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NUCLEAR AUXILIARY POWER UNIT DEVELOPMENT
JULY-SEPTEMBER 1962
(Title Unclassified)

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letter 4/17/73

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HA 3/1/04

by GG

DTIE, date

5/24/73

Wash DC

PROGRESS REPORT FOR

SNAP 2

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JULY-SEPTEMBER 1962

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Edited by
D. I. Sinizer

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I. SUMMARY

The flight system P & I diagram underwent extensive revision to reflect changes in the NaK and mercury systems and in the startup sequence. The nominal mercury temperature leaving the boiler was increased from 1145°F to 1160°F, reflective gold insulation was added in selected locations adjacent to the boiler and on the entire sub-cooler, a venturi was added downstream from the combined rotating unit (CRU), and a heat regenerator was added in the bearing drain lines. In the revised startup sequence all the mercury inventory will be contained in the injection tank rather than being divided between the injection tank and the pressure regulator tank. This change will significantly reduce the possibility of cavity flooding in the CRU during startup. The control system revision results in less reactivity insertion during the temperature transient after injection and prevents an overshoot of the steady-state temperature following the transient.

Component development in the primary subsystem is proceeding. Environmental tests of a NaK flow trimmer have shown that it is capable of controlling flowrate with pressure drop within the required range. A trimmer operated for over 4500 hr with 1200°F NaK with no change in performance characteristics. Two prototype orbital startup pumps met design requirements in bench tests. One pump operated for 130 hr at 70°F and 1900 hr at 1000°F. A second pump, still under test, operated for 338 hr at 70°F and 1841 hr at 1000°F. A four-resistor parasitic load heater operated under simulated service conditions (1.67 kw at 1200°F) for 4125 hr. A weld failure in a Mark II expansion compensator dictated a change in bellows material from PH15-7 Mo to AM350. Developmental models of thermoelectric pumps were fabricated and are now being instrumented prior to insertion in a loop for testing under simulated system conditions.

In vibration tests a high emittance coating ($\epsilon = 0.90$, $\alpha_s = 0.30$) withstood a strain of 2070 $\mu\text{in.}/\text{in.}$ (about 62,000 psi) with no apparent damage. Adherence to copper and aluminum substrates was excellent in thermal cycling tests simulating 10 cycles of ascent heatup rates. No change in total hemispherical emittance was observed up to 2000 hr on a copper substrate and to 1200 hr on an aluminum substrate at 600°F in a vacuum of 10^{-5} Torr. Irradiation with 1.25-Mev electrons to 3×10^{18} at 600°F or 10^{18} at 175°F caused no visual change in

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The coating and no significant change in emittance. There was no visual evidence of coating damage after 5×10^{15} thermal neutron and 10^6 fast neutron irradiation. For temperatures to 1050°F , gold-coated molybdenum foil is satisfactory for a low total hemispherical emittance (about 0.05) coating at least to 1500 hr at 10^{-6} Torr. For temperatures of 1050 to 1250°F , pure gold foil is satisfactory.

CRU-IV-M-1 operated in performance tests with cold nitrogen gas for approximately 2-1/2 hr at 40,000 rpm before the turbine bearing seized. During the test the turbine maximum efficiency was about 56%, compared to about 48% for CRU-IV-0. Tests results indicated that failure may have been caused by excessive bearing loading due to improper bearing drainage or particles in the nitrogen supply. A failure analysis which includes detailed metallurgical examination is in process to confirm this hypothesis. The failure was probably associated with test rig malfunction rather than defects in the CRU-IV itself. The CRU-IV-M-1 has been repaired for the next series of tests scheduled in late November.

Four CRU-IV components are in fabrication and will be used for subsequent tests with alternate bearing configurations. The cold gas test unit will be hot-gas tested to demonstrate that the CRU-IV-M modifications have corrected problems of realignment caused by thermal gradients in operation.

Bearing configurations were not optimized for this CRU-IV-M test. Later tests will use bearings which have shown excellent performance in the bearing test rig.

Capacitance probes will be used in later tests to develop needed information on operational characteristics and shaft-bearing dynamics.

Alternate bearing configurations, such as three-sector bearings, three-pad bearings and tilting pad bearings are being studied. With plain bearings half-frequency whirl could be suppressed by increasing load. No half-frequency instability appeared at speeds to 40,000 rpm with a three-sector bearing or up to 45,000 rpm with a three-pad bearing. A tilting pad bearing operated successfully for 100 hr of a planned 200-hr endurance test with operation as predicted analytically.

Four simulated orbital squirt starts were made with a CRU-III. Spinup to design speed took 110 sec but turbine flooding and drainage problems prevented stabilization at design speed. The mercury pump operated as predicted by parametric studies. The alternator performed satisfactorily in performance tests. A NaK pump completed a 1000-hr endurance test at 1000°F with no change in performance.

Performance analysis of CRU-V was completed and performance characteristics were calculated. The turbine will operate at 36,000 rpm with inlet pressure and temperature of 115 psia and 1150°F . Outlet pressure and temperature are 9 psia and 628°F , respectively. The alternator will produce 1800-cps ac at 76/132 v with a calculated efficiency of 87%.

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Three boilers were completed and performance tests revealed that the boiler thermal performance was satisfactory. Changes in the boiler fabrication procedure to avoid recurrence of pin-hole leakage observed during tests, will cause a slippage in power conversion subsystem (PCS-II) delivery.

Replacement components for PCS-II-0 to be used for performance testing in prototype system mockup (PSM-I) are still in fabrication. PCS-II-2, to be used for structural integrity tests in PSM-2 is scheduled for completion in October. PCS-II-3, to be used for orbital startup tests in PSM-3, is still in fabrication. The endurance test rig is complete and is ready for installation of the PCS-II-1.

In 3000-hr mercury loop tests at 700° F Haynes 25 filler and Nicrobraz 130 showed the least penetration of various materials tested. PH15-7 Mo in condition TH 1050 was severely embrittled at 700° F in the loop. In separation tests, more corroded material was collected in a Haynes 25-PH15-7 Mo bimetallic loop than in a monometallic Haynes 25 loop. In room temperature tests it was shown that Haynes 25 loses ductility on aging at elevated temperature. The degree of embrittlement is time dependent and occurs at a more rapid rate with increasing aging temperature.

Honeycomb RC-11-1 fabrication is on schedule; stainless steel bars are being used to simulate tapered tubes because of the difficulties encountered in the fabrication of tapered tubes. These difficulties are being overcome and RC-11-2 will be made of tapered rectangular tubes. Tubing and manifolds for the aluminum-steel RC-10 were completed and the structure is being assembled by brazing. Completion is scheduled for November 1962. Fabrication of the aluminum-steel RC-13 is on schedule with completion planned for 1963. Test procedures and schedules for thermal, structural, and vibration testing of RC-10 and RC-13 are in preparation. Honeycomb RC-6 (S/N-2) thermal performance tests have been initiated. RC-6 (S/N-1) is undergoing structural and vibration tests.

SNAP 2 PSM-1 redesign to incorporate flight system prototype subsystems and components was continued. Work was initiated on the PSM-1 operations manual. The heat source in this system, which replaces the reactor heat source in the flight system, will be computer controlled to simulate orbital startup. Modified cartridge heaters used in the ground test heat source have operated over 300 hr at 1300° F in vacuum as low as 10 microns. At higher temperatures heaters failed by arc-over in vacuum.

A five-part comprehensive test plan was devised for testing of critical components and subsystems of SNAP 2 PSM-3 in five stages. Major emphasis during this quarter was on installation of a test system for testing of the horizontal RC designed to simulate zero-g, and modification of the APU design to incorporate PCS-II-3 changes.

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Tests were performed on the SNAP 2 Developmental System (S2DS) reactor to determine the transients imposed on the NaK system during CRU spinup.

Safety analyses for APU shipments to flight test sites and for APU launch site incidents were initiated. A study of hazards during recovery from various postulated nuclear incidents has been completed.

A specification for SNAP 2 reliability requirements has been released.

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II. FLIGHT SYSTEM P & I DIAGRAMS

The flight system P & I diagram (AI Drawing No. 2BSD-07001) was extensively revised during the reporting period to incorporate changes resulting from the improved design of the CRU-V. The following significant changes are included in the revised diagram, which is scheduled for issue in the next reporting period.

A. NaK SYSTEM INSTRUMENTATION

The NaK system pressure-monitoring instrument tap was relocated from downstream of the startup pump to the CRU NaK pump inlet to eliminate an additional connection to the main NaK piping.

B. MERCURY SYSTEM INSTRUMENTATION

All mercury system instrumentation was reevaluated to adjust to the elimination of the jet drain pump, alternator cooling coil, and turbine journal bearing cooler from the CRU module design, and to accommodate the addition of a drain cooler heat exchanger and CRU exhaust vapor venturi. Temperature instruments were relocated and additional pressure instruments were added to monitor the revised CRU module configuration. Studies of transient performance expected in the mercury system determined instrument sampling rate requirements. Operating instrument span requirements were adjusted to reflect changes in system performance.

Improved analysis of RC aerodynamic heating experience required a reevaluation of RC temperature instrumentation. The location, number, and response requirements for these instruments are being revised. The RC pressure sensor (PS-202) tap was relocated from a position immediately downstream of the inlet of a condenser tube to a point immediately downstream of the CRU exhaust vapor venturi. Limited space for pressure sensor installation required relocation of the sensor. Reexamination of predicted startup thermal experience of the RC resulted in a reevaluation of contemplated instrumentation. A new instrumentation configuration is being developed to cover all aspects of RC thermal instrumentation, steady-state and transient.

Final selection of CRU bearing fluid instrumentation is dependent on the CRU bearing design. Flight instrumentation will provide for the measurement

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of bearing inlet pressure if flow regulators are provided for individual bearing lines. Alternatively, flow in each bearing line will be monitored if flow regulators are not provided. Alternator stator surface and hot spot temperatures are being reconsidered for flight instrumentation.

C. STARTUP SYSTEM INSTRUMENTATION

The flight instrumentation system was revised to reflect the design changes in the startup system. Changes in the startup sequence eliminated the requirement for the pressure sensor (PS-201) used to initiate opening of the delayed mercury injection valve after full injection pressure had been developed. Changes in the system to provide full mercury inventory storage in the injection tank eliminated the requirement for the mercury pressure regulator valve (V-108) which was deleted. Regulator-tank temperature monitoring and regulator-tank heaters were also deleted. The three-way nitrogen supply valve was replaced by a two-way nitrogen supply valve and a nitrogen bleed valve. A check valve was added to the nitrogen fill line.

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III. FLIGHT SYSTEM CONFIGURATION

A. APU DESIGN AND STRUCTURAL ANALYSIS

During the last quarter, the following designs and analyses were in progress or completed.

An aluminum-steel radiator-condenser (RC-13) was designed and the structural analysis completed. The outer surface is a low strength, high conductivity 1100-0 aluminum coated with a high emissivity coating. The tubes are an electron beam assembly of Haynes 25, while the frames are 2014-T6 aluminum except at highly loaded stations where A286 steel frames are used. The structure is designed to take the ground operation, launch vibration, maximum dynamic pressure, maximum acceleration, and aerodynamic heating loads in chronological order as they occur. The aerodynamic heating produces severe thermal stresses in the structure which causes the 1100-0 aluminum to yield. This deformation is not expected to alter the performance characteristics.

An inline expansion compensator was designed. The advantages of the inline compensator are less possibility of NaK freezing, better mounting quality, and lighter weight.

A thermal barrier was designed to protect the instrumentation compartment from the APU internal radiant heat. The barrier is designed to reduce the temperature to 165°F in this area. The material is Thompsoglass GS 15000, which has a density of 8 lb/ft³. Tests are being conducted to determine the strength properties of this material.

A preliminary analysis of the thermoelectric NaK pump was completed and released. The analysis concluded that the pump was satisfactory as designed for a mercury coolant.

Meteoroid protection studies were conducted and design curves were drawn for various materials as a function of thickness and vulnerable area. The curves of Figure 1 show the probability that no puncture will occur in Haynes 25, stainless steels, and aluminum alloys, respectively, after 1 year at 600°F for various combinations of vulnerable area and armor thickness. In these curves vulnerable area is defined as the inside cross-sectional area of RC tubes and manifolds projected perpendicularly on the RC surface.

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a.

b.

c.

Figure 1. Meteoroid Protection

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The calculation is based on an average projectile velocity of 30 km/sec with the armor thickness proportional to the $2/3$ power of velocity. Extrapolation of test data indicates that penetration as a function of meteoroid energy is reasonably well defined by these assumptions. The influx rate is now somewhat better defined than it had previously been.

A design specification for the aluminum radiator-condenser, RC-13 (NR7550-30), was released and the design specification for the honeycomb RC (NR7550-29) was begun.

Design layouts for test cones were drawn. The purpose of these cones is to simulate the thermal load conditions on an aluminum RC. The test data desired from these cones will provide design input for a flight aluminum-steel RC.

The Power Conversion Control Drawing 2BSD1-80003 was completed showing location of all PCS components.

A layout of the instrumentation wiring within the APU was begun.

Drafts of the following specifications were completed during this quarter:

- 1) NR7550-25 - SNAP 2 Parasitic Load Heater
- 2) NR7550-26 - SNAP 2 Ground Test Heater
- 3) NR7550-38 - SNAP 2 Reactor Simulator Test Heater
- 4) NR7550-21 - SNAP 2 Radiator Shield

A shield configuration for SNAP 2 was selected for the reference design. The shield weight has been increased to a total of 350 lb and consists of a 50-lb container and 300 lb of shielding material. The existing APU configuration will be maintained with the extra material being added to the bottom of the shield. The calculated dose levels are now within the Lockheed Missiles and Space Company (LMSC) equipment radiation hardening objectives.

A stress analysis of the Model 5-C boiler was initiated. This considers vibration loading, thermal and static stresses.

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IV. FLIGHT SYSTEM ANALYSIS

A. CURRENT DESIGN POINT

A schematic view of the SNAP 2 flight design system is shown in Figure 2. This figure supersedes the one issued on March 2, 1962 (System Description NA-2FS-60-003) and shown as Figure 2 in NAA-SR-7191 (p 16). Figure 2 incorporates the new spiral boiler design. Slight changes due to the different characteristics of the CRU-V have been incorporated. The mercury boiler exit temperature has been increased from 1154°F to 1160°F to provide for the additional heat loss between the new 5-C boiler and the turbine.

B. EVALUATION OF PROGRESS

1. Increased Boiler Exit Temperature Requirements

The new 5-C boiler requires a longer mercury vapor line between the boiler and turbine. Consequently, there is an increase in temperature drop from 4 to 10°F between the boiler and the turbine. Preliminary tests of the new 5-C boiler indicate that the higher required outlet temperature of 1160°F can be obtained.

2. Compensation for Bracket Heat Loads

Reflective gold insulation was added to eight condensing tubes and fins adjacent to the boiler and to the entire subcooler. This addition will compensate for the adverse effects of local RC heating due to hot support brackets from the boiler and NaK lines.

3. Increased Vapor Pressure Loss

The new CRU-5 will require a venturi which will be considered as a part of the CRU for the purpose of calculating pressure drop. The venturi will be choked during startup and will have a steady state loss of 0.12 psi. A design point pressure of 9 psia is required downstream of the venturi. No significant difficulty is anticipated in meeting this requirement.

4. Mercury Heat Regenerator

The new CRU-5 requires a regenerator to exchange heat between the bearing drain fluid and boiler inlet fluid as reported in the last quarterly. The latest CRU-5 module drawing includes drain lines from all three bearings to the regenerator.

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Figure 2. Schematic of SNAP 2 Flight Design System

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C. ORBITAL STARTUP

1. Startup Method

The specification for SNAP 2 Orbital Startup Performance Requirements was released during this reporting period as NR-7550-06. This specification provides the reference flight system sequence and performance requirements, as well as the predicted transients which will occur throughout the system during startup.

Figure 3 is a schematic of the reference startup system; it differs slightly from and supersedes Figure 3 of NAA-SR-7491 (Snap 2 Quarterly Report April-June 1962). The major difference in the startup method is that all of the system mercury inventory will be contained in the injection tank rather than part of the inventory being initially in the pressure regulator tank. The reason for this change was two-fold:

- a) The new method eliminates the valve on the regulator tank.
- b) The possibility of CRU cavity flooding during startup is significantly decreased by not having the low-pressure plumbing pressurized immediately at the time of injection.

The original reason for storing some of the inventory in the regulator tank prior to injection and providing only enough mercury in the injection tank to spin up the CRU was to save weight by decreasing the size of the injection tank.

The inclusion of a venturi at the vapor exit of the CRU was incorporated during this reporting period. During the phase of radiator preheat, the low condensing pressure is reflected back to the CRU. Without a nozzle in the vapor exit line, this would give rise to a low pressure in the CRU cavity and thus present a liquid flooding problem. The nozzle has the characteristic of producing a cavity pressure greater than the drain pressure under the conditions of full vapor flow to the radiator. During the time required to attain full vapor flow, the dead volume in the low pressure plumbing provides a sufficient void to prevent flooding. As the condenser comes up to pressure, the exit nozzle unchokes and produces less than a 0.12 psi steady state pressure loss.

2. Startup Analysis

The digital code used to determine primary loop transients resulting from orbital startup is currently being revised to incorporate detailed effects. The major modifications include:

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Figure 3. SNAP 2 Orbital Startup Schematic

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- a) Temperature effects on the NaK flow provided by the startup pump during the preheat phase of startup,
- b) Temperature effects on reactor heat transfer and reactivity coefficients,
- c) Temperature effects on the NaK flow provided by the CRU NaK pump.

Also in progress is the evaluation of the RC exit flow and temperature transient following opening of the exit valve at the end of radiator preheat.

3. Control System

The sensing point for reactor control in the SNAP 2 system is the boiler exit NaK temperature. The control system reported last period provided control drum step insertions at a rate of 1 step/100 sec, each time exit temperature fell below 1000°F. Further investigation of this control method indicated that the steady-state system temperatures following the injection transient would be about 60°F higher than the normal design point. The reference control system was revised during this reporting period to provide a slower stepping rate (1 step/400 sec) after primary loop preheat, and a bilateral control (1000 to 1030°F dead band) action.

The slower stepping rate results in less reactivity insertion during the temperature oscillations after injection. The bilateral control prevents an overshoot of the steady-state temperature after the injection transient. Delay of 400 sec in the revised control system after the temperature passes out of the dead band is provided before any control action occurs to avoid system limit cycling.

This revised system provides excellent temperature control. However, work is continuing to simplify the control system. It is expected that the analysis now in progress will indicate that bilateral control can be eliminated and that slowing of the stepping rate will be sufficient to avoid overshooting the design point temperatures following injection.

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V. SUBSYSTEM DEVELOPMENT

A. PRIMARY SUBSYSTEM

The objective of the NaK Component Development program is to design components integral to the NaK coolant system of SNAP 2 and qualify these components for use in SNAP 2 systems. These components include NaK flow trimmer, orbital start pump, parasitic load heater, expansion compensator, and the auxiliary ground heater. The program also provides for supporting liquid metal technology required for system tests.

1. Flow Trimmer

The function of the flow trimmer is to provide a means of adjusting the NaK flow to design flow conditions. Once set, during system acceptance testing, the trimmer is never altered. Flow is increased or decreased by lowering or raising the flow resistance of the primary loop. The flow trimmer must be capable of adjusting the pressure drop in the range of 2.5 psi to 3.5 psi at 70 lb/min.

The design of the flow trimmer was completed based on present specifications. The design (AI Drawing 7562-34001) consists of contoured steel crimping blocks welded to a section of system piping. A mechanical crimping device has been designed to operate the flow trimmer during qualification testing. Data were taken with the flow trimmer installed in both water and NaK loops. The correlated data are presented in Figure 4, which shows the required pressure drop range of 2.5 to 3.5 psi at 70 lb/min is obtainable with the flow trimmer.

Environmental qualification tests were performed. A flow trimmer was mechanically cycled once and installed in a NaK test loop where it operated over 4500 hr with 1200°F NaK at a flowrate of 70 lb/min without a change in performance characteristics. The flight weight of the unit is under 2 lb. Work is proceeding on the design of a remotely driven flow trimmer actuator.

2. Orbital Start Pump

The purpose of the orbital start pump is to circulate NaK at 5% of the design flowrate prior to spinup of the CRU and during startup. This flow is necessary to prevent NaK freezeup during prestart orbiting and to provide flow during startup of the system.

Figure 4. SNAP 2 Flow Trimmer Pressure Drop

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A dc conduction pump is being used for this purpose. The design was completed based on present specifications. Two pumps have been tested to date. The first pump was operated for 1300 hr at 70°F and 1900 hr at 1000°F. Under both conditions the pump met the design flowrate of 3.6 lb/min using less than 40 amp. The second pump is still undergoing testing. To date this pump has operated for 338 hr at 70°F and 1841 hr at 1000°F. It likewise met the design requirements. Both pumps satisfactorily met the environmental qualification tests. The weight of the pump is under 4 lb. The design is being released on AI Dwg. 7562-81007.

3. Parasitic Load Heater

The parasitic load heater is used to absorb power generated by the alternator over and above the immediate demand of the payload. This excess power is dissipated in the NaK system by the parasitic load heaters. As heat is absorbed by the NaK system, reactor power is reduced by the temperature controller. In the control system circuit six resistors of 3.23 ohms each are divided into two parasitic load heater units. One unit is installed in the reactor outlet line, the other unit is installed in the reactor inlet line.

In an earlier version of the control system, eight resistors of 12.4 ohms each were used. Therefore, all design work and testing was based on parasitic load heaters having four resistors of 12.4 ohms each. However, the testing accomplished on the 12.4 ohm resistors yielded the required information necessary for a satisfactory design of the 3.23 ohm resistor units.

A four-resistor parasitic load heater with four cartridge heaters has operated at the design rating of 1.67 kw and 1200°F for 4125 hr. Another unit of the same design underwent 1095 power cycles of 0 to 1.67 kw before failure of the first cartridge occurred. The design cyclic lifetime of the parasitic load heater is 1000 cycles.

A second design of four coaxial heater cables brazed to the outside of the NaK tubing was fabricated and is ready for testing in a NaK loop. The coaxial heaters have the lead connection swaged inside of the heater sheath. This will reduce the probability of heater lead failures. This design results in a weight reduction and eliminates any pressure drop due to the parasitic load heater.

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A change in the number of heater cables from four to three and a reduction in the resistance makes the coaxial design easily adaptable to the present specification. The weight is expected to be under 1 lb.

4. Expansion Compensator

The expansion compensator is used to absorb the 20% increase in NaK volume due to thermal expansion after reactor startup. In addition this component must regulate the NaK pressure to ensure that no NaK boiling or cavitation occurs in the system.

Two expansion compensators of the Mark II design were received and subjected to volume and pressure checks. One of these compensator bellows (PH-15-7 Mo) was installed in a hot NaK test facility and was cycled through 30 complete volume cycles of 0 to 325 in.³ before one of the welds failed. Subsequent review of this failure and testing on SNAP 10A bellows of the same material resulted in a change from PH-15-7 Mo to AM350. Also, the volume of the SNAP 2 system was reduced due to a change in boiler design which resulted in reducing the required volume of the expansion compensator from 325 in.³ to 190 in.³. New bellows assemblies were ordered based on these changes and are now on hand for testing. Assembly into the superstructure is being carried out prior to hot gas and hot NaK testing.

Work is continuing on the design of the Mark III inline compensator concept utilizing a large bellows and a small bellows working in opposition.

The flight weight of either a Mark II or a Mark III compensator is about 12 lb.

5. Auxiliary Ground Heater

The auxiliary ground heater is used during ground testing of the SNAP 2 system to simulate reactor power (53 kw).

The reference design is an inline cartridge heater with fourteen 4700-w heater cartridges. Induction heating is being investigated for use as the auxiliary ground heater. Such a unit promises reduction of flight weight to a minimum while maintaining the necessary reliability. Two vendors are investigating a design to meet the requirements and it is planned to provide a NaK test facility at the vendors to test the heater and power supply before the equipment is accepted by AI.

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6. Thermoelectric Pump

The objective of the SNAP 2 thermoelectric pump program is to provide a high reliability, lightweight, thermoelectric-powered dc conduction pump to be used as a backup for the on-shaft CRU NaK pump. A flow of 70 lb/min of NaK at 1000°F and 2.0 psi pressure head is required. According to the present schedule a 90-day endurance test will be completed by March 1963.

a. Current Status

Procurement and fabrication of development model pump test units, test equipment and facilities was completed. Two Pb-Sn-Te units were fabricated and are now being instrumented prior to insertion into the test loop. Several design changes were made during the reporting period as a result of materials compatibility and performance analysis studies. Increased structural strength and more efficient heat transfer were obtained.

Mapping of development model performance will be started within the next report period. Linking of the instrument consoles to the test loops is currently in the final phase. Expected steady-state temperature distributions have been compiled from an analog study to provide background test data. A test document detailing the test methods has been completed.

The Si-Ge pump effort was halted in August due to the successful long-term operation of the SNAP 10A Pb-Sn-Te development units. The designs and studies already developed have been tabulated and filed for possible future reactivation.

b. Design Improvements

An uninstrumented Pb-Sn-Te development pump is shown in Figure 5. The four Hg coolant tubes have been recessed into the copper cold junction plate. This change from the previously reported method of brazing the tubes to a flat cold junction plate substantially increases the structural strength of the unit in the area where initial thermal shock due to Hg injection is expected to be most severe, and increases heat transfer efficiency by providing larger heat transfer area adjacent to the coolant tubes. Pump performance is improved by about 10%.

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Figure 5. SNAP 2 Pb-Sn-Te Thermoelectric NaK Pump (Dev. Model)

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While the development model design was frozen early in this report period, efforts to increase performance and fabrication techniques were continued. Computer results indicate that a 10 to 20% performance improvement is possible by increasing and contouring the magnetic field. These parameter variations will be verified during performance test operations. Improvement in performance of follow-on flight units due to a decrease in thermoelectric element thickness and a change of NaK channel material is currently being analyzed. A NaK channel materials investigation is also being conducted to increase yield strength to meet the high NaK loop static pressures of 25 psi at 1000°F in orbit and 40 psi at 100°F during launch. Initial stress calculations indicate that yielding will occur at 19 psi for the in-orbit condition. The materials which offer the best advantages in strength and electrical properties are Haynes 25, Inconel X, and UDIMET 700. Results of these investigations and methods of incorporating these changes into the flight design will be reported in the next reporting period.

c. Test Program

Figures 6, 7, and 8 show the status of the three test loops. Loops 1 and 2 have been fabricated so that NaK can be used in place of Hg as the secondary coolant for the development model tests. Loop No. 3 will contain equipment for NaK to Hg heat transfer. The insulated portion of the system constitutes the primary NaK loop and the remainder, the secondary coolant loop. SNAP 2 temperature conditions will be simulated by controlling the primary loop temperature at 1000°F and insulating the secondary loop as required.

Instrumentation for the tests is located in a console and provides for continuous monitoring of flow and temperature. Transient conditions will be monitored by a Visicorder Oscillograph during startup and Hg injection tests.

7. Emittance Coating Development

a. Development Status of High Thermal Emittance, Low Solar Absorptance Coatings

A tailored high emittance coating ($\epsilon = 0.90$, $\alpha_s = 0.30$), which is adaptable to aluminum and copper substrates, is undergoing qualification tests for use on the SNAP 2 RC and the SNAP 10A thermoelectric converter. Previous testing of the coated panel had included thermal cycle tests from +600 to -100°F.

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Figure 6. Test Loop No. 1 — SNAP 2 Thermoelectric Pump (Nak-Nak)

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Figure 7. Test Loop No. 2 — SNAP 2 Thermo-
electric Pump (NaK-NaK)

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Figure 8. Test Loop No. 3 — SNAP 2 Thermo-
electric Pump (NaK-Hg)

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Mechanical vibration testing of the coating applied to the SNAP 2 copper honeycomb RC has been completed. A 2- by 4-ft test panel was fabricated of 0.005 in. skin, sandwiching 0.001 in. core PH15-7 Mo honeycomb materials with a 0.030 in. copper face sheet brazed to the honeycomb. The copper face sheet was coated with the high emittance material. One mercury tube running lengthwise through the panel was incorporated in the structure.

The emittance coating successfully withstood strain levels of 2072 μ in. ($\sim 62,000$ psi) without apparent damage. A 2-min test at the first resonant mode (22 cps) resulted in over 2600 cycles of reversed loading on the coating material. Lesser strain levels occurred during the tests conducted at the second and third resonant modes.

The various mode shapes were determined with small sugar crystals as shown in Figures 9 through 13. A panel torsion mode was observed at 9 cps (Figure 10). First bending occurred at 22 cps (Figure 11); second bending was at 69 cps (Figure 12), and third bending took place at 142 cps (Figure 13). The resonant frequency for each mode can be noted on the electronic counter located in the background of each picture. Figures 14 and 15 show magnified closeups of the emittance coating at areas of maximum strain for each mode after test.

The second environmental qualification test which was recently completed was a test on the adherence qualities of the high emittance coating. The environment simulated that which would be experienced by the coating during the ascent of the vehicle.

The tailored coating was applied to 2- by 3-ft aluminum and copper panels. The ascent heatup rate for the aluminum panel was ambient to 770°F in 141 sec. The ascent heatup rate for the copper panel was ambient to 680°F in 141 sec. Each panel underwent 10 cycles at these heatup rates. No damage to the coating occurred during these tests.

A further qualification test now being performed is long-term emittance stability. Stability data obtained to date are as follows:

Coating Substrate	Time (hr)	Temperature (°F)	Vacuum (Torr)	Total Hemispherical Emittance
Copper	24	600	10^{-5}	0.91
	1000	600	10^{-5}	0.91
	2000	600	10^{-5}	0.91
Aluminum	24	600	10^{-5}	0.90
	1000	600	10^{-5}	0.90

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Figure 9. Panel Before Test Series

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Figure 10. Response Pattern (9 cps)

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Figure 11. First Bending Mode Pattern (22 cps)

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Figure 12. Second Bending Mode Pattern (69 cps)

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Figure 13. Third Bending Mode Pattern (143 cps)

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Figure 14. Coating at Anti-node of 1st and 3rd Modes After Test

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Figure 15. Coating at Anti-node of 2nd Mode After Test

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Qualification tests to establish the stability of the tailored coating in a nuclear irradiation field continue. The initial high energy particles bombardment test on the tailored coating was performed in the AI Statitron. Prior to the electron irradiation, the total hemispherical emittance of the coated specimen was 0.90. During the Statitron test, the coated specimen was maintained at 600°F and received an integrated dose of 3×10^{18} nvt with electrons of 1.25 Mev energy. After irradiation, visual examination of the specimen showed no damage to or discoloration of the coating. The emittance of the irradiated coated specimen was 0.88.

Electron irradiation of the coated specimen was repeated. During this test the temperature of the specimen was maintained at 130°F to determine low temperature irradiation effects. Integrated electron dose was 10^{18} nvt at 1.25 Mev energy level. No damage to or discoloration of the coating occurred. The emittance of the irradiated coating was 0.89. The change in total hemispherical emittance of the coating noted during these tests may be more apparent than real since the observed change is within the 3% uncertainty of the measuring device.

The second high energy particle bombardment test of the tailored coating was performed in the SETF irradiation facility. On June 26, 1962 the SETF initiated a full power operation which continued through July 31, 1962. During this time the reactor logged 47,163 kw-hr. Tailored emittance coating samples were irradiated in an experimental capsule located ~2 ft directly below the core centerline.

The fast neutron current per watt at a point 2 ft from the core centerline is:

$$3.01 \times 10^4 \frac{\text{neutron}}{\text{cm}^2\text{-sec}}$$

The thermal neutron current per watt is:

$$1.39 \times 10^4 \frac{\text{neutron}}{\text{cm}^2\text{-sec}}$$

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Therefore, the coating specimens received an integrated thermal neutron irradiation of $\sim 5 \times 10^{15}$ neutrons/cm² and an integrated fast neutron irradiation of $\sim 10^{16}$ neutrons/cm².

On August 14, 1962, the coating specimens were removed from the irradiation tube and examined visually. These specimens included the tailored coating as applied to an aluminum substrate and to a copper substrate. In neither case was there evidence of physical damage to the coating.

b. Development Status of Low Thermal Emittance Coatings

To maintain the integrity of low emittance coatings, which are required to operate for 10,000 hr in the temperature range 800 to 1250°F, in a hard vacuum, it is necessary to interpose a diffusion barrier between the stainless steel or Haynes 25 substrate and the reflective coating. The alternative approach to the integral composite coating system is the use of low emittance foil which can be tackwelded or clamped to the substrate.

For use in areas in which the maximum operating temperature is 1050°F, it has been determined that gold-coated molybdenum foil is a stable low emittance coating system. Long-term stability tests of this coating system indicate no major emittance degradation. The data obtained to date is as follows:

Coating System	Time (hr)	Total Hemispherical Emittance
Two coats of Liquid	0	0.048
Brite gold type 8146 on	1000	0.055
0.001 in. Mo foil	1465	0.055

The stability test was performed at 1000°F, in vacuum (10^{-6} Torr). Further long-term stability tests of this coating system are continuing.

For use in areas in which the operating temperature of the low emittance coating system is in the range (1050 to 1250°F), the only stable coating system found to date is pure gold foil.

Welding techniques for application of the gold foil or gold-coated Mo foil to the various substrates of the SNAP 2 and SNAP 10A systems are being developed.

B. POWER CONVERSION SUBSYSTEM

The PCS is defined as the secondary (mercury) loop of the SNAP 2 APU excluding the RC. Specific areas of PCS development are as follows:

- 1) CRU which comprises a mercury vapor turbine, NaK pump, mercury pump, and alternator,
- 2) Mercury-lubricated bearings,
- 3) NaK to boiling mercury heat exchanger,
- 4) Orbital startup system,
- 5) CRU speed control,
- 6) PCS module (subsystem of PCS components for integration into an APU),
- 7) Materials research.

Highlights of PCS development progress during the quarter are summarized in the following text.

1. Development Status

The first interim CRU (CRU-IV-M-1) was installed in the performance test rig and operated until turbine bearing seizure caused shutdown. Hardware and test results analysis indicate improper bearing drainage may have caused the failure; metallurgical examination is in process to augment this analysis. Redesign has been incorporated and rebuild will be completed in time for the next scheduled test series.

The flight CRU, shown conceptually in Figure 16, has been firmly established. This concept incorporates improvements on, and the optimum features of, the CRU-IV unit. Design and development efforts continue towards completion of the final drawings and initiation of fabrication early in CY-63. Development of plain, tilting pad, and sector bearings continued during this quarter, with tests made on the various bearing types in the bearing test rig. Three new compact boilers were completed and thermal test results were highly satisfactory for the unit tested. Certain cold-working techniques used on the tubes were found to produce adverse effects such as pinhole leakage. The boiler fabrication schedule was altered, to remedy this situation. The schedule alteration caused slippage in PCS-II deliveries.

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Figure 16. CRU-V Selected Concept

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Four simulated orbital squirt start tests were made using a CRU-III. Design speed was obtained ~110 sec after Hg injection, but turbine flooding and drainage problems prevented stabilization at design speed.

Endurance tests on start system components revealed satisfactory operation. PCS work progressed satisfactorily with fabrication in process on each of the major subsystems.

Material research continued with a 3000-hr thermal convection loop test, aging tests evaluating Haynes 25 embrittlement, and investigation of crud separation.

2. CRU Development

a. Interim CRU Development

(1) Performance Testing

The first CRU-IV-M unit was assembled during the early part of August and installed in the performance test rig (see Figure 17). This unit has plain journal bearings with nominal diametral cold clearance of 0.002 in. for both the alternator and turbine bearings. A cold-gas test with nitrogen took place on August 17, at which time the unit was operated at full speed (40,000 rpm). Performance characteristics were excellent except that the turbine bearing drain flow was leaving the unit through the NaK rotor cavity. The test was terminated after 1-1/2 hr of operation to permit changes in the plumbing module to correct this condition.

The cold gas test was restarted on August 20, and after ~1 hr at a speed of 40,000 rpm, the turbine bearing seized. Disassembly revealed welding of the journal bushing to the bearing bushing (see Figure 18). Tentatively, the failure is attributed to improper bearing drainage, and foreign particles in the turbine. Pitting was evidenced on the first and second stages of the turbine at both the nozzle outside diameter, and the shroud ring (see Figure 19). The NaK end of the shaft was also slightly bent. Investigations are underway to determine the cause of failure. Figure 20 illustrates some major performance characteristics prior to failure.

(2) Mercury Pump

During the cold gas test of the CRU-IV-M-1, the Hg pump operating at 40,000 rpm delivered 40 lb/min at 560 psig as predicted.

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Figure 17. CRU-IV-M-1 in Performance Test Rig

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Figure 18. CRU-IV-M-1 Turbine Journal-Sleeve Seizure

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Figure 19. CRU-IV-M-1 Turbine Wheel Pitting

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Figure 20. CRU-IV-M-1 Prequalification Test Speed, Power and Turbine Pressure Test Dates: 8/17/62, 8/20/62

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Fabrication and assembly of a CRU-IV-M mercury pump was completed for component testing. Testing began during the latter part of August; however, the test-rig motor drive failed and the unit was disassembled for repair and inspection.

(3) Turbine

A plexiglass model of the CRU-IV-M turbine inlet scroll was constructed to permit investigation of the centrifugal separation action of Hg droplets in the inlet scroll. Mercury-nitrogen tests revealed that any liquid Hg entering the turbine inlet area will be carried by the gas stream and a turbine inlet is not necessary.

Proof testing of the CRU-IV-M turbine rotor was accomplished by a cold spin test to 49,000 rpm. This is equivalent to 46,000 rpm hot operation at which speed stress is $\sim 30\%$ greater than the stress at design speed for the first-stage wheel. Post-test inspection revealed no dimensional change in the wheel.

The CRU-IV-M-1 turbine was performance tested with nitrogen gas. The maximum efficiency was 56%, which is $\sim 8\%$ better than the CRU-IV-0 turbine under similar conditions.

(4) Alternator

The alternator to be used with the first CRU-IV-M was subjected to an acceptance-performance test in which it produced 3500 w at 80 v output with 87% efficiency. Tests to determine maximum power output at various speeds indicated a value of 4 kw at 80 v at 40,000 rpm. Increased I^2R losses (overheating) appeared to be the limiting factor. A 1000-hr, 700°F alternator-bore-seal endurance test was completed during this period with no leaks.

Bench tests revealed that numerous alternator rotor magnets were of poor quality. To correct this problem, fabrication procedures, and quality control techniques were reviewed, and it was recommended that the heat treatment procedure be modified. Two methods of demagnetizing the rotor were devised which now produce consistent, repeatable results, and minimum magnetic dissymmetry which minimizes a component of the rotating loads.

The CRU-IV-M-1 alternator was tested with a circuit containing capacitors and transformers. A capacitance of 40 mfd was found to be optimum.

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Spin test (44 K rpm for 5 hr) of the CRU-IV-M-2 alternator, conducted as a quality control check revealed no structural problems.

(5) NaK Pump

The 1000-hr, 1000°F rotor endurance test was completed successfully with no measurable decrease in magnet energy product. The 1000°F magnet stability test has accumulated over 2300 hr.

Performance tests were completed at room temperature, 600, 800, and 1000°F to determine pump performance as a function of NaK temperature. Analysis is in process.

(6) Stress Analysis

Analysis of the CRU housing established pipe load characteristics. The turbine inlet housing flange proved to be the most critical member with respect to bearing alignment. Calculation indicates that pipe loads are excessive and therefore the PCS must incorporate a more flexible connection to decrease distortion.

b. CRU-V Design and Development

(1) Performance Testing

Performance summary analyses have been completed for the CRU-V conceptual design and preliminary material selections have been made. Analysis of the selected conceptual design indicates that 36,000 rpm is the optimum operating speed. CRU-V design performance estimates are listed in Table I.

Analysis of bearing drain and subcooler Hg mixing indicated that the bearing lubricant temperature would decrease $\sim 140^\circ\text{F}$ when the RC subcooler outlet valve opens. The reduction in bearing lubricant inlet temperature results in a net increase in bearing radial clearance of 0.0002 in. An analysis was completed to determine the effect of using a nozzle in the vapor exhaust line to the RC. It was found that such a nozzle would produce a more rapid "can" pressurization during startup, thus reducing Hg flooding and thrust loads.

A dummy cradle was fabricated to evaluate mechanical and thermal distortions and a lubricant line seal fixture was fabricated to evaluate cradle-to-bearing housing sealing.

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TABLE I
CRU-V DESIGN PERFORMANCE ESTIMATES

<u>Turbine</u>		<u>Hg Pump</u>	
Speed	36,000 rpm	Inlet pressure to jet	6 psia
Inlet pressure	115 psia	Maximum inlet temperature	443°F
Inlet temperature	1150°F	Discharge pressure	525 psia
Discharge pressure	9 psia	Flow	50 ppm
Discharge temperature	628°F	Efficiency (with dynamic seal)	40%
Efficiency (maximum)	60%		
Flowrate	20 ppm		
<u>Alternator</u>		<u>Bearings</u>	
Frequency	1800 cps	Power consumption	
Voltage at gross power output	76/132 v	Alternator	~200 watts *
Efficiency at gross power output	87%	Turbine	~200 watts *
Number of phases	3	Thrust	140 watts
		Flowrate	
		Alternator	8 ppm
		Turbine	10 ppm
		Thrust	8 ppm
<u>NaK Pump</u>			
Pressure rise	2.0 psi		
Flowrate	11.7 ppm		
Efficiency	2.02%		

*Depends upon bearing configuration

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(2) Mercury Pump

The CRU-V mercury pump design was analyzed to optimize impeller configuration and performance, jet pump matching, and dynamic sealing for minimum leakage and thrust balance. The predicted performance of the pump configuration considered for this design application is shown in Figure 21. The jet pump in CRU-V is located 14 in. below the shaft centerline. With this design under ground test, impeller pressure is ~ 3.5 psi above the pressure which would result in cavitation.

A radial impeller design was completed and the impeller is being fabricated. A mixed-flow impeller design which incorporates an inducer stage on the inlet side of the impeller was designed.

A test was conducted to determine the effect of reverse flow at the jet pump inlet on jet pump discharge pressure. This test was performed with existing components.

Other tests initiated during this period were used to study the effect of using a diffuser instead of a volute for collecting the flow.

(3) Turbine

The CRU-V turbine conceptual and parametric analyses have been completed. In this design the first stage is subsonic with partial admission. The second stage is transonic with full admission. The overall turbine efficiency is calculated to be $\sim 60\%$. At 36,000 rpm, the first and second stage mean diameters are 2.0 and 2.18 in., respectively.

The interstage and main seal designs were completed. Estimated flow is 0.375 lb/min. The seals are simple labyrinths with 0.003 in. radial clearance. A seal test arrangement is being planned to provide facilities to test seals dynamically and statically.

(4) Alternator

Electrical, mechanical and thermal designs were studied to establish three-phase alternator performance in the CRU-V unit.

A stator assembly was thermally cycled for 1000 hr and then water quenched. The bore seal remained leak tight.

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Figure 21. CRU-V Pump Performance Characteristics

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Fabrication of stators is in process for CRU-V three-phase alternator development tests. Laminations of vanadium Permendur were recommended to improve stator thermal conductivity.

The design and fabrication of hardware for magnetic dissymmetry tests was started.

(5) NaK Pump

A diffuser scroll similar to past pump designs will be used in CRU-V. A constant pressure scroll and a constant area collector were both considered but rejected. Pump performance improvements will be developed by incorporating design changes into a research pump.

The present CRU-V concept will be designed so that the CRU shaft assembly can be removed from its housing without removal of the NaK pump housing. This design can be fabricated by casting rather than by tape-controlled milling. Costs, delivery times and design compromises are now being evaluated.

The rotor design will be similar to the one used in CRU-IV-M. The magnet length has been decreased which in turn decreases the overhung moment on the CRU shaft.

(6) Dynamic Analysis

Critical speed analysis of various shaft configurations for CRU-V indicated that a solid shaft will have higher critical speeds than a hollow shaft at bearing stiffnesses above 1×10^5 lb/in. in the first mode, and there are no discernible differences between shaft configurations below 1×10^5 lb/in. bearing stiffness (see Figure 22). Evaluation of balancing techniques at operating speed is continuing with an emphasis placed on establishing a CRU-V shaft design compatible with high speed balancing techniques.

(7) Thermal Analysis

A preliminary thermal analysis was completed for the CRU-V design. A more refined thermal analysis is in process. The temperature distribution in the CRU due to NaK preheat from 25 to 1000°F in 4 hr was calculated. Design of the alternator cooling fins for cooling with turbine exhaust vapor is in progress.

Figure 22. CRU-V Shaft Configuration Analysis

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(8) Stress Analysis

Detailed stress analysis in various areas was completed. Bearing thrust loads of 100 lb were found to cause only insignificant axial deflection at the bearing. A thermal shock of $270^{\circ}\text{F } \Delta T$ will not exceed the yield strength of the bearing, but will cause ~ 0.0002 -in. reduction in bearing clearance. The alternator rotor sleeve has excessive creep at 900°F , but is satisfactory at 800°F . With bearings of BG-41 material the radial clearance will increase ~ 0.0005 in. during NaK preheat and 0.0003 in. from room temperature to squirt start. Differential growth between the shaft and housing from the thrust bearing to the turbine seal is 0.0023 in. at the end of NaK preheat and 0.0018 in. during steady-state operation.

3. Bearings

During this report period, plain journal bearings with a single axial supply pad, three-sector uncompensated bearings, three-pad compensated bearings, and tilting pad bearings were analyzed.

a. Plain Bearing $C_d = 0.002$

Two parametric tests were conducted on the single axially fed plain bearing. Performance was satisfactory to a speed of 56,000 rpm. Unidirectional loads up to 60 lb/bearing can be supported at 30,000 and 40,000 rpm.

Threshold of half-frequency whirl was $\sim 27,000$ rpm with shaft weight acting and supply pressure at ~ 150 psi. At supply pressures of 480 psi, stable operation was achieved at all speeds up to $\sim 37,000$ rpm. Load required to suppress half-frequency whirl is shown as Figure 23.

Loading into the supply pad was limited to about 20 lb at 30,000 rpm. If loading into the pad is increased above this limit, the bearing lubricant supply can be cutoff so that the bearing is starved of lubricant and early failure can occur.

The first mode critical for this bearing appeared at about 7,000 rpm. At this point a phase angle change of 90° was observed. Disassembly and inspection after this test series revealed some discoloration and light scoring of the sleeves and journals.

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STABILITY CHARACTERISTICS

OF
PLAIN JOURNAL BEARING

$C_d = 0.002"$
 $L_d = 0.312"$
 $D = 0.625"$

Figure 23. Total Unidirectional Load per Bearing to Suppress Whirl (lb)

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The second test was conducted on the same bearing but with an unbalanced shaft equivalent to a rotating load of 30 lb/bearing at 40,000 rpm. Both synchronous and half-frequency whirl were observed.

b. Three-Sector Bearing $C_D = 0.001$

The series of shaft dynamic tests started last report period with a balanced shaft operating in a 0.001-in. three-sector bearing. A complete test with a rotating load of 30 lb/bearing at 40,000 rpm was conducted. The shaft was operated at speeds up to 40,000 rpm without any evidence of half-frequency instability.

c. Three-Pad Bearing (Orifice Compensated)

The three-pad bearing is identical to a three-sector bearing except that the axial drain grooves have been removed. In the initial test the bearing clearance was 0.001 in. but this test was terminated after reaching 20,000 rpm because of serious flow starvation.

A second test was conducted on the same bearing with a clearance of 0.0014 to 0.0015 in. Operation was satisfactory at all speeds up to 45,000 rpm. No half-frequency whirl could be detected under any of the pressure, flow, and load conditions tested. Amplitude of shaft displacement in the bearing was extremely small at all speeds. A third test was conducted on the same bearings except that the shaft was unbalanced to an equivalent rotating load of 30 lb/bearing. Again, operation was successful at speeds up to and above 40,000 rpm without half-frequency whirl. The synchronous component due to the rotating load increased until at 40,000 rpm it absorbed approximately half the bearing clearance.

The data from both tests are being reduced and analyzed.

d. Tilting Pad Bearings

A series of tilting pad bearing tests with pivot point diametral clearances of 0.0016 to 0.002 in. and 0.0026 to 0.0028 in. was completed and a 200-hr endurance test was started during the report period.

The initial series of tests was conducted with a balanced shaft, with a shaft unbalanced to an equivalent rotating load of 10 lb/bearing and finally with a shaft unbalanced to a rotating load of 20 lb/bearing. Operation under each

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condition was satisfactory without any trace of half-frequency whirl instability. Maximum loads imposed were 20 lb unidirectional at 40,000 rpm, and 15 lb unidirectional combined with 20 lb rotating load at 40,000 rpm. This appeared to be the safe maximum. Although the shaft locus or synchronous whirl amplitude increased with rotating load from 0 to 20 lb/bearing load the amplitude was quite independent of speed. This confirmed the previous estimate based on analysis that this type of bearing operates above the first mode critical of the shaft system and consequently rotates about a center line closer to its center of gravity. Some problems of the balls acting as pivot points, sticking in either shoe or housing was encountered but this may have been due in part, to the use of 52100 steel for the balls which resulted in rust and crud formation around the balls.

The second series of tests was equally successful and again performance was satisfactory at speeds up to 45,000 rpm. The shaft in the configuration with larger pivot point clearance of 0.0026 to 0.0028 in. did not appear to have any half-frequency whirl and side loads equal to the loads imposed in the first series of tests were supported. Preliminary reduction of data indicates that the performance of this bearing falls along performance prediction curves based on the turbulent flow equations established from the previous series of tests.

The third test currently in process is a 200-hr endurance test on the 0.0026 to 0.0028 in. pivot point clearance bearing with 20 lb/bearing rotating load. The prime objective of this test is to determine if a fretting problem exists at the pivot point with the current configuration. About 100 hr have been accumulated without apparent problems.

e. Subcontracted Bearing Development Studies

Quarterly progress reports from MTI and Airesearch on bearing development are included as Appendix A and Appendix B, respectively.

4. NaK To Boiling Mercury Heat Exchanger

Activity during this quarter consisted of complete assembly of three compact boilers and completion of several boiler tests. The first thermal test of the 5C-1 boiler was completed on August 16, 1962. The NaK temperature profile indicates that the boiler reached a conditioned state within minutes after the start of Hg flow; operation was highly satisfactory. Performance testing

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continued with an investigation of off-design performance and the demonstration of the reproducibility of the boiler temperature profile. When the 5C-1 boiler was removed from the test rig leakage between the NaK and Hg sides of the 5C-1 was detected in three of the four tubes located in the body of the heat exchanger coil. Sections of these tubes have been removed from the boiler for detailed metallurgical examination and analysis of failure.

5. Orbital Start System Development

A flight system thrust bearing regulator was installed on a CRU-III in the ATR for use in squirt-start tests. The regulator operated successfully in two such tests. More complete data will be obtained when the system is disassembled. Half-scale, small spherical shells were stress-coated to ascertain the validity of the equations describing the stresses existing in flight tankage. Development efforts continue on the bearing flow regulators, the liquid level compensating valve, injector tank heaters, and the boiler flow regulator.

A series of orbital startup simulation tests was made which included system NaK heating with and without auxiliary alternator heat, CRU static Hg injection, and CRU dynamic Hg injection. The CRU was installed in the test rig as shown in Figure 24. Auxiliary alternator heat was required because the alternator end of the CRU was still at ambient temperature after a 90-min heatup to boiler design temperature followed by a 30-min soak. The static injection test indicated that bearing flows are established within 10 sec after injection in a prefilled system.

Dynamic injection tests were made which verified the Hg pump prime capability, and the system was run for ~25 min on the CRU Hg pump before intentional shutdown. During this test, the boiler flow regulator was adjusted so that boiler flow was ~14 lb/min. At this flow maximum turbine inlet pressure was 80 psia. The maximum CRU speed obtained was 39,400 rpm, ~110 sec after injection.

A dynamic start test was made without alternator preheat. However, the CRU did not reach design speed because of CRU flooding. A third dynamic injection is planned. During this injection, bearing drain flow will be diverted to the system drain reservoir until CRU rotation begins.

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Figure 24. CRU-III Installed in Test Rig

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6. Speed Control

Activity during this reporting period was primarily that of testing and improvement, since fabrication and assembly of the remaining panels of the Model 6-2 control was completed. Fabrication is in process on the Model 6-1 panels. It was found that the center frequency of the 20-cycle control band shifted to 2010 cps during potting. However, response time is unaffected. This has been measured as ~ 0.010 sec from full off to full on.

The Model 6-2 (see Figure 25) was successfully temperature cycled over the specified design temperature range; and efforts are now underway to perform heat rejection tests on this unit. Preliminary specifications have been received for the CRU-V control (three-phase, four-wire system) and design efforts are in process.

7. PCS

Table II summarizes the major components of the PCS-II-0, PCS-II-2, and PCS-II-3 subsystems.

a. PCS-II-0

PCS-II-0 will be used for performance testing in PSM-1. The PCS-II-0 Model 4 boiler and support structure was removed from PSM-1 and returned to TRW for boiler failure analysis. Investigations revealed that a tube spacer was cocked, possibly during fabrication, which in turn permitted the tubes to assume an incorrect configuration. A tube leak was detected by a helium leak check. Metallurgical examination is proceeding. Replacement components for PSM-1 are still in fabrication.

b. PCS-II-2

PCS-II-2 will be used for structural integrity tests in PSM-2. The major efforts on this sub-system during the past quarter continue to be on analysis, design, procurement, and environmental test.

The PCS-II-2 final assembly drawing is in process and 95% of the details have been released. Completion of fabrication is expected in early October. The boiler (5C-3) is scheduled for vibration testing late in September. All purchased parts except the tanks and the N_2 pressure regulator will be received by TRW before early October. CRU-IV D-2 will be rebuilt and assembled during the last week of September. All tank support bracketry natural frequencies are above 200 cps. Acrylic plastic has been added to the boiler lateral supports, which will burn out after launching and thus restrict heat loss to the RC.

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TABLE II
PCS-II SERIES MAJOR COMPONENTS

	PCS-II-0	PCS-II-2	PCS-II-3
Present Status	Returned to TRW for failure analysis. TRW to supply new components	Fabrication stage PSM-2 (for environmental test)	Fabrication stage (for PSM-3)
Boiler	Model 5C	Model 5C	Model 5C
CRU	Interim CRU	Mockup CRU-IV	Interim CRU
Injection Tank	Flight type	One 9.84-in. diam spherical tank with heater	2 to 75-lb capacity (spherical) with line heaters
Pressure Regulator Tank	Flight type	12 63-in. diam flight (bellows type and without heater)	2 to 60-lb cap (bellows type w/surface heater)
N ₂ Tank	AI furnished	9.84-in. diam 2000 psi cap. spherical tank (injector tank shell)	Flight type
Structure	Interim with RC	Flight type (integrated with RC)	PCS II-1 type modified to accept 5C boiler
Speed Control	Model 4 console	AI furnished mockup	Model 5-1 console
Condenser	Flight system RC in AI vac. chamber	None at TRW. Flight type RC at AI	Horizontal RC in AI vac. chamber
Insulation	Gold foil (AI furnished)	Thermal shield TRW furnished w/o gold foil	Nonflight applied by TRW (2-kw max heat loss)
Performance Instrumentation	AI furnished	Pressure trans. mass mockups (no T/C)	TRW furnished

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Figure 25. Model 6-2 Speed Control

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~~CONFIDENTIAL~~c. PCS-II-3

PCS-II-3 will be used for orbital startup tests in PSM-3. All layouts are complete and fabrication of components is in process. The injector tanks were successfully tested. The support structure was reworked to accept the Model 5C boiler. As a result of the piping analysis, flexible metal hose is being added to the NaK pump inlet and turbine inlet line to meet allowable CRU pipe loads. The PCS-II-3 parts list and overall assembly drawing were completed. The 5C-2 boiler has been completed and is currently being used as a plumbing fixture. The endurance test rig (ETR) preparation has been completed and is ready for installation of the PCS.

8. Materials Research

The 3000-hr loop endurance test was completed early during this period and a report was published. The loop, fabricated by AI, was operated for 3000-hr continuously at a boiling and condensing temperature of 700°F. Haynes 25 filler and Nicrobraz 130 showed the least penetrations of the various materials tested. The PH15-7 Mo material in condition TH1050 was severely embrittled in the 700°F temperature region of the system.

A crud-separation loop test was also completed in September. This loop (see Figure 26) fabricated from Haynes 25 and PH15-7 Mo stainless steel, was operated for 1000 hr with Hg boiled at 1095°F, superheated to 1130°F, condensed at 1095°F, and subcooled to 400°F. Hg circulated at 40 lb/hr in natural convection two-phase flow. The separators removed about 69.3% of the corroded metal removed from the container walls. The loop contained 28.3% and the Hg contained 2.4% of the deposits. In general, the columbium getters (see Figure 27) appeared to be most efficient at operating temperatures between 730 and 600°F. The magnets appeared to be most efficient between 650 and 500°F. A higher potential for separation was indicated for the separators operating in tandem. A total of 5.5 grams of corroded metal was collected in the Haynes 25-PH15-7 Mo loop as compared to 3.2 grams in an all Haynes 25 loop.

A 90-day, 900°F capsule test was completed on AM350 and 18% nickel. Based on weight loss, these materials have been put in classification II, on the mercury corrosion resistance scale.

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Figure 26. Corrosion Loop Installed in Insulated Container

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Figure 27. Columbium Turnings Showing Heavy Amalgam Trapping on Entry Side

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Embrittlement tests were also carried out on Haynes 25 material. Aging treatments were conducted at temperatures ranging from 1000 to 2000°F for exposure times up to 5000 hr. Loss of ductility was confirmed through standard metallographic procedures both at room and elevated temperatures. In room temperature tests the severity of embrittlement was time dependent and occurred at a greater rate with increased aging temperatures (see Figure 28). Loss of ductility with aging is normal for Haynes 25, but the loss may be minimized by controlling the minor element composition.

Visual observations of the failed CRU-IV-M1 hardware indicate high machining stresses, which in turn may have caused spalling and the resulting pitting of various internal surfaces (see Figure 20). Investigation is currently in process on the turbine bearing sleeve-journal welding.

C. STRUCTURAL-HEAT REJECTION SUBSYSTEM

1. Design Status

The parallel development of stainless steel honeycomb and aluminum skin-stainless steel tubing RC concepts has been continued. The stainless steel honeycomb structure is the reference design, but efforts are continuing to accelerate the aluminum-steel backup concept of a RC. The external geometry of both configurations is identical with only the type of structure, number of tubes, and other small details being different. Both radiator-condensers have 120 ft² of surface area.

All design layouts and drawings have been completed for both prototype concepts. The "A, B, and C" changes of drawing 2PSM2-54005 for the fabrication of RC-11 (stainless steel honeycomb) have been released. The "A" change has been approved by the AEC and has been incorporated in fabrication. AEC approval is still pending on the "B and C" changes. The control drawing 7562-D222502, for RC-13 (Aluminum-Steel Radiator-Condenser), has been approved and released. Vendor fabrication drawings have been completed and approved.

2. Weight Reduction Program

Preliminary design for weight reduction for the honeycomb concept has been initiated. Items such as tapered tube-side meteoroid protection, reduced honeycomb face sheet thickness, and reduced honeycomb core sheet thickness

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Figure 28. Comparison of Room Temperature and 1000°F Test Temperatures on Bend Ductility of Aged Haynes 25

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are being investigated. These designs require future development, fabrication of sample panels, and testing. Weight calculations are 95% complete on the present RC-11 and ~50% complete on RC-13.

3. Thermal and Structural Performance

Except for minor improvements, the thermal performance characteristics have remained unchanged, as expected, since the last report period. The total required heat rejection is 50.2 ± 0.8 kw with 46.5 kw from the condensing and subcooling heat load, 2.6 kw from internal components, and 1.9 kw max, -0.3 kw min, from the external solar and terrestrial radiation load. Other characteristics are identical to those previously reported.

The RC-10 structural analysis is complete, but requires revision to reflect the tubing modification. RC-11 structural analysis has been started while the RC-13 analysis is finished and is being released. The structural test programs will verify the analytical methods and obtain data in any questionable area.

4. Fabrication Status

Fabrication and inspection was successfully completed on the tubing and manifolds for the aluminum-steel radiator-condenser. The aluminum skin was brazed to Haynes 25 tubing plated with titanium. The next operations are alignment in a layup fixture, and assembly. Some technique difficulties, such as inadvertent admission of oxygen, were encountered during the braze cycle, but these were solved readily. It is now estimated that fabrication will be completed by the last of October, 1962.

Fabrication of the honeycomb RC-11 radiator-condenser at Aeronca Manufacturing Company is proceeding. Fabrication difficulties delayed delivery of tapered rectangular PH15-7 Mo tubing. Consequently, rectangular PH15-7 Mo bar stock, simulating PH15-7 Mo tubing, was substituted in RC-11-1 so that the RC unit would not delay the scheduled environmental testing of SNAP 2 PSM-2, Phase II. The simulated tubing of RC-11-1 will not affect its usefulness in the program since RC-11-1 will be used only for structural and vibration testing. Unit No. 1 fabrication is on schedule.

The second honeycomb RC-11 unit, S/N 2, will incorporate tapered rectangular tubing because RC-11 (S/N 2) will be used for thermal performance testing. Development contracts for tapered rectangular tubing are being placed with four

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tubing fabricators. RC-11, S/N2, will be delayed, because of the delay in delivery of tapered rectangular tubing. Fabrication of tapered rectangular tubing appears to be a major problem in radiator-condenser procurement.

Spot-brazing equipment to be used to attach various brackets and supports to the stainless steel honeycomb RC was purchased. Operators have been trained in its use.

The purchase order has been placed for the aluminum-steel RC-13 and two test panels. All detailed fabrication drawings by Solar have been completed and approved. Fabrication is presently in progress. Completion of fabrication is scheduled for the last of December, 1962.

5. Test Programs

The RC-6, S/N2, thermal performance test assembly including the auxiliary mercury vapor supply system and instrumentation was completed. Only lower power runs have been made because of heater cartridge malfunction in the auxiliary boiler at the 50-kw power level.

Concentrated efforts are being made in the design and fabrication of additional auxiliary boilers to permit full-power-level runs, startup transient tests, and additional capability permitting other tests such as the Horizontal Tube Test and PSM-3 to operate concurrently on the same system.

The RC-6, S/N 1, was shipped to the L. A. Division for structural and vibration tests, after the damage from the thermal tests of PSM-1 was repaired. All arrangements and test specifications have been completed. Detailed test procedures and schedules for the required thermal, vibration, and structural tests for RC-10 and RC-13 are being prepared.

The honeycomb attachment test to determine allowable loads for the area braze, spot braze, and mechanical attachments, has been completed.

Structural test specimens of the fiberglass thermal isolation band separating the RC and the instrumentation compartment are in fabrication. The actual tests will be conducted during the next quarter.

D. ELECTRICAL AND CONTROL SUBSYSTEM

Details of the preliminary SNAP 2 electrical and control subsystem were developed during the reporting period. A preliminary schematic wiring diagram was prepared incorporating circuit provisions for APU control during all phases of APU operation. Alternative circuit designs were investigated to determine optimum circuit design with respect to weight, power consumption, reliability,

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and radiation damage resistance. Consideration of checkout and testing requirements has been given to all aspects of circuit design and component selection. Work has been initiated on the development of a complete specification to define the APU electrical and control subsystem. Work has also been initiated on the specification of electrical and control subsystem components. A general electrical subsystem specification is under preparation that will define electrical, control, and instrumentation subsystem design criteria. A test specification defining electromagnetic compatibility testing requirements is under preparation.

Considerable effort was made to determine the required principal electrical characteristics of the APU. It has been established that the APU output will be three-phase 1800 cps ac with a nominal output voltage of 120 v (rms) line to line.

Prototype short circuit protection capacitors have been ordered for environmental testing. Plans are being formulated for radiation testing to determine the effect of radiation on electrical characteristics of the capacitors. Quantitative data on the effect of radiation on the capacitor dielectric dissipation constant is required to establish thermal design specifications.

The radiation damage resistance of component parts of APU electrical and control components is under investigation and test plans are being formulated.

E. FLIGHT INSTRUMENTATION SUBSYSTEM

Work continued on the development of flight instrumentation requirements. The number of channels, measured parameter ranges and sampling rates, transducer types, power requirements, impedance characteristics, and signal-conditioning requirements are in the process of being determined. Preliminary circuit design has been established. A reference design instrument compartment configuration has been established. Investigation of the mechanical and thermal requirements has progressed to the point that the instrument compartment mechanical design and thermal environment can be specified. Prototype high temperature transducers have been ordered and evaluation of instruments for SNAP 2 use in high temperature liquid metals will be initiated upon the delivery of a NaK instrument test loop. This test loop is scheduled to be in operation by the end of the year. Maximum utilization of SNAP 10A experience is being made in the development of SNAP 2 instrumentation.

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VI. SYSTEM DEVELOPMENT

A. SNAP 2 PSM-1 THERMAL PERFORMANCE TEST

1. System Design

The redesign of the SNAP 2 PSM-1 system test to incorporate flight prototype components was continued during this reporting period. The helical boiler and the RC-6 were drained of NaK, mercury and NaK-mercury amalgam. The boiler was shipped to TRW for disassembly to determine the cause of failure and RC-6 was turned over to the Structural Development Unit for environmental testing. A new design of the simulated reactor (electrical heater) was completed and fabrication was initiated. Because of the heater failures, an acceptance test program for the individual heater cartridges was initiated and is being performed. Also, a heater cartridge test system was designed. This unit is being used in an attempt to determine the requirements for reliable operation of the heater cartridges with the terminals exposed to the PSM-1 vacuum environment and to establish the cause of arcing of the lead wires during operation. Component specifications for the NaK and mercury systems were prepared. These specifications delineate the performance, quality assurance, qualification, and acceptance test requirements for the PSM-1 system. A system description of the reactor simulator computer was prepared and work was initiated on the PSM-1 operations manual.

2. APU Design

The new design of the SNAP 2 PSM-1 APU is shown in Figure 29. This design incorporates the Model 5C boiler attached to the RC as in the flight system design. Use of the flight prototype NaK expansion joints and a dc conduction pump allows the PSM-1 NaK piping to be essentially the same as flight piping. The PSM-1 system will comprise CRU-IV-M, the flight prototype mercury injection tanks, and mercury pressure regulating tanks. The RC-6, shown in Figure 30, which is presently being performance tested in the Radiator-Condenser Test Loop, will be used in the revised PSM-1 system. The new simulated reactor shown in Figure 31 will be controlled by a computer for simulation of orbital startup. One simulated reactor will be qualified in the PSM-1 vacuum environment at SNAP 2 design conditions for 500 hr prior to extended use of an identical unit in the PSM-1 system. The NaK and mercury

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Figure 29. SNAP 2 PSM-1 APU

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Figure 30. RC 6

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Figure 31. Simulated Reactor

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system piping stresses were determined by using the piping flexibility code of the Service Bureau Corporation.

3. Heater Cartridge Acceptance Test

All heater cartridges used in the simulated reactor were baked out at 300°F to remove moisture trapped in the MgO insulation. In electrical checkout all wire resistance and resistance-to-ground measurements were satisfactory. The heater cartridges were dye-penetrant checked, radiographed, and helium leak tested. All cartridges passing these tests (84 out of 102) were installed in the test rig shown in Figure 32 for a NaK soak test. The heater elements were soaked in NaK over a temperature range of ambient to 1200°F for two thermal cycles. Circuit resistances and resistances to ground were measured at 100°F increments. The variation of electrical characteristics was also determined as a function of time. These measurements indicate that the resistance to ground of the elements underwent two major changes. The first change occurred after the absorbed moisture had been driven off by baking at 300°F for several hours. The second change occurred after high temperature baking. As a result of the low temperature baking, the resistance-to-ground increased to infinity at room temperature. The resistance dropped to about 5 megohms at 1000°F. After overnight heating at 1000°F, the resistance-to-ground values were in the 50 to 100 megohm range. After completion of acceptance testing, the heater cartridges were stored in polyethylene bags until needed for assembly into the simulated reactor.

When the cartridges are assembled into the simulated reactor, a helium leak test and resistance-to-ground measurement will be performed. After assembly a helium leak test and x-rays of all welds will be performed. The PSM-1 reactor simulator contains 36 heater cartridges in a single ring with NaK flow in an annulus. This design will provide the required NaK transients during pre-heat and injection startup with a minimum NaK volume. The overall height of the heater permits location of the inlet nozzle at the bottom center, which ensures a minimum circumferential temperature gradient.

4. Heater Cartridge Test System

A test in a vacuum environment under design conditions was initiated for the heater cartridges used in the simulated reactor. The purpose of this test

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Figure 32. Heater Acceptance Test Rig

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was to determine the mode and cause of failure of the heaters in the previous PSM-1 system tests. This test system is shown in Figures 33 and 34.

The first heater cartridge was subjected to operation under the following conditions:

NaK temperature	1100°F average
Pressure environment	10 to 80 microns
Voltage	230 v
Power	4.7 kw

This cartridge failed internally at the bottom after ~15 hr. The nickel lead wire separated from the nichrome resistance wire. This failure was attributed to the stringent service conditions imposed upon this test cartridge in which the wire temperature was ~1900°F and the heater underwent about 1000 thermal cycles between 1400°F and 1900°F. After this failure, the test apparatus was modified to permit operation at 208 v without thermal cycling.

A second heater cartridge failed internally after 147 hr at average test conditions of 250°F NaK, 4.0 kw, and 208 v. At the time of failure, however, the cartridge was being operated at 240 v where electrical discharge could occur in vacuum. Under these conditions the cartridge was generating 5.0 kw which is above the nominal rating of 4.7 kw at 230 v. The average NaK temperature was 147°F with a calculated nichrome wire temperature of 2300°F. This heater cartridge was exposed to mercury vapor and organic vapor in the region of the lead wires for 26 hr of operation at 208 v.

A third cartridge was operated for over 300 hr at 1200°F and 208 v, single phase in a vacuum environment varying between 10 microns and 3 mm Hg. Because the lead wire and terminal end temperatures of the cartridge remained cooler (~750°F) than actual PSM-1 operating conditions and the cartridge was operated with single phase instead of three phase, the test system was modified to permit closer simulation of the actual PSM-1 operating conditions. The heater cartridge installed in the modified test system failed after 24 hr of operation at 208 v, 3 phase, 4.0 kw due to an arc-over between lead wires at the surface of the lava seal at the terminal end of the cartridge. The arc-over occurred at a pressure of 28 microns Hg, the cartridge lead wires at 661°F and the terminal end at 1075°F. This failure appeared to be identical to lead wire failures observed in the PSM-1 system test.

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Figure 33. Heater Cartridge Test System

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A fourth cartridge was installed and failed after 10 hr of operation in vacuum at the PSM-1 temperature. This failure was also due to arc-over. Incipient melting of the nickel leads was evident at the surface of the lava seal. A fifth cartridge was installed and wired in a single-phase circuit. This cartridge also failed due to arc-over under PSM-1 operating conditions. Analysis of these failures is still in progress and conclusive results are not known at this time. However, 11 arc-over failures were observed when the cartridge terminal end was operating at the high temperatures of the PSM-1 system test.

B. SNAP 2 PSM-2 - STRUCTURAL MOCKUP

1. Phase I

SNAP 2 PSM-2 Phase I, consists of a structural mockup of the APU where stiffness and weight of the referenced honeycomb design are simulated. The configuration is the 134 ft², cone-cylinder RC, 180-in. APU.

During this quarter, low level vibration frequency surveys and the qualification level (100%) survey in the lateral direction were completed. During the low level lateral survey, the lag screws connecting the shield to the shield container failed and were replaced with heat-treated steel pins. It was discovered that the amplification factor in the lateral direction was ~20. The response at the reactor shield exceeded the design criterion of 2.5 g in the lateral direction during the first bending mode. With the high amplification, it will become necessary to design to a higher design criterion. As a result of this testing, the design criterion was revised to a 5-g response at the reactor shield assembly. The system response on the lateral direction during 100% level lateral run was visibly noticeable and movies were taken of the external system and internal structure showing the piping response.

2. Phase II

Detail design on all system components was completed in this period with the following exceptions: the payload adapter ring required for the new Agena-APU attachment and the reactor vessel base for the vessel shield attachment.

The specification for the PCS-II-2 for TRW was completed and transmitted for review. TRW will supply the PCS as components rather than an assembled PCS to help schedule difficulties encountered during the report period.

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Figure 34. Heater Cartridge Test Rig (Vacuum Chamber)

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Assembly procedures and facilities planning for the assembly and testing periods were studied. A general test plan was outlined and detailed requirements studies begun.

C. SNAP 2 PSM-3 ZERO-G SIMULATOR

The SNAP 2 PSM-3 test specification has been completed. This document delineates the tests required to demonstrate the feasibility of the present startup procedure. Specifically, these tests will provide the effects of interactions between the RC and mercury pump without the overriding effect of the liquid head in the condenser. The tests will also provide information concerning interface stability and overall system response throughout the startup sequence.

The major emphasis during this report period was the installation of major APU components, design and fabrication for preliminary testing of the horizontal RC, and modification of the APU design to incorporate PCS-II-3 changes.

A comprehensive test plan for sequential testing of critical components was established for the development phase of the test program. The Phase I development program is divided into parts designated:

- Ia Transient and steady-state thermal performance test of the RC,
- Ib Thermal performance test of the PCS-II-3, exclusive of the CRU-IV-M,
- Ic Thermal performance test of the RC with a prototype CRU mercury pump (transient and steady state),
- Id Thermal performance test of the RC with the PCS-II-3, exclusive of the CRU-IV-M,
- Ie Thermal performance test of the complete APU, including the CRU-IV-M.

Transient startup testing of the horizontal RC without a PCS necessitated the design and fabrication of a major test system. Incorporation of a CRU mercury pump (air driven turbine) within the test schedule will provide a means of evaluating interactions between the mercury pump, the mercury regulator

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tanks and the RC. This will enable design point as well as margin tests to be performed without the need of a complete PCS.

1. Installation of Major APU Components

The vacuum vessel shown in Figure 35 was successfully checked out by the vendor and installed at the test facility. The vacuum pumping system, identical to that in use for the SNAP 2 PSM-1 system test, was installed and the complete vacuum system checked out. The water system for the vacuum vessel was installed and checked out. This water system incorporates a bypass de-mineralized water loop to enable either the complete vacuum vessel or one section (top or bottom half) of the vessel to be maintained as high as 200°F. The RC shown in Figure 36 was instrumented with over 240 thermocouples and installed on a support structure within the vacuum vessel. The inert gas and vacuum system was also fabricated and installed.

All of the instrumentation required for APU testing was installed and wired within the console racks. In addition, a mercury auxiliary pump required for testing of the PCS-II-3 without a CRU was installed.

2. Design and Fabrication for Preliminary RC Testing

Detailed design calculations and assembly drawings were prepared for Phase I testing. Transient startup tests on the horizontal RC will require a bypass flow loop to permit use of the boiler within the adjacent RC Test Loop as a mercury vapor source. The boiler will be slowly brought up to its design power rating by circulating mercury through the bypass loop which incorporates a compact water-cooled condenser rated at 50 kw. Once steady-state conditions are obtained, the bypass loop will be valved off and an inlet valve to the RC opened. The RC will be brought to operating temperature and pressure by condensation of the mercury vapor within its tubes as specified in the present orbital startup method. A choked nozzle will be used to ensure that the mercury flowrate remains constant throughout the startup cycle. Transients occurring after the condenser discharge valve is opened will also be evaluated. A prototype regulator tank installed in the RC discharge line will enable tests to be made within a discharge pressure range of 5.0 to 7.0 psia. Instrumentation to be used for later APU testing was adapted for this initial test phase. Two 100-point temperature scanners and loggers capable of a maximum printout speed of 5.0 points/sec record the longitudinal temperature profiles of the RC tubes.

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Figure 35. SNAP 2 PSM-3 Vacuum Vessel

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Figure 36. SNAP 2 PSM-3 Radiator-Condenser

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At the end of this report period all components and liquid mercury lines for Phase I testing were installed; installation of the mercury vapor lines was 50% complete; wiring of the instrument racks was 95% complete; and installation of the electrical components and thermocouple wiring was initiated. A checkout of the high temperature pressure transducers was performed with the transducers at 600°F and their characteristics were determined. These units are extremely sensitive to handling and several malfunctioned either during or between calibration tests. Installation of the piping and components was designed to permit installation and hookup of the PCS-II-3 at a later date without the need for major modifications.

3. APU Design

Modifications to the PCS-II-3 design were slight and were concerned primarily with additional instrumentation required for the CRU-IV-M operation. A detailed review of the PCS-II-3 status was made and progress in the design and fabrication of the system was satisfactory. A major PCS-II-3 developmental problem, other than the CRU modifications, involved fabrication of the Model 5C boiler in that some trouble was encountered in cracking of the tube coils. A detailed specification was prepared for PCS-II-3 outlining the performance, acceptance and qualification testing requirements of the PCS including the CRU.

The allowable piping loads at the CRU nozzles were obtained and the NaK system piping drawings incorporating the Model 5C boiler were finalized. A detailed computer check of the piping stresses was initiated.

Detailed NaK component specifications were prepared in conjunction with the SNAP 2 PSM-1 component specifications. These specifications include acceptance and qualification testing requirements. In addition, a backup design study for a resistance NaK heater was initiated.

A detailed review was initiated of the thermal simulation requirements for an advanced horizontal RC with tapered rectangular tubes identical to present flight system specifications. A design layout drawing was prepared for a unit patterned after current RC-13A specifications.

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D. S2DS - SNAP 2 DEVELOPMENTAL SYSTEM

Tests have been performed on the SNAP 2 development system to determine the transients imposed on the NaK system under the condition of a rapid NaK flow increase as will be encountered during CRU spinup. The data obtained from these tests are presently being evaluated to ensure that the model being used to represent the reactor in system studies is adequate for large transient representation.

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VII. OPERATIONAL ANALYSIS

A. FLIGHT SYSTEM SAFETY

1. General

A Shipping Safety Report was initiated, which presents a safety analysis of APU shipments from Santa Susana, to Vandenberg Air Force Base (VAFB), Building 060, and from VAFB to Point Arguello Launch Complex. Although of immediate value to the SNAP 10A program, approval of this report will constitute informal acceptance of the general methods planned for other APU shipments. An addendum to this report dealing with the peculiarities of the SNAP 2 shipment will be written at a later date.

Recommendations on emergency procedures and responsibilities in event of an APU launch incident were initiated for submission to the 6595th Air Test Wing as an aid in the preparation of the Launch Pad Safety Report.

A study of the hazards during recovery from various postulated nuclear incidents was completed. These postulated incidents assumed the occurrence of a 35 Mw/sec excursion on land, 1.3 kw steady-state operation on land, 160 Mw/sec excursion in water, and 60 kw steady-state operation under water. The primary results of this study are as follows:

- a) After a 12-hr decay period following a 35 Mw/sec excursion, a man standing 10 ft from the reactor will receive less than 3 rem/hr.
- b) If earlier approach is required, a 1-hr decay period after a 35 Mw/sec excursion will permit a man to operate a crane at 50 ft and receive less than 3 rem/hr.
- c) With a shield consisting of 10 in. of paraffin and 1 in. of lead, a man can remain 70 ft from a 1.3 kw steady-state operating reactor and receive less than 3 rem/hr.
- d) A man can remain 11 ft away (water distance) from a reactor operating underwater at 60 kw and receive less than 3 rem/hr.
- e) Allowing 1 hr decay after a 160 Mw/sec excursion, a man can remain 6 ft (water distance) from a water submerged reactor and receive less than 3 rem/hr.

2. Launch Pad Fixed Monitoring System

The revised plan for a launch pad fixed radiation monitoring system was resubmitted by LMSC for Air Force review after incorporation of suggestions recommended by AI, AEC, and others. The revised system will consist of:

- a) Three particulate monitors of the moving filter type with readout channels located at:
 - 1) Launch Operations Building (LOB), monitoring outside or inside air,
 - 2) LOB Cable Tunnel Inlet,
 - 3) Launch Support Building (monitoring outside or inside air).
- b) Six detectors, each containing a neutron and gamma sensitive instrument with individual instrument readout located:
 - 1) On the umbilical mast (APU level),
 - 2) On the flume side of the pad,
 - 3) TV tower No. 44,
 - 4) TV tower No. 45,
 - 5) At the theodolite station,
 - 6) At the LOB.

All readout will be presented at the LOB. Use of the present pad alarm system is contemplated.

During all ground handling of the APU, the portable detection-alarm system designed by AI primarily for use during shipment will monitor the APU.

3. Aerospace Safety Program Monitoring

The preliminary results of the Aerospace Safety Program impact tests indicate that impact of the APU at terminal velocity of 550-ft/sec into water will not reduce the core to a subcritical state in all impact attitudes. Closed fission product release tests were initiated at the National Reactor Testing Station (NRTS). Fuel element temperatures of 3500°F were attained with induction heating methods. Only those aspects of the Aerospace Safety program of specific interest for SNAP 2 are described here.

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4. Neutron Activation Analysis

The recently written activation analysis code has been used to determine the dose rates resulting from neutron activation of the 316 SS reactor core vessel, Hastelloy-C grid plates and fuel element cladding, and Rene 41 springs. Formation of Co_{60} is by far the most significant long term hazard.

B. RELIABILITY PROGRAM

1. SNAP 2 Reliability Specification

The specification for SNAP 2 reliability requirements (NR 7550-05) was completed and released. Significant points in the specification are discussed in the following text.

a. Design Objectives

The total SNAP 2 APU reliability design objective is 0.80 probability of a successful mission operating for 1 yr in space. The reliability design objective for flight test is 0.90 probability of a successful mission operating for 90 days in space. These objectives have been allocated over the launch and pre-start, startup, and endurance segments of the mission. Probabilities consistent with the overall objective have been allocated to the major subsystems and components of the system.

b. Demonstration Objectives

The reliability demonstration objective is to demonstrate the flight test mission objective of 0.90 probability of success to a confidence level of 50% prior to actual flight test. This can be accomplished by subjecting each of 7 equivalent SNAP 2 systems to the simulation of a complete flight test mission. For practical reasons, three complete systems will be tested. The remaining four systems will be represented by sets of components.

c. Analysis Requirements

Probability analysis, failure mode analysis, and reliability stress analysis shall be used where applicable for optimizing the potential reliability of the system during the design phases prior to fabrication of flight system components.

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d. Data Reporting

The Malfunction Operation and Removal Report (MORR) data system shall be used to record reliability data originating from development, qualification, and acceptance testing.

2. Reliability Appraisal of SNAP 2 for Flight Test

An appraisal of the SNAP 2 reliability requirements for justification of flight testing was issued in rough draft. Major points of the appraisal included the establishment of reliability design objectives and demonstration requirements as noted in the reliability specification. The reliability objective of 0.90 for the flight test mission is based on a 0.99 probability that at least one out of two flight test missions will be successful. A comparison was made showing the level of confidence to which various subsystem and mission segment reliability objectives might be demonstrated under the present test program.

3. Startup Circuit Analysis

A probability analysis of several configurations for the startup solenoid-valve control circuit has been completed. A recommended circuit was presented on the basis of potential reliability. Attempts to provide increased reliability for the valve actuation mode of operation result in redundancy which in general, decreases the potential reliability of the system. The recommended circuit is proposed as a compromise to provide optimum total potential

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APPENDIX A MTI QUARTERLY PROGRESS REPORT

Final report on Conceptual Design for the CRU Development, MTI-62TR12 was issued. This report summarizes the evaluation of several design concepts and comes up with a proposed design incorporating bearings lubricated with mercury vapor.

A report, "On Theory and Experiment of Journal Bearings Operating in Turbulent Regime," MTI-62TR11 was issued and the results were presented by B. Sternlicht at the joint AEC-NASA meeting in Washington, D. C. , on July 23 and 24, 1962.

Report 62TR19 was issued on, "Survey of the Required Lubrication Analysis in Turbulent Regime." This report introduces the general problem areas and outlines a theoretical and experimental program. While the program is basic, its results will be directly applicable to any bearing geometry required for CRU's operating in the turbulent regime.

A research memorandum No. 7 was issued which covers, "Fluid Inertia in Turbulent Lubrication." In this memo an order of magnitude analysis is performed. The result indicates the usual lubrication approximation of neglecting fluid inertia and normal pressure gradients can be applied to the fully developed turbulent film without significant error. This conclusion permits great simplification of the theoretical analysis.

Report 62TR23 was issued on, "Calculated Design Data for Journal Bearing Arcs Operating in Laminar and Turbulent Regimes." This report gives design data on 60, 100, and 120° bearing arcs operating in laminar and turbulent regimes. This data can be used directly to predict performance of partial arc bearings. Eighteen tables are presented covering Reynolds number up to 11,000, eccentricity ratio to 0.8, and load angle to 240°.

A program was completed to calculate planar flow film velocity profiles and mean velocity from the mixing length hypothesis, assuming a turbulent core with viscous sublayers at the journal and bearing surfaces. The calculations were made for all possible combinations of positive, negative or zero pressure gradients, surface velocity and end conditions, the values of the coefficient and

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exponent of the Reynolds Number in Constantinescu's turbulent lubricant film equation. A report of these computations is in progress.

Programming of the three-dimensional bearing equation, which assumes superposition of the circumferential and axial flow components is about 80% complete. This will yield directly (for partial arcs as well as for full circular bearings) the load capacity and stiffness of bearings of finite length, without resort to empirical side leakage factors.

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APPENDIX B AIRESEARCH QUARTERLY PROGRESS REPORT

A theoretical and experimental program is being conducted to determine operating characteristics of mercury-lubricated journal bearings. The object of this bearing program is to provide an analysis, completely verified by a test program, to define the effects of variables that are pertinent to the performance of mercury-lubricated journal bearings in the laminar and turbulent flow regions. The effects of both the bearing hydrodynamics and the rotor dynamics are to be evaluated, so that the performance of mercury-lubricated journal bearings may be predicted. The results should permit the selection of an optimum combination of configurations for the journal bearing and the rotating assembly.

A summary of the tasks accomplished during this reporting period is presented in the following text.

HYDRODYNAMIC ANALYSIS

The initial hydrodynamic analysis for laminar flow was completed, and the finite difference equations were programmed for the digital computer. Sample problems were run for comparison with the existing closed form solutions.

The effects of fluid inertia were included in the analysis and computer program; however, no adequate two-dimensional solution is available to verify the magnitude of these effects. An improved expression for the inertia terms was derived and programmed. Results of this computer solution will be compared with the results of the previous computer solution and with the existing one-dimensional solutions. These studies will be described in a future report. A modified program is also being prepared in an effort to improve representation of the pressure distribution in the low pressure or cavitation area of the bearing.

The initial turbulent flow analysis was completed. The solution is basically an extension of the work of Constantinescu in which the turbulent stresses are found by Prandtl's mixing length theory. Two forms of this solution were derived. One form is based upon linearized expressions as suggested by Constantinescu; the other is based upon more complicated nonlinear expressions to represent the physical problem more closely. Both forms of the solution are being programmed and results will be compared with test data.

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DYNAMIC ANALYSIS

The dynamic analysis of the transient motions of a rigid rotor was completed and the numerical solution of the resulting expressions were programmed for the digital computer. Two programs were prepared. A preliminary program considers the rotor to be supported on bearings which have a linear spring rate so that the computer results may be compared with known solutions. The final program considers the rotor to be supported on journal bearings. Initial running of the programs on the computer is presently being done.

SINGLE BEARING TEST RIG

The purpose of the single bearing test rig is to obtain journal bearing performance data for various bearing configurations and to provide a source of test data which can be used to verify the analytical hydrodynamic journal bearing solutions.

The test rig parts have all been fabricated and the rig assembly is nearly complete. Before the rig assembly can be completed, the rotating assembly must be balanced and the test unbalance weights must be calibrated. The tooling for the balancing and calibration operating was designed and fabricated during this reporting period.

An extra rotating assembly is being fabricated as a backup test assembly. Stress analysis and overspeed tests will be conducted on this second assembly in an evacuated whirlpit. The tooling required for stresscoat and overspeed tests has been fabricated.

A major problem was encountered in the fabrication of the test rig when the outer ring, which is shrink fitted over the laminated core of the motor rotor, fractured during assembly. A second attempt was made after the outer ring, which was made from pure molybdenum, was stress relieved for a longer period of time. Again fracture of the part resulted. The problem was finally resolved by changing the material callout to molybdenum - 1/2% titanium, and putting the part through a 1 hr heat treat at 1800°F in a vacuum furnace after the rough machining operation.

MERCURY TEST FACILITY AND LOOP

During this reporting period, the new mercury test facility was completed and accepted from the contractor.

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The vacuum chamber was completed, stress relieved, surface cleaned, and deoxidized. The chamber was transported to the new test facility where it was cleaned with acid followed by an acetone rinse.

The vacuum chamber was positioned and installation of the attendant vacuum system components was initiated. Nearly all of the mercury loop equipment has been fabricated or purchased. Test rig instrumentation design, and checkout is paralleling the fabrication of the rig.

A pressure transducer calibration rig was built and used to compare flush mounted crystals with standard SLM crystals for response and sensitivity.

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