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SNAP MERCURY RANKINE PROGRAM
SNAP 2 STRUCTURAL EVALUATION
PROTOTYPE SYSTEM
(PSM-2)

AEC Research and Development Report

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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PROTOTYPE SYSTEM
(PSM-2)

By
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ABSTRACT

This report defines the SNAP 2, PSM-2, Phase-II, prototype system program. The need for a structural test item is discussed and the resulting objectives presented. A summation of the design, fabrication and assembly efforts is given. The test program is outlined and some preliminary results are discussed. This work was completed under the SNAP Mercury-Rankine Improvement Program.

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I. INTRODUCTION

A system for nuclear auxiliary power (SNAP 2) was designed to deliver 3 kw of usable electrical energy to a satellite or other space vehicle for a duration of 1 year. This particular unit was designed for flight testing with the Atlas-Agena launch vehicle. A typical flight configuration is shown in Figure 1.

To protect the payload and other instrumentation from radiation damage, the reactor was located in the nose of the vehicle. This location accomplishes two things: (a) it provides maximum distance between the nuclear source and the radiation-sensitive components, and (b) it allows an optimum vehicle configuration for a minimum weight radiation shadow shield.

This weight advantage easily offsets the disadvantage of a nose location which requires the SNAP unit to withstand the aerodynamic effects of pressure and heating.

A. SYSTEM DESCRIPTION

The heat source for the SNAP 2 system consists of an automatically controlled compact reactor (Figure 2) cooled by sodium potassium (NaK 78), a liquid metal. The reactor coolant transfers heat in a boiler superheater to the secondary loop, which contains mercury (Hg) as the working fluid (Figure 3). The NaK flow is maintained by a pump located on one end of the combined rotating unit (CRU), see Figure 4. (In current designs the NaK pump has been removed from the shaft.)

The primary loop must be kept void-free to prevent hot spots in the reactor; therefore, to control the pressure that results from the expansion of heated NaK, an expansion compensator (Figure 5) is used. Since piping is fixed at both ends (to the reactor at the top and to the CRU at the bottom), expansion joints are used to relieve longitudinal expansion. The piping and other components of the primary loop require insulation to minimize heat transfer (by conduction and radiation) to the surrounding components.

The secondary loop operation is a Rankine thermal cycle in which the Hg is boiled and superheated in the boiler, expanded in the turbine of the CRU, and condensed and subcooled in the radiator-condenser (RC), which radiates the excess heat to space (Figure 6). The CRU is an integral package with the

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Figure 1. SNAP 2 Flight Package

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Figure 2. Details Of The SNAP 2 Reactor-Reflector-Controls

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Figure 3. SNAP 2 Flow Schematic

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Figure 4. Cutaway Model Of CRU-IV

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Figure 5. Cutaway View Of a Typical Expansion Compensator

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Figure 6. Radiator-Condenser (RC-11)

following items mounted on one shaft: the electrical alternator, the turbine for driving power, and the pumps to maintain flow of NaK and Hg.

A section below the RC (Figure 7) contains all the instrumentation necessary to control the complete system and activate it once in orbit. This includes startup of the reactor as well as the other subsystems. The compartment is thermally isolated from the RC by a thermal barrier for radiation and a Fiber-glas ring for conduction. The lower portion of the instrument compartment attaches to an adapter ring which mates the SNAP unit to an Agena vehicle. The reactor is protected during launch by a nose cone which is ejected once orbit is achieved.

B. PSM-2 PROTOTYPE SYSTEM

The primary objectives of this test system are to verify the structural analysis of flight design and to supplement component structural testing by supplying system structural interactions. This prototype system is one of three test systems required for the SNAP 2 Development Program.

The nonnuclear prototype test system, PSM-2, was designed to verify the structural integrity of SNAP 2 for all phases of the launch environment. These are composed of a combination of steady-state and dynamic loadings such as acceleration, aerodynamic heating and pressure, and mechanically and acoustically excited vibrations of a random and periodic nature. A test specimen was designed using all available flight design information. Recent flight designs have changed somewhat, however, this specimen represented the latest flight concept at the time PSM-2 design was frozen. Mass and geometry mockups were utilized for the nonstructural components in cases where prototypes of the items were not available. Every effort was expended during the design, fabrication and assembly stages to ensure that the test specimen would have flight configuration and quality. The minor difficulties encountered during the assembly work were noted for consideration on future systems.

The test program outlines the testing methods used to obtain the structural data needed to fulfill the objective of this system test. Many of the tests have been completed at this writing and results will be forthcoming in a later report.

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Figure 7. Base Load Ring Subassembly With Tooling

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II. DISCUSSION OF TEST PROGRAM CRITERIA

A. NEED FOR STRUCTURAL TEST

The following discussion describes the flight environment of the SNAP 2 unit and the structural design conditions imposed upon it by these environments. The basic test program criteria were derived from this information.

See Figure 8 for the various phases of a SNAP 2 launch and orbital sequence used in the structural design.

1. Flight Environment

During launch, flight and orbit, the SNAP 2 unit will be subjected to the following environments.

a. Liftoff

This phase of flight consists of the liftoff of the Atlas-Agena-SNAP 2 vehicle. The loads during this period consist of acceleration that opposes gravity, some shock loads as the vehicle lifts off the pad, and mechanical vibration and a high acoustical noise level produced by the rocket engines. A limited amount of engine mechanical vibration is transmitted through the booster vehicle to the SNAP 2 unit due to the damping within the vehicle structure. The acoustical excitation is transmitted to the SNAP unit directly through the atmosphere. This acoustical noise level decreases as the vehicle gains altitude; the level will rise again as the vehicle approaches Mach I (speed of sound). The actual level at Mach I is not as high as that encountered during liftoff, but the acceleration loads are higher. After the vehicle passes through the speed of sound, acoustical noise will die away completely.

b. Aerodynamic Pressure Plus Maneuvering

As vehicle speed increases, the dynamic pressure (q) increases:

$$q = \frac{1}{2} \rho V^2 ,$$

where

ρ = air density in slugs/ft³

V = velocity in ft/sec.

Figure 8. Typical SNAP 2 Environmental Sequence

As velocity and altitude increase, air density decreases. The result is that dynamic pressure (q) reaches a peak value at some point in the flight path (see Figure 9). As dynamic pressure peaks, wind gusts or other perturbations will be encountered, requiring the vehicle to maneuver to stay on the planned trajectory. This maneuver results in a change of direction of the relative wind which is described as an angle of attack (α). The combination of $q\alpha$ then describes the maximum pressure loading that will be imposed on the external surface of the vehicle.

c. Maximum Aerodynamic Heating Plus Maximum Acceleration

As fuel is consumed in the booster, weight gradually decreases. This decrease in weight causes an increase in acceleration which peaks out just before booster engines cut off. At this point, maximum inertia loading occurs on the vehicle (see Figure 9).

As speed increases, air friction begins to heat the outside skin; due to rapid heating of the outside surface, temperature gradients exist throughout the structure. If these gradients become large the resulting stresses are large.

Figure 9. Typical Trajectory Loading

These two conditions, maximum inertia and aerodynamic heat, occur approximately at the same time during flight; therefore, for design purposes they were considered as a combined design condition.

d. Engine Burnout and Staging

As the booster engines are cut off, the high acceleration load decreases rapidly. At separation of the booster and second-stage ignition, shock loadings occur on the vehicle. The vehicle is then boosted into orbit.

e. Orbit

The orbital environment will consist of a high vacuum and low space temperatures. During startup of the SNAP 2 unit, the vehicle undergoes a series of thermal transients and their resulting gradients. During, and following startup, minor vibrations will be encountered as the CRU spins up from a standstill to operating speed.

2. System Structural Design Qualification

The flight environments previously described result in various design conditions. The SNAP 2 unit must then be loaded with these design conditions to verify its capability to survive these loads and accomplish its mission. PSM-2 is a prototype test system for this purpose; it must also verify the analytical design techniques used for the flight design structural analysis. A separate program will qualify the components to their own specific levels. For testing purposes, these conditions are grouped into two categories, dynamic and static.

a. Dynamic Loading

Dynamic loads are best described as those which oscillate or change rapidly; they include vibration, shock, and acoustic noise.

(1) Vibration

The vibration encountered will be periodic and random in nature. The response of the vehicle to vibration must be analyzed and evaluated. The state-of-the-art of analysis and testing of sinusoidal vibration is well developed. Therefore, vibration testing of the SNAP 2 structure will utilize sinusoidal input. Some random testing will be done since much of the flight environment is of a random nature. This random testing allows a comparison of the responses of the SNAP unit to both random and sinusoidal vibration.

(2) Shock

The SNAP 2 unit will be subjected to isolated shock inputs to determine if internal components are excited to levels above the inputs.

(3) Acoustic Noise

An acoustical environment will excite small components and lightweight, large area components. PSM-2 will be tested in an acoustical environment to determine the effects on the various components.

b. Static Loading

Static loads are comprised of aerodynamic pressure and inertia loads resulting from wind gusts or maneuvers and accelerations, respectively. The loads may be applied in any direction and the structure should be capable of carrying these loads for an indefinite length of time.

(1) Aerodynamic Pressure

Aerodynamic pressure loading applies a varying distributed pressure over the vehicle. The point of maximum pressure is determined by the angle of attack (α), see A. 1. b. of this section. An inertia load is present during the same period. This inertia load amounts to 2.4 g's in the aft direction, combined with 0.4 g's in the lateral direction. The lateral inertia load can or cannot be applied, depending on whether the resulting stresses in any particular area contribute to or subtract from the existing stresses. SNAP 2 analysis requires that this lateral load be applied during testing.

The previous loadings result in maximum body bending plus an axial load due to inertia and aerodynamic drag on the nose cone. The critically loaded area of the SNAP 2 unit then becomes the aft section, namely, the lower portion of the RC, instrument compartment, adapter ring, and Agena-SNAP 2 interface.

During testing, the unit is to be loaded by straps applying pressure to the RC through a whippletree and hydraulic strut arrangement. The major components will be loaded by a whippletree to simulate their respective inertia loads.

(2) Inertia Loading and Aerodynamic Heating

The vehicle acceleration during launch results in a maximum inertia load of 7.6 g's acting aft, plus a lateral inertia load of 1.0 g that can or cannot be applied, depending on whether it adds to or subtracts from the stresses in any particular area. It is critical for SNAP 2 to apply this lateral load during testing.

Due to air friction at high speed, the outside surface of the vehicle heats rapidly during boost. The resulting thermal gradients throughout the structure cause stresses proportional to the gradients. These gradients are exceptionally high in areas of internal restraint or support, such as frames, rigidly supported components, etc.

The timing of these conditions is such that the maximum inertia loads and aerodynamic heating occur at approximately the same time during launch. Therefore, for design purposes these loads are combined.

Critical areas for this load condition are the forward portion of RC, where the shield supports attach, and the brackets for all internally supported components.

During testing, PSM-2, will be loaded by hydraulic struts to simulate the inertia load on the heavier components, and the thermal effects will be simulated by the use of quartz lamps to heat the external surface.

B. PSM-2 CONCEPT

A test program was set up to determine the structural characteristics of the conceptual design when subjected to the loadings previously described. This program includes two phases with completely separate test vehicles for each. The first vehicle was used to establish test information for design as early as possible; mass mockups were used for the internal components, while the structural components, such as the RC, brackets, etc., simulated the stiffness (AE or EI) of flight design.

The second vehicle will provide more accurate data as the structural components are flight items and the internal components are prototypes or accurate mass-geometry mockups. This vehicle also incorporates design improvements which were determined during tests performed on the first vehicle.

1. Phase-I

The first vehicle of the PSM-2 system test was designated Phase-I. Vibration and shock tests were performed to obtain the required data.¹

a. Objectives of Phase-I

The objectives of Phase-I testing were:

- 1) Determine the vibration and deflection characteristics of the reactor relative to the shield;
- 2) Determine the vibration and deflection characteristics of the shield-reactor combination relative to the RC, accurately simulating the thermal expansion joint utilized to attach the shield to the RC;
- 3) Determine the response characteristics of the mockup power conversion subsystem (PCS) to substantiate the launch and orbital portions of the PCS design specification;
- 4) Substantiate the piping support spacing for the launch and orbital portions of the environmental design criteria;
- 5) Determine the type and location of the instrumentation for Phase-II testing;
- 6) Determine the flight instrumentation locations;
- 7) Determine the ground handling loads.

b. Description of Phase-I

PSM-2, Phase-I, was a structural mockup of a SNAP 2 unit designed to provide basic overall system responses and nominal vibration characteristics of the internal components (see Figure 10).

(1) RC Mockup

The RC mockup was fabricated from aluminum and the rings and stringers were riveted to the skin. It simulated the stiffness (AE and EI) of a brazed steel honeycomb RC-7. The shape of the RC was a frustum of a cone.

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Figure 10. Phase-I Structural Mockup

(2) Shield and Vessel

The shield vessel was flight designed and the shield material was simulated by using wood that had the same density as the real shielding material. It was possible, therefore, to have a mockup shield with the same shape and center of gravity as the real item. This was important as the method of supporting the shield must be simulated. The shield was supported in its containment vessel by tension straps which held it against the top of the vessel. The reactor-reflector-controls mockup was also mounted on the top and exterior of the shield vessel (Figure 10). The shield vessel was supported by the RC at eight attach points which were designed to allow the RC to slip radially during the thermal growth that would occur during startup and aerodynamic heating.

(3) Reactor-Reflector-Controls Mockup

The reactor-reflector-controls for Phase-I was a one-piece mockup with the center of gravity, weight, and method of attachment simulating those of the flight design. The mockup unit was made of a steel weldment.

(4) Instrumentation Compartment

The structural portion of the instrument compartment was composed of the longitudinal fittings and tension ties. The fittings were to carry the longitudinal loads, and the diagonal tension ties were to carry the body shear loads (see Figure 11). The skin was isolated from the RC and structure so that the heat from these items would not enter the panel. The instruments were mounted to the panels, which radiated the instrument heat load to space. The instrument packages for this vehicle were mass mockups.

This section was completely redesigned for the Phase-II vehicle as a result of the testing of Phase-I. The skin panels on Phase-II were structural, resulting in a higher natural frequency for the system.

(5) PCS Components

The PCS consisted of the boiler, CRU, and the injection, regulator and nitrogen tanks. The boiler was of the U-shaped design which was coiled and supported inside the RC. The mockup boiler was fabricated by using a tube of the proper diameter, bent to shape, and filled with a fluid that simulated NaK and Hg tubing. The tankage and CRU were mass-geometry mockups. All supporting bracketry approximated flight hardware.

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Figure 11a. Instrument Compartment

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Figure 11b. RC-7 Mockup With Piping, PCS, and Shield

(6) Piping, NaK and Hg

The NaK and Hg piping and their supporting bracketry were flight design items. The NaK components that were integral with the piping were mass-geometry mockups. These included the expansion compensator, flow trimmer, startup pump, and parasitic load heater (see Figure 11).

2. Phase-II

The second test vehicle for system tests is a detailed prototype of the SNAP 2 flight design (Figure 12) designated PSM-2, Phase-II.

a. Objectives of Phase-II

The objectives of PSM-2, Phase-II system test were utilized as guidelines during all aspects of work from design through testing. They were listed as primary or secondary to signify their priority should any problems or changes occur during the course of the program.²

(1) Primary Objectives

The primary objectives of Phase-II testing are:

- a) To meet the structural qualification levels of the basic flight loadings as given in Section VI, Test Program. These are the flight design qualification test levels for SNAP 2. This demonstrates the integrity of the design.
- b) To determine the resonance frequencies, amplification factors and mode shapes of the primary structure, the major subsystems and components, making sure that the components resonances are isolated from the primary structural resonances;
- c) To obtain the limiting conditions for all components and subsystems during the testing of a complete system to the specified system test levels. These responses are to be compared to the qualification levels specified for the components and the most severe would be used in the component programs.

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Figure 12. PSM-2, Phase-II With Nose Cone Removed

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- d) Verify the integrity of the NaK and Hg systems when subjected to a vibration and shock environment;
- e) Determine the effect of voids in the primary (NaK) system under a vibration and shock environment;
- f) Determine the load distribution and stress levels in the primary structure; compare these values to verify analysis;
- g) Determine any possible problem areas of resonance during orbital operation by independently exciting the CRU;
- h) Compare structural response of the system to analytical models and determining if flight design methods are adequate;
- i) Determine optimum locations of acceleration transducers for structural data from flight systems.

(2) Secondary Objectives

The secondary objectives of Phase-II are:

- a) Determine areas of possible weight reduction in the structural members;
- b) Develop assembly methods and techniques to be utilized on future systems;
- c) Develop techniques of test instrumentation and the location, installation and control of same for use on future systems;
- d) Add component test time to those prototype components included in the system so as to increase overall system reliability.

b. Description of Phase-II

Phase-II, a structural prototype of a SNAP 2 unit, was designed to provide accurate response data for the components as well as the overall structure.

(1) RC-11

The RC shown in Figure 6 is a brazed sandwich construction of PH15-7Mo stainless steel (SS) honeycomb and face sheets. Tapered copper fins are brazed to the outside surface. The tubes for Serial No. 1 (SN-1) are mockups made from PH15-7Mo SS tapered bars with holes drilled through them to obtain the correct section properties.

(2) Reactor-Reflector-Controls

The reactor vessel, gridplates and other fuel supporting elements are flight items. The fuel mockups are made from steel rods turned to the proper diameter to simulate the fuel weight. The reflectors and control drums are mass and geometric mockups made from magnesium. The control drum drive motors are actual flight items whose usefulness has been expended during their development test program.

(3) Shield

The shield vessel and its supporting brackets are flight design items. The shielding material is simulated by an epoxy resin to which micro-bubbles were added to provide the correct density and center-of-gravity.

(4) PCS-II-2

The PCS includes the CRU-IV-D2, the boiler, a Hg pressure regulator tank, and the startup system, which consists of the injector and nitrogen tanks, various valves, transducers, and connecting lines. These components are prototype units, except for the transducers which are mockups. The CRU shaft has been locked so that it will not rotate or chatter during vibration testing. All brackets and supports are flight design.

The injector and regulator tanks are loaded with Hg to simulate launch weight during all dynamic testing. The rest of the Hg system contains a vacuum to simulate launch conditions. This vacuum is monitored during dynamic testing to establish the integrity of the system for these loadings.

(5) Primary System (NaK)

The piping and components for the primary reactor coolant system are flight design hardware. In addition to the reactor vessel and the boiler, as previously covered, the pipe expansion joints, the NaK flow trimmer and the

startup pump are flight design items. The expansion compensator and the parasitic load heaters are mass and geometry mockups. All piping, support brackets, clamps and insulation techniques between the RC and the piping are those to be utilized on flight models. During dynamic testing, the complete primary system, including the reactor, is filled with an oil that closely simulates the weight of NaK.

(6) Base Load Ring Area

This portion of the vehicle includes the instrument packages, the adapter ring, the thermal barrier and its supporting structure. The instrument packages are mass-geometry mockups attached to the skin panels which serve as radiators to dissipate instrument heat, and as the structure between the RC and the adapter ring. A thermal isolation ring is used to resist conduction of RC heat to the instrument panels (Figure 13). This ring is made from laminated

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Figure 13. Base Load Ring Section

Fiberglas impregnated with phenolic resin. Radiation heat from the RC to the instrument packages is resisted by a thermal barrier which encloses the lower end of the RC, as shown in Figure 1. An aluminum cruciform structure simulates the Agena structure used to support the middle of the thermal barrier. The adapter ring is utilized at the base of the vehicle for ease of mating and attaching to the Agena. This ring serves as a load redistribution member that transfers loads from the monocoque-type structure of SNAP 2 to the eight attach points of the Agena structure. All items in the base load ring area are flight design, except the instrument packages.

(7) Nose Cone

The nose cone is a geometry-mass mockup. The attachments to the RC are flight design. It is used to carry drag loads and protect the reactor during launch; therefore, the load paths are accurate for this test vehicle.

III. DESIGN OF PHASE II

A. FLIGHT DESIGN STATUS

The reference design of the SNAP 2 flight test system, called flight design, was at an advanced stage but not complete at the initiation of design work on PSM-2, Phase-II. The flight design was utilized on problem areas or components that required long lead times and development programs. Much of this information existed in layout form. The design effort on PSM-2, Phase II, was to gather and coordinate the available data from the flight design work, complete the component detail drawings and design and make detail drawings of all other components required.

B. DESIGN LAYOUTS

Four basic layouts of the system were needed; they reflected current flight design data and established control points for system and assembly tool design. These layouts covered the design details of: (1) the base load ring - instrument compartment, (2) the forward portion of the unit including the reactor, shield, etc., (3) the internal components within the RC, such as the PCS, piping and NaK components, etc., and (4) the overall system.

C. DETAIL DESIGN AND FABRICATION OF COMPONENTS

1. Reactor-Reflector-Controls

The reactor vessel, core, etc., used by SNAP 2 was designed and developed within the SNAP 10A program for the joint use of both programs. The following items were used directly from SNAP 10A production: the vessel, a reactor top head, control drive motors, fusible link assembly and other small details. The gridplates were basically the same as SNAP 10A design except for material substitutions. Geometry-mass mockup fuel elements were designed for the system.

The internal and external reflectors and control drums for PSM-2, Phase II, are geometry-mass mockups utilizing magnesium instead of beryllium. These two materials have approximately the same density and required very little changes from flight design. The reflector and control drum supports and scram hinges were structural mockups.

The SNAP 10A reactor support base was a weldment; fabrication problems had been encountered in its development. The SNAP 2 reactor base being considered for flight design was an investment casting. Due to limitations of development time and expense, neither of these approaches could be used on PSM-2 as only one base was required. Therefore, a reactor base was designed that could be fabricated by machining. The material selected was 4130 steel heat treated to 125 ksi minimum. Welding of the reactor base plate to the reactor vessel posed a problem due to the different materials involved as the vessel is made of 18-8 SS. A satisfactory weld was eventually made. Future systems could avoid welding problems by using material for the base which is similar to that of the vessel. This would require thicker sections due to the lower structural allowables and would also correct a thermal expansion problem that could exist during operation of a real reactor.

2. Shield

The flight design requirements of the shield vessel are:

- a) Support of the reactor during launch,
- b) Operation at a temperature between 800 and 1000°F in orbit,
- c) Resist lithium hydride corrosion at these temperatures, and
- d) Remain leak-tight and maintain a pressure of approximately 30 psi for a minimum of 1 year.

These requirements were used for the design of the shield vessel for PSM-2, Phase II; however, since the shielding material is a mockup the vessel is not leak-tight.

3. RC-11

RC-11, SN-1, is a stainless steel brazed honeycomb sandwich structure. All parts are PH15-7Mo SS except the copper fins and braze material. The tubes are the only mockup item in this component; therefore, the vapor manifold was omitted since the RC cannot maintain a vacuum. The braze operation was performed on quarter panels which were then joined with full-length longitudinal welds. The rings were riveted to the two tees located at Stations 8.5 and 20. The fittings and tees that support the PCS and piping were spot brazed in place inside the RC.

4. PCS System

The detailed PCS components were designed by a subcontractor. The integration into the system was a joint effort consisting of the design of the supporting brackets, and development of methods of accurately locating the center-of-gravity of these components.

The initial method used to solve the heat transfer problem between the boiler and the RC, placed a plastic in contact with the boiler at the supporting clamps. This insulation will evaporate to space upon system startup. This method has subsequently been changed. The diameter of the boiler presents a large surface area to radiate heat to the RC; therefore, a heat shield located between the boiler and the RC is required. It is supported by the boiler attach brackets.

Pin-ended trusses or space frameworks are used for the tanks and CRU supports to eliminate the secondary moments in the structural members that are caused by the different thermal growths of RC and PCS components.

This system did not require a functional CRU, but did require an accurate mass-geometry mockup which would be leak-tight because the secondary loop would contain a vacuum during vibration testing. A CRU whose usefulness was expended was assembled for use in PSM-2.

The boiler, tanks, valves and filters are flight prototype items. The Model-5C boiler consists of an outside shell which contains the NaK and coiled Hg tubes. An evacuated tank is located in the center (dead area) of the boiler to decrease the volume of NaK required. The injector tank consists of a welded bellows, with diaphragms at each end for Hg containment, installed in a spherical pressure vessel. For operation, the outer shell is pressurized with nitrogen which forces the Hg out of the bellows. The nitrogen storage consists of a separate spherical pressure vessel. The regulator tank is a short cylinder with parabolic domes at each end. The Hg is contained between the tank and an internal diaphragm attached to welded bellows. The bellows have sufficient stiffness to maintain a pressure on the Hg. The transducers required for flight operation are mass-geometry mockups.

5. Base Load Ring Components

During Phase-I testing, the need for redesign of this area was illustrated. The resulting design is one of monocoque structural panels around the periphery of the compartment. Attached to the inside of these panels are the instruments with their protective housings. The instrument heat load and the limited size of the outside surface require all of the area to be utilized as radiating surface. Each panel is designed with a longitudinal lap joint at each end (Figure 14). This permits easy removal of eight of the panels; to remove the others, at least three will have to be removed at one time. The panels are fabricated from sheet aluminum which has been rolled to contour and trimmed to size. The mockup instruments (black boxes) are steel plates sized to meet the simulated weight requirements. The supporting boxes are sheet metal parts. Each package is assembled by mechanical attachments.

The lower portion of the instrument panels attach to an adapter ring. This ring is required to redistribute the loading from a monocoque structure to eight attach points on the Agena vehicle. This adapter ring has been included on flight systems.

The ring and attaching fittings are machined from a forged magnesium-thorium ring. The base ring was fabricated from magnesium tooling plate.

A thermal isolation ring joins the top of the instrument compartment with the bottom of the RC. This ring is a phenolic impregnated laminated Fiberglas material which possesses the structural qualities required, as well as the heat conduction resistance demanded for this service.

The flight design requirements of the thermal barrier are: (a) maintain a temperature drop from the RC to the instrument compartment of from 600 to 150°F, and (b) provide accessibility of the components supported in the RC for repair work as required during testing of PSM-2. In order to meet this thermal requirement, flight design is utilizing a cryogenic-type of insulation. It is constructed of layers of thin foil separated by a fibrous insulating material, such as glass or asbestos. The fragility of this component when subjected to vibratory loads requires a middle support which is supplied by a cruciform at Station 0. The attachments at Station 8 are continuous around the periphery of the unit and incorporates thermal isolation techniques to eliminate heat shorts in this area.

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Figure 14. PSM-2, Phase-II Instrument Packages and Panels

6. Piping and NaK Components

The flight design piping requires accurate positioning due to the angular momentum effects in a zero-g orbit, and a minimum heat flow to the RC by conduction and radiation. The insulation technique incorporated in the piping clamp design is one in which the clamp contacts the pipe at minimum points through the use of a coil spring. This spring is then supported by the clamp, which is thermally isolated from the support bracket by insulation. The different operating temperatures of the RC and the piping require a method that allows thermal growth longitudinally. The use of the coiled springs in the piping clamps allows slipping in this direction. To eliminate longitudinal stresses, expansion joints are located in the piping approximately midway between the various end attach or anchor points at the reactor and CRU.

To minimize heat radiation, gold foil is wrapped around the pipe. Two methods of attaching this foil are being used in order to compare them during vibration testing. One method utilizes clamps, the other spotwelds the foil to the piping.

During the fabrication and installation of the piping, adequate tooling is necessary to meet the angular momentum requirements. Also, in order to account for the tolerance buildup on the RC, the piping support brackets are designed to be drilled and trimmed on installation.

The NaK piping and expansion joints are fabricated from Type 321 SS. The Hg turbine exhaust which connects to the RC vapor manifold is made from Ph15-7Mo SS.

NaK components include flow trimmer, orbital startup pump, expansion compensator, and parasitic load heaters. The flow trimmer and startup pump are prototype designs. The flow trimmer is used to control NaK flow rate. This is preset during ground operation of the system. The startup pump is an electromagnetic (EM) pump that is used to maintain NaK flow during the period from reactor start until CRU operation. The expansion compensator and parasitic load heaters are mass-geometry mockups. On the flight system, the expansion compensator is required to account for the high expansion of the NaK due to the temperature rise from 70 to 1300°F. This is accomplished by a bellows since the NaK system must be void free. The parasitic load heaters are used to maintain a constant electrical load on the CRU during fluctuations in the payload demands. These heaters convert the excess electrical energy into heat which is returned to the NaK loop.

D. LOADS AND ANALYSIS

The loads used for design and analysis of the system are outlined in the following pages.³ They are based on using an Atlas-Agena combination as the launch vehicle. The trajectory will place the unit in a 700-mile orbit.

1. Dynamic Load Conditions

The dynamic loading conditions are equivalent test environments that include shock, sinusoidal and random inputs to the base of the SNAP unit. Also, the assembly is to be tested with an acoustical input and the CRU will be excited with a vibration input.^{4, 5}

a. Assembly Sinusoidal Vibration

The unit will be rigidly mounted to the shaker table and vibrated to the following levels:

Longitudinal	1/2-in. double amplitude	5 to 9 cps
(X Axis)	2.0 g	9 to 250 cps
	3.5 g	250 to 400 cps
	7.5 g	400 to 3000 cps
Lateral and Normal	1/2-in. double amplitude	5 to 7.5 cps
(Y and Z Axes)	1.5 g	7.5 to 250 cps
	2.0 g	250 to 400 cps
	7.5 g	400 to 3000 cps

The loading conditions along each axis will consist of a single sweep at a constant octave sweep rate proceeding from low to high frequencies in approximately 45 min.

b. Assembly Random Vibration

The assembly will be excited with white noise with a Gaussian distribution in the range of 15 to 2000 cps at a level of $0.05 \text{ g}^2/\text{cps}$. This loading condition will be applied along each of the 3 mutually perpendicular axes for a period of 5 min.

c. Assembly Shock Loading

The assembly will be subjected to the following shocks:

Longitudinal	+8.0 g	-2.5 g
(X Axis)		
Lateral and Normal	$\pm 2.0 \text{ g}$	
(Y and Z Axes)		

The shock pulse form will be an approximate half sine wave with the time duration of 6 msec. There will be 2 shocks in each direction for a total of 12 shocks.

d. Acoustical Loading

The assembly will be subjected to white noise with a Gaussian distribution with a spectrum level of 117 lb over the frequency range of 20 to 9600 cps for a period of 40 sec. If random capability is not available, then a siren level

of 135 db sweeping from 20 to 9600 cps at a constant octave sweep rate for a period of 2 hours may be substituted.

e. CRU Vibration

The CRU will be excited to 0.3 g in two perpendicular radial directions, with respect to CRU rotation, in a frequency range of 300 to 650 cps.

f. Assembly Response Restrictions

The assembly response to the shock, sinusoidal and random loadings will be restricted by an accelerometer located on top of the reactor-shield. The restriction levels are listed as follows (if amplification occurs, the input levels are to be sufficiently reduced so that these restriction levels are not exceeded):

- 1) Sinusoidal and Random Restrictions. The longitudinal response will be restricted to 3.5 g during that portion of the input below 250 cps.

The lateral and normal response will be restricted to 5.0 g during and below the first bending mode.

- 2) Shock Restrictions. The shock response will be restricted to +7.6 and -2.5 g in the longitudinal direction and ± 1.0 g in the normal and lateral directions.

2. Static Load Conditions

The static loads are separated into two combined loading conditions. The first consists of aerodynamic loading due to the maximum dynamic pressure times angle of attack, combined with the inertia load due to acceleration in the longitudinal and lateral directions. The second condition consists of superimposing the maximum aerodynamic heating and the maximum longitudinal and lateral accelerations. The dynamic pressure and the vehicle accelerations versus time after liftoff are presented in Figure 9.

a. Maximum Dynamic Pressure Times Angle of Attack

The shear, bending moment and axial load distributions for the dynamic pressure condition (maximum $q\alpha$) are presented in Figure 15. The shear, bending moment and axial loads occurring from the accelerations accompanying the dynamic pressure condition are presented in Figure 16. The weight distribution used for the acceleration loadings is presented in Figure 17.

Figure 15. Aero Loading at Maximum Dynamic Pressure Shear and Moment and Axial Load vs Station

Figure 16. Limit Inertia Loads at Maximum α

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Figure 17. Weight Distribution PSM-2A

b. Maximum Acceleration Combined With Maximum Aerodynamic Heating Condition

The longitudinal temperature distribution and history due to aerodynamic heating are shown in Figure 18. The circumferential temperature distribution is assumed to be constant. The maximum loading condition due to this aerodynamic heating is considered to act simultaneously with the maximum acceleration loads. The resulting axial load, shear and bending moment caused by peak inertia loads is presented in Figure 19.

3. Margins of Safety

The analysis of the structure for the above loading condition results in the minimum margins of safety presented in Table 1.³

The vibration analysis of the system predicted the resonant points of Table 2.

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Figure 18a. RC Ascent Temperature History
(Station 125)

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Figure 18b. RC Ascent Temperature History
(Station 107)

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Figure 18c. RC Ascent Temperature History
(Station 71)

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Figure 18d. RC Ascent Temperature History
(Station 11)

Figure 19. Limit Inertia Load at Maximum Longitudinal Acceleration

TABLE 1
MARGINS OF SAFETY

Item	Part	Condition	Critical Mode	Margin of Safety * Ultimate † Yield
RC-11	Forward end	Maximum ΔT on face sheets plus inertia loading	Intercell buckling	0.18*
	Aft end	Maximum dynamic pressure	Intercell buckling	0.70*
	Splice joint (forward end)	5.0 g side vibration	Compression	0.11*
	Station 124	5.0 g side vibration	Hoop bending	0.11*
	Shield bracket	Inertia plus aero heat	Weld shear	0.73*
	Pipe support spot braze	Piping vibration	Tension	0.08*
Base load ring	Panel	Maximum dynamic pressure	Primary buckling	1.65*
	Fiberglass ring	Maximum dynamic pressure	Bearing	0.26†
	Instrument package	Vibration	Bending of clip	0.15†
Adapter ring	Flange	Maximum dynamic pressure	Tension yield	0.00†
	Bolt pad	Maximum dynamic pressure	Bending	0.01†
	Tiedown bolt	Maximum dynamic pressure	Tension	0.40*
Thermal barrier	Barrier material	Inertia	Bending	0.31*
Nose cone	Basic cone	All		>2.00
	Ejection support fittings	Ejection load	Crippling	0.27*
Piping	NaK pipe in CRU	Vibration	Bending	0.15†
	Boiler bracket Station 54.92	Vibration	Bolt bearing	0.27†
	NaK pipe bracket Station 44.00	Vibration	Rivet bearing	0.24†
	NaK pipe Station 44.00	Vibration	Hoop bending	0.20*
	Pipe clamp Station 44.00	Vibration	Bending	0.14†
	Spring support	Vibration	Crushing (bending)	0.25*
Shield vessel	Ring Station 126.0	Vibration	Bending	0.27†
	Fitting-Pad	Vibration	Bending	0.01†
Reactor subassembly	Vessel support	Spring preload	Bending	0.12†
	Fusible link Assembly	Spring preload	Tension	0.29†
Components	Expansion compensator (mockup)	Vibration	Pipe bending	0.78†

TABLE 2
PREDICTED RESONANT FREQUENCIES

Resonant Mode	Frequency (cps)	
	Lateral	Longitudinal
First	19.226	98.854
Second	109.142	395.361
Third	190.896	658.259

IV. PSM-2 PHASE II ASSEMBLY

A. ASSEMBLY SEQUENCE

The PSM-2, Phase-II assembly is illustrated in the following listing. The subassemblies and components completion dates were required in sequence, as they were needed for final assembly; otherwise, they were completely independent of each other. The assembly sequence requires a step-by-step completion of each operation.

<u>Subassemblies</u>		<u>Assembly</u>
1. NaK piping	→	(1) NaK piping to PCS mating
2. PCS-II-2	→	
3. RC-11 support fitting and tees	→	(2) Install piping-PCS in RC-11
4. Base load ring	→	(3) Install base load ring to RC-11
5. Reactor-reflector- controls	→	(4) Install reactor
6. Shield	→	(5) Install shield
<u>Components</u>		
1. Nose cone	→	(6) Install nose cone
2. Thermal barrier	→	(7) Install thermal barrier

B. TOOLING

Special tools, slings and fixtures were required for the assembly of PSM-2, Phase-II. The building of these tools was performed by various outside tool fabrication companies.

The tooling was designed for both assembly and subassembly work. This was accomplished by providing a method of mating the subassembly tools to form an assembly tool for the two components. Thus, the piping tool mated to the PCS tool. The RC base drill fixture mated to the PCS tool for installation of the piping and PCS in the RC. The piping and PCS tools were then removed.

The RC base drill fixture mated to the workstand which located the base load ring subassembly. The workstand located a derrick which in turn located the tooling for positioning the reactor, shield, and shield support fittings.

C. SUBASSEMBLIES

1. NaK Piping

The subassembly of the NaK piping included piping spools, NaK components and expansion joints. These items were located by the tool in three directions: X, Y, and Z. The main concern in the tooling was to locate exactly the radial distance and angle from the centerline of the vehicle. Work on this subassembly proceeded with reasonable ease. Though the jig did not supply sufficient locators for expansion compensators in the longitudinal direction, this was accomplished with the use of blocks and C-clamps. Upon completion and inspection of the subassembly, it was noted that when the hold-down portions of the tool were removed, some residual stresses warped the piping at the reactor end. To correct this, a straightening procedure was done which involved heating the piping to warp it to the proper position while free from the tooling supports.* The piping subassembly and tool are shown in Figure 20.

2. Base Load Ring Subassembly

This work was broken into two subassembly tasks; the first was the mating of the adapter ring to the base plate. This was performed by the manufacturer of the base plate. The second task was the installation of the instrument panels with their mockup instrument package. The subassembly is shown in Figure 7.

One problem encountered was the excessive amount of time required to position the base plate and adapter ring on the assembly stand. This was done by layout methods and took approximately 6 manhours. The time could easily be reduced by using tool holes and pins in any subsequent subassembly work.

The second problem noted during this subassembly was that the tolerance buildup in the detailed parts allowed the mockup instrument packages to come within 0.005 to 0.030 in. of the top of the adapter ring. The drawing had indicated that approximately 1/8-in. clearance should exist here. It was decided

*Of course this method could not be used on a flight system

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Figure 20. NaK Piping Subassembly and Tool

that it was not necessary to rebuild this item, but this area would be watched during testing to see if the mockup instrument packages would hammer under vibration. If this problem occurred, some cushioning material was to be inserted in the space. The preload washers used in the attachment of the base plate to the adapter ring were not available in the initial assembly of these two components. These items were installed at a later date without disturbing the initial alignment of the two components by removing one bolt at a time and re-installing it before removing the next bolt.

3. PCS-II-2

The components of the PCS were installed in an assembly tool which provided locating pins and surfaces to accurately position these items. Upon installation of the boiler, it was noted that the Hg vapor outlet at the top was warped so that the pipe attaching to this point could not utilize the locating arm for the welding of this joint. However, it was more practical to allow the pipe to be slightly out of position than to try straightening the boiler. The CRU was mounted in the assembly jig and the following item noted: the Hg inlet tube in the turbine area was warped and this necessitated a rework of the mating-tube support clamp in order to complete this joint.

During fabrication of the regulator tank it was discovered that the locating holes for this component were not placed in the position previously agreed upon. To correct this situation, the assembly tool was reworked to position the tank properly. The Hg outlet tube to the tank obstructed the lower portion of the assembly jig; it was necessary to cut a slot in the jig to provide clearance. This situation also existed with the injector tank. The problem resulted from lack of final PCS design information during design of the tool. The installation of the nitrogen tank proceeded with no difficulties. The PCS transducer and flow regulator package required some tooling work to locate the supporting tee on the RC prior to installation of this unit into the PCS assembly jig.

During welding of the tubes, connecting valves, and the five major components, areas of minimum access were noted in many places. The chipless connectors design presented a problem in obtaining a good die-penetrate check of the welds. This problem occurred because two separate welds were located so that they overlapped and caused a crack in which the die was trapped. Future designs should separate these two welds, thereby removing the possibility of

cracks. The accessibility of the welding should also be considered on all future designs. Figure 21 shows the completed PCS subassembly with tool.

4. Reactor-Reflector-Control Subassembly

The reactor dummy core, gridplates, internal reflectors, etc., were loaded into the vessel and the reactor head was welded in place. The external reflector halves were preassembled. This involved mounting the control drums with their supporting arms and drive motors. These items were then mounted around the reactor with the installation of a fusible link strap and the scram springs. Figure 22 shows the completed subassembly.

5. Shielding

The subassembly of the shield involved filling the shield vessel with a mockup shielding material. This material was an epoxy with microbubbles added to obtain the same density as the real shielding material. Due to the chemical reaction heat generated during the curing time on this material, it was required that only thin layers be poured at any one time. To decrease the time required to fill the vessel, blocks of this material approximately 2 by 6 by 8 in., were cast prior to the actual casting of the material into the vessel. During the filling operation, these bricks were stacked in the vessel approximately 1-1/2 in. apart, thereby allowing pours to be made to the depth of 9 to 10 in. without overheating the shielding material. On the final pour in the bottom of the shield, the fitting was installed which will be used to apply loads to the shield during static testing. The density was checked at three points during the pouring operation to allow for any fluctuation in the density of the mockup of the shield material. If it was varying too much, it could be corrected in the next pouring operation by changing the density ratio of that mixture. The final weight of the mockup shielding material, including the fitting for load application, was 330 lb. The maximum desirable weight was 320 lb without the fitting. The final weight was acceptable as it would be conservative to test with the heavier shield.

6. RC-11 Support Fittings and Tees

This work on the RC involved the spot brazing of a tee and some clips to be used in mounting PCS components. These items had not been included at the start of RC fabrication because their locations were not available. The transducer and flow regulator package was mounted in such a way that part of

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Figure 21. PCS-II-2 Subassembly and Tool

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Figure 22. Reactor-Reflector-Controls Subassembly

it fit between two tees and another portion set outside of those two tees. When this package was received from the supplier, dimensions were taken and a tooling block was made to locate the tee at a proper distance from the tee already attached to the RC. While spot brazing this tee to the RC, the spot brazer ground wire burned a hole in a 5-mil facing between the RC frames at Stations 8.5 and 20. The 5-mil face and core were not thick enough to carry the current being used. This damage was repaired by attaching a doubler plate to the damaged inner skin with blind rivets. The clips used for support of the Hg line from the injector tank were spot brazed to the frame at Station 8.5. The spot brazing technique later proved unsatisfactory during installation of this line; spot brazes broke during a drilling operation required to mount the second half of the clip. Repairs were made with fusion welding. The shield support fittings were fusion welded to their attach points on the RC; tooling was used to locate and support the fittings during welding. The nose cone support fittings were riveted to the top ring of the RC.

D. FINAL ASSEMBLY

The step-by-step process of assembling the subassemblies into the completed unit is discussed in the following text.

1. Installation of PCS-II-2 to NaK Piping

This step in the assembly involved joining the PCS and NaK piping at the boiler and CRU. The two subassembly tools were mated for this operation. Figure 23 shows this step of assembly. During the mating, the mockup expansion compensator interfered with a transducer mounted on the turbine exhaust of the CRU and prevented alignment of the NaK piping at the point of attachment to the NaK pump on the CRU. To correct this situation, the transducer and its supporting brackets were removed and the opening in the turbine exhaust was plugged and leak checked. Upon completion of the NaK pipe welding, a leak check was made before proceeding to the next step.

2. Gold Foil Installation

To test the structural feasibility of gold foil insulation on NaK piping, two attachment methods were utilized on PSM-2. This was done in selected sections of pipe which were most likely to have the highest responses during vibration testing. One method of installation was strictly spot welding; with

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Figure 23. Assembly of PCS and Piping With Tooling Required

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the second method additional support was added by clamping the gold foil at an approximate spacing of 8 to 10 in. To protect the foil from damage during the rest of the assembly work, it was wrapped with strips of polyethylene sheeting which were removed after completion of assembly.

3. Installation of Piping and PCS in RC-11

The tooling located the RC with respect to the piping. This work involved installation of support brackets between the piping clamps and the RC supporting tees and fittings. It was slow and tedious work because it required match drilled holes at each point of attachment, and space was very limited for this type of operation. Figure 24 shows this step completed. A discussion of the problem area follows:

- a) The screws chosen for the PCS installation had torque set heads. This head is an offset cross design. Due to the limited accessibility, it was practically impossible to keep the driving tool in the slots while torquing to the desired torque values for proper screw installation. If the tool slipped, the head was damaged so that the screw had to be removed and replaced to obtain the proper torque values.
- b) The piping supports in the upper area of the RC were designed to mount to the RC on each side of the pipe. Tees were provided on the RC at these points and they were perpendicular to the surface instead of parallel. In the small diameter portion of the RC, this resulted in a decrease in the space between the brackets at the mounting point of the pipe clamp. To provide proper distances in the area of the top part of the boiler, it was necessary to rotate this portion of the boiler out approximately 1/4 in. and fabricate new brackets for this support point.
- c) Some of the PCS valves required shimming to approximately 3/16 in. thickness in order to mate with the supporting tee on the RC. This was due primarily to the method of locating these tees on the RC. They were located by angular dimensions and should have been located by two-dimensional coordinate methods.

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Figure 24. PCS and Piping Installed in the RC

- d) The brackets at the center-of-gravity of the CRU were heavier than those located at the opposite end. These were reversed on installation. To correct this situation, the thin-wall brackets were replaced by heavier brackets at both attachments.
- e) During installation of the transducer and flow regulator package, it was necessary to tack weld part of the nuts to the inside surface of the tees before installation, as it was impossible to reach the areas once the package was in position.

4. Installation of Instrument Compartment on RC

This installation went very satisfactorily. It involved positioning of the RC in the proper location with respect to the instrument compartment. This was easily accomplished with the tooling used. A drill fixture was utilized in the drilling of the 256, close-tolerance bolt holes required in the monocoque structure attachment. These holes were drilled through the panels, the thermal isolation rings and the Fiberglas angle that supports the thermal barrier. Once the holes were drilled in the angle supporting the thermal barrier, the angle was removed and the holes were enlarged. Special nuts were pressed into these holes. This provided an accurate technique for locating these nuts.

5. Installation of Reactor Vessel and Shield

The tooling was designed to position the reactor while the NaK piping was being welded to it. However, this tooling did not allow sufficient clearance for the proper welding of the lower connection, and it was impossible to utilize this tool without extensive rework. To correctly locate this component, the following steps were taken:

- a) The shield was located in the RC and the attaching holes were match drilled.
- b) The shield was then utilized to locate the reactor vessel, as these two parts has been match drilled during the subassembly stage as shown in Figure 25.
- c) The reactor vessel was then supported by part of the tooling and the shield was lowered out of position to allow access during welding.

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Figure 25. Reactor Vessel and Shield Mated

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- d) The weld joining the NaK piping and the reactor vessel was made.
- e) The shield was then repositioned and all connecting bolts between these components were installed.

6. Reflector-Controls Installation

The reflector half subassemblies were installed. This operation was a simple one, as these items had already been preassembled during subassembly effort. This step is shown completed in Figure 26 with transducer blocks and labels installed.

7. Thermal Barrier Installation

The thermal barrier and its supporting cruciform had been preassembled prior to installation of the instrument compartment on the RC. Therefore, this installation proceeded with little difficulty. It was noted that the fragility of the thermal barrier required care during the torquing operation of the attaching bolts. An earlier observation indicated that some PCS components would interfere with the thermal barrier once it had been installed. This was corrected by cutting clearance holes in the thermal barrier for these items.

8. Nose Cone Installation

The joint between the nose cone and the top ring of the RC was extremely tight. This condition was relieved by polishing the inside mating surface of the nose cone. As the nose cone would have to be removed and replaced during various portions of the vibration testing, the polishing was of additional benefit. The completed PSM-2, Phase-II, is shown in Figure 27.

E. Hg LOADING AND PRECAUTIONARY MEASURES

During vibration testing, it was highly desirable to have Hg in the injector and regulator tanks to provide a liquid mass supported in the same manner that it would be during flight. To assure maximum safety and quick cleanup in case of an accident or failure which would release Hg in the test area, the following precautions were taken:

- 1) The tanks containing Hg were bagged with polyethylene sheeting.
- 2) The bags were monitored with a Hg detection device.

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Figure 26. Reactor and Shield Installation Completed

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Figure 27. Completed S2-PSM-2, Phase-II

- 3) The area within the vehicle was monitored by the same device as well as personnel areas in the test facility.
- 4) The shaker table was covered with a sheet of polyethylene material to protect this component from being contaminated.
- 5) A trap was built around the shaker table to contain any Hg that might run off the table.
- 6) All floor areas in which Hg was handled or transported were covered with polyethylene sheeting.
- 7) The outlets provided in the tankage for filling with Hg were fitted with a special tee section of tubing which allowed the use of a completely closed loop during filling and draining.

BLANK

V. TEST PROGRAM

The following program outlines the planned testing effort that will be performed with the PSM-2, Phase-II, system. The successful completion of this program will result in meeting the system objectives listed in Section II of this report.

A. DYNAMIC TESTING

This testing will be performed in the Environmental Laboratory, Building 027, of the Nuclear Field Laboratory at Santa Susana. References 4 and 5 give a more detailed accounting of these tests.

1. Mode Studies

This series of tests utilizes a small shaker to input a vibration loading to the center-of-gravity of the reactor-shield combination. The input is in the three axes, X, Y, and Z. This series of tests will provide data on the resonant frequencies and mode shapes of the structure and internal components. The data will be utilized in locating and obtaining the maximum use of limited instrumentation on subsequent tests.

2. Lateral Decay Tests

This test involves rigidly attaching the base of the unit to the floor and applying a 1000, 2000, and 3000 lb series of loads to the reactor-shield combined center-of-gravity. These loads will then be released by a quick disconnect mechanism. The decaying vibration produces data from which damping ratios and natural frequencies will be obtained.

3. Low-Level Resonant Searches

This series of tests will be performed on the large shaker in all three axes recording all datum points. The data from these tests will be used to check the response of all components before proceeding to the high-level testing, thereby obtaining a high degree of confidence in the prototype system while subjecting it to short duration and low-level sinusoidal inputs.

4. High-Level Sinusoidal Tests

The input levels during this series of tests are those given in Section IV.D of this report, and are measured at the base of the unit. These are the levels which will be used during qualification of the flight design. These tests will be performed in three mutually perpendicular axes and two runs are required in each axis to record all datum points.

Magnetic tape recording equipment will be utilized to record as much of the data as possible during this series of tests. This method of recording data is desirable for three reasons. First, it will provide permanent records which can be reproduced. Second, electronic methods can be utilized to reduce the large quantity of data required and their versatility allows filtering, amplifying, etc. Third, the accuracy and various methods of presenting or comparing the data are highly desirable.

5. Random Tests

The random test will be performed on the large shaker in the three axes and all instrumentation shall be recorded. The input levels are presented in Section III.D of this report. These tests will provide a comparison of the system response to the two types of vibration input, sinusoidal and random.

6. Shock Tests

This series of tests will be performed on the large shaker to all levels shown in Section III.D of this report. These are qualification levels. The shocks shall be applied at a low level first so that the amplification can be measured and extrapolated so that the response restrictions are not exceeded.

7. CRU Vibration Tests

The CRU will be excited to those levels given in Section III.D by using a small shaker. Data will be recorded to establish the response of other components in the system. These tests are to determine the effect of CRU vibration during orbital operation.

8. Acoustic Testing

This testing is to determine the response of the system and its components to an acoustical environment. The results will be compared to other testing methods to establish their adequacy in determining the basic structural

response of the system. An acoustic test chamber large enough to handle a SNAP unit is available at the Los Angeles Division of North American Aviation, Inc. The levels given in Section III. D will be used in this series of tests.

B. STATIC TESTING

These tests will be performed in the Static Test Facility in Building 042 at Santa Susana.

1. Simulated Aerodynamic Pressure Plus Inertia Tests

This series of tests will apply simulated loads for this design condition, as given in Section III. D. The test system will be mounted on a load platform which will provide a method of measuring the reaction loads at the base. The pressure loads will be applied to the RC by straps which will contact it over 180° arc, thus simulating the major portion of the aerodynamic pressure radial distribution. These straps will be placed 12 in. on centers and will be 10 in. wide. This will produce a very close simulation of the pressure over the full length of the RC. The other components will be loaded by straps, pads and fittings.

All of the load applying devices will be connected to hydraulic struts by a network of beams, rods and links called whippletrees. Each strut will have an accompanying load cell attached in series with the strut to allow an accurate determination of the exact load being applied to the system. Sufficient strain gages will be located on the structure to confirm the loads distribution and the critical stress areas. Loads will be applied in 10% increments to the following levels: 50, 100, and 125% of limit design load. Between each of these levels, the resulting data will be reduced and evaluated before proceeding to the next load level. At the beginning and end of each test, all instrumentation will be read with zero load on the specimen.

2. Simulated Maximum Inertia Load Plus Aerodynamic Heating Tests

The load conditions that will be simulated during this series of tests are presented in Section III. D of this report. The simulated inertia loads will be applied to each component by hydraulic struts through a set of tie rods and beam linkage. Load cells and instrumentation will be used to accurately measure the loads being applied and the reactions loads at the base. The aerodynamic

surface will be heated at the rate necessary to simulate the predicted temperature distribution for a flight system. This will be accomplished by quartz lamps arranged around the test specimen. The temperature controlling techniques must have sufficient accuracy to avoid overheating which would damage the structure. A series of tests will be performed to these levels: 50, 75, 100, and 125% of limit design loads. The data from each test will be reviewed and evaluated before proceeding to the next level. Strain gages and thermocouples will be located throughout the structure as well as critical areas. The resulting data should be sufficient to verify stress and aerodynamic heating analyses.

VI. RESULTS

A. PHASE-I

The design, assembly and testing of SNAP 2 PSM-2, Phase-I has been completed. The results of the mockup system tests contributed significantly to the design of Phase-II in the following areas. The load carrying members in the instrument compartment were changed to a monocoque type structure to raise the overall system natural frequencies. The shield-to-RC attachment was also changed from a radial slip joint to a fixed attachment. After these changes were incorporated on Phase-I the first resonant frequencies were 53 cps in the longitudinal direction and 14.5 cps in the lateral direction.⁶

B. PHASE-II

The design, fabrication, and assembly of the SNAP 2 PSM-2, Phase-II, prototype system has been completed. Those portions of the testing that have been completed are as follows: the low-level resonant search, the lateral decay test, the high-level sinusoidal vibration, random vibration in X axis, CRU orbital vibration, 50, 100, and 125% aerodynamic pressure test.

This report presents only the preliminary test results as the data from the tests performed to date is in various stages of reduction or evaluation. It is also intended that upon completion of the test program and data evaluation, another report will be issued covering the results of the complete test program.

The lateral decay tests indicated a first resonant mode of 18.7 cps with a viscous damping ratio of 0.033. The tests performed on the large shaker-slip table combination experienced a reduction in the first resonant mode. Additional tests were performed to gather data on the granite block and slip table to evaluate their contribution to this problem. The reduction and evaluation of this data is incomplete at this time.

A failure occurred in the Hg-containing bellows of the injector tank. The time of failure is not known as the Hg was contained within the outer shell of the tank. This discovery was made during the draining operation after completing the dynamic testing. Also, a leak in the evacuated Hg system occurred at a weld connecting a mockup transducer line to the turbine exhaust. This leak was repaired so that testing could continue with a vacuum in this portion of the system.

A response of the edges of the RC tapered copper fins was observed in some areas during the early tests on the large shaker. An investigation revealed the lack of a braze bond in these areas, most of which were too small to be recorded on the inspection records, as small voids were considered acceptable. These voids did not seem to propagate during the remainder of the vibration testing.

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