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PROGRESS REPORT
SNAP 2
NUCLEAR AUXILIARY POWER UNIT DEVELOPMENT
JULY-SEPTEMBER 1961
(Title Unclassified)

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SNAP REACTOR,
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M-3679 (25th Ed.)

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PROGRESS REPORT

SNAP 2

NUCLEAR AUXILIARY POWER UNIT DEVELOPMENT

JULY-SEPTEMBER 1961

(Title Unclassified)

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Editor

M. SHACKELFORD

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I. SUMMARY

The SNAP 2 configuration dimensional and shape restraints were established during the previous report period (see NAA-SR-6691). System engineering during the current report period was directed toward completing the overall system design and analysis. Mechanical arrangement and structural support of all major system components were established as shown in Figure 1. A flight instrument cold compartment was designed into the system at the lower portion of the APU adjacent to the Agena vehicle. The 150°F cold compartment is thermally protected from the inside surface of the 600°F radiator-condenser of the APU, this arrangement providing a less severe thermal environment for the selection of flight instrumentation. The 134-ft² radiator area as specified by the system analysis was established within the height limitation by a cylindrical section and a frustum of a cone. Rectangular cross-section tapered mercury condenser tubes and tapered copper fins were incorporated into the condenser design to reduce weight. System weight was calculated at 1580 lb based upon preliminary design drawings of all major components. Environmental design criteria were set for each component and subassembly and for the complete APU during this preliminary design period, thus establishing structural and mechanical requirements. The system design point established the performance requirements of each major component.

System analysis resulted in establishing a required 5% flowrate to prevent NaK freezing during prestartup in orbit. Circulation of the NaK acts to distribute the sensible heat stored by the more massive structures (principally the reactor) to the cold regions in the NaK loop. Based upon a uniform system temperature of 65°F at the time of launch, a 5% flow prevents the NaK temperature from falling below 25°F for 17 hr in orbit before system startup.

Selection of the dual injection method for system startup was made during this report period. The startup consists of preheating of the system to the design point temperature of 1200°F (reactor exit) followed by mercury injection simultaneously into the hot boiler and the Combined Rotating Unit (CRU) bearings. Mercury vapor produced by the boiler causes the CRU to spin up and, consequently, the primary loop NaK flow to increase above the 5% value produced by the separate startup pump. Mercury vapor exhausts from the turbine cause the condenser temperature to increase to design conditions (600°F).

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Component development during the report period resulted in 1) fabrication on the first completed copper-clad steel honeycomb radiator-condenser, 2) fabrication progress on an orbital startup pump based upon thermoelectromagnetic concept, 3) operation of a developmental NaK expansion compensator, and 4) Combined Rotating Unit (CRU) testing. Manufacturing operations, including leak testing of the first radiator-condenser, were completed, and the unit was prepared for installation in the first SNAP 2 thermal system test (PSM-1). Fabrication of a second condenser identical to the first unit was initiated, to be used for thermal performance evaluation and improvement in manufacturing techniques. The developmental expansion compensator was operated over 150 hr at design temperature; the unit performed satisfactorily and provides the experimental basis for the flight configuration design.

At the close of the last reporting period, CRU-III-3 was operating and continued to operate to 285 hr, when an alternator bearing failure occurred. CRU-III-1 operated 1 hr and 18 min before an alternator bearing seizure stopped the test. The unit was operating at 40,000 rpm, turbine-driven by hot gas, when seizure occurred after mercury bearing flow was reduced from 7 to 5 ppm. CRU-III-2 operated 45 min when it failed due to turbine bearing seizure. Since the initiation of the CRU-III test program a year ago, 11 of 13 operational malfunctions have been associated with bearing failures. Table III summarizes the CRU tests. A detailed review of the bearing design, material selection bearing loads, and shaft bearing characteristics is currently in progress. This program is directed toward identification of the problem area, intermediate short-range solutions, and long-range solution supported by a thorough bearing development program.

Major components of the first non-nuclear thermal system test, PSM-1, have been fabricated and delivered to the test site. Completed components are the vacuum tank, vacuum pumping equipment, radiator-condenser, NaK-Hg process instrumentation, NaK components, piping, and structural support members.

Preliminary design, including 70% of the fabrication drawings, was completed for the first system environmental test, PSM-2.

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Figure 1. Flight System Configuration

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II. PIPING AND INSTRUMENTATION

REVISIONS			
REV	DESCRIPTION	DATE	SIGNATURE

LEGEND

- T TEMPERATURE
- TC TEMPERATURE CONTROLLER
- F FLOW
- P PRESSURE
- Pd DIFFERENTIAL PRESSURE
- PH POSITION
- FR FLOW REGULATOR
- LS LIMIT SWITCH
- F- FREQUENCY
- R RELAY
- PS PRESSURE SWITCH
- NDT NEUTRON DETECTOR THERMOPILE
- NDI NEUTRON DETECTOR ION CHAMBER
- YD GAMMA DETECTOR
- A ACCELEROMETER
- S STRAIN GAGE
- C CONTACT
- W POWER
- TRM. CLIPLESS DISCONNECT

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Figure 2. Piping and Instrumentation

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III. FLIGHT SYSTEM CONFIGURATION

System mechanical and structural detail design began based on the configuration studies completed last report period. Fixing of the configuration allowed selection of the radiator-condenser and shield geometry, which in turn allowed detail mechanical design of most other components to proceed. Integration of the components into the assembly is about 40% complete and is limited only by the component design progress. (Figure 1 is an artist's drawing of the flight system configuration.)

Weight reporting and control procedures were improved and implemented. Center-of-gravity locations of the total system and the various components will be reported in the future. The current system weight status is shown in Table I.

Preliminary studies of the nose cap were initiated in order to furnish criteria to LMSC (Lockheed Missiles and Space Co.) for their final design. Tie points, load paths, and ejection mechanisms are being specified.

Aerodynamic heating and loads during the atmospheric ascent of SNAP 2 trajectory were developed on a preliminary basis to establish their effect on system design. Mold line temperature profiles, ΔT through all structural connections adjacent to the mold line, and APU-Agena mating differential expansion are being developed from these studies.

A low-temperature (150°F) instrumentation compartment at the base of the APU was included in the design. Problems encountered in development of high-temperature instrumentation and integration of APU equipment in the Agena payload led to this selection.

System descriptions outlining the performance, configuration, and structural requirements for the reactor-reflector subassembly, shield, expansion compensator, and flow trimmer were completed.

Preliminary angular momenta studies were begun. Preliminary results based upon limited accuracy due to incomplete component designs show that existing Agena attitude control requirements will be difficult to satisfy. Extremely tight installation tolerances and rigid control of thermal expansion directions will be required for piping and components.

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A preliminary draft of the General Environmental Specification for SNAP 2 was completed. Stress, temperature, vacuum, and radiation levels for the various flight conditions were specified, as well as ground handling conditions.

Static stress and dynamic response analysis was completed on the component integration requirements for load rings, bracketry, etc., as well as the overall system.

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IV. SYSTEM WEIGHT BREAKDOWN

System weights have been obtained from the studies described in Section III and are shown in Table I. Weights are presented as (1) current design, (2) SNAPSHOT objectives, and (3) operational weight objectives that can be achieved after the SNAPSHOT program. An explanation of the current design basis for the weights is included to assign a confidence level to them.

TABLE I
SNAP 2 WEIGHT TABLE

	Current Design Weight (lb)	SNAPSHOT Weight Objectives (lb)	Operational Weight Objectives (lb)	Current Status (Design)
Reactor assembly (NaK wet)	152	148	130	Detail
Reflector-controls assembly	108	110	110	Conceptual
Piping (NaK wet, Hg dry)	35	20	20	Preliminary
Startup pump (NaK wet)	4	18	18	Preliminary
Heater (NaK wet)	2	8	8	Preliminary
Expansion compensator (NaK wet)	8	14	14	Preliminary
Boiler (NaK wet, Hg dry)	110	85	70	Preliminary
CRU and auxiliaries (NaK wet, Hg dry)	50	45	45	Preliminary
Radiator-condenser (dry)	278	220	190	Preliminary
Startup system (hardware only, dry)	80	70	62	Preliminary
Hg inventory	158	75	70	Preliminary
PCS controls and instrumentation	44	45	40	Estimate
System instrumentation, wiring, insulation	59	37	30	Estimate
Diagnostic instrumentation	99	50	0	Estimate
Structures	43	55	50	Preliminary
Shield assembly	340	290	200	Preliminary
Destruct device	10	10	7	Estimate
Contingency	0	50	-	-
TOTALS	1580	1350	1064	

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V. SYSTEM ANALYSIS

A. CURRENT DESIGN POINT

The design point is a listing of system parameters which reflect the best estimates of component performance in a system optimized for minimum weight. The current design point will be considered the requirements for the flight system.

The bases for the current design point are the following estimates of CRU component efficiencies and APU power requirements:

Component Efficiencies

Alternator	0.84
Turbine	0.53
NaK pump	0.022
Mercury pump	0.47

Electrical Power Requirements (kwe)

Payload	3.0
CRU speed control	0.1
Telemetry and reactor control	0.1
System degradation	0.3
Total alternator output	3.5

The major component duty requirements are:

Turbine output*	5.80 kwm
Reactor power	53.8 kwt
Boiler heat transfer	51.1 kwt
Radiator-condenser heat rejection	50.4 kwt

The overall efficiency from core thermal power to payload electrical power is 5.57%.

The design point system operating conditions are:

Reactor

Inlet NaK temperature	1015°F
Outlet NaK temperature	1215°F
Flow	72.4 lb/min
Pressure in reactor core	30 psia

*Abbreviations e, m, and t represent electrical, mechanical, and thermal respectively.

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Turbine

Inlet temperature	1150°F
Inlet pressure (total)	112 psia
Outlet temperature	615°F
Outlet pressure (total)	7.7 psia
Total turbine flow (mercury)	20.1 lb/min
Leaving moisture (turbine exhaust)	3% liquid

Boiler

Mercury inlet temperature	483°F
Mercury outlet temperature	1154°F
Mercury inlet pressure	215 psia
Mercury outlet pressure	116 psia
NaK inlet temperature	1215°F
NaK outlet temperature	1013°F

Radiator Condenser

Mean mercury condensing temperature	601°F
Mercury outlet temperature (mean at pump suction)	375°F
Outlet pressure (pump suction head)	6.0 psia

B. EVALUATION OF PROGRESS

No major design point changes have occurred since the last quarterly report. System design characteristics which have been resolved during the last quarter are discussed below.

1. NaK Freezing

An investigation was made of the transient temperatures in the NaK loop during the period between launch and startup. This analysis indicated that a flow rate of 5% (3.6 lb/min) was effective in preventing the NaK temperature from falling below 25°F. Circulation of the NaK acts to distribute the sensible heat stored by the more massive structures (principally the reactor) to the cold regions in the NaK loop (reactor inlet line). Five percent flow will prevent freezing for 17 hr in orbit if the system temperature is a uniform 65°F at the time of launching.

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3. Parasitic Load Dissipation

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C. ORBITAL STARTUP

During the last quarter one the major engineering efforts has been directed toward establishing the flight system startup technique. A SNAP 2 Flight System Startup Specification has been written and is currently being issued. This document is to provide the basis for startup system development leading to the flight system tests.

The analog computer simulation of various SNAP 2 components and subsystems provided the information on which a flight system startup technique was selected. Mercury injection studies were completed on a flight-type boiler and the experimental data thus obtained was factored into all analytical studies. Proposed flight system startup tankage, piping, and overall startup equipment has been established and incorporated into a SNAP 2 flight system P&I diagram (Figure 2).

The technique to be used for flight system startup is termed the Dual Injection Method. It is convenient to consider system startup as two distinct phases. The first phase is the preheating phase and includes only the reactor and primary NaK loop startup. The second phase concerns the startup of the mercury loop or power conversion system. These two phases are described in some detail below.

1. Preheating Startup Phase

After a suitable orbit has been achieved and verified, a command telemetry signal initiates the system startup sequence. The reactor, which is nominally \$4.87 subcritical, achieves criticality through a series of safety drum step insertions and control drum ramp insertions. The primary NaK coolant, which is flowing at about 5% of design flow, is heated from ambient to normal design temperatures. When the reactor exit temperature of 1200°F is achieved, the control drum insertion ceases and a temperature controller maintains the exit temperature in a range between 1200 and 1230°F. This completes the preheating phase of startup.

A number of important system parameters has been established for the preheating startup phase. These are as follows:

Reactor source power	10^{-8} watts
Startup NaK flowrate	3.6 lb/min

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Effective control drum rate	0.005 °F/sec/drum
Actual drum stepping rate	0.01 steps/sec/drum
Drum step size	0.5 °F/step/drum
Peak power transient during preheating	65 kw

Startup of the Power Conversion System is initiated after a steady-state condition is achieved at the end of preheating.

2. Mercury Injection Phase

At the end of preheating the primary NaK loop is hot, 5% NaK flow is under way, reactor power is at about 3.8 kw, and the boiler temperatures are near design values. The system mercury inventory is injected simultaneously into the hot boiler and the CRU bearings to initiate the Power Conversion System (PCS) startup sequence. Mercury vapor produced by the boiler causes the CRU to spinup and hence causes primary loop NaK flow to increase. As the mercury vapor is discharged from the turbine to the radiator-condenser (R/C) it is heated from ambient to design temperature. During the heating period pump cavitation is prevented by a pressure regulator located at the mercury pump inlet and isolated from the R/C by a closed valve. This valve is opened when the R/C temperature reaches 600°F. The time required for startup of the PCS is about 7 min.

The important parameters for mercury injection are as follows:

Injection boiler flow rate (full flow)	20.1 lb/min
Injection pressure	450 psia
Total mercury inventory	150 lb
Maximum decrease in boiler exit temperature during injection	100°F
Maximum reactor transient power	100 kw
Control drum rate during injection	0.2 steps/min/drum
Control drum step size during injection	0.5 °F/step/drum

System startup experimental investigations are planned for S2-PSM-1 and S2-PSM-3 non-nuclear systems. Analog computer simulation has been prepared which will be used to control the power to electrical heater on both of these non-nuclear systems. The objective being to make the heaters operate

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with the characteristics of the SNAP 2 reactor. This will allow accurate startup experiments to be performed.

The CRU NaK pump transient limitations have been relaxed from the previous heating rate of 300°F/hr to a value of up to 2000°F/hr. This change resulted from tests performed on the pump. The added freedom in startup afforded by this change has been factored into the current startup effort.

D. CONTROL AND SIMULATION ANALYSIS

The control information included in the previous quarterly report has been modified somewhat, based on changes in total reactor drum worth and additional simulation analysis. The controller will be of a bi-lateral type for both startup and long-term control. During startup the two control drums will be stepped in at a fixed rate, by a given amount, simultaneously. The control criteria are listed below. These numbers are nominal values and have additional constraints as to repeatability, hysteresis, and drift.

Temperature control band	1200 to 1230°F
Drum step size	0.5°F/drum
Total drum worth	\$2.10
Maximum reactivity step	2.1¢ (for one drum)
Dead time for long-term control	5 min

Effort has continued on a total SNAP 2 startup and control simulation. This work is considered important in order to completely analyze the various prototype developmental systems and to study analytically the control and startup characteristics of the proposed flight system. One principal area of effort concerns the analysis of a prototype flight boiler. A dynamic model has been started for analysis on both the analog and digital computers.

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VI. COMPONENT DEVELOPMENT PROGRESS

A. RADIATOR-CONDENSER DEVELOPMENT

1. Design Status

The design of the flight-type copper-clad steel honeycomb radiator-condenser has been revised to conform to the latest system configuration. To incorporate the required 134 ft² radiating area within the 130-in. height limitation, it was necessary to form the radiator-condenser with a cylindrical section and a frustrum of a cone included. Rectangular cross section tapered condenser tubes and tapered copper fins have been incorporated to reduce weight. Brackets are attached to the inner surface for support of the radiation shield, boiler, CRU, and nitrogen and regulator tanks. In the upper part of the unit, conduits are provided for electrical cable passthrough.

The aluminum shell-tapered steel tube design has also been modified to include the conical and cylindrical sections, as well as the necessary bracketry. Extensive structural analyses must be completed before final design details can be determined for this concept.

A beryllium shell test cylinder has been designed to incorporate typical longitudinal and transverse welds in the beryllium skin, mechanical fasteners, attached brackets, and 24 condenser tubes. Design parameters were selected to relate to a full-scale radiator-condenser.

2. Weight Reduction Program

Further reduction in weight of the copper-clad steel honeycomb radiator-condenser will be achieved by tailoring the structural design to the actual applied loads at each station, by optimum use of the meteoroid protection characteristics of all incorporated material, and by advancing the state-of-the-art in fabricating steel honeycomb sandwich structures. This implies reducing margins of safety to the absolute minimum, shaping the meteoroid protection material by full use of chemical milling techniques, and reducing braze alloy and face sheet thicknesses. A coordinated design, analytical, and experimental fabrication approach is being initiated along these lines.

Advanced design and fabrication efforts are being pursued to explore the feasibility of incorporating beryllium tapered fins on steel honeycomb, use of

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beryllium for the heat transfer, structural, and meteoroid protection characteristics, and use of diffusion-bonded titanium honeycomb sandwich with tapered aluminum fins. Each design concept shows potential weight savings but extensive feasibility work must be accomplished before detail design and analysis can proceed.

3. Overall Thermal and Structural Performance

Based on the new system design point requiring approximately 51 kw to be rejected from the radiator-condenser, the minimum weight of the copper-clad steel honeycomb radiator-condenser is achieved with 44 condenser tubes. Nominal fin thicknesses are 0.016 in. over the center of the tube and 0.003 in. at mid-fin. The resultant fin effectiveness is about 0.83. The average condensing temperature is 600°F and the subcooler outlet temperature is 306°F. Equivalent thermal performance of the aluminum shell radiator-condenser is achieved with 24 tubes and 0.063-in. fin thickness.

Structural calculations show that the end boost phase loading and maximum dynamic loading conditions can be accommodated satisfactorily in the copper-clad steel honeycomb design. Aerodynamic pressures and temperatures were considered in these analyses. Physical parameters were 1/4-in. cell, 1-mil ribbon, 5/16-in. honeycomb core height, and 0.005-in. facing sheets. Thermal and static stress analyses are continuing for the aluminum shell design in order to determine proper frame spacing, load ring details, and design of attachments.

Structural analysis was performed for the beryllium test cylinder in order to select design parameters which would result in the same structural failure mode for the cylinder as for the full-scale radiator-condenser.

4. Fabrication Status

During the report period all manufacturing operations on the first copper-clad steel honeycomb radiator-condenser for the S2-PSM-1 test were completed, and the unit was prepared for shipment from Rohr Aircraft Corporation. It was necessary to braze five quadrants in order to produce four acceptable panels for this unit. After brazing, the quadrants were assembled by means of longitudinal riveted joints, the vapor manifold was welded to the 72 condenser tubes, an emissive coating (PT404) was applied, and the unit was helium leak checked.

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A second unit identical to the first one was ordered, to be used for thermal performance component tests and static structural tests. Manufacturing planning for this unit has been initiated.

A contract was negotiated and awarded to Solar Aircraft Company for fabrication of an aluminum shell-steel tube radiator-condenser. A detailed design and fabrication schedule has been prepared; the detail drawings for the radiator-condenser and the titanium plating cell (for plating of the steel armor prior to brazing to the aluminum skin) were started; the graphite crucible for the plating cell was ordered; and some sheet and braze alloy has been ordered for preliminary studies.

An invitation to bid on fabrication of the beryllium test cylinder was submitted to eleven potential suppliers. Six firm proposals were received and evaluation was initiated.

In the experimental fabrication program, two small panels were brazed using different alloys to attach the tapered copper fins. This effort proved the feasibility of the concept, and showed that copper-manganese alloy is acceptable whereas the sterling silver-lithium alloy is too aggressive for brazing the thin copper fin. The detail parts for a larger panel are being prepared, which will include square tubes and meteoroid protection. Thermal conductivity specimens have been prepared for a separate test program. A vibration test panel was also fabricated for a test to determine damping characteristics of the honeycomb sandwich. Beryllium and titanium brazing experiments have been conducted, and evaluation of diffusion-bonded titanium honeycomb sandwich has been initiated to provide information for the weight reduction program.

5. Test Programs

The first radiator-condenser received will be assembled into the S2-PSM-1 system test, where thermal performance of the unit will be determined. The duplicate unit will be assembled into the radiator-condenser test loop where more extensive instrumentation can be employed to determine performance over a wider range of variable input parameters. A preliminary test plan has been written for the latter series. Following performance testing, the second unit will be subjected to static structural tests (including simulation of aerodynamic pressures and temperatures) to confirm or modify methods of prediction, and

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to provide additional design information. The dynamic characteristics of the typical honeycomb section are being determined in component setups. A small vibration test panel has been subjected to decay tests to establish longitudinal damping coefficients. Two larger panels incorporating condenser tubes, one with and one without copper cladding, are being fabricated for use in a more extensive vibration test series.

The test plan has been written for an experimental condensing mercury pressure drop test program, and the required apparatus is being assembled into the radiator-condenser test loop. The purpose of this program is to obtain pressure drop data over a wide range of conditions which will be used to verify or modify the procedure developed for computing condensing pressure drop for mercury. The procedure was published in NAA-SR-6333, "Pressure Drop for Flowing Vapors Condensing in a Straight Horizontal Tube," June 1961.

B. FLUID SYSTEM DEVELOPMENT

The objectives of the fluid system testing program are to develop components integral to the liquid metal coolant system and provide general liquid metal coolant technology to the overall SNAP 2 project.

1. Primary System Test

The primary system test was completed on August 15, 1961. One hundred hours of continuous operation at an average coolant temperature of 1100°F was obtained plus many runs of lesser duration. Problems encountered in the loading procedure were alleviated and a revised loading procedure has been prepared.

2. Orbital Start Pump

An orbital start pump is currently being fabricated based upon a thermo-electromagnetic pump concept using two cartridge heaters for thermal sources. This pump is designed to provide 1% NaK flow during the prestartup period and 5% flow during the startup of the system.

3. Expansion Compensator

Upon completion of the primary system test, over 150 hr of operation at temperature of the developmental expansion compensator was completed. The unit performed satisfactorily and design of the flight configuration is proceeding based upon the results obtained with the developmental unit.

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4. Parasitic Load Heater

A parasitic load heater has been designed using two cartridge-type heaters. The unit is presently being fabricated for performance and environmental tests. The NaK pressure drop through the unit is less than 0.035 psi at design flow. The total weight of the unit including NaK is 1.6 lb.

5. SNAP 2 NaK Loading System

The drawings for the SNAP 2 NaK loading system have been completed. The system includes a refrigeration system for cold-trapping and a vacuum system for evacuating the system before loading starts.

6. Radiator-Condenser Test Loop

Construction of the radiator-condenser test loop is in progress. The boiler, EM pump, vacuum vessel, and drain and fill tank have been mounted in place and the interconnecting pipe welded. An orifice type flowmeter has been designed and calibrated. Installation of the mercury condensing pressure drop section of the loop is now being assembled, manometers mounted into place, and other instrumentation connected.

7. Component Environmental Development

Preliminary environmental test evaluation of a prototype NaK expansion compensator has been completed. The compensator, oil-filled for NaK simulation, was extended 0.6 in. from fully closed and sealed to duplicate expected launch liftoff conditions. The specimen withstood qualification shock and vibration inputs with no apparent damage. The maximum response at vibration resonances was nominal ($\sim 1/8$ in. total deflection of the bellows end) which would result in no significant stresses in this flexible assembly. Evaluation will continue at other extended lengths of the bellows. The effect of gas overpressure will be determined.

The large vibration system has been satisfactorily installed and checked out for sinusoidal excitation of large specimens. A support fixture to adapt the APU to the shaker for longitudinal excitation has been received and checked out. Equipment for lateral excitation (granite slip block, magnesium slip plate, and shaker drive head) will be received this month. Instrumentation for the indicating and recording of specimen acceleration and strain response is nearly

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complete. A mass mockup of S10-PSM-1 has been fabricated, and complete system checkout in both the longitudinal and lateral directions with sine, random, and shock inputs will be initiated prior to S10-PSM-1 testing.

8. Emittance Coating Development

In an evaluation of low thermal emittance coatings for use as radiative insulation for the primary system piping and components, the following criteria were considered:

- a) Diffusion rates
- b) Infrared emittance, 900 to 1200°F
- c) Method of coating application
- d) One-year shelf life (oxidation)
- e) Sublimation rates
- f) Weight

The various metals considered as low emittance coating materials were aluminum, aluminum-bronze alloy, copper, gold, nickel, palladium, platinum, rhodium, and silver. Gold was determined to be the optimum choice as low emittance coating material for SNAP 2, whereas aluminum is undergoing test as a low emittance coating for SNAP 10A. The reasons for precluding the use of the other metals in preference to gold and aluminum are as follows:

Aluminum-bronze alloy - (1) The method of application would be as a foil, and (2) the highly polished alloy would tend to oxidize during a one-year shelf life. This oxidation increases the emittance.

Copper and Nickel - (1) Slight oxidation would occur during the one-year shelf life, and (2) severe oxidation, accompanied by a sharp emittance rise, would occur in the event of a vacuum pump failure during startup test.

Palladium - This metal has a higher emittance than aluminum or gold.

Platinum - At 1200°F the emittance of platinum is approximately 0.09 in comparison to a value of 0.04 for gold.

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Silver - This metal has an extremely high sublimation rate (approximately 0.003 in. per year) at 1200°F in the SNAP operational environment.

In the choice of a method of application of the gold coat, it is noted that the sublimation rate for gold at 1200°F in the SNAP operational environment is approximately 5 μ -in. (5×10^{-6}) per year. In many of the commonly used procedures for application of gold coatings such as vacuum deposit, electrolytically brushed-on gold or fired-on gold paste, the coating thickness obtained is in the order of a few micro-inches. Consequently, the method of application must be one which produces thicker gold coats such as electroplating, plasma-spraying, or use of gold foil.

In the investigation of electroplated gold as the low emittance coating, samples of gold plated from both an acid bath and a cyanide bath were tested. In all cases, tests of the gold plate on stainless steel, which was held in the temperature range of 900 to 1200°F in air and in vacuum, resulted in formation of a blue-black contaminant on the surface of the gold. This contaminant causes a sharp rise in the emittance of the gold surface; thus electroplated gold is not a suitable application technique.

Specimens of gold foil tacked to stainless steel have undergone long-term tests at 1200°F in air and in vacuum. In one test a 0.002-in. thick polished gold foil was tack-welded to an Inconel heating element and held at a temperature of 1200°F in air for 1000 hr. No change in the highly reflective appearance of the gold was noted throughout the test and, in addition, metallographic examination of the tack weld points showed no trace of diffusion of gold into the substrate.

Total hemispherical emittance measurements of "as-received" and polished gold foil have been performed. Emittance measurements of 0.038 to 0.040 in the temperature range of 900 to 1200°F were obtained for both the as-received and the polished gold foil.

To ensure the adherence of the fold foil to the stainless steel substrate, substantial testing of tacking 0.001-in. gold foil to 0.010 and 0.020-in. wall stainless steel tubing was performed. Utilization of a "Weldmatic" set at a low watt-second rating resulted in a very strong bond between the gold foil and the substrate. Metallographic examination of the fused bond between the gold

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foil and the stainless steel tubing showed no penetration of the gold below the outermost surface of the tube.

Finally, specimens of plasma-sprayed aluminum and gold are presently undergoing tests. Samples of as-received and highly polished gold and aluminum coatings as applied to stainless steel are being held at 1000°F in air. After 300 hr of test, no change in the highly reflective surface of the gold and aluminum coatings has been noted. Metallographic examination of the samples is being performed to determine rates of diffusion.

For the development of high thermal-emittance, low solar-absorptance coatings, further work is being performed on the basic "tailored" coating designated as NAA-X115B. This coating has a total hemispherical emittance of 0.84 and a solar absorptance of 0.22.

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C. POWER CONVERSION SYSTEM (PCS) DEVELOPMENT

1. Introduction

Development of the SNAP 2 power conversion system for the past quarter has been concentrated on the CRU bearings. Two previous tests of approximately 500-hr duration on the CRU-I and CRU-III bearings revealed surface damage to the plain-type bearing. As a result of the observed surface damage the basic bearing configuration was altered to a sector-type bearing. The sector-type bearing was designed to avoid low-pressure regions on the unloaded side of the plain bearing and thereby eliminate the possibility of lubricant cavitation which can induce surface wear and erosion. Limited CRU testing and component testing has given assurance that the sector-type bearing can avoid the cavitation erosion type of bearing damage. Combined rotating unit tests of the new bearing, however, have resulted in a relatively random test duration of between 1 and 285 hr. As a result, a detailed evaluation of bearing characteristics has been undertaken related to the following areas:

- a) Bearing load capacity.
- b) Hydrodynamics.
- c) Bearing materials and strength.
- d) Bearing geometry.

Construction of a high-temperature bearing test rig was completed during the reporting period. Preliminary results in this rig indicate a load capability of the bearing at 40,000 rpm of 80 lb per bearing applied unidirectionally. This rig was operated at temperatures to 300°F which gives good assurance that the load capability of the bearing is considerably in excess of anticipated loads of the CRU.

A plexiglass rig of 2-1/2 times actual bearing size was constructed to evaluate hydrodynamics of the bearing. With the aid of high-speed photography, assurance was obtained that good fluid coverage is obtained with the sector feed configuration used in the CRU.

A detailed review of bearing materials resulted in a change to a modified 440 stainless steel. The new bearing material with reduced surface hardnesses provides an increase in bearing ductility of eight times that obtained with

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18-4-1 tool steel. In addition, the coefficient of the thermal expansion of the new bearing material more nearly matches the housing and shaft materials, thereby reducing induced stresses and strains due to thermal growth. Because of this reduced relaxation of pressfits in the housing portion of the bearing, the bearing geometry remains more nearly that of the cold machined condition.

A series of component tests on the bearing and CRU housing has revealed a tendency for the sectors to assume a slightly cuspal shape and, with elevated temperature operation, a slightly bell-mouthed shape. These two effects could have a pronounced influence on the bearings' load-carrying capability. The material change, along with bearing design changes, should alleviate these problems. An evaluation of these bearing improvements in the CRU will be obtained early in the next reporting period by tests of CRU-III units.

Another bearing geometry investigation related to alignment is presently in progress. Initial test results have indicated that little difference in bearing operating exists for a misalignment of 0.0004 in. No change in bearing pressure-flow characteristics could be observed for the misaligned case; however, the speed at which incipient whirl occurred was found to be 2000 rpm higher for the misaligned bearing. Misalignments of 0.0004 in., 0.0008 in., and 0.0012 in. are expected to be tested in the near future in an evaluation of this aspect of the bearing geometry in the CRU. The combination of stress analysis and thermal distortion tests with actual CRU hardware has indicated that bearing misalignment could be as great as 0.0008 in. under hot operating conditions.

Turbine bearing housing modifications are currently being reviewed to determine improvements in bearing alignment under the hot operating conditions. Hot operation of the bearing on the component test fixtures provides assurance that the bearing problem can be overcome with proper design of the CRU bearing mount.

Other aspects of the power conversion system development are proceeding well. Component requirements for thermal shock have resulted from analytical and experimental investigations of orbital startup. Test data on both the boilers and the NaK pump have indicated that the required thermal shocks can be tolerated by these components.

Recent experimental data regarding the Haynes embrittlement has indicated that this material exhibits sufficient ductility in the embrittled state to

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Figure 3. SNAP 2 Power Conversion System - Separate PCS Concept

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Figure 4. SNAP 2 Power Conversion System - Direct Attachment Concept

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pump starting conditions, and minimization of complexity. Prior to startup, all mercury is located in the injection tank (or tanks). During CRU spinup, the boiler receives mercury from the injection tank; the bearings do likewise with the bearing drain flow ducted to the pump inlet pressure regulating tank. This regulating tank maintains pump inlet pressure at 6.0 ± 0.5 psia. The CRU pump is primed by this pressure during spinup and begins supplying system mercury flow when injection tank mercury is exhausted. Throughout startup and until condenser pressure is sufficient to supply the needs of the mercury pump, the subcooler discharge is closed with a valve.

Injection and regulator tanks based upon 120 and 150 lb of mercury inventory were conceptually designed. The design of a special liquid-level adjusting valve to be used during ground testing was begun. The purpose of this valve is to provide a variable restriction to subcooler discharge flow so as to cancel hydrostatic heads. This valve will permit the R/C to operate with the vapor-liquid interface in its design position and still insure that the CRU pump inlet pressure is also at its design value. The valve will be installed to bypass the subcooler shutoff valve and will be inactive for flight operation.

The layout design of the boiler for the flight design was completed. This boiler design has been designated Model No. 4. It is identical to the Model No. 3 boiler used for PCS-II-1 except for helix diameter (52 in. rather than 39) and for provisions to better withstand thermal shocks from NaK inlet transients. Table II is a tabulation of component weights for the flight PCS.

3. PCS-II-1 Development

PCS-II-1 is a preprototype flight power conversion system. It is being used to provide early data on the performance of the flight system components individually and as a system.

During the reporting period the Model 3 boiler used in this system was performance tested. The boiler-structure combination was installed in the acceptance test rig. Figure 5 shows PCS-II-1 (currently planned for use in PSM-3 system test) boiler structure installed in this test rig. System and rig shakedown testing along with the performance testing were accomplished. The boiler section of this report presents a summary of the boiler's performance during these tests. These first tests show the boiler capable of excellent steady-state performance. At the close of the reporting period, the boiler was in operation to obtain off-design steady-state and squirt start data.

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Figure 5. PCS-II-1 Installed in Acceptance Test Rig

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TABLE II
SNAP 2 POWER CONVERSION SYSTEM
WEIGHT ESTIMATES

Item	Weight (lb)
Boiler	80
CRU module	53
Injection tanks	36 (2-dry)
Regulator tank	44 (2-dry)
Pressurizing tank	7
Mercury plumbing	22
NaK plumbing	2
Gas plumbing	4
Mercury inventory	150
NaK inventory	34
Speed control	30 (est)
Wiring	15
Brackets	12
TOTAL	489

Modifications to this system resulting from flight PCS requirements were begun. These changes affected the CRU module and mercury injection and regulating tank portions of the system.

A boiler structure unit similar to PCS-II-1 was partially fabricated during the quarter. This system, designated PCS-II-0, utilizes a Model 3 boiler identical to that in PCS-II-1.

4. PCS-I Development (Endurance Test Rig)

The majority of PCS-I activity during the quarter was associated with investigation of subnormal boiler performance. During PCS-I-1 tests in June, it was found that boiler performance was below previous results. The boiler was operated for long durations (370 hr total) over a wide range of mercury and NaK flowrates and temperature conditions. Figure 6 shows temperature vs length profiles for this boiler during normal operation and during the June tests.

Of the several explanations for the low performance, the most plausible appears to be that a change of the mercury tube surface characteristics has

Figure 6. PCS-I-1 Boiler Profile

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occurred. If the mercury cannot wet the boiler wall surface, a decreased mercury side heat-transfer coefficient will result. In an attempt to induce rewetting, mercury with magnesium and titanium in solution was circulated through the boiler for 111 hr at a temperature of 700-800°F. After flushing the boiler with clean mercury, a 105-hr boiler test showed no noticeable improvement in performance.

The addition of a mercury preheater in the boiler inlet line resulted in higher quality vapor being produced. This preheater permitted mercury to be introduced into the boiler at a temperature within 40°F of the outlet NaK temperature. The boiler profile, however, was still far from normal.

On August 15 the boiler was removed from the PCS and subjected to an acid cleaning procedure. A procedure recommended by the Haynes Company was used in attempts to restore the mercury tube surfaces to their original pretest condition. Examination of the boiler after cleaning revealed that the cleaning had not been sufficient to accomplish the objective. The boiler was then cleaned with modified aqua regia acid. This procedure has successfully cleaned treated samples of Haynes 25 that could not be wet by mercury prior to cleaning. After cleaning, laboratory-cleaned samples were readily wet by mercury. Visual examination of the boiler mercury passages after the aqua regia cleaning showed them to be far from bright and clean. It was therefore felt that the treatment had not been comparable to that of laboratory cleaning and that mercury probably would not rewet the boiler.

Because of the need for PCS-I-1 to be available for CRU development and acceptance testing, a boiler made of 316 stainless steel mercury tubes was installed and boiler testing began the last two days of the quarter. The Haynes 25 boiler will be subjected to further treatment and examination as part of the investigation of the decreased boiler performance.

5. Combined Rotating Unit (CRU) Development

a. Bearing Development

During this past quarter, the primary effort in the CRU development program has been directed toward the journal bearings and their integration into the turboalternator package. Since the initiation of the CRU-III test program a year ago, 11 of 13 operational malfunctions have been associated with bearing failures. Table III summarizes the CRU-III tests.

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TABLE III. CRU TEST RESULTS RELATED TO BEARINGS

Unit	Test No.	Test Date	Duration	Assembly	Facility	Bearing Type			Bearing Clearance		Results			General Remarks
						Thrust	Alt.	Turbine	Alt.	Turbine	Thrust	Alternator	Turbine	
CRU-I	7 Tests	8-3-59 to 5-30-60	488 hr 29 min	Clamped	Perf	Step 18-4-1	Plain 18-4-1	Plain 18-4-1	0.002	0.002				Bearing rust caused inability to start on one test -- no other bearing problems
CRU-II-1	6 Tests	11-2-59 to 7-9-60	36 hr 39 min	Clamped	Perf	Step	Plain	Plain	0.002	0.002				No bearing failure
CRU-II-2	2 Tests	4-26-60 5-4-60	9 hr 5 min	Clamped	Perf	Step	Pad	Pad	0.001	0.001				No bearing failure
CRU-III-1	CRU-III-1-1	8-16-60	0	Clamped	Perf	Step	Pad	Pad	0.001	0.001				No test - NaK pump distortion
CRU-III-2	CRU-III-2	9-26-60	5.3 min	Welded	PCS-2-1-1	Step	Pad	Pad	0.001	0.001				Loss of bearing clearance thru thermal expansion
CRU-III-1	CRU-III-1A-1	10-18-60	4 hr 31 min	Clamped	Perf	Step	Pad	Pad	0.0011	0.0015/ 0.0016		Excellent condition	Failed Journal welded to bearing - cracked into 3 sections	Clean unit
CRU-III-2	CRU-III-2A	10-26-60	10 sec	Welded	PCS-1-1A-1	Step	Pad	Pad	0.001	0.0017	Chip			
CRU-III-1	CRU-III-1C-1 CRU-III-1C-2 CRU-III-1C-3	11-30-60 12-1-60 12-7-60	1 hr 30 min Cold gas 79 hr 25 min Hot gas 26 hr 55 min	Clamped	Perf	Step	Pad	Plain	0.001	0.0020		Failed Welded Cavitation erosion evidence	Excellent condition	Alternator bearing failure after 100 hours - Cavitation erosion evidence in alternator bearing
CRU-III-3	CRU-III-3A	1-5-61	2.5 sec	Welded	PCS-1-1B	Step	Plain	Plain	0.0021 0.0022	0.0020				Chip in labyrinth
CRU-III-2	CRU-III-2B-1 CRU-III-2B-2	1-16-61 2-9-61 2-15-61	517 hr 71 hr	Clamped X801055-3 Turbine Hsg	Perf	Step	Plain	Plain	0.0019 0.0020	0.0020 0.0021		Cavitation erosion marks	Failed Journal welded to bearing	500 hour qualification test plus 60 hours at reduced bearing flow (2 ppm). NaK rotor fretting. Improvements* in this and subsequent units.
CRU-III-4	CRU-III-4A	3-7-61	2 hr 20 min	Clamped X801055-3 Turbine Hsg	Perf	Step	Plain	Plain	0.0020	0.00225 0.00230	Scored on alternator side	Bearing seized Shaft & bushing scuffed. Not Welded.	Failed Lightly welded Heavy wear 0.004-0.005	Labyrinth seal rub seizure damaged all 3 bearings.
CRU-III-5	CRU-III-5A	3-31-61	2 hr 21 min	Welded X801055-3 Turbine Hsg	PCS-1	Step	Plain	Plain	0.0020	0.0024		Slight wear with scratches	Failed Heavy wear	Increased turbine labyrinth seal clearance to 0.008/0.009

*Improvements:

NaK pump housing modified to reduce heat
 NaK rotor mounting modified to reduce heat
 Hollow shaft incorporated to reduce heat
 Labyrinth seal lengthened to reduce heat

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TABLE III (Continued)

Unit	Test No.	Test Date	Duration	Assembly	Facility	Bearing Type			Bearing Clearance		Results			General Remarks
						Thrust	Alt.	Turbine	Alt.	Turbine	Thrust	Alternator	Turbine	
CRU-III-1	CRU-III-1D-1	4-25-61	1 hr 22 min	Clamped X802711 Turbine Hsg	Perf	Step	Plain	Sector	$\frac{0.0020}{0.0021}$	$\frac{0.00185}{0.00195}$		Journal scuffing 1/2 way	Failed Heavy bearing wear Shaft scoring	Deterioration of turbine bearing performance caused shutdown. Turbine journal wear radially eccentric.
CRU-III-3	CRU-III-3B-1 CRU-III-3B-2	5-25-61 5-31-61 to 6-17-61	6.8 hr cold gas test 235 hr at des cond	Clamped X802790 Turbine Hsg	Perf	Spiral 18-4-1	Sector	Sector	$\frac{0.0016}{0.0017}$	$\frac{0.0016}{0.0017}$		Failed Section of bear- ing welded to journal	Scoring and scuffing	Cold gas satisfactory; alternator (on hot gas test). Bearing seized, probable foreign particle; dry run 10,000 rpm caused chips.
CRU-III-1	CRU-III-1E	7-26-61	1 hr 18 min	With NaK Rotor Clamped X802854 Turbine Hsg	Perf	Spiral	Sector	Sector	$\frac{0.0014}{0.0016}$	$\frac{0.0015}{0.00165}$		Failed Seized		Alternator bearing failure at 40,000 hot gas. Seized after reducing flow from 7 ppm to 5 ppm.
CRU-III-2	CRU-III-2C	8-19-61	45 min	With NaK Rotor Clamped X802711 Turbine Hsg	Perf	Spiral	Sector	Sector	0.0016	$\frac{0.0016}{0.0017}$	Slight scoring	Slight scoring	Failed Seized & weld- ed	Sleeve welded to shaft and cracked through feed grooves. (18-4-1 suspected as brittle; design not optimum for stress.)
CRU-III-4	CRU-III-4C	9-29-61	1 hr 12 min	With NaK Rotor Clamped X802711 Turbine Hsg	Perf	Spiral 18-4-1	Sector BG 41	Sector BG 41	$\frac{0.00215}{0.00205}$	$\frac{0.00220}{0.00225}$			Failed Heavy wear	Cold gas; turbine bearing failed at 30,000 rpm; intentional stop.
CRU-III-4	CRU-III-4D	10-13-61	42 min	With NaK Rotor Clamped X821110 Turbine Hsg	Perf	Spiral 18-4-1	Sector BG 41	Sector BG 41	$\frac{0.00192}{0.00195}$	$\frac{0.0019}{0.0020}$	Scored	Failed Journal wear on one side	Failed Heavy wear	Thrust bearing misalignment suspected. (Indication of shaft vibration at 37,000 rpm)
CRU-III-3	CRU-III-3C	10-26-61	41 min	No NaK Rotor Clamped X821056 Turbine Hsg	Perf	Spiral 18-4-1	Sector BG 41	Sector BG 41	$\frac{0.0016}{0.0016}$	$\frac{0.00177}{0.00184}$	Failed 0.0006 mis- aligned	Slight scratches		Hot gas. Thrust bearing deteri- oration at 30,000. Intentional stop. Alternator locking pin missing at disassembly. Alter- nator bore seal scuffed.
CRU-III-5	CRU-III-5D	11-4-61	3 hr 46 min	No NaK Rotor Clamped	Perf	Spiral 18-4-1	Sector BG 41		$\frac{0.0016}{0.0017}$	$\frac{0.00165}{0.00180}$	Eccentric wear pattern	Failed Heavy wear 0.003-0.005 groves	Slight wear	Hot gas successful run at 40,000 low turbine inlet pressure. Alternator bearing deterioration after 10 minutes full turbine pressure. Suspect high rotating loads.

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The circumferentially grooved, the load pad, and the axially grooved bearings were discarded in favor of the three-sector bearing because:

- 1) Evidence of erosion indicated the probability of lubricant cavitation induced by the low-pressure regions in the unloaded side. The interrupted surface of the three-sector bearing precludes this possibility.
- 2) The large running clearances required for adequate lubricant flow reduced load carrying capacity and stability. The multiple feed and short surfaces of the three-sector bearing assure adequate flow with smaller clearances.

Analysis of the alternator bushing design and its installation into the CRU indicate that the two failures of the three-sector bearings were the result of excessive stress induced by heavy press fits. These fits were necessitated by differences between the coefficients of thermal expansions of the bearing, housing, and shaft materials. From Figure 7, the differential expansion of the journal sleeve on the shaft, and of the bushing, is evident from the heat-affected white zones. (The taper evident in the photograph is from the bias cut made on the sample.) Figure 8 shows a photoelastic model of a three-sector bearing press-fitted into a ring. The stress at the bottom of the groove is three times that at the inner surface. To eliminate this problem, BG-41 (440C modified with molybdenum) has been substituted and a change in the method of bushing installation has been made.

The two failures of the three-sector turbine bearing cannot be explained as simply. The complexity is evident from the fact that the turbine bearing successfully operated for 285 hr and 30 min (CRU-III-3B-2) without failure. On the other hand, turbine bearing failures (CRU-III-1D-1 and -2C-1) occurred in less than 2 hr of hot gas operation. The detailed investigation and results to date may be arranged according to the following areas:

(1) Bearing Geometry

This effort centers around the effect of the CRU housing on the bearing configuration without regard to hydrodynamic considerations. Part of the problem arises as a result of adapting the external configuration of the three-sector bearing for installation into existing CRU housings.

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Figure 7. CRU-III-3B Alternator Bushing and Journal

Figure 8. Photoelastic Stress Pattern
for the Sector-Type Bearing

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Distortion of running surface: The stress lines in Figure 8 indicate the distortion in the bearing due to the interference fit. For purposes of alignment and concentricity the bearings are finish-ground in the housing. At operating temperatures, differential expansion between the housing and bushing reduces the interference fit. The bore, which was originally cylindrical, assumes a clover-leaf configuration. The difference between the high and low points is 0.0002 to 0.0003 in. Substitution of BG-41 for 18-4-1 decreases the difference between coefficients of thermal expansion. Elimination of the feed annulus in the outside diameter of the three-sector bearing will strengthen its resistance to distortion and is being incorporated into the turbine bearing housing redesign.

Bearing clearance reduction: Analysis and results of indirect experiments indicate the possibility of a reduction in clearance of the three-sector bearing under hot operating conditions. Although CRU test data do not verify this conclusion completely, reduction in running clearance coupled with other geometric effects can result in bearing failure. The use of BG-41 and the ability of the three-sector bearing to operate at larger cold clearances will eliminate the problem source.

Bearing Alignment: Simulated thermal tests of the CRU-III housings indicate that thermal distortion of the bearing mount and housing flanges, as well as changes in C-clamp bolt tension, affect bearing alignment to varying degrees. In these tests, misalignment of as much as 0.0008 in. over the 0.406-in. bearing length was noted. Continued stress and deflection analyses and experiments will produce the design refinements necessary for minimizing misalignment.

(2) Bearing Materials

Recent metallurgical investigation reveals that the consumable electrode vacuum melt 18-4-1 currently used for bearing materials is deficient in two significant areas. As shown in Figure 9, the quality of the 18-4-1 material is very poor as evidenced by the presence of substrate pits and general porosity. Pits recently noted in newly ground bearings have been analyzed to

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be the result of carbide particles being torn from the surface. The successful long-time use of softer ($R_c 57$) BG-41 journal sleeves in the Free Running Rig (FRR) and friction and wear tests of BG-41 on BG-41 indicated that 18-4-1 could be replaced. Investigation is continuing to determine whether a softer ($R_c 45$) material such as Haynes 25, which has a more nearly compatible coefficient of thermal expansion, can be used for bearings.

Figure 9. CRU-III-3B Turbine Journal ($\sim 60X$)

(3) Bearing Hydrodynamic Performance

Hydrodynamic performance is covered in the bearing subcomponent section of this report. Analyses and tests to date show that if the configuration and alignment of the bearing can be maintained, radial loads exceeding 80 lb per bearing can be sustained.

b. Bearing Testing

The emphasis on bearing development resulted in a large increase in both test and analysis activity during this report period. Accelerated testing of the three-sector bearings was made possible by the addition of three new test rigs. During this report period two of these rigs, the bearing endurance test rig (BETR), with high temperature capabilities, improved instrumentation and

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load capacity, and the transparent flow rig (TFR) became operational. Together with the FRR these rigs were utilized to generate valuable data on the performance and capabilities of the three-sector bearings. The third new rig, a CRU-II, modified to simulate the operating conditions of the CRU-III, neared assembly completion during the end of this report period.

Results of the development tests conducted during this report period strengthened the confidence in the ability of the three-sector bearings to meet the ultimate performance requirements. Specifically, the journal bearing demonstrated the following capabilities:

- 1) Load-carrying capacity in excess of 80 lb per bearing.
- 2) Operation at diametral clearances from 0.0014 to 0.0021 in.
- 3) Satisfactory performance at reasonable misalignments.
- 4) Ability to suppress whirl instability by increasing bearing lube supply pressure.
- 5) Freedom from cavitation and erosion.
- 6) Ability to start and stop with applied loads in excess of 20 lb per bearing without damage at lube supply of 20 psi.
- 7) Satisfactory operating with rotating loads of 30 lb per bearing and at half frequency whirl over extended periods (up to 100 hr).

The thrust bearing which has demonstrated trouble-free operation during previous rig and CRU tests was further evaluated. In this report period the spiral-groove double-face thrust bearing was subjected to loads in excess of 30 lb and satisfactorily withstood momentary loads of 46 lb.

The basic three-sector bearing was tested in the FRR with lengths of 0.350 to 0.447 in. Results of these tests followed expected trends. As bearing length was increased, load-carrying capacity increased, but as a consequence it became more difficult to suppress half-frequency whirl. With longer bearings

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it became increasingly difficult to supply lubricant at reasonable supply pressures. The shortest bearing (0.350 in.) evaluated to date still had a load capability in excess of 40 lb. Since the shorter bearing requires less flow, has a lower power loss, is more stable and somewhat less sensitive to misalignment than longer bearings, it will be evaluated further.

Two types of misalignment tests were conducted using the FRR. In the one case, the shaft was misaligned by applying loads to each bearing in opposite directions. In the second instance misalignment of 0.0004 in. was machined into one bearing. The up and down loading type test operated satisfactorily, although with increased instability, at 40,000 rpm. The bearings with the built-in misalignment indicated no significant change in performance. The maximum misalignment which can be tolerated has not been established to date.

A variety of cold and hot tests was conducted in the BETR using a standard (0.625 in. diameter, 0.407 in. long, 0.0017-in. diametral clearance) three-sector bearing made of 18-4-1 Blue Chip. Although serving as a test rig shakedown, these tests showed that much useful parametric data can be gathered with this rig. With the improved instrumentation it is possible to accurately establish static and dynamic load deflection characteristics at different supply pressures, attitude eccentricity loci at different speeds, and the effect of pressure on suppressing whirl in addition to other standard tests. Preliminary dynamic hot flow checkouts using the package pump were successfully completed. Lube inlet and reservoir temperatures of 270 and 350°F were obtained without difficulty.

During this series of tests, the three-sector bearings operated successfully at 30,000 and 40,000 rpm with applied loads of 80 lb per bearing in either the up or down direction. Start and stop tests with applied loads in excess of 20 lb per bearing were successfully completed. Stable operation of speeds from 0 to 40,000 rpm were obtained with only shaft weight load (2.5 lb per bearing) by increasing supply pressure to 150 psig. Preliminary reduction of attitude eccentricity data reveals large attitude angles and the marked influence of speed and supply pressure on bearing performance. Photographs of the BETR are shown in Figures 10, 11, and 12.

Figure 10. Bearing Endurance Test Rig (BETR) Console

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Figure 11. Bearing Endurance Test Rig (BETR) Auxiliary Plumbing

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Figure 12. Bearing Endurance Test Rig (BETR) Test Fixture

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The BETR was disassembled in preparation of a hot dynamic endurance test on bearings identical to those installed in CRU-III-4C. The removed bearings (18-4-1) were in satisfactory condition.

Fabrication and assembly of the Transparent Flow Rig (TFR) was completed during this report period. Concentric and eccentric tests on a model bearing, 2-1/2 times the size of the standard three-sector bearings, were completed. These tests revealed no evidence of cavitation and visual observation indicated that the individual pads were operating flooded at Reynolds numbers equivalent to those obtained from 0 to 40,000 rpm with the SNAP 2 bearings. A photograph of this rig is shown in Figure 13.

Fabrication and assembly of the modified CRU-II test rig neared completion at the end of this report period. The improved instrumentation of the BETR was duplicated for the modified CRU-II rig. Additional temperatures will be included on this rig to obtain information on thermal gradients in the bearing areas.

c. CRU Testing

At the close of the last reporting period, CRU-III-3 was operating and continued to operate to 285 hr, when an alternator bearing failure occurred. CRU-III-1 was tested and also failed due to an alternator bearing seizure. CRU-III-2 exhibited a turbine bearing seizure. Bench tests have been conducted on CRU hardware to supplement analysis in the areas of stress, misalignment, and distortion.

The change in bearing material and minor geometry changes are expected to alleviate the bearing problems encountered in these tests.

CRU planning and status at the close of the reporting period is as follows:

- CRU-III-1E - being used for bench tests.
- CRU-III-2C - scheduled for fabrication completion
October 20 to be used in squirt-start
tests in PCS-II-1.
- CRU-III-3B - being used for weld flange tests.

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Figure 13. Sector Bearing Transparent Flow Rig (TFR)

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- CRU-III-4C - will be ready for initiation of 50-hr test in performance rig on October 2.
- CRU-III-5C - scheduled for completion with 18-4-1 bearings by October 2.
- CRU-III-6 - drawings not released as yet (this new unit will incorporate all improvements indicated by previous experience).
- CRU-IV-0 - scheduled completion date November 1.
- CRU-IV-1 - scheduled completion date December 15.

d. Alternator

Performance of the alternator in component and CRU tests has caused no significant problems. The design objectives of efficiency and power output have been met and significant improvements have been made in the stator bore seal. However, several problems remain to establish reliability of the alternator itself as well as the effects on CRU operation.

Rotor pole asymmetry has been an unknown quantity for some time in CRU development. The principal problem stemming from alternator rotor pole asymmetry is the rotating shaft bearing loads caused by the unequal magnetic force exerted by each of the six poles of the rotor.

The rotors in current use have an asymmetry much better than rotors received in the early parts of the SNAP 2 program where rotating loads of 40 lb were not unusual. At present, the highest permissible asymmetry in a CRU alternator rotor is that which results in a load less than 15 lb.

One of the problems involved in this investigation was the development of a method of measuring the amount of asymmetry that existed in a given permanent magnet raw stock as received from the vendor. A method used earlier in the program attempted to measure the flux density at each of the 6 poles and use the measured flux density to establish a number indicating percentage asymmetry. This method proved to be relatively unreliable and recently a more reliable and repeatable method has been adopted which measures the actual force caused by the magnetic asymmetry.

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This investigation included tests to verify that it was possible to accurately estimate the magnetic asymmetry of a magnet by checking only the raw magnet as received from the vendor. It was found that this was possible and therefore it was not necessary to completely fabricate and finish an alternator rotor in order to accurately check the magnetic loads caused by asymmetry.

Since the magnetic asymmetry is caused principally by the amount of quality control used by the magnet supplier, other vendors have been contacted in order to find a better rotor magnet source. All rotor magnets presently in stock have been checked by the new method and future magnet stocks will be checked by the same method.

The fixture used for measuring rotor pole asymmetry also provides information on the radial load induced by eccentric locations of the alternator rotor within its stator. This information may be useful in helping to stabilize bearings in the CRU when operating in zero gravity. Figure 14 shows the results of tests made in this rig.

The alternator power lead connector has received considerable attention in this reporting period. Three vendors have attempted to supply connectors for this application. The specifications include leaktightness and 600°F ambient. One of the three vendors has not been able to supply any successful connectors. The second connector vendor has supplied 5 connectors which checked leaktight upon receipt. Those connectors however have not been able to withstand the thermal stress of soldering lead wires. Connectors from the third vendor have withstood all the fabrication procedures with no increase in leakrate. These connectors, however, exhibit leakrates from 20 to 50% of the maximum allowable.

Thermal shock tests of the alternator stator have been conducted to evaluate the ability of a glass bore seal to maintain integrity. The tests consisted of heating the alternator stator to a predetermined temperature and then placing the stator into a container of water at 60°F. Two quenching tests were made with a stator at 260°F with no leaks developing in the glass bore seal. A second test was conducted with the alternator temperature being 360°F before being placed in 60°F water with the result that the glass bore seal developed small leaks. The third test was from 310°F for a ΔT of 250°F. This test was performed twice with no leaks developing. It is felt that these tests were relatively severe and provide confidence that the stator can withstand the thermal shocks that will be experienced in a PCS application.

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Figure 14. Unidirectional Magnetic Force vs Rotor Eccentricity

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A cast Haynes 21 stator frame design is being evaluated. Objectives of casting the alternator stator frame would be principally to reduce cost and alternator lead time. The use of Haynes 21 in the stator frame would also provide greater compatibility between coefficients of thermal expansion of the stator.

e. NaK Pump

Performance testing of the CRU-IV-type pump showed that the design objectives have been achieved. At 11.8 gpm, 40,000 rpm, and a NaK temperature of 1000°F the pump developed 3.5 psi with an efficiency of 2.35%. During this reporting period the effects of changes in various parameters was investigated.

Tests were run to determine distortion of the pump diaphragm when subjected to NaK temperature transients approximating those encountered during system startup. The first tests were run by measuring the diaphragm cold before and after subjecting the pump to thermal transients. No significant permanent distortion resulted when the NaK temperature was increased from room temperature to 1000°F at rates of 200, 500, and 1000°F/hr. The transient which occurs when mercury is injected into the boiler at startup was simulated by dropping the NaK temperature from 900 to 775°F in 30 sec. No significant permanent distortion resulted. The test with a heatup rate of 1000°F/hr was repeated with the diaphragm position being measured during the transient. Again distortion was not significant. The results of these tests indicate that thermal distortion of the pump diaphragm during NaK temperature transients is not as critical as it was considered previously.

Performance tests were run on the CRU-IV-type pump to determine the effects of NaK temperature and air gap on pump performance. The results are tabulated below. All data points were run at a speed of 40,000 rpm and with a flow of 11.8 gpm.

<u>Air Gap (in.)</u>	<u>NaK Temperature (°F)</u>	<u>Developed Head (psi)</u>	<u>Efficiency (%)</u>
0.015	1030	3.5	2.3
0.015	1000	3.6	2.32
0.030	1030	3.1	2.17
0.030	1000	3.2	2.17

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<u>Air Gap (in.)</u>	<u>NaK Temperature (°F)</u>	<u>Developed Head (psi)</u>	<u>Efficiency (%)</u>
0.030	980	3.25	2.21
0.045	1030	2.70	2.07
0.045	1000	2.75	2.05
0.045	980	2.85	2.12

A test was run with the CRU-IV-type pump using temperature points to determine the temperature distribution throughout the pump. This test was run at design flow and speed with a NaK temperature of 1030°F. The results showed that the rotor pole face temperature was 1040°F. This test was run to provide information relating magnet temperature to NaK temperature. Such information will be useful in determining NaK temperature limits when magnet temperature limits have been determined.

f. Turbine

The major effort in this reporting period has been devoted to design of the CRU-IV turbine. Because the CRU-III turbine efficiency was less than that predicted by analysis, the CRU-IV turbine design analysis has been quite intensive. Several methods of analysis have been compared with the result that the design shows assurance of meeting design objectives.

Because it is impossible to predict analytically the exact effect of certain parameters, the first three CRU-IV's are to be provided with instrumentation as an aid in evaluating CRU test data. In addition, there are slight differences in the interstage collector and the second stage blading between the three turbines in CRU-IV-0, IV-1, and IV-2. The CRU-IV-1 design was changed from that of CRU-IV-0 because slight design point changes resulted in some mismatch in second stage blade heights. CRU-IV-2 incorporates a larger interstage collector and the corresponding change in second-stage blading to account for slightly different inlet conditions resulting from a more efficient collector design.

While CRU-IV turbine performance will not be established until CRU-IV testing is started, the analytic assurance of meeting design objectives is good. With the instrumentation provided and the slight differences in design in the three units, any discrepancies between analytic and experimental performance can be pinpointed and corrected.

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g. Mercury Pump

Mercury pump performance in component and CRU tests has been satisfactory. Design objectives have been met with the Number 7 pump design. Tests have shown that this pump is capable of providing discharge pressures from 300 to 600 psi by changing impeller diameter.

Tests were conducted during the reporting period to determine the startup capabilities of the mercury pump. Three types of tests were conducted: (1) instantaneous loading at design inlet pressure and speed; (2) running fill at shutoff and design inlet pressure; and (3) maximum acceleration at shutoff and design inlet pressure. The pump performed well in all tests with no indications that the pump will provide limits for orbital startups.

The mercury pump test rig is being modified to serve as a hydraulic test stand as well as a pump test rig. It will be used to calibrate valves, flow regulators, etc., prior to their installation into the system.

Mercury pumps have also been designed, tested, and installed for use in the new bearing test rigs. A transfer pump is provided in each test rig and a pump in each of the test fixtures.

h. Test Rig Status

The performance test rig is utilized primarily for CRU development because it provides the maximum data for performance evaluation. Instrumentation is provided which allows any component to be studied more thoroughly in any particular test. Since this rig will also be used to evaluate performance of CRU-IV, provisions are being made to accommodate both CRU-III's and CRU-IV's with a minimum installation time.

The endurance test rig was designed with the purpose of obtaining endurance data from system operation. PCS-I-1 is installed in this rig and the utilization during the reporting period has been devoted to investigation of the boiler conditioning problem.

The acceptance test rig serves to evaluate performance of complete systems. During this reporting period, construction of this rig was completed and its various systems and auxiliaries were checked out. The PCS-II-1 boiler and structure were installed and boiler tests were started.

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6. Boiler

A computer program has been completed to facilitate calculating steady-state stresses in the tube sheet region of SNAP 2 type boilers. This program permits investigation of the effects of materials, geometry, and operating conditions on structural reliability. This analysis has shown that maximum stresses in a 316 SS boiler reach 50% of the 10,000-hr rupture stress. For Haynes 25 the corresponding figure is 30%. Both materials appear adequate from the point of view of steady-state stresses.

Consideration is being given to the problem of estimating the effect of numerous squirt-type starts on boiler life. Analysis of the transient thermal stresses evolved is quite complicated and, consequently, a program of squirt-start thermal shock testing has been undertaken. A rig is being constructed to test several short boiler inlet sections. These sections will be thermally shocked repeatedly in a manner closely simulating the temperature and pressure transients occurring during boiler squirt starts. Detailed internal temperature and pressure transients as well as a series of thermal fatigue runs will be obtained to aid in evaluating present tube sheet design, various materials, and alternative tube sheet welding methods.

A PCS-II boiler was operated for approximately 75 hr at near design temperature and flow conditions. Heat flux improved markedly over the first 40 hr; thereafter the improvement was gradual. Boiler NaK temperature plots at 10, 40, and 60 hr which demonstrate this conditioning process appear in Figure 15. Boiling occurs in the steeper portions of the curves. As the boiler test progressed the boiling section moved toward the mercury inlet end of the boiler and became shorter. At the same time, superheat length, the flat portion of the curve toward the 1200°-NaK inlet end, lengthened. The last plot shows the boiler operating precisely as it was designed to operate. There is no suppressed boiling. Boiling occurs in a rather short section of the boiler. The test ended prematurely due to test rig condenser operating difficulties. Further boiler tests including squirt starts will begin as soon as condenser repairs and modifications can be made.

The experimental portion of the boiling research program has been completed and the data reduced. Analysis of the reduced data has been completed and work on the boiling research topical report continues.

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Figure 15. PCS-II Boiler Conditioning Process

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7. Control

The frequency of the SNAP 2 alternator is controlled at $2000 \text{ cps} \pm 1\%$ by a frequency-sensitive parasitic load type of control. The control for the flight system had as a design objective the capability to operate in a 600°F environment. As the development progressed it became apparent that the nonavailability of 600°F diodes was a limit in control design. Because of this component the control design progressed with a 400°F operating capability. Work on development of a high-temperature control was halted, however, with the decision to locate the control in the relatively cool instrumentation compartment. These new low-temperature requirements will result in lower control power requirements (100 watts vs 150 watts) and in a unit which is 12 to 15 lb lighter in weight.

Studies to determine frequency discriminator design variables and core properties in order to achieve optimum discriminator designs are near completion. In these studies, components and core sizes were varied one by one to determine their individual effects on discriminator power output. Data from these tests remain to be analyzed.

Temperature tests of a low temperature control have been completed. They covered the complete operating range of -65 to $+165^\circ\text{F}$. Over this range, frequency drift was 7 cps demonstrating that special temperature compensating circuitry will be unnecessary.

Detailed heat transfer calculations have been made to determine optimum component location and radiating surface area requirements for the packaged control. It is important that the flight control be so designed that heat can be dissipated at a radiating temperature low enough to insure reliable component performance.

8. Startup System

A general scheme for starting and shutting down the PCS in orbit and on the ground has been formulated. The startup sequence begins when a solenoid valve opens permitting liquid mercury to enter the system from a mercury squirt tank. Nitrogen gas working behind a bellows drives the mercury out of the squirt tank. Mercury enters the boiler at approximately a flow rate 50% of design. As this initial flow into the boiler vaporizes, the pressure level in the boiler builds up. When boiler exit pressure reaches a predetermined level

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(6 psia) a pressure-sensing switch routes mercury to bearings and the mercury pump. The turbine begins to rotate. As CRU shaft speed increases, the NaK pump begins to supply the boiler with design flow. The boiler and bearings continue to receive mercury from the squirt tank, and the CRU pump does not begin to supply system mercury flow until squirt-tank mercury inventory is exhausted. A valve closes the subcooler discharge until condenser pressure reaches a level sufficient to supply the needs of the mercury pump.

During startup and normal operation, it is important that mercury pump inlet pressure not fall below 6 psia to avoid cavitation. A condenser pressure regulating tank between the mercury pump inlet and the subcooler discharge adjusts system mercury inventory to compensate for changes in system operation which might affect pump inlet pressure. Sun-shade transients in orbit, for example, affect condenser radiating effectiveness and require condenser inventory and liquid level changes. This condenser pressure regulating tank is operated by a bellows with spring rate such that mercury inventory is drawn from or injected into the system keeping pump inlet pressure at 6.0 ± 0.5 psia.

Flow regulators are used in the system to maintain constant flow to bearings and boiler. Hydrostatic head is nonexistent in orbit, but must be considered during ground startup and operation. During normal operation, the condenser liquid level is 6 in. above the mercury pump inlet. During startup, while the radiator-condenser is being heated up, liquid level can rise considerably higher. A liquid-level compensating valve is being developed which will prevent the alternator from flooding due to the resultant hydrostatic head.

9. Materials Evaluation

A columbium-Haynes 25 loop test was terminated after 1700 hr due to a leak in the superheat section. The loop was sectioned and metallographic examination showed that columbium is highly resistant to mercury corrosion at 1200°F. Analysis also showed that the columbium acted as a getter for the material removed from the Haynes 25.

A 410 stainless steel loop has accumulated in excess of 3000 hr of operation. Two burnouts were encountered in the superheat section and this section was replaced with 446 stainless steel. The loop is currently operating satisfactorily.

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During the reporting period a problem was brought to light regarding potential embrittlement of Haynes 25 at high temperatures. This problem was indicated by qualitatively bend-testing samples taken from the Haynes 25 loop which had run for 5000 hr. Additional evaluation has shown that the embrittlement is not as severe as was originally indicated. Recent tests have indicated that the ductility of this material will remain adequate for use of Haynes 25 as the boiler material.

The Haynes 25 boiler in PCS-I-1 has exhibited continued resistance to wetting. The boiler did not wet after exposure to mercury containing titanium and magnesium additives. These difficulties prompted some wetting tests on Haynes 25 samples. Previously exposed samples were tested for wetting at 900°F with and without additives. Some samples were pickled to remove the surface coatings. Results are tabulated below for exposure duration to obtain wetting.

<u>Condition</u>	<u>Additives</u>	<u>Wetting</u>	<u>Exposure Hours</u>
As exposed	None	No	1000
As exposed	20 ppm Mg-Ti	Yes	20-30
Modified <u>aqua regia</u> pickle	None	Yes	84
Haynes solutions pickle	None	Yes	400
Modified <u>aqua regia</u> pickle	20 ppm Mg-Ti	Yes	20

A Haynes 25 test loop has been designed to evaluate separation of corrosion products. This test loop will utilize baffle and magnetic separators.

Results of capsule testing during the reporting period are tabulated below.

<u>Material</u>	<u>Test Time (days)</u>	<u>Temperature (°F)</u>	<u>Classification</u>
Haynes 25	30	1200	II
Haynes 25-Ti	30	1200	II
AISI 1010	30	1200	II
410	30	1200	III
PH 15-7 Mo	30	1200	III
Columbium	30	1200	I
Supermendur	60	900	II
Haynes 8187	30	900	II
405	90	900	II

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VII. NON-NUCLEAR DEVELOPMENT SYSTEM

A. PSM-1 DEVELOPMENT SYSTEM

The primary objective of the PSM-1 system (Prototype System Mockup) is to design, fabricate, install, and operate a non-nuclear package system test of the flight test configuration. The specific objectives are as follows:

- 1) To obtain design, fabrication, and installation information for the flight package configuration.
- 2) To obtain non-nuclear performance data for the flight package configuration. This includes both design and transient conditions.
- 3) To test and develop orbital startup techniques and startup equipment.
- 4) To prove the suitability of NaK system cleanup, loading, and sealing techniques for a void-free system.
- 5) To obtain performance information for the radiator-condenser in a simulated heat transfer environment.

The PSM-1 design points have been established as follows:

Turbine efficiency	0.46 (CRU-III design)
Turbine flow (mercury)	20.1 lb/min
Turbine leakage	0.6 lb/min
NaK flowrate	72.4 lb/min
Reactor (electrical heater) power	55 kw
Alternator output	2.5 kw

Installation of the PSM-1 system is in progress in Building 032. Several major system components have been fabricated and delivered. These components are as follows:

- 1) The APU vacuum tank.
- 2) The mercury and NaK system process instrumentation.
- 3) The vacuum pumping system for the vacuum tank.
- 4) The radiator-condenser copper clad-steel honeycomb-tube design (Figure 16).

Figure 16. PSM-1 Radiator-Condenser Design

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- 5) The NaK system components and piping.
- 6) The load ring and support structure.

The vacuum tank, vacuum pumping system, and process instrumentation have been installed at the test site. Installation of additional components, which require prior installation of the NaK mercury boiler, will be made upon receipt of the PCS-II-0 (Power Conversion System) boiler. This unit is scheduled for delivery during the first week of November 1961.

The APU vacuum tank is made in three sections - a bottom support section, a middle shell, and a top shell. The bottom support section contains the penetration nozzles required for the vacuum line, electrical power leads, thermocouple leads, liquid metal instrument transmission lines, and mercury injection lines. The vacuum pumping system consists of a mechanical roughing pump and a mechanical booster pump which begins operating when the system pressure has been reduced to 15 mm Hg.

The instrument console consists of eight racks - two for CRU alternator instrumentation, five for mercury and NaK process instrumentation, and one for the simulated reactor heater controller. In addition, transient instrumentation will be utilized to monitor system performance during startup and to record system perturbations. A programmer will be incorporated to automatically start and operate the system after test data have been obtained to provide the information required for automatic operation.

A system design was prepared for a preliminary series of tests prior to installation of the CRU-III which will permit boiler conditioning, determination of the NaK and mercury piping system operating characteristics and heat losses, and determination of the radiator-condenser performance characteristics at PSM-1 design conditions. The major modifications to the PSM-1 system are the inclusion of a mercury pump, a NaK pump, and a nozzle and desuperheater to thermodynamically simulate the CRU turbine. This system will also permit injection tests and should provide test data which can reduce the test time required for startup studies with the CRU-III in the PSM-1 system. All components for this system modification have been received. The PCS-II-0 boiler will be utilized in this modified system. Minor repiping is required upon receipt of the CRU-III, scheduled for January 1962 delivery, in order to convert the system to the PSM-1 test system.

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B. PSM-2 PHASE I DEVELOPMENT SYSTEM

During this quarter the criteria package containing the test plan for the vibration and shock tests, detailed schedule, and preliminary design sketches was prepared and released; 100% of the preliminary design input was completed; 70% of the fabrication drawings were completed including the radiator-condenser mockup assembly, reactor mockup assembly, power conversion mockup system, NaK piping, startup system components, and various structural brackets and supports; and procurement has been started on the released drawings.

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VIII. OPERATION ANALYSIS

A. SYSTEM FLIGHT SAFETY

The basic purpose for the SNAP 2 (SNAPSHOT) safety program is, as stated in the previous quarterly report (NAA-SR-6691), to provide independent, non-failsafe, primary and backup safety features for all phases of SNAPSHOT sequences from shipment to launch and orbit.

In conjunction with SNAP 10A safety effort, a design specification has been generated which enumerates the inherent and design safety features (reference design features) proposed to accomplish the above criteria. This specification is being reviewed for the purpose of implementing these features with hardware which will have not only a high probability of positive action but also minimum reduction of system reliability. The applicability of these safety features has been determined during the various operational sequences and a constant liaison effort is maintained with Navy range and Air Force launch-pad personnel to assure that no conflicts will occur with their respective procedures.

Data on range of magnitude and description of various excursions which might occur during the following sequences has been obtained for the SNAPSHOT preliminary safety report.

- 1) Shipment from Santa Susana to VAFB (Vandenberg Air Force Base).
- 2) Integration and checkout of the APU at VAFB.
- 3) Shipment from VAFB to the launch pad.
- 4) Mating of APU and vehicle.
- 5) Countdown sequence.
- 6) Launch to orbit.

For each of these possible nuclear accidents, a fission product release model has been assumed and the radiological consequences are being established. Prompt integrated cloud gamma and beta inhalation and deposition doses have been determined as a function of time and distance downwind and crosswind for various meteorological conditions and height of plume rise. Computer codes using Holland's variation of Sutton's equation for gamma doses and Convair's

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code for the remainder of the dose calculations have been completed. A code is also being developed for fission product diffusion through the fuel elements, and a more refined heat transfer code is in progress which will verify the release model assumptions.

The proposed closed fission product release tests are being studied to determine the most advantageous method of obtaining data on the releases from SNAP fuel elements at elevated temperatures. From the selection of fission products whose percent yield is to be measured, the diffusion coefficients of all fission products in the fuel element can be evaluated for use in the aforementioned diffusion code. The open fission product releases under the same test would provide particle size information and a verification of the meteorological diffusion parameters for a SNAP-type fuel element. However, the possibility of performing a florescent dye meteorological study at the launch site utilizing the results of the closed release tests (i.e., particle size distribution) may reduce the usefulness of the open fission product release tests.

B. FLIGHT INSTRUMENTATION

Report period efforts consisted largely of specifying system readout and control requirements. Instrumentation needs are in two categories - components required for operational use of the APU and the diagnostic system needed to explain the SNAPSHOT flight characteristics and history. The first category instruments and control components were selected on a basis of absolute need for future APU power generation as a working vehicle component. The diagnostic requirements were settled within limits set by weight allotments, telemetry signal accuracies, and inability to check the parameter in ground testing.

Operational measurements needed are as follows:

<u>Instrument No.</u>	<u>Function</u>
T-102	Temperature - NaK - core out
T-118	Temperature - NaK - boiler out
T-173	Temperature - Hg pump inlet
T-165	Temperature - R/C outlet header
T-148	Temperature - R/C inlet header

Instrument No.

Function

ΔP-302	Differential pressure - NaK pump
P-303	Pressure - Hg turbine inlet
P-306	Pressure - Hg pump discharge
ΔP-308	Differential pressure - bearing lube filter
Pn-407	Position indicator - expansion compensator bellows
Pn-405	Position indicator - control drum No. 3
Pn-406	Position indicator - control drum No. 4
F-504	Flow - Hg boiler flow
E-701	Electrical - alternator frequency
E-702	Electrical - alternate voltage phase B
E-703	Electrical - alternate voltage phase A
E-706	Electrical - parasitic load current phase B
E-707	Electrical - parasitic load current phase A
C-814	On-off - scram signal
C-815	On-off - scram verify signal
C-803	On-off - APU malfunction

The total system, including the above and the diagnostic requirements, is shown on the P&I diagram (Figure 2).

An instrumentation list and general system description have been completed based on the above efforts. These will be used to prepare component specifications for system procurement.

Development of electrical interface specifications was begun with LMSC (Lockheed Missiles and Space Co.) in coordination meetings. Telemetry signal conditioning, power characteristics, APU electrical load, and circuit protection requirements are being finalized.