electrical. Attempt to reconcile discrepancies between experiment and calculation. Devise additional tests, if necessary, to provide additional information required in the understanding of these discrepancies.

Evaluate the performance of the GPR relative to flight reactor specifications.

4. FLIGHT REACTOR

Activities in the engineering of the flight reactor are listed in Figure 6 with the time phasing shown. Associated major milestones are listed in Table 7. Descriptions of work in the various activities are presented next.

TABLE 7
FLIGHT REACTOR SCHEDULE MILESTONES

1. Complete Design of Flight Reactor	January 1981
2. Complete Fabrication of Flight Reactor	April 1982

4.1. DESIGN AND ANALYSIS

The design and analysis of the flight reactor is an across-the-discipline re-evaluation of the design of the GPR making full use of GPR test data. Design changes from GPR are evaluated relative to their impact on system reliability and are held to an absolute minimum number.

Complete final design of reactor ground support equipment.

Devise procedures and software to be used in the evaluation of reactor performance from in-flight data.

Work with mission engineering personnel in finalizing procedures for power system integration and operation.

4.2. FABRICATION

Fabricate the flight reactor. A detailed manufacturing plan will be written.

Fig. 6. FLIGHT REACTOR DEVELOPMENT SCHEDULE

CALENDAR YEAR		79	80		81		82		83		84
FISCAL YEAR		80		81		82		83		84	
ACTIVITY											
	1. DESIGN AND ANALYSIS										
	2. FABRICATION										
	3. QUALITY ASSURANCE										
	4. RELIABILITY										

4.3. QUALITY ASSURANCE PLAN

The flight reactor quality assurance plan will be detailed in Ref. 5.

4.4. RELIABILITY PLAN

The flight reactor reliability plan will be detailed in Ref. 7.

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