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PROGRESS REPORT

SNAP 10A

NUCLEAR AUXILIARY POWER UNIT DEVELOPMENT

JANUARY - MARCH 1964

(Title Unclassified)

AEC Research and Development Report

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PROGRESS REPORT

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JANUARY - MARCH 1964

(Title Unclassified)

By

JOHN STEWART

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I. PROGRAM OBJECTIVES

The objective of the SNAP 10A program is to develop a nuclear power system for space application. This development effort will lead to flight tests. The system is being developed to the following specifications:

- a) An electrical output of 500 watts at 28 volts should be provided over the system lifetime of 1 yr.
- b) Maximum system weight should be 950 lb, including the special components and diagnostic instrumentation necessary to complete the flight test objectives. The operational SNAP 10A system design objective is 775 lb. The shield in this system will be designed to provide protection for the electronic payloads in the flight vehicle in the present configuration, which provides 17-1/2-ft separation between reactor and payload.
- c) The SNAP 10A system shall use the SNAP 2 reactor with minimum modifications.
- d) The system will be essentially static in its operation. Power conversion will be accomplished by a thermoelectric generator coupled to the reactor heat source by means of an electromagnetically pumped liquid-metal heat-transfer loop.
- e) The system shall be designed to eliminate the need for active control following orbital startup.
- f) The system will be qualified to withstand the environment encountered in vehicle ascent and space environments.
- g) The unit must be designed to facilitate safe ground handling and launching, and must be developed to contribute a minimal radiological hazard at launch to the launch facilities, personnel, and inhabitants of surrounding dwellings.
- h) The power conversion subsystem shall be of a design to accommodate future growth.
- i) The shield shall be so designed that over a period of at least 1 yr the total integrated dose at the dose plane, 17-1/2 ft from the bottom of the reactor, shall not exceed 10^{12} nvt and 10^7 r.

II. SUMMARY

The 90-day test of the first full-power endurance run on a SNAP 10A system was successfully completed on January 15, 1964. This system, designated FSM-1, is similar to the flight units, except that electrical rather than nuclear heat is used within the reactor core to furnish power. A total of 2336 hr (100 days) of successful operation with a reactor core outlet temperature above 900°F generated 906 kwh of electricity by thermoelectric conversion. The overall system performance was as expected throughout the test. Posttest analysis of all major components is continuing. Test results indicate that the SNAP 10A flight unit will initially produce 565 watts in orbit.

Twenty-two flight TE modules are continuing to operate at 110% of design conditions, with five exceeding 200 days of operation. Using these present test data, the overall converter subsystem reliability for surviving acceptance testing, prelaunch, and launch is demonstrated to be 0.996 at 90% confidence.

Five flight-type thermoelectric pumps have logged up to 100 days each at the design flowrate and are continuing testing to ascertain total life capability. The first full-qualification expansion compensator has progressed through acceptance-level shock and vibration, initial thermal, qualification-level shock and vibration testing, including helium leak checking, satisfactorily.

A second nonnuclear flight qualification system, FSM-4, and the first nuclear flight qualification system, FS-1, are approaching the initial pretest checkout phase.

GLOSSARY

CRT	Cathode ray tube
Curie-Dose	Fission product inventory program
EMI	Electromagnetic interference
FMU	Functional mockup (launch vehicle)
FS	Flight system
FSEM	Flight system electrical mockup
GI	Gastrointestinal
GTH	Ground test heater
GTK	Ground test kit
LLI	Lower large intestine
LMSC	Lockheed Missile and Space Company
NPU	Nuclear power unit
NNPU	Nonnuclear power unit
PSM	Prototype structural mockup
RSH	Reactor simulator heater
RTD	Resistance thermometer detector
S	Stomach
scfh	Standard cubic ft/hr
SI	Small intestine
TE	Thermoelectric
Torr	1 mm of Hg vacuum
THUNDERHEAD	External cloud gamma dose program
TM	Telemetry
TMA	Thermal mechanical acceptance
ULI	Upper large intestine

III. ENGINEERING AND ANALYSIS

A. ENGINEERING SUMMARY

The SNAP 10A Program has progressed to the stage where the major activity concerns system and component testing. Consequently, the primary SNAP 10A design operating characteristics have not been changed during the last quarter.

Results of the FSM-1 system test, together with the results of component testing of the NaK pump, fuel element, and TE converter, indicate that an initial power output of 565 w will be achieved in the flight test. The results of the FSM-1 system test also have substantiated the predicted, low, system degradation rates.

Component development and the FSM-1 system tests have indicated weaknesses in certain of the system assembly techniques. These weaknesses, for the most part, have been overcome by the redesign of the NaK pump radiator thermocouples, a change in the technique used in the attachment of the RTD's to the piping, and a change in the method of wrapping and attachment of the gold-coated molybdenum foil.

Tests of several design specimens for the welded joint between the NaK line and the upper manifold have been completed. Based on the results of these tests, the fitted and shaped nipple with a "butt-filled" weld configuration will be used in the flight system. American Super Temp Wire will be used for high-temperature wiring throughout the NPU, a decision based on results of extensive testing including radiation tests.

Electrical system tests indicated that the reactor control system was sensitive to transient interference. This problem has been eliminated by placing a large value capacitance between the temperature sensor input leads to the reactor controller.

The above minor engineering changes were made to overcome potential weaknesses in the original system designs that were revealed by tests. All these changes have resulted in an increased flight system performance reliability.

B. DESIGN INTEGRATION

1. General

Several areas of investigation were established during the quarter to initiate improvements in design, specification, and assembly techniques. These

areas included the NaK piping system pinch-off and seal weld, attachment of resistance temperature measuring devices to NaK piping, and the wrapping and attachment of gold-coated molybdenum foil which acts as an emissivity coating. Work in these areas is continuing and will soon be completed.

A checking survey was conducted to verify conformance of the latest revisions of major assembly drawings, master layouts, and coordination drawings and documents.

2. Design Changes

Detail design changes to flight system components initiated during this quarter are summarized below, together with reasons for the change.

a. NaK Piping Manifolds

Assembly drawings were revised to designate use of the "new" upper manifold design which uses a "butt-fillet" weld configuration. It replaces the previous design which utilized the "pull-out" at the NaK supply line-to-upper manifold joint. The new manifold design has demonstrated improved cycle life during shock and vibration testing.

b. Expansion Compensator Microswitch Mounting

The spring lever which actuates the expansion compensator microswitch was changed to permit switch actuation at nominally 1-in. bellows displacement. System tests disclosed actuation at ~ 1.2 in., which was inconsistent with proposed system usage. The change also eliminates a potential jamming of the lever and the switch by providing more complete instructions for adjustment at assembly.

c. Assembly Tolerance

The allowable variations in core vessel roundness following welding of the vessel head was reevaluated. Tests indicated that the original requirement establishing roundness at 0.003 TIR was not realistic. Drawings have been changed to specify roundness within 0.010 in. Roundness of the vessel after welding of the vessel head primarily affects the fit of the external reflector.

3. Weight Status

The current SNAP 10A weight breakdown is shown in Table 1. There was no weight change during the quarter, thus the unit weight remains at 979.1 lb. The weight objective for SNAP 10A is 950 lb.

TABLE 1

SNAP 10A FLIGHT SYSTEM WEIGHT STATUS REPORT

Number	Component	Specific Weight (lb)	Current Status		NaK Weight (lb)	Weight Changes Since Last Report (lb)	Over or Under Weight (lb)	Center of Gravity Location (in.)
			Present Design Complete	Weight (wet 70°F) (lb)				
1.	Reactor core	135	95	136.4	2.3	0	+ 1.4	112.1
2.	Reactor vessel and grid plates	30	95	31.3	4.8	0	+ 1.3	108.8
3.	Reflector structure with reactor controls	108	95	106.5	-	0	- 1.5	112.7
4.	Radiators-converters, including supports and converter tubes	150	85	154.3	11.1	0	+ 4.3	49.4
5.	Piping, including support	23	90	24.3	9.4	0	+ 1.3	74.3
6.	Structure	80	95	83.1	-	0	+ 3.1	40.0
7.	Operational instrumentation	46	90	61.2	-	0	+15.2	18.3
8.	Expansion compensator, including support	12	85	13.3	1.0	0	+ 1.3	10.1
9.	Pump, including support	20	90	21.4	0.1	0	+ 1.4	124.2
10.	Shield and casing	225	95	217.2	-	0	- 7.8	90.4
11.	Destruct system	9	-	-	-	0	- 9.0	-
12.	Diagnostic instrumentation	40	90	55.6	-	0	+15.6	33.1
13.	Flight test system contingency	12	-	10.0	-	0	- 2.0	-
14.	Ejectable heat shield	30	85	32.8	-	0	+ 2.8	50.5
15.	Instrument compartment heat barrier and instrument compartment bracketry	30	80	31.7	-	0	+ 1.7	3.1
	Totals	950		979.1	28.7	0	+29.1	72.9

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C. INSTRUMENTATION AND CONTROL

1. General

The delivery of the flight electrical mockup (FSEM-3) to LMSC and the successful operational testing of 10FSM-1 have provided confirmation of instrumentation design philosophy. Irregular instrumentation performance during FSM-1 operation was thoroughly investigated for evidence of possible unsuitability for the flight environment. FSM-1 instrumentation consisted of preflight-type instrumentation and did not represent the quality characteristic of the flight-type equipment. Results of these efforts generally indicated the need for improved quality control procedures for vendor supplied materials and items. These improved procedures have been implemented for the flight instrumentation procurement.

2. High-Temperature Wire

The suitability of American Super Temp Wire has been confirmed by environmental test programs supplemented by tests to establish its resistance to radiation. The selection of a suitable high-temperature varnish or cement, used at the terminations to prevent insulation fraying, called for additional testing which resulted in the approval of Foster A6A3A high-temperature varnish for this application.

3. Startup Controller

Early systems tests disclosed random, but chronic, malfunctions of the reactor control system. These were diagnosed as being caused by transient interference upsetting the output timing sequence. Tests in the laboratory confirmed the diagnosis and revealed a certain degree of susceptibility of the controller to particular transient types of interference conducted into the controller temperature sensor input. Inasmuch as the early tests did not reflect flight-type shielding and grounding, it was projected that the correct wiring installation employed on the flight system would resolve the problem. Compatibility testing at LMSC with FSEM-3 showed that this improved the situation, but did not eliminate the inherent susceptibility. As a result of further tests, it was decided to lower the circuit impedance at the controller input by shunting a large-value capacitance across the temperature sensor input loads. Laboratory tests have shown a satisfactory reduction of the EMI susceptibility as a result of this measure.

4. Converter Impedance Measuring Device

Operation of FSM-1 permitted an actual performance evaluation of the instrument used for measuring the internal impedance of the thermoelectric converter under dynamic operating conditions. Impedance measurements recorded were compared with those made by conventional means (i.e., using the open circuit method). Initial disagreements in readings by the two methods were attributable to test setup variables such as differences in points of connection, excessively long test leads, error in the 400-cycle supply frequency and voltage, and the influence of the Peltier effect. When these variables were eliminated, agreement to within 2% was obtained and it was concluded that the device was entirely suitable for its purpose in the flight systems.

5. Relays

Relays for use in the SNAP 10A radiation environment have been supplied with special coil impregnants and coatings. These relays have exhibited random failures during tests attributed to the special varnish coatings. These coatings tend to flake off microscopic particles which are electrostatically attracted to the charged open contacts, thus preventing a conductive path when the contacts are closed. A change to heat shrinkable polyethylene tubing for the relay coil jacket has been made and should resolve this problem. However, an intensive product search also is being made in an effort to obtain a still more reliable relay.

6. Solid-State Fast Neutron Dosimeters

Twelve solid-state fast neutron dosimeters have been operationally tested in the Shield Test Facility. Preliminary review of the data indicates a very satisfactory device, entirely suited to fast-neutron flux mapping in the flight systems. Measurable values of integrated flux starting at 5×10^{11} through 1×10^{15} nvt are feasible. It is planned to provide three different ranges by selection of a range setting resistor for the range of 5×10^{11} to 1×10^{13} ; 1×10^{12} to 1×10^{14} ; and 1×10^{13} to 1×10^{15} nvt.

There is a degree of temperature dependence in the present circuit, the extent of which will require additional testing to determine whether or not compensation will be required. Experimental data indicate a measurement accuracy in the above ranges of 10%.

7. Expansion Compensator Instrumentation

Errors in the position data obtained from the FSM-1 expansion-compensator position transducers during systems tests were traceable to oxidization of the connector pins, resulting in unbalanced resistances in the two legs of the 400-cycle bridge formed by the transducer windings. Spot welding the inter-connecting cable leads directly to the connector pins in the flight system has eliminated this source of error.

8. Potting of Exposed Terminals

Exposed terminal connections on the electrical current shunts and also on the 400-cycle transformer presented the possibility of accidental shorts or grounds. These areas are now being coated or encapsulated with Silastic RTV-732, a silicone compound, to provide the desired degree of protection.

9. NaK Pump Radiator Fin Thermocouples

Installation problems with the earlier design of the subject fin thermocouples prompted a redesign which is now incorporated in the flight systems. This allows a more reliable final installation configuration with reduced handling stresses, and has resulted in improved thermal characteristics, thus providing more accurate temperature readings.

D. SYSTEM ANALYSIS

The system analysis report for this quarter consists primarily of extensions of analyses reported in previous quarters.

1. Prestartup Orbital Operation

Extensive analytical work was conducted on the determination of the SNAP 10A system thermal behavior in the orbital environment prior to system startup. The system model used for this work has been evolved over a period of about 2 yr. In this quarter, it was possible to demonstrate the validity of the model by comparison with test data taken in the Prestartup Orbital Test conducted on the FSM-1 system. The data comparison suggested several improvements in the earlier models. The indicated improvements were made, and good agreement was obtained between model predictions and test results as is shown below. The improved model was then used to predict system behavior in the space environment.

The system thermal model has been described in previous Quarterly Progress Reports. Basically, the SNAP 10A system has been divided into a large number of heat transfer nodes, with appropriate heat balances written for each. This results in a system of nonlinear ordinary differential equations with time as the independent variable and system temperatures as the dependent variables. The system behavior is obtained by integrating these equations on the digital computer. Approximately 350 separate system and environment temperatures are simulated in the computer solution.

The FSM-1 Prestartup Orbital Operation test results also were discussed in the last Quarterly Progress Report. By describing the FSM-1 system environments in terms acceptable to the computer model discussed above, it has been possible to obtain computer predictions of the test results. These computed values then may be compared with the test data to determine the model accuracy. Such a comparison is presented in Figure 1. The results shown correspond to the 9% flow, constant sun-constant shade test. The transient response of certain key system variables, as predicted by the computer model, is shown as the solid line. The corresponding test data points were obtained from system thermocouple readings recorded on a data logger. The agreement is exceptionally good. A similar comparison for the 4% flow run is shown in Figure 2. The agreement again is good. Figures 3, 4, 5, and 6 show a detailed comparison of system temperatures from model and test for one time point. The time shown corresponds to the end of the Lamps On portion of the test. The basic grid in the figures gives the computed values. The test values are shown circled at the location appropriate to their position on the system. The agreement between the measured and predicted values is within the scatter shown by the data.

The same basic model was used to predict the system behavior in the space environment. Only the portion of the program describing the system environment was changed. The predicted transient response of key system variables after orbit injection is shown in Figure 7. The run shown corresponds to a system flowrate of 4% of design, with a constant sun-constant shade orbit, and an orbital altitude of 700 miles. The detailed system spatial temperature distribution at equilibrium conditions in this orbit is shown in Figures 8 through 14.

It was concluded from this study that the present system meets its design objective; namely, that it will be capable of normal operation after an extended

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Figure 1. Comparison of Computer Model Results With Test Data, FSM-1, 9% Flow Run

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 Figure 2. Comparison of Computer Model Results with Test Data,
 FSM-1, 4% Flow Run

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Figure 5. Comparison of Test Data and Computer Results, NaK Tube Final Conditions

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Figure 6. Comparison of Test Data and Computer Results, Structure Final Conditions

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Figure 7. SNAP 10A Prestartup Orbital Analysis,
Constant Sun-Constant Shade Orbit

Figure 8. Effective Space Tem-
perature Distribution (°F),
Constant Sun-Constant
Shade Orbit

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Figure 9. Heat Shield Equilibrium Temperature Distribution ($^{\circ}\text{F}$), Constant Sun-Constant Shade Orbit

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Figure 10. Radiator Equilibrium Temperature Distribution ($^{\circ}\text{F}$), Constant Sun-Constant Shade Orbit

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ORBIT ALTITUDE - 700 mi
FLOWRATE - 4% OF DESIGN
RUN No. 7532-65

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Figure 11. NaK Tube Equilibrium Temperature Distribution (°F), Constant Sun-Constant Shade Orbit

Figure 12. Structure Equilibrium Temperature Distribution (°F), Constant Sun-Constant Shade Orbit

ORBIT ALTITUDE - 700 mi
FLOWRATE - 4% OF DESIGN
RUN No. 7532-65

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Figure 13. Neutron Shield Case
Equilibrium Temperature
Distribution ($^{\circ}\text{F}$), Constant
Sun-Constant Shade Orbit

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Figure 14. Pump and Reflector Tem-
perature Distribution ($^{\circ}\text{F}$),
Constant Sun-Constant
Shade Orbit

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prestartup period under space environmental conditions. In particular, the minimum system temperature is such that plugging of the NaK will not occur.

2. Reactor Outlet Temperature at the Start of the Active Control Period

The behavior of the reactor outlet temperature at the start of the active control period was investigated to determine whether an over-temperature condition existed. Two different sensor cases were considered. Case I was a study of the present temperature sensor switch control. Case II was a study of a possible converter current switch control. The purpose of the investigation was to determine if there was a possibility of the reactor outlet temperature exceeding the assumed maximum limit of 1030°F.

The following factors were considered as contributing to a possible over-temperature condition:

- a) The time constant of the sensor switches
- b) The thermal and nuclear time constants of the system
- c) The relatively large time constants of the system, such as the radiation shield
- d) The Peltier heating of the converter.

The effect of reactivity losses due to hydrogen redistribution and xenon poisoning was not included in this analysis. The effects of the factors considered occur before reactivity losses effects predominate (~5 hr after the start of the active control period). Reactivity losses tend to decrease reactor power and outlet temperature. Therefore, an increasing outlet temperature condition, if it does exist, can only last until the reactivity loss due to the hydrogen redistribution and xenon poisoning predominates.

The behavior of the reactor outlet temperature at the end of the startup transient and the beginning of the active control period is shown in Figure 15. The behavior of the system for the same period with converter current sensor control is shown in Figure 16.

As the result of the investigation, the following conclusions were made:

- a) A reactor outlet temperature of 1030°F will not be exceeded if the temperature-sensor switch time-constant specification (1 min) is met.

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Figure 15. Initial System Behavior During the Active Control Period

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Figure 16. System Response for Converter Current Control

- b) The storage heat effect (large-system time constants) causes the reactor outlet temperature to decrease within 2 to 3 min after the sensor switch closes. Therefore, this is a beneficial effect which tends to reduce any potential over-temperature condition.
- c) Reactivity losses due to hydrogen redistribution and xenon poisoning would prevent any long-term over-temperature condition.
- d) Recent TE pump information indicates that the absolute maximum temperature of 1030°F is unnecessarily conservative. The pump can tolerate temperatures of greater than 1030°F for reasonable periods of time without excessive damage.
- e) The time constant specification of the sensor switch can be relaxed. For example, if the time constant was increased from 1 to 5 min, the maximum reactor outlet temperature would be 1042.5°F. However, less than 1/2 hr after the maximum had occurred, the temperature would be 1030°F and would still be decreasing.
- f) There is less change of excessive reactor outlet temperature using a converter current sensor than a temperature switch sensor, provided system components perform as expected.

Based on the preceding statements, there appears to be no danger of an excessive reactor outlet temperature occurring at the start of the active control period.

3. Effect of Ground-Test Heater on Expansion Compensator and Support Structure Temperatures

An analysis was performed to determine the effect of ground-test heater efficiency on the expansion compensator and support structure temperatures. The analysis was an extension of that reported in the last Quarterly Progress Report in which the predicted temperature distribution was given for the flight system operating at full power. Figure 17 shows the temperature distribution given by the extended analysis for the case of 93% heater efficiency. Also shown in the figure is the expansion compensator temperature for a heater efficiency of 90%. The installed ground-test heater will be designed to limit expansion compensator temperature to a maximum of 775°F.

Figure 17. Temperature Distribution for SNAP 10A Structure with Ground Test Heaters

4. Simulating Operating Reactor Temperatures During FSEM-2 Electrical System Test

An approximate analysis was performed to determine the feasibility of using an electrically heated, solid-core assembly in which eight cartridge-type (FSM-1) heaters are placed in the periphery of the core. The analysis established heat balances for two cases of heater surface temperature; 1300 and 1400°F. The maximum calculated heat flux was less than half that used in the FSM-1 system test to maintain a core surface temperature of 1000°F and a reflector surface temperature of about 700°F. The results obtained were based on four heat balance equations relating electrical heater input power to the rejection of heat from heaters, core, reactor top head, and reflector to the vacuum vessel enclosure and neutron shield. Based on the stated results of the analysis, FSEM-2 tests will be conducted under conditions of simulated reactor operating temperatures.

E. SAFETY ANALYSIS

An internal review of the analytical methods used in determining the total injury probability of reentering SNAP 10A systems was conducted following issuance of the final draft of the Flight Tests Safeguards Report. As a result of this review, the areas listed below were identified as requiring additional effort or refinement in calculational methods. For completeness, all areas are listed without regard to the particular quarter for which the required work was scheduled.

1. Power History of the Reactor

The power history of the reactor determines the fission product activity in the fuel elements. Should a malfunction of the shutdown devices occur, followed by long-term reactor operation, the power history would be contingent upon reduced NaK flow resulting from thermoelectric pump degradation, which is time dependent. A digital code that describes this operation has been developed. The effort required in this area has been essentially completed.

2. Analytical Model for Fuel-Element Handling Accident

One of the potential accidents evaluated in the Safeguards Report for the SNAP 10A Flight Tests is land impact of reentering fuel elements. The probability of a fuel element being discovered and handled before it has reached a given dose rate is a function of the decay rate of the fission product activity in the fuel element, and the population density and terrain on which the fuel element falls. A reevaluation of the mean discovery time for fuel elements in various population densities has been initiated.

3. Analytical Model for Post Reentry Criticality Hazards

Another potential accident evaluated in the Final Safeguards Report is post reentry criticality. Should this accident occur, a fission product cloud could be released following a self-terminating excursion. The prompt, direct dose associated with an excursion assumes negligible proportions (unless a person were immediately adjacent to the reactor) when compared with the potential dose to the thyroid from fission product inhalation downwind. The probability of a person receiving a given exposure is a function of the power history of the reactor prior to the excursion, meteorological parameters, and the population density distribution downwind. A reevaluation of the analytical methods used in

determining the probability of a person being in the effected area in low-population densities has been initiated. The population density distribution has been extensively studied during this quarter, and results are reported below.

4. Distribution of Water on the Earth's Surface

One of the potential reentry accidents evaluated in the Final Safeguards Report for the SNAP 10A Flight Tests is the impact of a reentering system into a municipal water supply. Through corrosion and leaching, any remaining radioactivity associated with the unit could be released into the water supply. The magnitude of the dose an individual could receive from ingesting the contaminated water would depend on many factors: (1) quantity and type of radioactive materials, (2) amount of water consumed, (3) duration of the ingestion period, (4) leaching rates, and (5) the size and storage characteristics of the water supply. A study of the size and storage characteristics of municipal water supplies has been reported. However, the general distribution of the world's estimated water supply, both fresh and saline, has since been determined and is shown in Table 2.

TABLE 2
DISTRIBUTION OF WORLD'S ESTIMATED WATER SUPPLY

Location	Surface Area (mi ²)	Water Volume (mi ³)	Percentage of Total Water
<u>A. Surface Water</u>			
Fresh water lakes	330,000	30,000	0.009
Saline lakes and inland seas	270,000	25,000	0.008
Augment in stream channels	-	300	0.0001
<u>B. Subsurface Water</u>			
Soil moisture and vadose water	50,000,000	16,000	0.005
Ground water within depth of 1/2 mi	50,000,000	1,000,000	0.31
Ground water-deep lying	50,000,000	1,000,000	0.31
Total Liquid Water in Land Areas	50,600,000	2,070,000	0.635
Icecaps and glaciers	6,900,000	7,000,000	0.15
Atmosphere (sea level)	197,000,000	3,100	0.001
World ocean	135,500,000	317,000,000	97.20
TOTALS (Rounded)		326,000,000	100.0

5. The Effect on the Total Injury Probability Caused by Variations in the Shutdown and Reentry Disassembly Parameters

The parameters of reactor shutdown (caused by ejection of the beryllium reflector assembly) and reentry disassembly (caused by aerodynamic heating and ablation) determine the configuration of the core at impact. The configuration just prior to impact, along with the impact media, determines the potential exposure to which a population could be exposed. The effect of varying the parameters of shutdown and reentry disassembly is reported below.

a. Population Density Distribution in Latitude Bands

The distribution of population on the earth's surface is an important parameter in evaluating the total injury probability from reentering SNAP 10A systems. The hazards associated with direct dose from handling radioactive fuel elements, and with the thyroid dose from fission product inhalation following an excursion, are strongly dependent upon the population distribution near the impact point. The third primary exposure mode, ingestion of contaminated water following impact into a municipal reservoir, is less dependent because water sources are not always immediately adjacent to the populations they serve.

Consequently, an intensive effort has been made to confirm the population density distribution as shown in the SNAP 10A Flight Tests Safeguards Report. This effort consisted initially of a literature survey and correspondence with organizations specializing in population studies, viz., population research libraries and the Bureau of Census. The literature survey permitted updating data already obtained, but provided very little new information. Correspondence with the specialized libraries and the Bureau of the Census* confirmed the fact that on a world-wide basis, few comprehensive data are available concerning population density distributions >500 people per square mile. Such densities are characteristic of towns and cities. To estimate the population density distribution over all density ranges, it was therefore necessary to combine the

*The Foreign Demographic Division of the Bureau of the Census is currently engaged in a project to provide separate urban and rural population estimates in rectangles of the Earth's surface measuring 20' latitude by 30' longitude. While data have been prepared for some portions of the Earth's surface, the project has not been completed. The Defense Communications Agency, National Military Command Systems Support Center, is the sponsor of the project. A request for access to the data already developed has been forwarded via the Atomic Energy Commission.

available data for <500 people per square mile with city population density data obtained from a world-wide city distribution and an area, population-density, city-size relationship. The density distribution was determined for 10° latitude bands to provide information for orbits of all types. The results are shown in Figure 18. A comparison of the population density distribution, as shown in the SNAP 10A Flight Test Safeguards Report, with the new density distribution is shown in Figure 19. The improvements are due to more recent data, better measurement techniques employed for data compilation in densities <500 people per square mile, and a much improved city distribution.

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Figure 19. Fraction of Land Area Occupied by People of Population Density N or Greater

Figure 18. Fraction of Land Area Occupied by People of Population Density N or Greater for Various Latitude Belts

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(1) Densities <500 People Per Square Mile

The data for population densities <500 people per square mile were obtained from the "Statesmans Yearbook - 1963." These data are in the form of a world map showing the area delineation for the following population density ranges:

- a) 0 to 1 person
- b) 1 to 5 people
- c) 5 to 25 people
- d) 25 to 100 people
- e) 100 to 500 people
- f) >500 people

The map size was increased by photoenlargement, and the areas of each of the population density ranges for 10° bands of latitude were measured with a planimeter.

(2) Population Densities >500 People Per Square Mile

The area distribution for population densities >500 people per square mile is not available. However, it has been approximated by the following method:

- a) The city size distribution was determined on a world-wide basis by 10° latitude bands. This work was accomplished using data compiled by the United Nations for 190 countries and territories ("Demographic Yearbook - 1962," United Nations), and adjusted for the remaining countries. The results for the world-wide distribution are shown in Figure 20.
- b) The relationship between city population and the area occupied by the cities was determined using data available for the United States ("County and City Data Book - 1962," United States Department of Commerce). A curve program was applied to data for 500 United States cities; the results are shown in Figure 21. It was assumed that city area-population relationship on a world-wide basis would be the same as that derived for the United States.

- c) The city size distribution was combined with the city area-city population (size) relationship to obtain the total area occupied by cities within discreet population ranges. The result is shown in Figure 22 as the total area occupied by cities having a population greater than a given value, N .
- d) From the relationship between city population and the area occupied by a city, the population density of the metropolitan and urban areas were determined over the city population range. The result is shown in Figure 21 as population density vs city population for various city sizes.
- e) The population density over these discreet ranges was combined with the total area occupied by cities within these ranges to obtain the total area occupied by various population densities >500 people per square mile. The result was then combined with the total area in the various population density ranges <500 people per square mile. The final result is shown in Figure 18 as the fraction of land area occupied by a population density N , or greater, for various bands of latitude.

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Figure 20. Number of Cities in the World as a Function of City Population

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Figure 21. Urban Area and Metropolitan Area as a Function of Population (United States)

Figure 22. Total Area of Cities with Population N or Greater for Various Latitude Belts

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b. Effect on Total Injury Probability of Varying Shutdown Parameters

Reactor shutdown is effected by severance of a retention band which holds the reflector assembly in place. A fusible link in the band may be melted by a heater, actuated either by ground command or by onboard automatic devices such as a low-voltage trip. Certain estimates were required concerning shutdown for the Flight Test Safety analysis. The effect of varying the estimated probability of shutdown at 1 yr has been analyzed, and the results are reported below.

(1) Effect on Fission Product Inventory

Following shutdown, the fission product inventory is diminished by radioactive decay. The length of time between shutdown and reentry determines the residual activity in the fuel elements at impact. If the reflector assembly does not eject prior to reentry, the length of operation and the power level of the reactor may determine whether or not the reflectors will be ejected by atmospheric heating during reentry. Self-welding of components in a space environment conceivably could prevent such an ejection. It is assumed that if the reactor has operated for 10 yr near full temperature, self-welding has occurred. The aerodynamic heating pulse during reentry is then assumed insufficient to disassemble the core. If reflector ejection does not occur, the reactor will continue to operate near full power until degradation of the thermoelectric pump

initiates NaK stagnation (or, possibly, loss of NaK). One of these events is assumed to occur at 10 yr. The fission product activity in the fuel elements is a function of the power history of the reactor.

(2) Assumptions

- a) The reactor operates near full power for 10 yr, and at an ever decreasing power thereafter. Or, at 1 yr, complete reactor shutdown occurs with varying probabilities, as indicated in Figure 23.
- b) Reentry disassembly probability is 0.99 until self-welding occurs at 10 yr, at which time the reentry disassembly probability becomes 0.01
- c) The probability of impact disassembly should reentry disassembly fail is 0.65 for land impact and 0.01 for water impact.
- d) If the core survives impact, the probability is unity that criticality will occur due to eventual reflector addition (water from rainfall, etc.). For calculational purposes and conservatism, criticality is assumed to happen immediately upon impact.
- e) Post reentry criticality is defined as a 70-Mw-sec excursion (self-terminating). Although steady-state operation terminated by an excursion could occur, the probability of occurrence is an order of magnitude less and for simplification of data presentation is omitted here.
- f) The postulated exposure modes to a population are direct dose from fuel element handling, and thyroid dose from fission product inhalation following an excursion.

(3) Results

The assumptions above were combined with the power history of the reactor by the method used in the Final Safeguards Report for the SNAP 10A Flight Tests. Figure 23 shows the total probability of injuring one or more persons as a function of orbital lifetime for various shutdown probabilities at 1 yr. The primary contributor to the total curve before 200 yr is the fuel

Figure 23. Probability of Injuring One or More Persons as a Function of Shutdown Probability at 1 yr

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handling accident. After this time, power degradation in the reactor reduces the fission product inventory to the extent that the primary contributor is the thyroid dose from post reentry criticality. The spread in the curves is the combined effect of reflector ejection and accompanying reactor shutdown before reentry, and the length of time allowed for fission product decay before reentry.

(4) Conclusions

The potential significance of reactor shutdown by the end of 1 yr of power operation for orbital lifetimes greater than about 4 yr is illustrated in Figure 23. Reflector ejection (shutdown) not only lessens the hazard from fuel element handling, but also decreases the excursion probability. Reflector ejection greatly increases the probability of atmospheric disassembly, which would prevent an excursion. For example, if the reference reactor shutdown reliability of 0.80 at 1 yr is increased to 0.99, the probability of injuring one or more persons by fuel element handling is decreased by a factor of 10 to 20 for all orbit lifetimes greater than about 4 yr. The injury probability from a nuclear excursion, for orbits slightly greater than 1 yr, is decreased by a factor of 10.

c. Effect on Total Injury Probability of Varying Reentry Disassembly Parameters

The aerodynamic heating pulse received during reentry may be insufficient to ablate the core vessel and release the fuel elements if the beryllium reflector system is not ejected prior to, or early in, the reentry phase. If self-welding has occurred, the reflectors may be retained and may absorb enough heat during reentry to prevent complete ablation of the core vessel and subsequent release of the fuel elements. If the core then should survive impact also, criticality could result due to reactivity addition (such as rain water). According to the analytical assumptions employed, failure of atmospheric disassembly implies self-welding of the reflector assembly. In this case, the reactor is assumed to have remained at power through the reentry phase. The structural integrity of the reactor system after the reentry heating pulse, and the type of medium encountered upon impact, determines whether or not impact disassembly will occur. An analysis has been performed to determine the sensitivity of injury probability calculations to disassembly assumptions. The results are reported below.

(1) Assumptions

- a) The reactor operates near full power for 10 yr. However, the probability of shutdown at 1 yr is estimated at 0.8.
- b) The reentry disassembly parameter is varied between 0.01 and 0.99, as shown in Figure 24. After self-welding of components at 10 yr, the disassembly parameter is assumed to be 0.01.
- c) The probability of impact disassembly should no reentry disassembly occur is 0.65 for land impact and 0.01 for water impact.
- d) If the core survives impact, the probability is unity that criticality occurs due to eventual environmental reflector addition.
- e) Post-reentry criticality is defined as a 70-Mw-sec excursion (self-terminating).

- f) The postulated exposure modes to a population are the same as for the shutdown variation study; i.e., fuel element handling and thyroid dose from inhalation of airborne fission products following an excursion.

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Figure 24. Probability of Injuring One or More Persons as a Function of Reentry Disassembly (D) for Various Orbital Lifetimes

(2) Results

The assumptions were combined with the power history of the reactor by the method used in the Final Safeguards Report for the SNAP 10A Flight Tests. Figure 24 shows the probability of injuring one or more persons as a function of orbital lifetime for various reentry disassembly probabilities. It is of interest to note that even though the parameter of reentry disassembly is varied through two orders of magnitude, the probability of injury by fuel element handling varies less than a factor of two. The thyroid exposure from an excursion follows the reentry disassembly parameter directly through two orders of magnitude. These results are due to the assumption involving impact disassembly. A probability of 0.65 is assumed for impact disassembly, and it is further assumed that fuel element handling will occur if the core is disassembled. Therefore, regardless of the variation in reentry disassembly, 65% of the time the core will disassemble on impact if not already disassembled by reentry forces.

(3) Conclusions

It can be seen from Figure 24 that after a few days of power operation, the effect of decreasing the probability of atmospheric reentry disassembly of the reactor has only a small effect on the total post-reentry hazard. This result can be attributed primarily to the assumption that in 65% of the impacts on land area, breakup of the reactor will occur if atmospheric disassembly has not taken place previously. Thus, the probability of the fuel-element handling-exposure mode can only vary between 0.65 to 1.0, regardless of the atmospheric disassembly assumption. Moreover, the dominance of this source of potential hazard during the shorter orbital lifetimes further minimizes the effect on the atmospheric disassembly probability on the total risk. For example, with disassembly probabilities of 0.99 and 0.01, the probability of injuring one or more persons is calculated as 0.085 and 0.075, respectively, for a 1 yr orbit lifetime.

d. Code Development

New nuclear data on short, half-lived fission products recently made available has been incorporated into the Curie-Dose computer code. The results are shown in Figure 25 for gamma dose rates. Also shown for comparison purposes are previous gamma dose-rate results. Lack of nuclear decay schemes for isotopes having half-lives in the order of a minute or less are responsible for the decrease in slope for times less than 1 min. Data for these isotopes will be incorporated into the code as they become available.

e. Support Documents

The SNAP 10A Power System Shipment Safeguards Report was revised in accordance with the recommendations of the Reactor Safeguards Committee and published in final form. This report describes the procedures and safeguards provided for transporting the SNAP 10A power system from Santa Susana to the Naval Missile Facility, Point Arguello.

The Final Safeguards Report for the SNAP Prelaunch Test Facility, Vandenberg Air Force Base, was reviewed prior to its publication.

The SNAP Prelaunch Test Facility Operations Manual was revised to incorporate comments received as a result of internal circulation of the first draft. The material has been assembled in such a manner that, in the event efforts on the manual are re-initiated, a second draft may be easily facilitated.

This manual describes the reassembly, testing, and handling operations to be carried out in the SPTF. Included are the operational and administrative procedures and checklists associated with these operations.

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Figure 25. Total Fission Product Gammas for a 70-Mw-sec Excursion and No Prior Operation vs Decay Time, Showing Effect of Reactor Gamma Decay Data

F. RELIABILITY ANALYSIS

The planned termination of the FSM-1 endurance test has been followed by the completion of nondestructive examinations. Approximately 75 observed malfunctions remain to be fully explained by destructive postmortems. It is estimated that about 15 require positive corrective action prior to flight. Since much of the instrumentation on the FSM-1 system was for flight design, many of these malfunctions were predicted and corrective action had been implemented for the flight systems.

Data on pumps, converters, drum drive motors, and ground test kits have been summarized and reviewed during the quarter. The performance reliability of each of these products has shown a tremendous improvement over that of a year ago. No specific reliability problem was apparent from the data available.

As reported last quarter, the probable NPU reliability for survival to 90 days of power operation is estimated at 0.697 for a flight test in FY 1965. Figure 26 shows the likely relationship between flight success probability and launch date (assuming all the Atlas-Agena support functions are satisfactory at all times, and assuming constant engineering effort).

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Figure 26. Relationship Between Flight Success Probability and Launch Date

IV. DEVELOPMENT TEST SYSTEMS

A. FSM-1 NONNUCLEAR QUALIFICATION TEST SYSTEM

1. Description

The FSM-1 system represents the first fully integrated, nonnuclear, flight design test system. Some of the components installed are different from the present flight design. However, the FSM-1 is a sufficiently accurate representation to be extremely useful in evaluating flight system results. The test program was eminently successful in meeting its objectives and providing an exact indication of what can be expected during the FSM-4 test qualification program. Specifically, the electrical core heater used for nuclear heat simulation is a proven device, and the NaK cart performed satisfactorily by cleaning the NaK charges, filling, and circulating the system NaK inventory.

Prelaunch checkout procedures, tests, and startup control were demonstrated with no difficulty.

Demonstration of system capability in terms of power output, flowrate, thermal transients, degradation rates, and endurance has been accomplished by fulfilling the objectives for the FSM-1 test system. The postmortem phase of the program remains to be concluded and is the final objective of the FSM-1 system.

2. FSM-1 Thermal Testing

The 90-day test of FSM-1 was terminated at 14:00 on January 15, 1964, after a total of 2336 hr of successful operation at core outlet temperatures above 900°F and 2496 hr above 500°F. During the test the system operated at steady-state conditions with the core outlet temperature controlled at 990°F. By the time shutdown was completed, a total of 906 kwh of electricity had been generated.

Overall system performance during the test was generally excellent. The initial outputs of the thermoelectric converter and pump were close to predicted values (Table 3) although, as expected, they fall short of flight performance goals primarily because of the earlier generation components used and the ground test environment. Degradation rates averaged over the entire 90-day period were somewhat higher than predicted (Table 4). However, after 1600 to 2000 hr of operation, degradation (except for converter power) had decreased to less than the predicted rates.

TABLE 3
SUMMARY OF FSM-1 90-DAY TEST PERFORMANCE

	Start of 90 Days	End of 90 Days	FSM-1 Design Point
Temperature Summary (°F)			
Core outlet-converter inlet	990	990	990
Core inlet-converter outlet	845	838	866
ΔT	136	152	124
Average core-average converter	923	913	928
Inlet converter radiator	656	640	678
Outlet converter radiator	528	529	554
Converter TE ΔT	297	298	271
Structure	727	724	750
Expansion compensator	717	710	750
Reflector	665	671	650
Instrument compartment	125	121	140 max
Electrical Summary			
Converter power (watts)	427	366	435
Internal resistance (ohm)	1.69	1.92	1.6
Open circuit voltage (volts)	52.9	53.2	53.3
Closed circuit voltage (volts)	26.5	24.8	27.0
Current (amps)	16.1	14.8	16.0
Hydraulic Summary			
NaK flowrate (gpm)	11.1	10.0	11.5
System pressure drop (psi)	0.75	0.63	0.78
Operating pressure (psi)	8.3	7.5	10.0
Efficiencies (%)			
Converter overall	1.23	1.06	1.33
Converter Carnot	23.9	23.9	22.5
Converter device	5.12	4.42	5.91
System thermal	1.09	0.95	-

TABLE 4

CONVERTER AND PUMP AVERAGE DEGRADATION RATES

	Degradation Rate (%/1000 hr)		
	Overall*	Corrected†	Predicted§
Power	-5.1	-4.5	-1.1
Internal resistance	+7.4	+4.8	+5.6
Open circuit voltage	+0.6	+0.1	+1.75
Flow	-2.8	-3.8	-3.5

*Overall rates were calculated using the following expression:

$$\text{Percent/1000 hr} = \frac{\left(\text{Value at end of } \begin{smallmatrix} \text{90-day test} \end{smallmatrix} \right) - \left(\text{Value during thermal } \begin{smallmatrix} \text{reference test} \end{smallmatrix} \right) \times 100}{\left(\text{Value during thermal reference } \begin{smallmatrix} \text{test by 2300 hr/1000 hr} \end{smallmatrix} \right)}$$

The only correction made was to normalize the converter value to an average NaK temperature of 922°F and the flow to an outlet temperature of 990°F.

†Corrected rates were calculated using the following expression:

$$\text{Percent/1000 hr} = \frac{\epsilon_i \left(\frac{\text{Degradation rate during time}}{\text{period } i} \right) \left(\frac{\text{Length of time}}{\text{period } i} \right)}{\epsilon_i (\text{Length of time period } i)}$$

In addition to temperature normalization, converter rates were corrected for (a) core heater power transients, and (b) absence of interleg connectors between A-modules.

This was done by not including step changes caused by either a or b. It is felt this was justified because a nuclear flight system would not undergo degradation from these sources. No additional corrections were made in pump degradation rates because no changes due to outside factors were noticed.

§Predicted rates were based on a flight system operating for 1 yr. Because degradation rates are initially high and decrease with time, rates averaged over 1 yr tend to be lower than those averaged over only 90 days.

The values of some of the more important system parameters at the beginning and end of the test are shown in Table 3. FSM-1 design points are included for comparison. It should be noted that these design points are for the FSM-1 system in the test environment and are not flight system design points.

Table 4 gives the measured and predicted average degradation rates of the early generation converter and pump.

Figures 27 through 35 show how the most important system parameters varied during the test. Figure 27 is a qualitative history of the core outlet temperature and converter power output. The temperature drops and changes in power output due to momentary losses of core heater power on November 6 (650 hr above 900°F), November 18 (940 hr above 900°F), and December 17 (1,630 hr above 900°F) are shown. The only permanent power loss occurred on November 6. It amounted to 5 watts and was the result of a partial open circuit in the converter. The other two partial opens on December 15 and 17 cured themselves. The most probable explanation for these opens is that a radiator in an A-module partially separated from the thermoelectric stack but was forced back down by thermal gradients as the radiator cooled.

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Figure 27. FSM-1 90-Day Test Core Outlet Temperature and Power History (not normalized)

Figure 28 shows the accumulated test time over 900 and 500°F, and includes the accumulated time at temperature during NaK loading and the thermal reference test.

Figure 28. Accumulated Time Above 900 and 500°F

Figure 29. Total Power Output (normalized to 922°F)

Figure 30. Total Converter Voltage (normalized to 922°F)

Figure 31. Total Converter Current (normalized to 922°F)

Figure 29 shows the converter power output normalized to an average converter temperature of 922°F, which was the average NaK temperature at the beginning of the test, corresponding to a core outlet temperature of 990°F. Because of flow degradation, the average temperature decreased with time even though the core outlet temperature was held constant. As a result, converter power also decreased. To show true converter performance independent of outside effects, all converter parameters were normalized to 922°F. The decreasing power degradation rate shown in Figure 27 is apparent.

Figure 30 shows the converter open- and closed-circuit voltages normalized to 922°F. Closed circuit readings were taken with the load resistance at approximately 1.6 ohm. The apparent shift in open circuit voltage at 325 hr above 900°F was due to an improvement in measuring techniques. Figure 31 shows the converter current normalized to 922°F.

Figure 32 shows the calculated internal resistance normalized to 922°F. The decreasing rate of degradation with time shown in Figure 27 is apparent here, also. The step increase at 650 hr above 900°F was due to the most severe, core-heater power transient. The apparent increase at 325 hr above 900°F was due to the improvement in open-circuit-voltage measuring techniques.

Figure 33 shows the inlet and outlet temperature histories of the converter NaK, hotstrap, and radiator temperatures.

Figure 34 shows the histories of the average converter NaK, converter hotstrap, converter structure, expansion compensator, thermal barrier, reflector, converter radiator, neutron shield case top, and instrument compartment temperatures. The neutron shield took longer to reach equilibrium than the other components because of its large heat capacity. No significant changes in emissivities as a function of time are apparent from these or any other system temperatures.

Figure 35 is the system heat-balance summary and shows the electrical power to the core heater, the heat gained by the core NaK, the heat delivered to the converter, and two estimates of the heat radiated by the converter radiators. The core heater power was a measured value. The I^2R losses in the heater leads and the heat radiated from the reactor-reflector assembly were calculated and subtracted to obtain the heat gain by the NaK in the core. Losses from the pump and supply lines were then subtracted to give the heat delivered

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Figure 32. Total Converter Internal Resistance (normalized to 922°F)

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Figure 33. Converter Temperatures

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Figure 34. Average Component Temperatures

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Figure 35. Heat Balance Summary

to the converter. The losses from all other parts of the system were calculated based on measured temperatures and subtracted from the heat delivered to the converter to obtain one estimate of the heat rejected from the converter radiators. The second estimate was obtained by calculating the amount of heat radiated based on measured radiator temperatures. The good agreement of the two independent estimates provides a check on the accuracy of the heat balance.

Figure 36 shows the NaK flowrate as indicated by the pump flowmeter (fringe flux voltage) and a heat balance. The basis for these methods was explained in SNAP 10A Quarterly Progress Report, NAA-SR-9293. The one based on the heat balance is the more accurate. A sharp decrease in pump degradation after 1600 to 1800 hr is obvious. This pattern of increasing flow for the first few hundred hours, constant degradation for the next 1500 hr, and almost no degradation thereafter, is similar to that obtained from long-term pump development tests.

Figure 37 shows the system pressure drop. The decrease and eventual leveling out merely reflect similar changes in NaK flowrate.

3. Posttest Examination

On January 15, 1964, the thermal test of the FSM-1 Nonnuclear Power System was terminated after 90 days of successful operation at design operating temperature. At that time, an extensive posttest investigation program of those components that had malfunctioned or displayed erratic behavior during the test program was initiated.

The program was divided into two phases; i. e., nondestructive and destructive. By definition, the nondestructive investigations consisted of those checkouts made with the components in place, while the destructive investigations pertained to those checkouts to be performed after removal of the components from the system.

The nondestructive portion of the program has been completed. The system was divided into the following seven areas for purposes of investigation:

- a) Reactor assembly
- b) Thermoelectric converter
- c) Liquid metal components
- d) Structural and emissivity members

Figure 36. Total NaK Flowrate
(normalized to 990°F)

Figure 37. System Pressure Drop
(normalized to 990°F)

- 3) Startup and control circuitry^{*}
- f) Diagnostic instrumentation^{*}
- g) Malfunction circuitry^{*}
- h) Miscellaneous

Both electrical and physical checkouts were conducted in each area. In conducting the electrical checkouts, the initial measurements were made from the junction box external to the vacuum chamber. Subsequent measurements were then made, working progressively from the junction box back to the component itself. The following paragraphs reflect the results obtained during the post-test program.

a. Reactor Assembly

One of the two drum drive mechanisms became inoperative approximately 12 hr after startup and remained inoperative throughout the test program. An approximate 50% reduction in the drum-drive circuit power consumption accompanied the malfunction.

Upon shutdown, the temperature controller was wired to drive the control drums out during the periods of active temperature reduction; however, only drum No. 1 stepped out, initially. At a system temperature of approximately 750°F, during the 800 to 700°F temperature ramp, drum No. 2 also began to step out. From that point, down to ambient temperature conditions, both drums continued to perform in a satisfactory manner.

An initial electrical checkout of the No. 2 control-drum actuator circuit indicated normal resistance readings for the motor and brake coils. Isolation of the circuit from ground was very good, being in excess of 100 meg. All electrical connectors, both the 700-series reactor interface connectors and the individual component connectors, looked to be in acceptably good condition upon disassembly. A subsequent checkout, however, revealed that when the interface connector was stressed, a decade increase in the actuator circuit resistance (~13.0 to ~150 ohm), through the series-connected motor and brake coils, was produced. No such resistance changes were witnessed in the parallel-connected motor-coil portion of the circuit; therefore, the problem would seem to be

^{*}Exclusive of those associated with the reactor assembly and/or the thermoelectric converter.

associated with the brake-coil connector pin. The particular connectors used in the system have a history of developing sporadic, high-contact resistances. Improved connector assembly techniques are being incorporated.

The demodulator portions of the systems were checked using a reference sensor-table fixture, where a simulated drum position could be produced very accurately. The output of the reference sensor was supplied to the demodulators, using the system connectors and cabling, and the resultant output signal was recorded. The curves of drum position vs millivolt output signal thus obtained compared very favorably with the specified calibration.

A check of the reflector-core vessel clearances proved them to be essentially the same as the pretest values, indicating very little, if any, vessel warpage and/or reflector assembly shift.

b. Thermoelectric Converter

The FSM-1 converter was known, on the basis of early module tests, to contain a diffusion bond between the tungsten SiGe shoe and the aluminum radiator which was unstable for the required time at temperature. Brittle intermetallics would form and, upon thermal cycling, thermal stresses would cause premature mechanical failures through these intermetallics. This known deficiency attributed approximately 7.5 watt of the total 40 watt of power degradation on FSM-1. This bond has subsequently been modified on flight hardware and is now completely stable.

The electrical power connections to the converter, and certain internal connections, on FSM-1 were of a mechanical type. During the ground system test conditions the mechanical contacts oxidized or otherwise deteriorated, causing a resistance increase and hence a power loss, estimated at approximately 14 watt. Future converters for flight systems have all-welded electrical connections which should not suffer from this effect either during ground or flight test.

The ground test conditions on FSM-1 were such that oxidation of some of the protective thermal radiation shields occurred, resulting in increase shunt heat losses in the converter and, hence, loss of power. It is estimated that something like 5 watt of degradation could be attributable to this factor.

During ground testing of FSM-1, special voltage taps were placed on the system, not part of the flight instrumentation system, to provide further ground-test diagnostic information. After shutdown of the unit, it was subsequently determined that some of these voltage taps had suffered a substantial reduction in the resistance to ground. It is estimated that approximately 4 watt of power were lost through these ground paths.

c. Liquid Metal Components

The components covered under this heading include the core heater assembly, expansion compensators, and the thermoelectric pump.

(1) Core Heater Assembly

The isolation resistance of each core-heater power lead to the structure was measured shortly after power to the heaters was terminated. The loop resistance of the individual heater elements compared very closely to pretest data, nominally 8.5 ohm. The isolation resistance was somewhat greater than pretest values, as was expected after the long-term bakeout afforded by the thermal test. The lowest value recorded was 50 meg.

(2) Expansion Compensators

After the test, room-temperature calibration checks were conducted on the expansion compensators, both with and without the gravity-compensator spring assemblies. The resultant data of system pressure vs deflection, with the gravity-compensating spring assemblies in place, compared favorably with the pretest data with respect to rate; however, the preload value (or breakaway point) was approximately 0.9 psi lower than originally observed. Subsequent checks of the gravity-compensator spring assembly indicated the preload on the springs had relaxed from an initial setting of 160 lb to nominally 135 lb. This 25-lb decrease corresponds to a decrease in system pressure of approximately 0.6 psi. The difference of approximately 0.3 psi was accounted for when the expansion compensators were calibrated with the gravity compensator assemblies removed. Their indicated preload values had decayed from the initial 0.6-psi preload to a nominal value of 0.2 psi. Figure 38 shows the +Z gravity compensator - expansion compensator assembly.

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Figure 38. Expansion Compensator-Gravity
Compensator Assembly

(3) Thermoelectric Pump

Only a visual inspection of the thermoelectric pump has been conducted to date. Extensive pump performance tests are to be conducted when the pump is removed from the system.

d. Structures and Emissivity

A visual inspection of the structure bracketry and piping system revealed no evidence of deformation, indicating little, if any, relative movement between mating parts due to differential expansion. Clearances between the shield and the support legs at all four points were equal to, or greater than, 3/16 in. Clearances between the structure and the penetrating piping elbows appeared to be sufficient, since no indications of binding were noted.

Some of the temperature-control emissivity surfaces of the NNPU were observed to have residues which had been deposited during the test program. Most of the residues seemed to be oily.

An analysis of the oily contaminant revealed it to be composed of oil from the pumping system; however, the ester content in the substance was very

high. The oil evidently had backstreamed from the pumping system and deposited on the cold heat sinks.

The surface of the gold foil installed on the converter tubes and the hot straps appeared to be in very good condition; however, approximately 30% of those surfaces observable were loose, indicating spot weld failures. The surface was still bright, with a noticeable lack of deposits or oxidation. Approximately 50% of the hot-strap gold foil had been removed during the assembly and checkout operations to eliminate converter shorts. On those straps where the foil had been removed, the copper appeared bright and in good condition.

e. Startup and Controller

During the pretest checkouts, startup simulation, and shutdown (the only times the controller was programmed), the controller displayed a definite susceptibility to electromagnetic interference. It was noted on numerous occasions that the initiation of test rig and/or facility functions would cause the controller to reinitiate an in-process pulse sequence.

f. Diagnostic Instrumentation

Included on FSM-1 are diagnostic instruments which will enable a person to determine inflight operation of the SNAP 10A system. There are four types of instruments: (1) thermocouples, (2) resistance thermometer detectors, (3) event markers, and (4) position indicators. All event markers are considered diagnostic, irrespective of the circuit function monitored.

(1) Resistance Thermometer Detector

Of the 16 RTD's on the system, the six which were clamped into place functioned satisfactorily. Eight of the remaining ten were brazed to the system piping and appeared to read off-range due to the brazing operation.

(2) Thermocouples

Out of a total of 29 thermocouples on the FSM-1 system, only two failed completely due to open circuits. The remaining 27, when properly installed, operated within expected limits.

(3) Event Markers

Of the 12 diagnostic event markers, two indicated a malfunction. One was a contact on one-half of the KOR relay circuit which indicated that the controller was operating. The other event marker was on the K8 relay and did not close when the K8 relay operated. A posttest investigation confirmed that the K8 contact remained open when the relay was powered.

(4) Position Indicators

Of the two position indicators for the expansion compensators, one did not function because a connector was improperly used. A change has been incorporated in the flight design to prevent a connector on the flight vehicle from behaving in this manner.

g. Malfunction Circuitry

The components displaying abnormal behavior during the FSM-1 testing are discussed below.

(1) Temperature Switches

Five temperature switches were employed on the FSM-1 system. None of these failed during the test, but TS-4, during a posttest calibration, indicated a drift to approximately 1026°F from the pretest set point of 1064°F. The five temperature switches used are shown in Figure 39.

(2) Low-Voltage Switches

During the 90-day test, the two low-voltage switches operated satisfactorily. During shutdown, however, one switch exhibited no precise set point below 21 volt. The normal trip point is approximately 22 volt.

(3) Microswitches

Of the 14 microswitches tested on FSM-1, none was observed to malfunction during the test.

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Figure 39. System Temperature Switches

B. FSEM-2A ELECTRICAL MOCKUP TEST SYSTEM

1. Description

The FSEM-2A system is an electrical mockup of the SNAP 10A flight system comprised of all electrical, control, and diagnostic instrumentation on a complete shell structure. All electrical startup and control hardware, diagnostic instrumentation, and system wiring employs the current flight design and latest installation techniques. The reactor core vessel contains a mass mockup for correct weight distribution during vibrational testing and is provided with an FSM-1 test-type lid designed for incore cartridge electrical heaters. The reactor mass mockup has been modified to accept 11 core heaters for heating the reactor area instrumentation during thermal vacuum tests. A qualification-test TE pump, including the outlet piping with diagnostic and control instrumentation, completes the reactor area installation. Six TE legs have been attached to the shell to enable realistic testing of power- and voltage-tap wiring attachments and the converter thermocouples. A pair of instrumented expansion compensators and the instrument compartment complete the electrical system. Lead weights have been attached to the shell to simulate the mass of the missing TE converter legs during the vibrational testing. Figure 40 shows the FSEM-2A instrument compartment after assembly to the structure.

The purpose of this electrical mockup is to serve as an electrical test system at AI. This system will undergo continuous and detailed performance tests of the electrical, control, and diagnostic instrumentation as an integrated system. Component and subsystem electrical interactions such as radiated noise, signal cross-talk, switching transients, and peak power loads will be investigated in detail. The effects of vibration, temperature, and vacuum environments on the electrical systems will be investigated by a series of environmental tests. The FSEM-2A system will be available to resolve component and subsystem integration problems observed in previous ground testing. The FSEM-2A is an electrical test bed that can solve future electrical-system problems encountered during future ground testing or flight tests.

2. Test Objectives

The primary objective of the FSEM-2A test program is to demonstrate the ability of the flight electrical, power, and diagnostic instrumentation to

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Figure 40. FSEM-2A Instrument
Compartment

survive acceptance tests, ground handling, and the launch environment and to perform within acceptable limits thereafter. Specific test objectives are:

- a) To conduct a series of electrical tests:
 - 1) To measure the initial electrical parameters, such as circuit electrical isolation from ground. These measurements will be the initial, system reference values. The reference tests will be repeated at specific intervals during the program and when malfunctions or failures occur. The goal of the electrical reference tests is to improve our ability to qualify the electrical systems as acceptable by external measurements and to provide a means of ascertaining degradation.
 - 2) To life test the electrical components and subsystems that compose the launch, orbital startup, orbital control, malfunction, and end-of-life electrical and instrumentation

systems. These tests will demonstrate that the operational lifetime of these systems exceeds the required operational lifetime with an adequate safety margin.

- 3) To establish the electrical compatibility and functional operation of all electrical subsystems as an integrated unit.
- b) To measure the peak vibrational loads imposed on the electrical components and the mounting hardware during a typical launch. An electrical and/or reference test will be made at specific intervals during the vibrational tests to verify that the electrical systems have not deteriorated.
- c) To demonstrate that the electrical, control, and diagnostic instrumentation systems will perform at the system operating temperatures in the simulated space (thermal-vacuum) environment. Electrical reference tests will be made at room temperature and at the system operating temperature.
- d) To conduct further electrical or environmental tests to resolve electrical system problems discovered during past or future ground testing and flight test programs.

Plans were generated during the present quarter for additions and modifications to the existing test facilities in which the FSEM-2 will be tested. During this quarter an FSEM-2 Test Plan was written and preliminary test procedures were prepared for the reference test, the launch and orbital-sequence life test, and the thermal-vacuum test. A vibrational test specification was completed.

3. Technical Accomplishments

At the beginning of the present quarter, the assembly effort on the unit had progressed to the point where the high-temperature bundling had been completed, routed through the shell, and the instrument compartment was ready for attachment to the structure.

The instrument compartment was mated to the shell, and termination of the high-temperature wire in the instrument compartment was performed. The diagnostic instrumentation (RTD's, TC's) and the high-level neutron detection

system were installed and terminated. After the completion of the wiring in the compartment, a check of the wiring was performed.

Concurrent with the above activities, the reactor head, pump, and handle bar were assembled, along with the expansion compensators. A core mockup assembly was fitted to the core tank and then integrated with the unit. Six thermoelectric legs were attached to the structure, capped off, and filled with water to simulate the effect of NaK in the tubes during vibration. The legs were oriented on the shell so that they had a typical power tap and voltage tap wiring attachment.

During the latter part of the quarter, a decision was reached to incorporate a heater assembly into the mockup core. This necessitated the removal of the top head assembly (reactor head, pump, and handle bars) as well as the wiring in the upper area. Provisions were made in the core mockup to accommodate a group of heaters.

Work on the unit has been halted for lack of the reactor reflector assembly. Final checkout of the NPU has been performed to the point where it is necessary to have the reflector assembly to complete the testing. Figure 41 shows assembly progress at this writing.

Figure 41. Electrical Mockup
Assembly Progress, FSEM-2A

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C. FSEM-3 SNAP 10A/AGENA ELECTRICAL COMPATIBILITY TEST SYSTEM

1. Description

FSEM-3 is an electrical mockup of the SNAP 10A flight system. Control and instrumentation equipment is flight-qualified hardware. All electrical components on FSEM-3 have passed acceptance tests. FSEM-3 was assembled in accordance with flight system drawings, except for special mockup requirements. Mass mockups of the reactor, pump, and an empty radiation-shield container are provided for simulation of the metallic mass of the flight systems and to provide for the mounting of electrical components. NaK piping is not used, and the thermoelectric converter circuit is simulated by PSM-2, a power supply with variable open-circuit voltage, internal resistance, Peltier effect, and time constants. Diagnostic and control device locations in the mockup areas approximate as closely as possible the flight system configuration.

The PSM-2 output is in series, with the wire routed on the converter shell duplicating the thermoelectric converter current path.

Flight system electrical requirements (e.g., wire routing, terminations, connectors, shielding, bonding, etc.) are imposed to assure that FSEM-3 is electrically identical to the flight units.

FSEM-3 was assembled for use with an updated Agena functional mockup (FMU) during combined systems testing, EMI compatibility investigation, and flight vehicle checkout at LMSC, Sunnyvale.

2. Test Objectives

FSEM-3 tests at LMSC were to commence with checkout of the updated FMU. Electromagnetic interference (EMI) testing in the anechoic chamber at Sunnyvale was to follow. The purpose of EMI testing was to demonstrate compatible operation of the two mockups in a self-generated electromagnetic radiation environment. In addition, the prelaunch electromagnetic radiation signature was to be obtained to verify that the vehicle and payload will not interfere with other vehicles and launch complex equipments. Verification of compatibility between the space vehicle and payload with the launch pad environment was planned.

Additional system tests were planned with FSEM-3 and the FMU, after the conclusion of EMI testing, to establish a greater degree of confidence in

compatible operation of the vehicle and payload throughout all phases of operation — prelaunch to failure. At the conclusion of the test program, FSEM-3 was to be used to check out the Agena flight vehicles.

3. Technical Accomplishments and Testing

The test program was terminated at the beginning of this quarter before the completion of the updated FMU. FSEM-3 and its associated test equipment were placed in storage at LMSC. Personnel assigned to support the test program were recalled to AI.

D. FS-1 NUCLEAR QUALIFICATION TEST SYSTEM

1. Description

The SNAP 10A FS-1 system is the first nuclear qualification test system that will undergo full-scale ground testing for extended periods using, as the heat source, an operating nuclear reactor. The FS-1 test program will duplicate to the fullest practical extent the actual operating environment of the flight system design during system startup and orbital operation. Power Test Vault No. 2 at the SNAP Environmental Test Facility, Building 024, will be used for the nuclear qualification test. The space environment will be simulated in a vacuum chamber furnished with cold walls.

The FS-1 test system is not a true qualification system because it is not exactly like the flight system design. There are metallurgical, fabrication, and detailed component differences. Nevertheless, the engineering concept is identical to the flight system, and all components are of the flight-type design. All equipment will be acceptance tested, but not necessarily flight qualified.

The following modifications from the standard flight configuration were made to the FS-1 system.

- 1) A temperature-actuated band release device on the reflector assembly will not be installed.
- 2) An expansion compensator adapter will be installed to compensate for gravity effects during ground tests.
- 3) A coarse drum drive will be installed on the two coarse drums during testing.

- 4) The reflector-assembly band device will be modified to reduce the band tension and to incorporate a pin which will release the band when actuated by a pneumatic pin puller.
- 5) Live pyrotechnic firing squibs were installed for the structural tests and, where necessary, simulating devices will be provided during acceptance and power testing to meet other test requirements.
- 6) The ejectable heat shield is on the FS-1 system only for the structural tests.
- 7) Additional instrumentation is provided to supplement diagnostic instrumentation.

The principal objective of the S10FS-1 nuclear qualification test program is to demonstrate that the ground test system will meet design performance requirements throughout the factory-to-orbit sequence of operations. To accomplish the principal objectives, the following basic requirements must be met:

- 1) Demonstrate that the system is not detrimentally affected by the structural or acceptance tests.
- 2) Verify system operation under simulated space environment during the startup phase and the transient phase.
- 3) Demonstrate the system performance under simulated space environment over an integrated period of 90 days at design power and temperature.
- 4) Determine by experiment the following performance characteristics of the system under nuclear and simulated space environment:
 - a) Check the automatic start sequence, test the startup equipment on an operating system, and verify that the sequence of events and the rates of reactivity insertion are programmed correctly.
 - b) Test the automatic reactor outlet controller to show that the controller will maintain the reactor outlet temperature within specified limits.
 - c) Determine the change in reactivity with time when operating under simulated space conditions.

- d) Measure temperature profiles and the rate of temperature change during startup operation with nuclear heat.
- e) Determine operation of the nuclear instrumentation in a thermal, nuclear, and vacuum environment.
- f) Determine operational characteristics of the thermoelectric converter and the thermoelectric pump during startup and operation with nuclear heat.

2. System Technical Accomplishments

During the last quarter the FS-1 test program was temporarily suspended for 1 month. Subsequently, the FS-1 test program was reinstated and FS-1 acceptance testing resumed.

Two expansion compensators were fabricated and installed on the FS-1 system. These units are of the flight-type design except for differences in moly coating and limit switch installation. The hub of the top support, rather than the outer post, is moly coated on the FS-1 units. Moly coating is provided to prevent cold welding in space. This discrepancy will not affect performance of the expansion compensator. The bracket which secures the limit switch required rework so that the switch would actuate at the proper compensator deflection. Brackets for the flight units have been redesigned.

A flight-type pump was ordered to replace the pump now installed on FS-1. The replacement pump will meet the flow requirements of the flight system. Accompanying the flow increase will be an increase in power output as well. The pump was fabricated, acceptance tested, and delivered for installation.

The redesigned expansion-compensator ground test adapters, which compensate for gravity effects on system pressure during ground testing, were fabricated, acceptance tested, and delivered for installation. Supporting hardware for the adapter, to reduce the loads applied to the expansion compensator post, was delivered for installation.

A mass mockup of the temperature-actuated band release device will be installed on FS-1 in place of the actual device. There is no test requirement for this device, since it was to be locked out to prevent possible actuation. The mass mockup will simulate the thermal characteristics of the actual device during the FS-1 test.

The band tension on the reflector band was reduced from 175 to 60 lb by removing a few spring coils (to eliminate extensive structural testing of the band release device). To avoid relying entirely on electrical actuation for shutting down the reactor (i.e., drum drives and electrically actuated band release device), the band was modified to incorporate a pin which, when pulled by a pneumatic cylinder, will release the band and thus shut down the reactor.

The ground test kits (GTK) will be used to drive the coarse and fine drums during acceptance testing in the Acceptance Test Facility and low-power tests in the SNAP Environmental Test Facility. For power testing, the ground test kits on the fine drums will be replaced with flight drives. The coarse drum actuators during power testing initially were to be modified ground test kits. Because of the high reliability and radiation hardening of the flight actuators, the modified flight actuators are being used instead to drive the coarse drums.

The major effort during the report period was devoted to improvement of test instrumentation and procedures to provide better thermal and flow data during the FS-1 test. To improve flow measurement, two approaches are taken:

- a) More accurate and extensive calibration of the TE pump flowmeter during pump acceptance testing. With the improvement in calibration procedures since the calibration of the FSM-1 and original FS-1 pumps, and with data taken over the entire temperature range of interest, the uninstalled accuracy should be substantially better than the nominal $\pm 10\%$.
- b) Calorimetric calibration of the installed pump. Power input to the ground test heaters and NaK temperature rise across the heaters will be measured during nonnuclear thermal testing. Flowrate will be calculated as follows:

$$q = \frac{K (Q_{EI} - Q_{I^2R} - Q_{RAD})}{\Delta T}$$

where

q = volumetric flowrate (gpm)

K = temperature dependent constant, which includes NaK specific heat and density, and conversion factors for units

Q_{EI} = measured electrical power input (kw)

Q_{I^2R} = calculated I^2R losses in heater leads (kw)

Q_{RAD} = calculated radiant heat losses from heaters (kw)

ΔT = NaK temperature at inlet to heaters, NaK temperature at outlet of heaters ($^{\circ}F$)

An extensive heat transfer and error analysis indicates that flow can be determined to within $\pm 7\%$ by this method.

To improve thermal measurements, special thermocouples are being installed in addition to the flight thermocouples for the following purposes:

- a) Calorimetric calibration of the installed pump
- b) Measurement of critical component temperatures which cannot be accurately determined by analysis
- c) Establishment of the heat losses from a nuclear system.

Installation drawings and instructions have been prepared for these special thermocouples.

The now-completed 10FSM-1 data reduction and analysis program was evaluated, and recommendations for the improvement of the FS-1 program were made. As a result, the output format of the FS-1 computer program has been completely revised.

3. Acceptance Testing

Acceptance testing of FS-1 was begun this quarter. The FS-1 Nuclear Qualification Test System was received in the Acceptance Test Facility, February 27, 1964. The physical and electrical examinations that document the condition of the FS-1 SNAP Unit have been completed, and the test system is being integrated with the facility in preparation for fuel loading. The completed tests follow:

- a) Physical Inspection Before Testing
- b) Power System Electrical and Instrument Check
- c) Power System Startup Sequence Test
- d) Installation of Ground-Test Drum Drive Kits

The Instrumentation Connection and Checkout tests were started, but completion was held up pending completion of the facility instrumentation calibration. Each of these tests prepares either the power system or the facility for the next operation. In the Physical Inspection test the SNAP Unit and its subassemblies are examined to document their condition and determine what repairs are required before proceeding with testing. The Power System Electrical and Instrumentation Check provides reference data showing continuities, response to applied impulses, and assembled locations of electrical circuits and instrumentation. The electrical response of a simulated startup sequence is monitored during the Power System Startup Sequence test. Installation of Ground Test Drum Drive Kits mates drum drive mechanisms to the reflector control elements to provide for motion, position sensing, and SCRAM capability.

At present, the operations crews are being familiarized with the control room system operations and critical and postcritical tests. This is being accomplished by having each operator operate the control console, operate interlocks, drive and scram the control drums, and perform a dry run loading of the fuel, void filler block installation and removal, and reflector installation and removal.

Reactor operation awaits Atomic Energy Commission authorization for fuel loading and low-power physics tests.

4. Test Facility Operations

a. Installation of Test System and Facility Checkout

The reflector handling in Building 024 was improved and made safer through fabrication of a platform. The platform will be mounted on the top of the second section of the vacuum chamber and will offer a work space for personnel installing the reflectors. The base section of the chamber was reworked to receive the liquid-nitrogen cold plate. The vacuum system was made more reliable by the installation of an auxiliary roughing pump which will afford continuous operation of the vacuum system in case of failure of the original pump. The system is piped in such a manner that if one pump fails it can be isolated and repaired while the other unit continues to operate. Mockup equipment has been fabricated for the demonstration of the reflector assembly release by the pneumatically actuated pin-puller device.

The wiring inside the vacuum vessel is being changed to incorporate American Super Temp wire to the fine drum actuators, and ceramic bead insulated wire to the coarse drum actuators and the electrically actuated band-release device. This is being done to incorporate wire that has proved more resistant to high temperature and the radiation environment in the vacuum chamber. This change makes the system more reliable for long-term operation. The wiring to the test vault is being modified to locate the reflector-drum flight-position-sensor demodulator and the expansion-compensator flight-position-sensor demodulator outside the test vault. The radiation dose rate in the instrument compartment will be several orders of magnitude greater than is expected in space because of the reflected radiation from the walls of the vacuum vessel and test cell. Demodulators located in the instrument compartment are therefore expected to fail because of radiation damage early in the test. To have position indication for the duration of the test, the demodulators will be located outside the test vault.

The precision Datex sensor, the precision position sensor for the fine-reflector control drums, was subjected to thermal vacuum study for a period of 800 hr to simulate use in FS-1 test. Torque measurements taken after the study indicated a rise of 0.7 oz-in. was exceeded, thus eliminating the unit from the test program. A Vernitron sensor is currently under study as a possible replacement for the Datex sensor.

All thermocouple wiring to the data logger has been checked with a millivolt source from the terminal board in the vault to the logger.

Remote handling and viewing were improved with the installation of mounting tracks along the east and west walls of Vault No. 2 for the in-vault TV camera system. This will give more coverage for remote assembly and disassembly of equipment in the cell. The tri-hoist assembly has been modified for more flexible operation, and the remote handling tools have been adapted for use in the disassembly of the vacuum chamber.

b. Operation of Test Facility

Oral certification examinations were completed on February 12, 1964. Eleven operators were formally certified after results of the various examinations were reviewed.

All three vault refrigeration compressors were connected in parallel to provide backup in the event one of the compressors failed.

The FS-1 system was mounted on the vacuum-chamber base plate in Vault No. 2, and reflector installation and removal provisions were checked out satisfactorily. After completion of the reflector checkout, and with the FS-1 system still in the cell, the cell was sealed and a complete atmosphere exchange was conducted. Although no leak rate tests were performed, the leak rate was sufficiently low that atmosphere control was not a problem. During the atmosphere exchange the nitrogen control system, infiltration exhaust system, and oxygen analyzers were checked out and found to be operating properly.

At the conclusion of the above test, the cell was opened and the FS-1 system was moved to Vault No. 1 for storage. An atmosphere exchange also was conducted with the system in Vault No. 1 to provide an inert atmosphere to minimize system corrosion. The system was stored in Vault No. 1 until it was moved to the Acceptance Test Facility.

A doorway has been provided in the metal portion of the new access area wall at the intermediate level. The door is for emergency evacuation of the intermediate area of the vacuum equipment room. The door will be sealed with a breakaway seal during normal operation.

Periodic revision of the facility and system manuals has been initiated. The manuals must be revised to incorporate recent facility and system modifications and additions.

c. Analysis, Test Program Management, and Safeguards

It has become apparent that the environment in the vacuum vessel during the FS-1 test will adversely affect the operation of the precision Datex control-drum position readouts originally planned for use during the FS-1 power test (Section IV-D-3-a). It was decided to eliminate the Datex readouts and use the flight position sensors as the primary indication of control drum position. A procedure was written to calibrate the flight position sensors, during non-nuclear thermal tests in the SNAP Environmental Test Facility, against the Datex units which are mounted on the ground test kits. The ground test kits with Datex units are later replaced with flight actuators for use during power tests.

A guide that will assist the operator in a decision concerning the use of the setback deferral switch has been prepared. The general criterion is the establishment of a safe or unsafe plant status prior to setback deferral or setback initiation.

E. FSM-4 NONNUCLEAR QUALIFICATION TEST SYSTEM

1. Description

The FSM-4 system is a complete nonnuclear power test unit identical to the flight system, except that electrical heaters are used in place of a nuclear core. All subsystems (the converter-radiator, control system, structure, NaK system, and flight instrumentation) are of the final flight design and are being assembled with the same philosophy as outlined for the flight systems. Improvements resulting from the FSM-1 tests have been incorporated in the FSM-4 system design; e.g.,

- a) The converter system is now constructed from flight-design Type-V modules. The converter intermodule and interleg electrical connectors and voltage and power taps have been redesigned to provide improved reliability.
- b) The thermoelectric pump is the final flight design. The flight design with thicker radiator fins has been incorporated in the FSM-4 pump, and improved low-flow power taps and flowmeter taps have been installed.
- c) A flight-type temperature-actuated band (reflector) release device is being installed on FSM-4.
- d) A flight-type electrically actuated band (reflector) release device is installed on FSM-4.
- e) The fusible link assembly has been redesigned and is of the final flight configuration.
- f) Power conversion system improvements are listed in Table 5. The flight system design incorporates 0.18-in.-diameter by 0.190 in.-long slotted studs which are stud welded directly onto the radiator, thus increasing reliability of the electrical circuit.

TABLE 5
TABULATED CHANGES IN FSM-4 FROM FSM-1

Item Modules	Identification of Change	
	FSM-1	FSM-4
1. Modules	Type 1 and 2	Type VF
2. Power taps	Cu studs	Al studs
3. Voltage taps	HGEK high-temperature wire	Al straps
4. Interleg connectors	Cu straps, mechanically connected	Al straps welded connection
5. Emissivity	Black chrome oxide	White tin oxide

g) Instrumentation — Difficulty in maintaining adequate process control during fabrication, and damage to the thermocouples from handling and installation, required a redesign of the radiator fin TC for use on FSM-4 and the flight system.

To reduce the effect of the difference in coefficient of thermal expansion, a Kovar screw replaces the stainless-steel screw in which the thermocouple is encapsulated. An alumina spacer is used to insulate the thermocouple sheet from the screw.

During qualification testing of the relays, it was discovered that relays failed to function because of the flaking of the M1 varnish which encapsulates the relay coil. Small particles of this varnish collected on the relay contacts, prohibiting the relay from closing. A polyolefin shrinkable tubing is now used to encapsulate the coils in place of the method using the glass tape coated with M1 varnish.

Through development testing, it has been discovered that the heat employed in brazing RTD's directly to NaK piping increases the sensor resistance and destroys the calibration. Brazing of RTD's directly to the NaK piping has been discontinued for FSM-4 and the flight system. A Cu block is now brazed to the NaK piping, and the RTD is inserted in an opening provided in the Cu block.

A change made in the vehicle three-phase 400-cps power supply has necessitated the incorporation of a one-to-one isolation transformer in the power supply for the converter degradation measuring device.

Mechanical temperature switches used for heat shield ejection operated satisfactorily during the startup, simulating ejection at 225°F, which is within original calibration tolerances of $245 \pm 25^\circ\text{F}$. Recalibration during shutdown revealed a drift-up in actuator temperature of 350°F on TS-6, but with no change in TS-5. Corrective action has been taken in the design of internal components. Calibration procedures have been revised to assure qualification of temperature switches for FSM-4 and the flight systems.

The 10FSM-4 nonnuclear power unit will have all the above listed modifications incorporated into the system prior to environmental testing. All components installed in the unit will have successfully passed acceptance testing. Qualification testing will have been completed, with the exception that endurance testing of some components will not be completed.

The following individual test phases will demonstrate the capability of the flight system to withstand these test phases without either catastrophic failure or serious performance degradation:

- a) Preoperational test
- b) NaK fill and cleanup
- c) Acceptance test
- d) Simulated launch vibration and shock loads
- e) Low-temperature environment during prestartup orbital operation
- f) Startup
- g) Full-power operation for a continuous 90-day period

The 10FSM-4 system will be subjected to shock and vibration testing while filled with NaK at both acceptance and qualification levels.

Acceptance testing of all components assigned to the FSM-4 NNPU is completed with the exception of the NaK pump, isolation transformer, electrically actuated band release device (EABRD), and the four temperature switches. These items are currently on test or in fabrication.

2. Technical Accomplishments

Additional design improvements that have arisen as a result of previous assembly and/or testing experience on the FSEM-3 flight system electrical mockup, the FSM-1 nonnuclear qualification testing, and component tests, have been incorporated into the flight design and the FSM-4 unit. Design improvements which were incorporated in FSM-4 during this quarter are as follows:

- a) The upper-piping manifold weld detail at the supply line was changed from the pull-out design to a fillet weld design to increase the strength of this joint.
- b) The radiator fin thermocouples were redesigned to provide ease in fabrication and to improve reliability. Acceptance and qualification testing of these TC's has been completed.
- c) Alternate designs were prepared for attaching RTD's to NaK piping and are currently being tested.
- d) Design work was continued on the instrument compartment to permit the use of electronic temperature switches for reactor control as a backup to the reference design.
- e) Additional wire clamping details were added to facilitate assembly.
- f) NaK-pump emissivity process specification was changed to eliminate flaking of the emissivity coating on the pump radiators.
- g) A capacitor was added to the startup controller to attenuate pulses arriving at the controller.
- h) The expansion compensator microswitch was modified to increase the margin-of-failure indication.

3. Assembly and Checkout

At the beginning of the present quarter, assembly of the unit progressed to the point where the TE legs had been installed and welded to the lower

manifold. The high-temperature wire harnesses had been assembled and the instrument compartment completely wired and checked out.

Difficulty in welding the upper manifold to the reactor vessel assembly caused a weld failure which necessitated removal of a portion of the manifold to effect the repair. (Approximately 9° each side of the +Y axis was removed from the manifold and a new piece put in.) Figure 42 shows the repaired weld area. The reason for removal of this amount of manifold was to facilitate the repair. The 405 welds, which consisted of the two TE legs directly below the +Y inlet, and the two elliptical welds were postheat treated using heaters specifically designed for this purpose.

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Figure 42. Repaired Weld Area

Installation of the upper manifold instrumentation RTD's and TC's was effected, using a new braze process which is discussed in section V-B-3. The upper inner and outer bands and the lower outer bands were then installed. The NPU support legs were drilled and the ejectable heat shield bracketry was installed. At this writing, the electrical wire bundles are being installed in preparation for the installation of the instrument compartment and final termination of the wire bundles. Figure 43 shows the state of completion of the unit at this time.

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Figure 43. Nonnuclear Mockup
Assembly Progress, FSM-4

4. Test Facility

To successfully meet the program objectives, a test rig is being assembled which, when mated with the Nonnuclear Power Unit (NNPU), will create an environment simulating as nearly as practical that expected in space. The following test facilities either have been or are being assembled.

a. Vacuum Facilities

The NNPU will be thermal-vacuum tested in an 800 ft³ cylindrical vacuum chamber. The three-piece vessel assembly is fabricated of mild steel and externally cooled with a closed-loop, deionized water system. The chamber can be evacuated to less than 0.1 micron by a 20-in. oil diffusion pump. The diffusion pump, in turn, is backed by two 300-cfm mechanical fore pumps. The second of the two provides redundancy to the basic system, thereby ensuring reliability to the planned 1-yr endurance test. Figure 44 presents the physical layout in the laboratory, including the chamber and diffusion pump. A flow diagram which illustrates the redundant pumping system is shown in Figure 45. To date, the engineering layout of the revised system has been completed and the hardware necessary to complete the modification has been ordered.

The closed-loop water system that cools the pumping system and vacuum test chamber has been completely overhauled, and its critical components have been replaced. Spares for the water pump and motor, heaters for the diffusion pump, and valve solenoids for the pneumatic controls are maintained in storage for immediate replacement in the event of a failure.

The system's electrical diagrams have been updated and redrawn to aid in the troubleshooting.

Figure 44. FSM-4 Test Facility

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Figure 45. FSM-4 Vacuum Pumping System

b. Support Ring Stack

The power system will be bolted to a stack of rings which allows the interface connectors to be plugged in and which thermally and electrically isolates the system from the vacuum vessel base. An attempt will be made to simulate the isolation experienced by a power system in a space environment. A cross section of the support ring stack is shown in Figure 46. Included are a simulated mating ring, the spacer ring through which the interface cabling is dressed, and the support ring which separates the cold plate from the vessel base.

c. Interface Heat Sink

A circular cold plate, serviced by freon-12 refrigeration fluid, is located directly below the instrument compartment to simulate the cooling effect of the vehicle heat sink. It is sandwiched between thermal insulating materials which, in turn, are located between the spacer and support ring.

d. Vacuum Chamber Mechanical Hardware

A number of deletions, changes, and additions have been made to hardware within the vacuum chamber. The instrument compartment and

Figure 46. FSM-4 Vessel Support Ring Stack

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thermoelectric-pump heat sinks have been outdated by the use of full cryogenic walls. Therefore, they have been removed from the test chamber, and the supporting refrigeration system was necessarily resized. Originally, a 5-ton-capacity system was to service three heat sinks or roughly three times the remaining heat load. In conjunction with the capacity change, it was also necessary to revise the system for compressor redundancy to ensure reliability for the 1-year endurance run. To satisfy both capacity and endurance requirements, two compressors, each having a capacity of approximately 1 ton, were installed in parallel. A flow diagram of the system now employed is shown in Figure 47.

The vertical wire trays have been relocated inward on the chamber radius to eliminate an interference problem existing with the cryogenic walls. In conjunction with this modification, upper and lower horizontal wire trays were fabricated and installed to the chamber. These trays serve a dual purpose of containing the power and signal wires and adding structural rigidity to the vertical wire trays.

e. Full Cryogenic Heat Sink

A full, cylindrical, cryogenic heat sink, shown in Figure 48, is installed concentrically between the power system and the vessel wall. The purpose of the 7-ft-diameter, 14-ft-high sink is to simulate the extremely cold thermal environment experienced by an NPU in orbit prior to startup. The heat sink, which is made up of two half cylinders manifolded to common inlet and outlet lines, is serviced by a 2600-gal liquid-nitrogen (LN_2) storage tank and vaporizer equipped with a temperature controller. The vaporizer and controller convert the LN_2 to a gas and maintain the mean sink temperature at -160°F . As the system's supply of LN_2 is depleted, the tank may be refilled by truck deliveries. The periodic transfer of liquid from the truck to the tank is supported by a transfer pump which allows the test in process to continue without interruption. Figure 49 shows a flow diagram of the system.

f. Cryogenic Wall System

Walls have been acceptance tested and proof fitted to the FSM-4 vacuum chamber. Some minor fitting problems were encountered, and corrective action has been completed. Figure 48 shows the walls successfully leak checked and installed to the vacuum chamber.

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Figure 47. FSM-4 Freon System for Interface Heat Sink

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Figure 48. FSM-4 Full Cryogenic Heat Sink Installed in Chamber

The interconnecting plumbing extending from the cryogenic wall flanges to the building wall has been installed and partially insulated.

An 18 by 25-ft concrete pad was poured external to the test building for the purpose of supporting the liquid-nitrogen storage tank and vaporizer. A leased 2600 gal storage tank, equipped with a transfer pumping system, has been installed on the pad and is ready for service.

g. Hoist Fixture

A special hoist fixture is being provided to assemble the vacuum vessel with the utmost caution. A particularly critical assembly problem exists when the cryogenic panels are installed within the chamber. The radial clearance existing between the vessel and heat sink walls is but a few inches, owing to the extent of different equipment which is compacted within the test chamber. The hoist fixture being provided to resolve the problem is a motor-driven cable-drum assembly. The fixture can raise and lower the chamber with sufficient control to eliminate swinging and erratic stops and starts. Figure 50 illustrates the crane-suspended fixture hoisting the center section of the vacuum chamber. The fixture is to be capable of safely lowering and raising the 5300 lb center section of the vacuum vessel at a maximum speed of 3 ft/min. The vessel section has been statically balanced, as will be the hoist fixture, to ensure the maximum possible vertical travel and also to minimize the possibility of interference between the walls and the vessel section.

h. Radiant Heaters

Eight radiant heaters will be installed concentrically about the NNPU in an octagonal array for the purpose of simulating the heat input of the sun on the orbiting power system. The heaters will be divided into two banks of four, each capable of being programmed to simulate the sun-shade effects of an equatorial orbit and the constant input of a polar orbit. The heater elements are constructed of nichrome filaments inside a quartz tube and are installed concentrically with a near-parabolic reflector. Two elements make up a single assembly capable of a radiant output of 3 kw of electrical power. Each heater has an overall length of 90 in. and a reflector width of 4 in. They are supported and positioned at an optimum height and symmetrical location on heater stands which are securely mounted to the vessel's base.

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Figure 49. SNAP 10A FSM-4 Liquid Nitrogen System to Support Cryogenic Walls

Figure 50. FSM-4 Motorized Hoist Fixture

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The wiring of the radiant heater power and control console, and the control transformer panel has been completed. A functional checkout of the system from the vacuum vessel interface up to the building power supply was accomplished, with no discrepancies noted.

i. FSM-4 Core Heaters

During the previous report period the core heater power and control system had been performance tested to the expected operating power of 40 kwe. Calibration and polarities on all instruments were acceptable. During the latter part of this report period, at the conclusion of the FSM-1 test program, it was concluded that the existing power wiring should be changed from 12 gage to 10 gage wire inside the vacuum chamber. This is due to the warm operation of 12 gage wire on FSM-1 (in air) and the need for endurance capability on all parts of the FSM-4 test rig. The change was initiated but not completed during the quarter. The core heater control system was examined, and the engineering was completed, on the use of a voltage programmer for the startup transient, control wiring for the steady-state operation using a controller of the current actuating type (CAT), and an emergency dc supply in case of power failure.

j. Profile Monitor

A visual dynamic display of converter leg temperatures during the NaK loading operation, as well as other dynamic parameters, are to be observed on a 17-in. square cathode ray tube. In the case of NaK loading, each of 40 converter-tube temperatures will appear on the screen as a square pulse whose height is directly proportional to the analogue temperature signal. NaK plugs and/or faulty instrumentation can be identified readily by this dynamic monitoring system.

A provision is included to attach a camera and hood assembly to photograph any particular observation for future reference.

k. Test Console

A test console is provided to simulate the functions of the ground checkout equipment used prior to launch to provide monitoring capability for the many diagnostic circuits of the power system, and to provide simulated commands normally generated in flight by telemetry equipment. The test console is equipped with several 28 volt dc supplies to power the system

circuits, a dc supply to simulate the pump startup battery, and a 400-cps, 115-volt, 3-phase power supply to run the position indicator circuits. Any or all of 40 circuits can be monitored on a 40-channel, 0-to 28-volt events marker. Lower-power dissipation lamps monitor the status of relays, position switches, and other contact closures. A series of toggle switches distribute the 28-volt power supply output to the various system busses. Finally, command functions initiated normally in the block house, in flight, or just for test purposes are provided. Figure 51 shows the test console, displaying each of the items or functions discussed.

1. Thermal Console

A thermal console has been designed and built to monitor and control thermal functions of both the power system and the facility. As shown in Figure 52, the console is equipped with instruments monitoring the chamber cooling water flow, a temperature recorder-indicator used in conjunction with a 40-channel switch used to back up the data logger, the primary temperature recording device, and alarms (audible and visual) to monitor the following:

- 1) Loss of cooling to the diffusion pump
- 2) Over-temperature on the diffusion pump
- 3) Low main-cooling water flow
- 4) High core-outlet temperature on the NNPU
- 5) Loss of chamber vacuum

Also, a 100-point voltage indicator is available to serve as backup to the voltage channels read normally on the data logging system. The controller used to regulate the power to the core heater of this nonnuclear FSM-4 is of the current actuating type (CAT). Its control current output feeds a magnetic amplifier, which in turn controls the output of the 100-kva Saturable Reactor. The CAT controller is capable of automatic or manual control, and serves as a core outlet-temperature recorder as well.

Running-time meters on the thermal console register the time the power system has operated in excess of 500°F and hours in excess of 900°F. Power monitoring instruments are provided, as shown on the left in Figure 52, to indicate phase, volts, amps, and total kilowatts dissipated by the 3-phase circuits of the core heater.

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Figure 51. FSM-4 Test Console

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Figure 52. FSM-4 Thermal Console

A load bank of the rheostat type, continuously variable from 0 to 6 ohm, is provided to dissipate up to 750 watts of the useful electrical power available from the FSM-4 converter. Direct-indicating voltage and amperes, and the total kilowatt hours dissipated by the load bank are recorded.

With the exception of updating the various wiring, the only modification to any of the consoles is that of incorporating the necessary circuitry to measure converter open- and closed-circuit voltage.

m. Data Logger

The remaining significant monitoring device, the data logging system, is shown in Figure 53. It has a capacity to log 301 data points distributed as follows:

- 1) Channels 0 to 5 are used as calibrate channels
- 2) Channels 6 to 194 are used for logging TC outputs
- 3) Channels 195 to 249 are used for voltage outputs
- 4) Channels 250 to 300 are used for millivolt signal levels.

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Figure 53. FSM-4 Data
Acquisition System

The output from the digital voltmeter on the data logger is serialized and fed into an electrical typewriter where the data is presented in engineering units on an original and three carbon copies. In addition, the output is digitized and recorded on punched tape for coupling to a high-speed data reduction program.

The logger has been wired to the facility J-box. All wiring associated with the instrumentation readout, including that connecting the J-box to the vessel interface, has been updated to reflect the latest test instrumentation channel assignments. Each of the consoles and the data logger has been functionally checked, with no discrepancies or malfunctions being noted.

n. NaK Loading System

The NaK system, consisting of the NaK loading cart, instrument console, and plugging loop, is to be coupled to the NNPU during the loading phase of the test program. The cart, modified since its first application on FSM-1, serves to pump, heat up, and cold trap the NaK. The determination of NaK quality will be ascertained by a plugging loop plumbed external to the cart. The various temperatures and flows existing throughout the system are monitored on the instrument console. The NaK system will be integrated to the NNPU by interconnecting plumbing routed through the vessel interface flange into the chamber. The fill and return lines are plumbed and bracketed along the vertical wire trays to their respective connections on the power-system header assembly. The drain line is routed directly from the vessel interface to the NNPU connection on the lower manifold.

The NaK loading system, which was used to load the FSM-1 system, has been modified and functionally checked out. The revised system includes the NaK loading cart, instrument console, and also a separate plugging loop. The cart no longer has an operative plugging loop, but does have a cold trap for removing NaK oxides. The system is to be "proofed" in the loading of FS-1 prior to being used on the FSM-4 NNPU.

V. FLIGHT TEST SYSTEMS (FS-3, FS-4, FS-5)

A. FLIGHT TEST PROGRAM SUMMARY

1. Description

The planning for the orbital flight test program has been redirected to a single flight test late in the Spring of 1965. Both FS-3 and FS-4 are being assembled and acceptance tested to provide a concurrent flight spare. Assembly of FS-5, the third flight system, is being held in abeyance and the parts placed in protective storage.

An Atlas/Agena D is to be used to place SNAP 10A in earth orbit. The launch configuration is shown in Figure 54.

The flight test program provides for the proof test of the SNAP 10A system under actual operating launch and orbit conditions. The Lockheed Missile and Space Company (LMSC) is responsible for the launch vehicles (Atlas and Agena), and for integrating the launch operations at Vandenberg Air Force Base (VAFB), and Navy Missile Facility at Point Arguello (NMFPA). The Atlas D boost vehicle is built by General Dynamics Astronautics (GDA), the associate contractor to LMSC for the Atlas vehicles.

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Figure 54. Atlas/Agena/SNAP 10A

The flight vehicle is a 2-1/2 stage, liquid-fueled, satellite launch rocket in which the satellite stage uses a SNAP (nuclear power supply). In operation, the entire Agena upper stage becomes the orbiting satellite. Payload equipment (and in this case the nuclear power supply) is attached to the Agena structure.

The Atlas D vehicle will be used as the boost portion (1-1/2 stages) of the vehicle. The Atlas D is 67 ft 7 in. in length, and 10 ft in diameter, and consists of a half-stage booster and a full-stage sustainer.

For the Atlas/Agena combination, a 13-ft-long tapered adapter section is attached to the Atlas. This sleeve contains stage-separation pin pullers, Atlas retrorockets, Agena destruct charges, and the ascent radar beacon antenna.

The Agena satellite vehicle is based on a design used in Air Force and NASA programs. With the SNAP 10A nuclear power unit in place, the vehicle is about 40 ft long and 5 ft in diameter, and uses a Bell Aerosystems Model 8096, 16,000-lb-thrust, liquid-propellant rocket engine. This engine model provides restart capability. The existing Agena vehicle design will be adapted for this launch with forward installation of the SNAP test unit and secondary payload devices.

2. Assembly and Checkout

Assembly effort on the flight systems during the quarter has been primarily centered around FS-3. The FS-4 system assembly had been curtailed because of program redirection.

At the beginning of the quarter, FS-3 assembly began with the welding of the converter; preparation of the wire bundles, both high- and low-temperature, and the mechanical assembly of the instrument compartment. Assembly of the thermoelectric legs progressed smoothly, with only a short delay during February when the stud welder began to shoot the studs erratically. It was necessary to replace some components in the welder and requalify the machine. Figure 55 illustrates the progress of the TE legs during the assembly period. The plateau during the week between January 17 to 20 was the result of the stud welder being inoperative. The studs are normally installed prior to the welding of the modules into legs.

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Figure 55. Thermoelectric Leg Assembly Week Ending

The preparation of the instrument compartment, both mechanically and electrically, progressed smoothly with completion of the compartment wiring during the week of March 16 to 20. Figure 56 illustrates the completed instrument compartment.

The reactor vessel assembly was received on February 29, and drilling and fitup of the assembly was completed in four days. The TE legs were then installed on the unit, and fitup of the lower manifold was effected. Welding of the lower manifold to the TE legs was completed on March 27. At this writing, the upper manifold is being fitted prior to welding to the TE legs. Figure 57 illustrates the state of completion of the NPU.

B. FLIGHT SYSTEM TECHNICAL ACCOMPLISHMENTS AND STATUS

1. Design

The SNAP 10A Flight Test Systems comprise four SNAP Units designated FSM-4, FS-3, FS-4, and FS-5. The FSM-4 unit is a ground test system incorporating flight-design qualified and acceptance tested components, except that electrical heaters are used in place of the nuclear core, and additional diagnostic instrumentation for ground test is installed. Additional information on the FSM-4 systems is given in Section IV-E.

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Figure 56. SNAP 10A Instrumentation Compartment

The design of the Flight Test Systems is complete except for changes and improvements resulting from qualification testing, assembly experience, FSEM-3 flight-system electrical mockup testing, and FSM-1 posttest examination. The changes and improvements incorporated into the design of the flight system during this quarter are as follows:

a. Structure

The ejectable heat-shield ejection-spring mounting bracketry has been modified. The reactor electrical interface connector extensions have been modified and relocated to obtain greater clearance between bracket and reactor electrical connector housing during heat shield ejection. A redesigned connector support-shelf assembly has been incorporated for the relocated connectors.

4-1-64

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Figure 57. SNAP 10A
Nuclear Power Unit

b. Electrical and Instrumentation

A tantalum capacitor is being added to the reactor control circuit to eliminate EMI susceptibility. A change in insulating material on the nonlatching SC relays from ML varnish-impregnated glass tape to polyethylene tubing or Teflon has been incorporated. Pt-404, a high-emittance enamel, has been added to the main and auxiliary relay boxes to reduce operating temperature.

c. Heat Shield

Thermocouples previously used for destruct charge and firing-unit temperature monitoring have been relocated on the heat shield. Heat shield receptacle mounting brackets have been modified to permit assembly of wires to receptacle remotely from heat shield.

d. Destruct System

The destruct system, which is no longer required, has been eliminated.

e. NaK Components and Piping

A fillet welded hot-NaK-to-upper-manifold junction has been incorporated in the design because of its improved fatigue life.

2. Fabrication

Fabrication of components for the flight systems was continued. Engineering orders were released for fabrication of the thermoelectric pump for the FS-3 system. Detail parts for the FS-3 and spare pump are being fabricated. A complete converter complement of the Type-V module leg assemblies was fabricated for the FS-3 system. Approximately 108 modules have been fabricated for the FS-4 system, with acceptance testing complete on 46 of these modules.

Delivery of all diagnostic instrumentation is complete except for the thermal switches, gamma detector, neutron flux detectors, and power supplies. Qualification and acceptance testing are continuing on other instrumentation components. Wiring of relay boxes for the flight system continued. Instrument compartment and structures and instrument bracketry fabrication have been completed and delivered to the assembly area. Wiring of the FS-3 instrument compartment is approximately 70% complete.

Fabrication of lower and upper manifolds for the flight system was completed, as was fabrication and delivery of all parts for the shell structures. Fabrication of ejectable heat shields for the flight system is continuing.

The FS-3 radiation shield is complete and in the final stages of acceptance testing. The FS-4 radiation shield has been returned to Oak Ridge for rework because of unacceptable quality of the final closure weld. The shield casing for the FS-5 system is complete and is at Oak Ridge for the installation of the shield material.

3. Assembly and Checkout

As reported in the previous quarterly, the assembly of a piece of equipment to automatically program the post heat-treat cycle of the thermoelectric converter legs was in progress. The unit was finished during the third week in

February. The operating parameters are presently being established to give the performance required in accordance with the heat treat specifications. Figure 58 shows the completed console.

4-1-64

7561-54870

Figure 58. Post Heat-Treat
Programming Console

As a result of the FSM-1 thermal test, it was determined that the brazing of the RTD's to the NaK plumbing caused the sensors to lose their calibration. The high temperature (1350°F) required to braze the RTD's was cause for the calibration shift. The most convenient method dictates the brazing of a copper block to the piping in the detail state, and the insertion of the RTD into the block. Figure 59 illustrates the components required for the brazing operation; a copper block, the braze material (Incusil 15), and a carbon block.

4-1-64

7561-54872

Figure 59. Brazing Operation Components

The copper block is inserted into the carbon block, which is attached to a spot-braze power supply by a hand gun. The current passes from one electrode to the other and causes the carbon block to heat. A temperature of 1350°F is reached in approximately 15 sec. The braze flows and secures the block to the piping. Figure 60 illustrates the hand gun in position. Upon completion of the brazing operation, the RTD is inserted into the block and secured by crimping the block around the RTD until the sensor is locked in place. A set screw is then installed into the block to assure that the RTD is held in place.

3-26-64

7561-54828

Figure 60. Hand Gun Position for Brazing Components

BLANK

VI. DEVELOPMENT

A. THERMOELECTRIC CONVERTER

The objective of this portion of the program is to develop and fabricate the thermoelectric modules for the power conversion system. The principle efforts involved are (1) converter design and analysis, (2) development engineering, (3) module fabrication, (4) acceptance testing, (5) qualification testing, and (6) developmental testing to determine the limits of performance and to provide experimental confirmation of design points.

A total of 225 Type-VF modules was received for converters FS-3 and FS-4, bringing the total of Type-VF modules received to date to 447. A significant increase in the manufacturer's yield occurred during this period.

Five Type-IV modules exhibited only minor degradation in accumulating additional test time under design conditions to a total in excess of 7300 hr; two of these modules have operated over 8000 hr. Twenty-two Type-V modules continued operation at 110% of the design condition; 4800 hr of operation have been attained by five of these modules.

The FSM-1 converter performed as predicted during the latter part of the 90-day test. Visual examinations and electrical measurements were initiated after completion of the test. No shorts were located in the converter.

1. Design and Analysis

A qualification test of the converter component hardware, including TE leg attachment hardware and electrical connectors, has been completed. The test assembly consisted of five C modules; two series interleg connectors, each having two straps; 26 stud-wire parallel interleg connectors; one voltage tap assembly and one power tap assembly mounted on a partial shell structure. The assembly was subjected to full flight-qualification levels of vibration. Three interleg stud wire connectors and one series interleg connector, consisting of two straps, failed during the vibration run.

Since the function of the stud-wire interleg connectors is to provide an alternate current path through adjacent radiators in case of an element separation, failure of the stud wires does not result in failure of the converter. The one series connector that failed was between the outer two modules on the

assembly. Radiators on these two modules were not interconnected with the stud-wire connectors, as was the case with the other adjacent modules. It was observed that the outer leg experienced considerably more movement than the other modules during the test. As a result, it is felt that the failed connector was subjected to stresses of a greater magnitude than would have existed had the stud wire been used.

2. Development

Investigations for improving the reliability of the lower compensator-to-hot strap braze joint and the radiator hot-shoe diffusion bond were continued. Examination of unetched sections of failed compensator-hot strap joints determined that separation initiates at the joint circumference and occurs at the boundary between a silver-colored section on the compensator side and a copper-colored section on the hot strap side. Tests were initiated to determine the cause for lack of complete diffusion in these weak joints, since good braze joints exhibit a graduated color change in the same region.

Two approaches for improving the radiator bond are being examined. One approach incorporates design changes in the radiator hot-shoe region to prevent contact between nickel and aluminum in load carrying areas. The second area of investigation is the diffusion bonding of aluminum to metals other than copper. Favorable results have been obtained with titanium, niobium, vanadium, and silver.

Tensile testing of silicon-germanium alloys above room temperature determined that the strength increases with temperature. The 67% silicon alloy exhibits a maximum strength of double the room temperature value at 1100°C. The maximum strength of an 80% silicon alloy occurs at 300°C at a value 35% greater than the room temperature value.

The elastic properties of silicon-germanium were determined by the sound wave pulse-echo technique at room temperature. The Young's modulus, shear modulus, and Poisson ratio values, shown in Table 6, indicate similar elastic behavior of the N- and P-type silicon-germanium.

TABLE 6
ELASTIC PROPERTIES OF SiGe

Type	Dopant	Young's Modulus ($E \times 10^6$ psi)	Shear Modulus ($G \times 10^6$ psi)	Poisson Ratio (μ)
P	Boron	19.4	7.9	0.23
N	Arsenic	17.8	7.1	0.25

3. Production

The manufacturer supplied 225 Type-VF modules during the report period for use on converters FS-3 and FS-4. The module yield prior to salvage and rework operations increased markedly from 41 to 61% as the result of improved processing procedures and revision to the gold ring depression specification. A slight increase in the module yield after salvage and rework also occurred. The weekly percent yield values are shown in Figure 61.

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Figure 61. Manufacturer's Thermoelectric
Module Fabrication Yield

Dimensional and electrical deviations from specification continue to be the major source of module rejection and have remained fairly constant during this report period. Table 7 shows the deviations from specification which were found during the acceptance testing of 447 Type-VF thermoelectric modules

received to date. These deviations are considered minor, and the majority of the modules were used in flight systems.

TABLE 7
MODULE DISCREPANCIES

Number of Modules	Type of Discrepancy	Disposition of Module
171	Gold ring depression	Flight system usage
4	Gold foil-to-hot strap gap	Reworked and used for flight
1	Gold foil strap loose	Reworked and used for flight
1	Gold foil missing from hot strap	Reworked and used for flight
2	Clip stud off location	Used for testing
3	Clip stud thread damage	Reworked and used for flight
3	NaK tube end oversize	Used for testing
1	NaK tube end nickel	Used for testing
4	NaK tube end to radiator oversize	Flight system usage
1	Tube end squareness	Used for testing
1	Burrs on NaK tube	Reworked and used for flight
1	Low resistance to ground	Reworked and used for flight
26	Module resistance high	Flight system usage
2	Double gold foil on hot strap	Reworked and used for flight
2	Crack in gold ring	Used for testing
1	Horizontal crack in moly disc	Used for testing
1	Crack in SiGe	Used for testing
1	Separation in copper disc	Used for testing

The results of the inhouse acceptance testing are shown in Table 8. The shock and vibration test was deleted from the acceptance test sequence after testing 269 Type-VF modules without failure. The 40-lb static load test will continue to be used to locate weak elements.

4. Evaluation

a. Mechanical Testing

Table 9 is a summary of the manufacturer's test data. No module failures in quality assurance, hatchet, and super-hatchet testing were experienced during this report period.

TABLE 8
AI TEST DATA, TYPE-V MODULE

Test Sequence	Module Type	Steady-State Operation			Thermal Cycling			Steady-State Operation			Shock and Vibration			Steady-State or Static Load			Tensile Test	
		MF/MT	EF/ET	El. Rate Each Loc. Parts/1000	MF/MT	EF/ET	El. Rate Each Loc. Parts/1000	MF/MT	EF/ET	El. Rate Each Loc. Parts/1000	MF/MT	EF/ET	El. Rate Each Loc. Parts/1000	MF/MT	EF/ET	El. Rate Each Loc. Parts/1000	MT/ET	Load Range (lb)
TMA Short Sequence	V DEV.	No Test			50X, 10 min up, 30 min down			No Test			No Test			Static Load, 100 lb			To Separation	
	V P				3/20	7/193	36 W-W							13/20	25/186	107 SiGe 27 W-W	20/135	60/323
	V F				0/14	0/150								9/14	17/150	113 SiGe	14/111	75/450
TMA Long Sequence	V DEV	100 hr, 1100°F			50X, 10 min up, 30 min down			50 hr, 1100°F			No Test			Static Load, 100 lb			To Separation	
	V P	0/20	0/194		0/20	0/194		0/20	0/194					8/20	14/194	26 W-W 46 SiGe	20/154	11/340
	V F	0/14	0/150		0/14	0/150		0/14	0/150					11/14	16/150	93 SiGe 13 Cu-W	13/96	45/350
Accelerated Test Sequence	V P	0/28	0/282		0/28	0/282		0/28	0/282					6/6	18/60	300 SiGe	28/217	125/575
	V F																	
Qualification Test Sequence	V P	100 hr, 1060-1120°F			50X ~30°F/min			8 hr, 1060-1120°F			No Test			Static Load, 100 lb			To Separation	
	V P	0/18	0/416		0/18	0/416		0/18	0/416					11/18	22/416	53 SiGe	15/157	60/360
	V F																	
Acceptance Test Sequence	V P	100 hr, 970-1030°F			50X ~30°F/min			100 hr, 970-1030°F			Spec. Levels			Steady-State Operation			To Separation	
	V P	0/19	0/448		0/19	0/448		0/19	0/448		0/19	0/448		0/19	0/448	0	9/106	100/450
	V F	0/16	0/380		0/16	0/380		0/14	0/332		0/14	0/332		1/14	0/332	3 W-Al	1/6	225/415
Acceptance Test Sequence	V P	Visual and Dimensional		Resistance		Shock and Vibration		Static Load		Visual and Microscopic								
	V P	MF/MT	EF/ET	MF/MT	EF/ET	MF/MT	EF/ET	MF/MT	EF/ET	MF/MT	EF/ET							
	V F	0/19	0/408	0/19	0/408	0/19	0/408	0/19	0/408	0/19	0/408							
Acceptance Test Sequence	V F	0/330	0/8140	0/330	0/8140	0/269	0/6424	0/330	0/8140	0/330	0/8140							
	V F																	

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TABLE 9

MANUFACTURER'S TEST DATA, TYPE-V MODULE

Quality Assurance Test	Submitted to Test	Vibration		200 hr S.S. Plus 16 TC		Shock and Vibration		Static Load Test		Tensile Test				
		Tested	Failed	Tested	Failed	Tested	Failed	Tested	Failed	Tested	Shoe-SiGe	SiGe	Mo-Ins	Other
	Mod/El	Mod/El	Mod/El	Mod/El	Mod/El	Mod/El	Mod/El	Mod/El	Mod/El	Mod/El	El Load Range	El Load Range	El Load Range	El Load Range
Cumulative Total To Date	28/280	27/270	0/0	26/260	0/0	19/190	0/0	19/190	0/0	13/116	3 ²⁵ ₂₉₂	48 ¹⁷⁴ ₅₀₅	64 ²²² ₄₆₅	1 ³⁶⁰

Hatchet Test	Submitted to Test	TC & S (44)		Tensile Test				
		Tested	Failed	Tested	Shoe-SiGe	SiGe	Mo-Ins	Other
	Mod/El	Mod/El	Mod/El	Mod/El	El Load Range	El Load Range	El Load Range	El Load Range
Cumulative Total To Date	38/354	35/328	1/3	34/275	16 ¹⁵⁵ ₃₈₅	109 ²⁰ ₄₄₅	135 ²¹⁰ ₄₈₈	15 ⁹⁹ ₄₁₀

Super Hatchet Test (Optional)	Submitted to Test	TC & S (240)		Tensile Test				
		Tested	Failed	Tested	Shoe-SiGe	SiGe	Mo-Ins	Other
	Mod/El	Mod/El	Mod/El	Mod/El	El Load Range	El Load Range	El Load Range	El Load Range
Cumulative Total To Date	9/98	9/98	0/0	9/89	8 ⁵ ₂₅₈	30 ⁵ ₃₈₆	50 ¹⁵³ ₄₅₀	1 ¹⁶²

Tensile Test (End Test Pieces)	Submitted to Test	Type-N Tensile				Type-P Tensile			
		Shoe-SiGe	SiGe	Mo-Ins	Others	Shoe-SiGe	SiGe	Mo-Ins	Others
	Element	El Load Range	El Load Range	El Load Range	El Load Range	El Load Range	El Load Range	El Load Range	El Load Range
Cumulative Total To Date	563	33 ¹⁵ ₃₅₃	118 ¹⁵ ₄₁₀	115 ¹⁵³ ₄₂₅	0	11 ⁶⁸ ₃₅₀	28 ⁷⁵ ₄₂₀	238 ¹⁷⁰ ₅₆₇	4 ²⁸⁵ ₄₃₀

TYPE V NaK TUBE ASSEMBLY DATA

Furnace Run Acceptance Test	Submitted to Test	T S 240		Tensile Test					
		Tested	Failed	Tested	W-Cu	Cu-Ins	Ins-Mo	Mo-Cu	Other
	NTA/Stack	NTA/Stack	NTA/Stack	NTA/Stack	Stack Load Range	Stack Load Range	Stack Load Range	Stack Load Range	Stack Load Range
Cumulative Total To Date	99 1098	99 1098	1 2	96 977	3 ³⁸ ₁₆₈	1 300	473 ⁴⁵ ₆₀₅	11 ²⁶⁰ ₄₃₃	489 ⁸⁵ ₅₆₅

ELEMENT SHOE BONDING TEST DATA

Shoe Bond Acceptance Test	Submitted to Test	Type-N Tensile				Type-P Tensile			
		Tested	Shoe-SiGe	SiGe	Cement	Tested	Shoe-SiGe	SiGe	Cement
	Element	Element	El Load Range	El Load Range	El Load Range	Element	El Load Range	El Load Range	El Load Range
Cumulative Total To Date	876	464	60 ⁶⁰ ₇₆₀	152 ⁷⁵ ₆₀₀	252 ¹⁴⁵ ₇₆₀	394	17 ¹⁶⁵ ₇₉₇	35 ²⁷⁴ ₈₁₂	342 ¹²⁵ ₇₂₀

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The results of the AI thermal-mechanical testing program are summarized in Table 8. During this report period 17 Type-VF modules containing 150 elements were subjected to the Thermal Mechanical Acceptance (TMA) short sequence test, and 19 modules containing 170 elements were tested through the TMA long sequence. This brings the total of Type-VF modules tested through each TMA test sequence to 28 modules containing 282 elements.

Nineteen Type-VP modules and 14 Type-VF modules have now completed qualification testing through shock and vibration without failure. On the basis of the 780 elements in these modules, element reliability (probability of success through this portion of qualification test) is at least 99.72% with 90% confidence, or 99.9+% with 50% confidence.

The distribution of breaking loads, as the result of tensile testing at the end of each test sequence, is shown in Figure 62. The magnitude and distribution of the loads required to cause separation have not changed significantly for modules received during this quarter, indicating that the fabrication process has remained under control.

b. Performance Testing

Twenty-seven modules were on qualification performance test during this report period. The five Type-IVP modules have now accumulated over 7300 hr of operation; two of these have been on test for over 8000 hr. No significant change in performance was observed, as indicated in Figures 63 and 64. These modules are being tested at the design hot-strap temperature; the data are normalized to an average temperature gradient of 282.5°F.

Of the nine Type-VP modules on test, five have operated over 4800 hr and four accumulated about 4000 hr of testing before being removed from test. These four were heavily oxidized due to the loss of vacuum in the test system. Five Type-VF modules have been run in excess of 3300 hr; another six have been tested for ~2000 hr. Two of the latter modules were removed from test; one became heavily oxidized when exposed to air, and the other failed as the result of being thermally shocked. The hot-strap temperatures for these modules are 110% of the design conditions. Figure 65 is typical of the Type-V module performance characteristics. An average normalizing temperature gradient of 330°F was used in calculating open circuit and power output values for these modules.

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Figure 62. Module Breaking Load Distribution, Type-V Module

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Figure 63. Type-IV Module Performance, Modules R610-3 and R776-5

4-27-64 7561-01389
Figure 64. Type-IV Module Performance, Modules R626-1, R712-2, and R607-2

4-27-64

7561-01390

Figure 65. Type-VP Module Performance, Modules X1200-1, X1188-3, and X1185-5

The performance data obtained on the Type-V modules, as well as that of the Type-IV modules, are consistent with the average values of the Types I, II, and III modules. The average rates of change of the three performance properties for Types IV and V modules are compared in Figures 66, 67, and 68 with the minimum and maximum value curves shown as solid lines, obtained in testing large numbers of Types I, II, and III modules. Figure 69 shows the average performance characteristics for various periods of module fabrication. All data points were adjusted to a temperature gradient value of 305°F. The cause of the high values for Type-VP modules is being investigated, since these modules are identical to the Type VF.

The one Type-VF module which failed during qualification testing was X312-1. The failure occurred at the bond between the upper shoe and the radiator after the module was thermally shocked following a facility power failure. The module had accumulated 2250 hr of testing when failure occurred.

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Figure 66. Module Power Output Rate of Change

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Figure 67. Module EMF Rate of Change

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7561-01316

Figure 68. Module Resistance Rate of Change

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7561-01317

Figure 69. Module Performance Test Summary

Metallographic analysis of the bond determined that 1 mil of free copper was present and that separation occurred at the interface between the aluminum-copper compound and the copper. Separation at the radiator bond on earlier type modules occurred only when the aluminum had diffused completely through the copper. Examination also found a large amount of porosity present at the separation in a location within the original copper plate. Six other elements from this module failed in areas other than the radiator bond at normal separation loads when tensile tested to failure. All evidence indicates that failure of the radiator bond of this module is the result of an inferior copper plate.

c. Converter Testing

After completion of the 90-day test, a post-mortem examination of the FSM-1 converter was initiated. Visual examination of the converter located a number of stack separations. Four modes of stack failures were observed:

(1) upper compensator-to-radiator bond, (2) radiator-to-upper shoe bond, (3) failure in SiGe element near upper shoe, and (4) lower shoe-gold disc-lower compensator bond. The predominant location of failure was between radiators No. 1 and 13 on the A modules. These radiators are the thick (0.063 in.) radiators which are characteristic of the Type I and II modules used on 10FSM-1. These particular modes of failure were experienced during qualification testing of modules, and the quality of these joints has been greatly improved in Type-V modules.

Electrical measurements made on the converter have shown that no shorts exist in the converter or instrumentation, with the exception of the leads going up to the special voltage taps at the top of the converter. These leads were found to be shorted together and to the supporting structure because of insulation breakdown. It is believed that the shorting of these leads was responsible for the observed power fluctuations during the 90-day test.

Approximately 18 of the 40 w of power degradation during the 90-day test are attributable to shunting through these shorts and to inadequacies in the mechanical electric interconnectors. Welded-type interconnectors are used on flight converters to eliminate the latter source of power loss.

The rates of change of the power output, open circuit voltage, and the internal resistance during the 90 days of the 10FSM-1 operation are shown in Figures 70, 71, and 72, respectively. The line curves on these figures are estimates of the expected rates of change based on the Types I and II module qualification testing. The converter behaved as predicted during the latter part of the test.

Figure 71. FSM-1 Converter EMF Rate of Change

Figure 72. FSM-1 Converter Resistance Rate of Change

B. THERMOELECTRIC PUMP

1. Objectives

The objective of the pump development effort is to provide the system with a reliable thermoelectric-powered dc conduction pump capable of satisfying the system requirements. The system requirements include:

- a) Delivery of 13.2 gpm of 1010°F NaK at a pressure of 1.1 psi
- b) Delivery of at least 10.4 gpm at the end of 1 yr
- c) A means of measuring flowrate
- d) Delivery of 0.48 gpm when operated at 90°F from a 40-amp power source (battery)

e) Weight of 22 lb or less

f) Ability to withstand the environmental conditions imposed by system use.

The main objectives during this report period were to (1) continue testing and observe factors involved with degradation, (2) evaluate the effectiveness and feasibility of using the iron foil barrier in the thermoelectric elements, and (3) to improve the compression bar design.

2. Performance Data and Analysis

During this report period three pumps were fabricated and added to the test program. Table 10 shows the test milestones and status of the various pumps.

Degradation occurred during environmental testing and during prolonged operation at operating temperature. The pumping performance of all pumps tested has shown a loss as the result of environmental testing (although the loss in some pumps is small). Figure 73 shows the loss in pump, and Figure 74 shows the loss in wall voltage. At a given flowrate, the wall voltage is a function of the current in the electrical circuit. The reduced current resulting from the environmental test is indicative of an increased electrical resistance, which in turn is indicative of a mechanical impairment.

Degradation due to prolonged operation is shown in Figure 75. The degradation of all pumps shown has similar characteristics. Generally, it is found that except for disturbances caused by malfunctions in the test facility, the pumps degrade more or less uniformly until about 2000 hr, and thereafter degradation nearly ceases. The degradation observed during life tests is attributed to increased thermoelectric generator resistance with operating time. To confirm this, a pump was operated under standard conditions with the thermoelectric generator open-circuited. The NaK was circulated by an auxiliary pump in the test facility. The open-circuit voltages as a function of time are shown in Figure 76. This shows that the open circuit N-element voltage is substantially constant in the 1000-hr test. Hence, the degradation observed in pumps is not attributed to N-element voltage degradation. The open-circuit voltage of the P elements is more erratic, although no degradation occurred

TABLE 10

SNAP 10A TE PUMP TEST MILESTONES AND STATUS

Pump Designation	FQ-1	FQ-2	FQ-3	FQ-4	FQ-5	010	011	012	013	014	015	016	017	018	019	020	021
Radiator Fin Coating	3-5	4-11	5-3	5-7	7-22	8-1	8-14	8-28	9-24	10-7	9-9	10-9	11-5	11-4	12-10	12-19	1-27
Magnetization	3-6	4-12	5-17	5-8	7-23	8-2	8-17	11-7	10-2	10-12	9-16	10-14	11-7	11-5	12-12	12-19	1-28
Environmental Test-Acceptance Test	3-15	4-15	5-20	5-13	-	-	8-21	-	-	-	-	-	11-20	-	-	-	-
NaK Operation - 20 hr at 1010°F	3-27	4-19	6-10	5-19	7-24	8-5	8-21	-	10-9	10-16	9-19	10-15	11-23	11-8	12-17	12-27	1-30
Performance Map at 1000, 900, and 800°F	3-29	4-20	6-11	5-20	7-25	8-6	8-21	11-12	10-10	10-17	9-20	10-15	11-23	11-8	12-17	12-27	1-30
Prereactor Flow Test	4-1	4-23	6-12	5-22	7-26	8-7	8-21	11-13	10-11	10-17	9-20	10-25	11-25	11-9	12-18	12-28	1-31
Initiation of Qualification	4-16	6-24	8-27	7-26	-	-	-	-	-	-	-	-	12-28	-	-	1-22	-
Ten Thermal Cycles	5-15	6-24	9-14	-	-	-	10-15 to 11-6	-	-	Dam- aged	-	-	1-16 1964	-	-	-	-
NaK Operation - 40 hr at 1010°F	6-14	7-20	9-14	-	-	-	-	-	-	Dam- aged	-	-	-	-	-	-	-
Environmental Test-Qualification Test	9-17	9-25	10-4	-	8-9	8-26	9-10	11-27	10-17	-	9-30	-	11-27	-	-	12-30	-
Pressure vs Flow	9-25	10-1	11-5	-	8-14	8-28	9-11	12-3	10-24	-	10-4	-	12-7	-	-	1-13 1964	-
Initiate Life Test at 1010°F	10-2	11-8	-	8-2	8-14	9-6	9-13 11-8	-	11-25	-	-	11-1	-	11-15	12-20	2-6 1964	2-6
Complete 6000 hr test at 1010°F	12-19	12-17	-	-	9-11 shut- down	-	Pump sent to Desoto	-	-	-	10-12 sent to HQ	Pump sent to Desoto	-	-	1-24 shut- down	-	-
Special Tests	-	-	1-16 1964	-	-	-	-	-	10-31	-	-	-	-	-	-	-	-

NAA-SR-9593
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Figure 73. SNAP 10A TE Pumps, Pressure vs Flow, 1010°F NaK

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Figure 74. SNAP 10A TE Pumps, Wall Voltage vs Flow, 1010°F NaK

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Figure 75. Pump Flow vs Time, 1010°F NaK

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Figure 76. Seebeck Coefficient vs Time at 1010°F NaK, Pump FQ-3

during the 1000 hr test. In the interval, 150 to 250 hr, a current was passed through the elements to determine their resistances. The P elements were disturbed by this, as shown by the abrupt drop in voltage at 165 hr. Ignoring this disturbance, it is apparent that the P-element open-circuit voltage does not degrade with time. Hence, the pump degradation is not attributed to a P-element voltage degradation. This test is interpreted to substantiate other data indicating that pump degradation is attributable to resistance changes.

To determine the sensitivity of the degradation to the operating temperature, the NaK temperature of one pump was increased from the design value of 1010 to 1100°F. This pump had operated 3290 hr at 1010°F, and its degradation characteristic had been well established. The data on this test are shown in Figure 77. Upon increasing the NaK temperature, the pumping rate increased. Thereafter, the pump behaved very much like a new pump. After about 200 hr, degradation became noticeable, and by the 1000-hr period the degradation vanished. The percent degradation was approximately the same as in the operation at 1010°F. The operation at 1100°F did not induce a self-perpetuating damage, as might be expected, but merely caused a temporary disturbance after which the pump performance became steady at a new value. A consideration of the flow curve and data from other tests indicates that the degradation occurs

during the time the thermoelectric elements are being accommodated in their mounting. After this period of adjustment, the degradation decreases to a very low value.

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Figure 77. Flow vs Time and ΔT Thermoelectrics vs Time, Pump FQ-4

Posttest examination of several development pumps showed copper and other objectionable contaminants in the lead telluride and lead-tin-telluride of the elements. Analysis showed that the contaminants entered by migration through the powdered-iron element contacts. To prevent this, a barrier consisting of a thin iron foil was placed between the powdered iron contacts and the copper or braze surfaces. Pumps 016 through 021 used this barrier. The effectiveness of contamination prevention by this means appeared certain. However, the associated exchange of a mechanical joint for a metallurgically bonded joint was questionable.

Pump 017 was sectioned after testing, and examination of the elements showed that the iron foil barrier is effective in preventing the migration of copper into the thermoelectric material. Figure 78 shows micrographs of the elements from pumps 015 and 017. In pump 015, no barrier exists. The tellurium vapor migrated through the iron to the copper and formed a Cu-Te

Pump 015 N (Unetched)

Pump 015 P (Unetched)

Pump 017 N (Unetched)

Pump 017 P (Unetched)

Figure 78. Micrographs of Thermoelectric Pump Elements Showing the Effect of an Iron Foil Barrier

material. This material then migrated through the powdered iron to the thermoelectric material. The barrier prevents contact between tellurium vapor and the copper. As a result, no Cu-Te material is found in the copper, and no copper or braze constituents are found in the thermoelectric material.

Two pumps using the iron foil barrier were subjected to the environmental test. One of these, pump 017 showed a large reduction in the wall voltage as a result of the mechanical forces. The reduction in pumping performance was large, but not significantly larger than some pumps having no barrier. Data are shown in Figures 73 and 74. Pump 020 suffered a typical loss in the environmental test. It is assumed that this type joint may be more vulnerable to the mechanical forces. So far as electric current and heat transfer are concerned, the mechanical joint has been entirely satisfactory.

So far as overall pump performance, and particularly degradation, are concerned, the barrier offers no discernible advantage at this time. Life tests are continuing.

The compression bars of all pumps tested through SN 018 are very difficult to adjust to maintain uniform pressure over the area of the thermoelectric element. As a result of the difficulty in adjustment, an arbitrary and nonuniform loading has been applied. The loading is applied through the aluminum radiator base, and the aluminum yields enough to improve the load distribution. However, since there is evidence that the degradation is related to creep in the materials and the matter of physical adjustment in the element support as discussed earlier on the 1100°F operation, a design to minimize this was made. The new design consisted of stiff compression bars which do not bend over the region of contact with the radiator. This was intended to provide uniform loading over the area. To accommodate thermal expansion differences, disc springs were placed under the heads of the compression bolts. Pumps 019, 020, and 021 were made using this compression bar design. Pumps 019 and 020 were damaged in manufacture. They were tested briefly, but so far as evaluation of the compression bar is concerned, the results were meaningless. Pump 021 showed excellent performance during its initial operation, but it began to degrade at a very high rate. A leak in the pump throat forced termination of the test. It is not known yet if the high degradation rate was caused by the NaK leak or other factors. This misfortune precluded an evaluation of the new compression bar design.

Figure 79 is a photograph of a pump made for the 10FSM-4 system. Except for the aft support outrigger (shown taped), the pumps described during this report period were visually identical.

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Figure 79. SNAP 10A TE Pump, FSM-4 Model

C. INSTRUMENTATION

1. Vendor Development and Testing

Vendor-conducted qualification tests have been successfully completed on all diagnostic and control instrumentation systems, except temperature switches. Four of six switches failed during qualification tests reported in the Quarterly Progress Report for October through December 1963. These were closely scrutinized in post-mortem examinations. During the current quarter the switch manufacturer incorporated several design and process improvements: (1) the interior hookup wires were changed from copper to stainless steel and were attached to contact pins and terminal pins by spotwelding rather than silver soldering, (2) the bellows assembly which hermetically seals the adjusting mechanism was redesigned to provide a wider range of adjustment and to reduce stresses in the bellows diaphragms, (3) cleaning procedures were modified

to eliminate entrapped contaminants and moisture, (4) welding procedures were modified so that all switches are purged and sealed in an inert atmosphere, and (5) a helium leak check was performed.

Four test specimens representing the two basic switch types, normally open and normally closed, were then assembled and subjected to critical tests in the qualification sequence, including shock, vibration, and the 72-hr combined temperature-vacuum-endurance test in which some of the qualification specimens had failed previously. Test equipment had been considerably upgraded since the preceding test series. The electrical test circuits incorporated a SNAP 10A-type relay with arc-suppressing diode, and the vacuum test facility was modified to maintain switch head temperatures below 750°F and to permit more accurate monitoring of probe temperatures.

Three of the four specimens tested performed satisfactorily. Calibration of the fourth specimen, a normally closed switch, shifted downward by 30°F as a result of shock and vibration. The switch was again subjected to the shock and vibration environments with a resultant calibration shift of only 2°F, which was within the accuracy limits of the monitoring instrumentation. The temperature-vacuum-endurance test was then performed, and the switch operated within applicable tolerance limits. Both types of switches were considered qualified.

To precondition normally closed switches, the vendor has incorporated in his manufacturing process a short, random-vibration test and thermal cycling. These procedures are employed whenever the switch is reset, either at the vendor's plant or during calibration at AI.

Following the completion of the qualification test program, the vendor modified the configuration of all contact arm assemblies. The thickness of each contact-bearing arm, machined from an Inconel S investment casting, was reduced to permit the silver brazing of a prefabricated eyelet containing the contact pin assembly. This change was necessitated by the inability to maintain adequate process and quality control over parts fabricated to the former configuration, a process which required fusing in place a glass insulator to hold the contact pin assembly in the arm.

It was shown by analysis that this change would have no influence on the thermal function of the switches, but that vibration was a potentially critical

environment. To complete the requalification of the two switch types (normally open and normally closed) which are used for heat shield ejection and high- and low-temperature malfunction circuitry activation, the vendor has assembled one of each representative type. These are currently being prepared for qualification-level vibration inputs, with thermal operation checked before and after the test.

2. AI Developmental Testing

Tests were conducted to resolve existing instrumentation problems and to investigate potential problems in the environments associated with the problem. Limited developmental tests on backup devices were performed.

a. Resistance Temperature Detector

Developmental tests were performed to determine the reasons for malfunctions of the RTD's brazed to stainless-steel NaK tubing. Tests to evaluate the effects of thermal shock and maximum temperature exposure during brazing were conducted. The apparent cause of the malfunctions due to brazing appears to be hydrogen contamination which increases the resistance on the surface of the platinum resistance element. This postulation and the reversibility of the process was verified by drilling a pinhole in the sheath at the sensor tip and baking at 1450°F for 24 hr. A recovery of ~ 9 of the original 14°F shift at 800°F resulted.

Torch brazing and slow and rapid electric-heating brazing were used without complete success. Investigation of alternate methods (no braze) of attaching RTD sensors to stainless-steel tubing was initiated.

b. Solid-State Integrated Neutron-Flux Detector

Twelve developmental units were fabricated (Figure 80). Of the 12 preirradiated transistors selected, 10 had a beta gain of $4 \pm 1\%$; one was high (4.63); and one was low (3.12). Ten units were not potted, thereby permitting maximum accessibility for adjustment and modification. Two units were potted to assure that potting would not significantly change the operational characteristics. Cadmium cups were placed over the transistors in two units to assure that thermal flux was not a factor in transistor degradation.

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Figure 80. Solid-State Integrated Neutron-Flux Detector
Test Assembly

The 12 units were irradiated to about 1.35×10^{14} , using the test set-up shown in Figure 81. All the response curves were in close agreement and within the envelope of the two extreme curves shown in Figure 82.

c. Expansion-Compensator Position Indicator

Analyses and tests confirmed that the previously reported erratic operation of the position indicator was due to variable contact resistance of the oxidized pins at the transducer connector. The following temperature tests were performed on two flight-type position transducers and demodulators with the cables brazed to the transducer connector pins.

(1) Transducer Temperature Drift and Cycling Tests

With the demodulators at ambient temperature, the transducers were subjected to 72-hr drift tests at 200, 400, 600, and 800°F, followed by two temperature cycles between ambient and 800°F. The worst-case drift of +0.3 to -1% is within specification limits. During the temperature cycling a sharp increase of 3 to 10% of full-scale output occurred at 600°F.

Figure 81. Test Console for
Neutron-Flux Detectors

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Figure 82. Integrated Flux Detectors
No. 59 and 61

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(2) Demodulator Temperature Cycling Tests

With the transducers at ambient temperature, the demodulators were cycled between ambient and 140°F. The output increased with temperature almost linearly to a 4% of full-scale increase at 140°F.

d. Irradiation Testing of Nonradiation-Hardened Relays

Radiation tests were conducted on off-the-shelf, nonradiation-hardened relays to determine if they were acceptable for use on SNAP 10A. Six relays, two SC11DP and four SL11DP, were irradiated to a fast neutron dose of 9×10^{13} nvt and then to a gamma dose of 2×10^7 r. No degradation of electrical characteristics was noted after the neutron exposure. After the gamma exposure, infinite resistance was measured across one pair of closed contacts on one relay. On a second relay, the resistance across a set of closed contacts increased from 25 to 117 mohm.

The irradiated relays and several nonirradiated relays were uncased and examined microscopically. Embrittlement and flaking of the Teflon insulation were found only in the irradiated relays. Narrow strips, which appear to be Teflon, were found near the contacts (Figure 83). A narrow strip of similar material was noted between the contacts, whose resistance was 117 mohm, after radiation (Figure 84).

Based on the above limited testing, these off-the-shelf relays are not acceptable for use on SNAP 10A.

e. High-Temperature Wire

Samples of S10A high-temperature wire were subjected to five thermal cycles between ambient and 900°F, and a 100-hr soak at 900°F in a vacuum of about 10^{-6} Torr, to evaluate their relative merits. The results are tabulated below in order of descending insulation resistance.

<u>Quantity</u>	<u>Sample Type</u>	<u>Lowest Insulation Resistance</u>
2	Unbaked silicone sized insulation	6.8×10^9
2	Baked silicone sized insulation	1.5×10^7
2	Baked epoxy sized insulation	10^7
2	Unbaked epoxy sized insulation	2.1×10^5

Figure 83. Irradiated Relay Contacts
Showing Teflon Flaking

Figure 84. Irradiated Relay with
Teflon on Contact

f. Diode Irradiation

Five 1N647 diodes were irradiated to a fast neutron dose of 10^{14} nvt and a gamma dose of 3×10^5 r in a vacuum, about 10^{-5} Torr, and at an average temperature of 140°F. Postirradiation measurements indicated that the inverse leakage current increased by a factor of about 7, and the forward voltage drop increased by a factor of about 2.5. The capability of the degraded diodes for suppressing inductive relay kick was verified by tests.

g. Converter Impedance Measuring Device

Tests were conducted to determine the effects of temperature on the capacitor-resistor voltage divider and the blocking condenser in the device. Due to an increase in dc blocking condenser leakage current, the output increased 3% of full-scale, linearly, to 140°F.

h. Foster High-Temperature Varnish

Temperature tests were conducted to assure that coating the end terminations of high-temperature wire with varnish did not impair the wire's insulation resistance. A typical wired bulkhead plug with the end terminations of the wire coated with Foster varnish was subjected to the thermal vacuum soaks tabulated below. The data show that the insulation resistance was adequate at SNAP 10A temperatures, but decreased to unacceptable values at high temperatures.

<u>Temperature (°F)</u>	<u>Total Hours</u>	<u>Lowest Insulation Resistance</u>	<u>Vacuum Torr</u>
900	328	8×10^8	3.6×10^{-7}
1000	25	1.8×10^8	3×10^{-6}
1100	23	7.3×10^6	8×10^{-6}
1200	70	10^5	1.5×10^{-6}
1300	23	3×10^4	10^{-5}

3. AI Qualification Testing

Component qualification testing is performed to demonstrate the performance capabilities and reliability of the individual components while operating in, or being exposed to, particular environments. The particular components that were tested and the results are as follows.

a. Relays

Qualification tests were performed on the Potter and Brumfield types SC-4674-2 and SL-4314-2, and the Filters type LL-26R18R relays. The specimens were subjected to the following environments; acceleration, vibration and shock (16 relays of each type), and low-temperature and thermal vacuum (7 relays of each type). Three failures of the SC-type relay have been encountered. Two failures resulted from the acceleration test and one resulted from the vibration test. All causes of failure were due to high contact resistance. It has been determined that the high contact resistance is caused by small bits of the insulating material used on the relay coils. This material becomes loosened from the coils during shock and/or vibration, settles on and gets mashed between the contacts, and causes a high-resistance path. Both SL and SC relays are made by the same manufacturer, and the same type of insulating material is used on the relay coils. Therefore, SC-4674-2 and SL-4314-2 Potter and Brumfield relays are not qualified for use on the SNAP 10A system.

No degradation has occurred to the Filters relays due to environmental exposure in the testing program to date.

b. Ejectable Heat-Shield Connectors

All qualification tests, except thermal vacuum, were performed during the previous reporting period. The thermal vacuum tests performed on two sets of connectors completed the test program, and the results of all tests are summarized below.

Approximately 60% of the forces (30 measurements) required to unmate the connectors exceeded the 3-lb limit set forth in the procurement specification. Another discrepancy was loose brush assemblies, which became more evident at the conclusion of the thermal vacuum test. The loose pins caused the contact resistance to be erratic and in some instances exceeded the specification limit (50 mohm). This component is not qualified for use on the SNAP 10A system.

c. Low-Voltage Trip Device

Two low-voltage trip devices were subjected to qualification vibration and shock levels, a 9-day thermal vacuum test (average temperature at 130°F, 1×10^{-7} Torr), and an ambient-temperature-pressure endurance operations test.

Two other specimens were subjected to failure mode vibration and shock testing (vibration to 50 g's, shock to 65 g's) while operating. None of the specimens displayed deterioration in operating characteristics, degradation in electrical characteristics, nor physical damage as a result of the environmental tests. This design is fully qualified to the environments in which it was tested.

d. Expansion-Compensation Position Switch

Testing performed during this period included thermal cycling in a vacuum, thermal vacuum endurance (9 and 4.5 days on specimens, respectively), and humidity. The qualification status of this item has not been determined at this time because insulation resistances measured during thermal vacuum tests were less than 1 meg.

e. Radiator Fin Thermocouples

Two radiator fin thermocouples have been subjected to vibration and shock testing, while mounted on a partial TE leg shell structure, and thermal cycling in a vacuum. Steady-state thermal-vacuum endurance testing is currently being performed.

f. Relay Box

The qualification test specification was completed. Fabrication and checkout of the test console, to be used in actuating and monitoring the relay box performance, was completed.

D. STRUCTURAL AND NaK COMPONENTS

1. NaK Tube Sealing

To develop a reliable technique for sealing the SNAP 10A NaK system, an investigation was initiated to improve the quality of tube pinching. Preliminary investigations have indicated that cracks are usually present at the small, sharp-bend radii at the ends of pinched sections. Therefore, a program is in progress to determine the extent of such cracks and to minimize them. Attempts have been made to correlate the extent of cracking with wall thickness and tube diameter, and to correlate sealing efficiency with crushing load.

To evaluate the effect of wall thickness on the extent of cracking, numerous pinched specimens were subjected to metallographic examination. Pinched

specimens of 7/16 in. OD tubing with wall thicknesses of 0.012, 0.016, 0.020, 0.028, and 0.035 in., and 1 in. OD tubing with wall thicknesses of 0.010, 0.016, 0.020, 0.028, and 0.035 in. were included. The 35-mil wall-thickness tubing was 316 SS, and the other samples tested were of 321 SS. All tubing was received in a cold rolled and annealed condition.

Experimental results showed that the least wall cracking occurred on 1 in. OD by 0.035 in. wall tubing. The extent of cracking (crack depth over wall thickness) exhibited a downward trend with increasing wall thickness.

The fill tubes on each system are fabricated from 316 SS bar stock drilled on the ID and milled on the OD. Examination of pinched, as-machined tubing has revealed severe cracking on the OD as well as the cracks emanating from the ID

These machined fill-tube mockups were subjected to an annealing treatment and then pinched. No evidence of external cracking could be observed in the annealed pinched tubing. Therefore, it was recommended that the machined bar stock be annealed prior to pinching. Photographic results of pinched sections are shown in Figure 85.

2. Upper NaK Manifold

a. Description

Because of the failure of a weld at the intersection of the NaK supply line to the upper manifold on the 10FS-1 system, a development effort was initiated to establish a weld joint design capable of exceeding a given cycle life when subjected to vibration testing. The weld failure occurred primarily as a result of contact with the structural members during shock and vibration testing of the system. The vibration testing performed on development units essentially duplicates this condition. The weld failure on 10FS-1 was repaired, and the system advanced to subsequent assembly work. Units of the new design are intended for installation on the 10FSM-4 and subsequent flight systems.

b. Technical Accomplishments and Status

(1) Design

Four configurations, as outlined in Figure 86, were subjected to the vibration testing. Variations in the heat treatment of configurations (c)

As-Machined Pinched-Tube Sharp
Bend Radius (50X - Etched
with FeCl_3)

Sharp Bend Radius of Pinched
Tube Subjected to Localized
Anneal (50X - Etched
with FeCl_3)

Figure 85. Results of Pinched NaK Tube Sections

and (d) were tested, but did not significantly affect results. Configuration (c) exhibited the best cycle life of all the variations tested. This joint configuration was incorporated into an upper manifold design which otherwise remained unchanged. The four configurations were as follows:

- a) Existing pull-out-to-nipple butt weld joint with weld metal blended to parent metal by filing. Weld size $\sim 1/8$ in.
- b) Same as (a) except four finger plates added to reinforce the joint.
- c) Fitted and shaped nipple with butt-fillet weld configuration.
- d) Existing pull-out-to-nipple butt weld joint. Weld size $\sim 1/16$ in.

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Figure 86. Four NaK Manifold Supply-Line Weld Configurations

(2) Procurement and Fabrication

A total of 12 units of the new design was released for procurement action, and purchase orders were placed for complete fabrication by the vendor who had previously supplied detail components which were then weld assembled by AI.

Upper manifolds for the 10FSM-4 and 10FS-3 systems and spare units were completed this quarter. Some delay in completion occurred because of a weld porosity problem of the TE nipple-to-manifold welds. This problem did not affect the NaK supply line-to-manifold welds and was essentially eliminated by changing from a consumable weld insert to a bare filler wire in making the weld. Incomplete cleaning of the weld inserts was subsequently determined to be the cause of the porosity.

c. Tests

Measurement of the maximum amplitude of tube displacement during shock and vibration testing of the 10FSM-1 system was taken from the data and was duplicated in the testing of weld joint specimens. The values used were 0.180 in. double-amplitude displacement at a lever arm ~ 12 in. from the weld joint and test frequency of nominally 30 to 35 cps. Figure 87 represents the test setup and the point of failure of the various specimens. This failure point was relatively consistent, regardless of the sample tested.

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Figure 87. NaK Manifold Supply-Line Weld Test Setup

The butt-fillet weld joint (Configuration c, Figure 86) attained an average cycle life of 7550 cycles for the six units tested. This number of cycles exceeds that attained in testing of the alternate configuration and represents a reasonable factor of safety beyond the minimum permissible life of 2000 cycles. The butt-fillet weld joint was, therefore, selected as the configuration to be used for the flight system manifolds.

3. Ejectable Heat Shield

a. Introduction

The ejectable heat shield consists of an aluminum honeycomb shell in the form of a truncated cone which covers the NPU radiators. The shield serves as a passive, thermal-control surface using solar radiation to prevent the NaK from freezing while in orbit prior to reactor startup. The heat shield is split lengthwise into halves so that it and all attached parts, including the destruct charge, can be ejected during reactor startup.

b. Technical Accomplishments and Status

The receptacle mounting bracket of the heat-shield breakaway connector was redesigned to permit mating of the connector after the shield is installed. The shields presently in fabrication for FS-3, FS-4, and FS-5 will include this change. The stop order placed on the shields during this period has caused a delay of ~2 weeks in delivery.

A potting compound (Stycast 2561 MM) is presently being tested for use on the receptacle of the shield. The heat shield connector is being requalified using this potting material to provide an increase in clearance on the mating surfaces of the connector.

The destruct system has been removed from all flight system drawings. No further testing or fitup is planned for the destruct system on the FSM-4 system. Partial shipment of the spare bracketry has been delivered during this period.

A study of the heat shield temperatures during orbit indicates that under adverse conditions local areas of the shield could reach 405°F, rather than the 318°F as anticipated. The shield has previously been tested to 350°F. Additional tests are planned to verify the integrity of the adhesive and emissivity coatings at 400°F.

A report has been written covering the results of the heat-shield ejection tests.

E. EXPANSION COMPENSATOR

An expansion compensator is provided in the NaK coolant system to (1) compensate for the 120 in.³ change in NaK volume caused by thermal expansion from ambient to operating temperature, (2) to maintain a void-free coolant system, (3) to regulate the system pressure at a minimum of 5 psia initially and a minimum of 4 psia after 1 yr, and (4) to ensure that neither NaK boiling nor cavitation occurs.

Two expansion compensators are provided in each SNAP 10A Power System to equalize weight distribution and increase reliability. The design volume expansion for each unit is 60 in.³.

1. Fabrication

During this reporting period nine new bellows, fabricated of AM-350 stainless steel and heat treated to SCT 850°F condition, were received. These bellows are of flight configuration. The designated use of the bellows assemblies is as follows: four for qualification tests, two for the FS-1 system, and three for the FSM-4 system. Quality of the expansion compensator bellows has greatly improved as a result of revised quality control procedures.

Of the nine bellows assemblies received, three were found to have the following pore defects:

<u>Bellows Serial No.</u>	<u>Number of Pores</u>	<u>Maximum Pore Size (in.)</u>	<u>Distance from Root of the Weld (in.)</u>	<u>Minimum Weld Bead (in.)</u>
102	1	0.005	0.005	0.040
103	3	0.005	0.010	0.032
110	1	0.004	0.008	0.035

The satisfactory test results of the two expansion compensators, which were installed in FSM-1 and operated for 90 consecutive days, and the results of fatigue-cycling tests performed on three bellows justified the approval of compensators with the minor, indicated deviations from the weld specification. The FSM-1 expansion-compensator bellows assemblies were known to have weld

thinning and porosity greater than exists in the nine recently fabricated units. Also, the three bellows bearing serial numbers 003, 004, and 3 were subjected to fatigue cycling tests. These bellows failed after 44,508, 17,810, and 33,940 cycles, respectively. Since only 10 thermal-mechanical cycles are required, a large margin of safety exists. A fatigue cycle consisted of deflecting the bellows from 0 to 1.46 in. expansion at room temperature.

A new order for eight additional bellows has been placed and is to be utilized for FS-3, FS-4, and FS-5 systems and for qualification testing.

The program to establish and qualify an alternate source for bellows assemblies has encountered difficulties. One order for 10 bellows assemblies, which were to be fabricated out of Inconel X, has been cancelled because the bellows assemblies were not to specification. An order from another vendor to manufacture 10 bellows assemblies has produced, to date, delivery of only one acceptable unit.

2. Test Program

a. Acceptance Testing

After inspection, several expansion compensator units were subjected to the full acceptance test sequence as follows:

- 1) Helium leak detection
- 2) Ambient temperature zero set and calibration of expansion compensator unit
- 3) Vibration test
- 4) Helium leak detection
- 5) Pressure test at high temperature and calibration of position indicator
- 6) Installation and calibration of ground test spring
- 7) Helium leak detection

Figures 88, 89, and 90 show bellows pressure vs bellows deflection, transducer output vs bellows deflection, and bellows pressure vs bellows deflection with the ground test spring unit installed, respectively, for expansion

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Figure 88. Pressure-Deflection Curves for Compensator SN 007

Figure 89. Acceptance Test Curves, Compensator SN 007, Transducer-Demodulator SN 1008

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Figure 90. Ambient Temperature-
Pressure-Deflection Curves for
Combined Expansion
Compensator-Ground Test
Spring Unit

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compensator 10FS-34001-007. The same curves plotted for expansion compensator 10FS-34001-008 are shown in Figures 91, 92, and 93. Both expansion compensators were found to be acceptable for system use and were delivered to Building 013.

b. Development

In the course of acceptance testing FS-1 expansion compensators, it was found that the limit switches actuated when the bellows extended to 1.116 in. The holes in the switch mounting brackets had to be enlarged to relocate the switches to actuate at 1.00 ± 0.050 in. bellows deflection as specified in the System Description. This was accomplished without reworking the switch levers.

During the thermal acceptance test on an FS-1 compensator, bellows assembly bearing SN 103, the coating on the center post cracked and flaked off. This unit was coated in the same manner as the FSM-1 compensators, using a method now considered obsolete, and did not require that the surface to be coated be grid blasted and ultrasonically cleaned prior to coating.

The newly established molydisulfide coating procedure for use on the center posts was developmentally tested on two stainless-steel rods. The coating passed tests, including 750°F vacuum operation and subsequent, high-g vibration testing, without exhibiting any damage to the coating. The coating method is being employed on FSM-4 and flight system compensators.

Figure 91. Calibration Curves for
Compensator SN 008 and
Transducer-Demodulator SN 1007

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Figure 92. Pressure Deflection
Curves for Compensator SN 008

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Figure 93. Ambient Temperature-
Pressure-Deflection Curves for
Combined Expansion
Compensator-Ground Test
Spring Unit

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Expansion compensator bellows, bearing SN 017, 018, and 019, were installed in NaK loops and subjected to endurance tests. The tests are still in progress. Figures 94, 95, and 96 show the operating pressure vs time. The operating pressure is the pressure to maintain the bellows expanded to 1.46 in. (60 in.³) at an operating temperature of 750°F.

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Figure 94. Operating
Pressure vs Time,
Bellows SN 017

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Figure 95. Operating Pressure vs Time, Bellows SN 018

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Figure 96. Operating Pressure vs Time, Bellows SN 019

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Figure 97. Operating Pressure vs Time, Bellows SN 007

NAA-SR-9593

Expansion compensator bellows, bearing SN 007, was installed in a furnace and operated for 1538 hr at 800°F. The internal and external environment was argon gas. The test was stopped after a temperature excursion to 1120°F caused by malfunction of the furnace temperature controller. The bellows was at a temperature between 850 and 1120°F for 9 hr and underwent rapid relaxation. The bellows was then removed from the furnace, it is being subjected to metallurgical examination. Figure 97 is a plot of operating pressure vs time for bellows SN 007. Table 11 summarizes the development test results as of March 15, 1964.

As was reported in the previous quarterly report, a new 5.078-in. mean-coil-diameter spring had been designed to assure an initial system pressure of 1.0 psi, initially, and 4.0 psi after 1 yr at operating conditions in the event of extreme bellows relaxation. The high relaxation rate was indicated when bellows assembly bearing SN 010 was tested in a NaK loop. However, these results were found to be erroneous because of a thermocouple error. The operating test temperature of the bellows was 950^{+0}_{-50} °F instead of 800°F. Since then, three bellows assemblies, bearing SN 017, 018, and 019, have been subjected to relaxation tests using NaK as the test fluid. The new test temperature was 750°F, as specified in the latest revision of the Systems Description. As can be seen from the pressure vs time curves (Figures 94, 95, and 96), the relaxation rate is very small for these three bellows, and it has been decided to omit the 5.078-in. spring and thereby avert a weight penalty.

c. Qualification

During this reporting period, four test loops have been completed for qualification testing of the expansion compensators.

F. GROUND TEST HEATERS

Ground test heaters are required to provide thermal power to the SNAP 10A units during nonnuclear system qualification tests and for acceptance testing of SNAP 10A flight systems. The nonnuclear system qualification heater is used in the FSM-1 and FSM-4 test systems in place of the nuclear reactor; this heater is designated the Reactor Simulator Heater (RSH). The nominal thermal requirements are 38 kw for steady-state operation, and 70 kw maximum for simulation of startup transients. This heater must also simulate the reactor mass and hydraulic characteristics.

TABLE 11

SUMMARY OF EXPANSION COMPENSATOR TEST RESULTS

Bellows Serial Number	Bellows Pressure Differential		Test Temperature (°F)	Internal Environ- ment	External Environ- ment	Accumulated Cycles 0↔60 in. ³ Displacement ~75°F↔Test Temperature (cycles)	Accumulated Test Hours at 60 in. ³ Deflection and Test Temperature (hr)
	Initial Preload (psid)	Present Preload (psid)					
018	5.0	4.6	750	NaK	Air at 10 ⁻³ Torr	66	304
017	9.80	9.20	750	NaK	Air at 10 ⁻³ Torr	12	936
019	4.85	4.60	750	NaK	Air at 10 ⁻³ Torr	12	968

Springs on units 018 and 019; drawing Number 10FS-34004, one 2.2-in. diameter coil spring
 Springs on unit 017; 10FSM1-34013, 10FSM1-34014, and 10FSM1-86008 (Ground Test Adapter)

Pressure contribution of the springs for units 018 and 019 = 1.8 psi

Pressure contribution of the springs for unit 017 = 6.75 psi

The heater used for acceptance testing of the SNAP 10A flight system units at design operating condition is designated the Ground Test Heater (GTH). The nominal thermal rating required is 40 kw. This heater consists of an even number of electrical heater units, half in each of the two reactor coolant return lines.

1. Technical Accomplishments and Status

a. Reactor Simulator Heater Fabrication

Two additional reactor simulator heaters have been fabricated, acceptance tested, and are ready for system use. One unit is to be installed in FSM-4; the second unit is a spare.

b. Radiant Ground Test Heater

(1) Design

Design of a 4-kw radiant half-heater unit with integral reflector was completed. One clamp-on unit is required on each NaK return leg to provide the full 40-kw thermal input to the NaK system. Spatial restrictions limit the number of full 8-kw tantalum-ribbon heater units to two per return leg. The half-heater section is interchangeable with one section of the full heater units; this heater differs only in that one heater section is opposed by a reflector unit, rather than a complementary heater section.

During fabrication of the prototype tantalum-ribbon radiant heater for flight system qualification (Figure 98), minor design modifications were required in structural details and in the number of shields to facilitate heater fabrication and to increase the thermal efficiency of the heater. The need for increasing the heater efficiency from 87 to ~93% is due to the fact that the expansion compensator dictates the limiting temperature of the system; previously, the allowable heat losses within the structure were limited by the permissible maximum temperature of the TE converter. The expansion compensator is made of AM-350 heat treated to the 850°F aging condition. Heating of the compensator to a temperature in excess of 800°F can cause rapid relaxation of the bellows assembly. Thermal analysis of the system indicates that this temperature will be exceeded if the heater efficiency is less than ~93%.

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Figure 98.
SNAP 10A Radiant Half-Heater

The following design changes were made to improve heater efficiency by decreasing radiation and conduction heat losses:

Variable	Previous Flight System Design	New Flight System Design	Net Effect
Number of shields	11	14	Decrease radiation heat loss
Number of top and bottom shields	10	15	Decrease radiation heat loss
Shield spacing	0.010 in.	0.020 in.	Decrease conduction heat loss

Two 0.002 and one 0.005-in. tantalum shields were added to the existing 11 shields. These shields are being spot-welded to the inside surface of the outer jacket and to the support walls of the inner shields. The conduction loss due to contact between adjacent shields was corrected by increasing the shield spacing, which minimizes shield-to-shield contact. Contact occurs during thermal expansion of the shields as a result of shield buckling.

Several drawing discrepancies also were uncovered during fabrication. In general, these discrepancies concerned the need for adjustments to

the fit-up between heater sections to close crevices to further reduce heat losses. Top and bottom shields did not seal the diagonal gap (see Figure 98) across the top and bottom of the heater. To accomplish this, five 0.005-in. shields were added to both the top and bottom of one half-section of the heater. These were designed to overlap and seal the diagonal gap.

(2) Fabrication

The following flight-system design radiant heater units are being fabricated for development, qualification, and system utilization:

Development Heaters = 2

Qualification Heaters = 3 full heaters
= 2 half-heaters

FS-3 = 4 full heaters
= 2 half-heaters
= 1 spare heater

Fabrication of one developmental heater has been completed and has satisfactorily passed endurance testing. Finished tantalum parts and beryllium parts are available for the second developmental heater, which is currently being assembled. Machining of beryllium parts for all remaining heaters is partially completed; all rough machining has been done. Forming of tantalum parts for the remaining heaters is underway.

Two NaK test loops are being fabricated to augment the existing loop being used for developmental testing of radiant heaters. The new loops, one of which has been completed, will be used for qualification and acceptance testing.

2. Tests

a. Reactor Simulator Heater

A test program is being performed to verify that the sheathed-lead heater cartridges being used in the SNAP 10A reactor simulator will operate satisfactorily at nonnuclear system test conditions.

Table 12 summarizes test data obtained with six heater cartridges of the same manufacture as elements installed in the FSM-1 and the FSM-4 reactor simulators. Data shown are as of March 19, 1964.

TABLE 12

FSM SHEATHED-LEAD HEATER CARTRIDGE ENDURANCE TEST

Heater Number	Total Operating Time (hr)	Voltage (rms)	NaK Temperature (°F)	Seal Temperature (°F)	Resistance-Megohms		Remarks
					Lead-to-Ground	Lead-to-Lead Sheath	
W-102	7800	165, 3 phase	1310	-	0.65	1.5	1037 hr at 167-165 v. 537 hr at 120 v. 6210 hr at 120 v and 1000°F
W-138	7800	165, 3 phase	1310	1123	0.15	0.45	
W-141	7800	165, 3 phase	1310	1143	0.90	1.5	
W-149	6570	120, 3 phase	1015	865	68	190	
W-153	6570	120, 3 phase	1015	860	68	190	
W-154	6570	120, 3 phase	1015	860	70	160	

Heater elements W-102, W-138, and W-141 were subjected to an increase in NaK temperature from 1000 to 1300°F after 6210 hr of operation, to provide heater operating data applicable to advanced SNAP 10A systems. All heater elements continue to operate satisfactorily, except for heater W-138. A progressive decrease in resistance-to-ground has occurred since the NaK temperature was elevated. One megohm is the minimum specified requirement. The NaK temperature will be restored to 1000°F.

The FSM-1 reactor simulator heater performed successfully during the entire system test, meeting all startup and endurance requirements. Table 13 summarizes the heater performance.

TABLE 13

FSM-1 REACTOR SIMULATOR HEATER PERFORMANCE

Power Level (kw)	Mean NaK Temperature (°F)	Total Operating Time (hr)
39 to 40	>900	2340
25 to 30	~500	150

The continued satisfactory operation of heater elements undergoing endurance testing and the successful operation of the FSM-1 heater demonstrate the reliability of the reactor simulator heater using sheathed-lead elements and also indicate that the FSM-4 heater should meet all operational requirements.

b. Ground Test Heater

A flight-system design, tantalum-ribbon radiant heater has been placed on qualification test. The specified endurance requirement is 100 hr at a pressure of 10^{-2} Torr and a nominal power of 8 kw. At present this heater has accumulated 286 hr of operation. Of this total, ~118 hr have been logged at a pressure of 10^{-2} Torr and a nominal power input of 7 to 8 kwe. The remaining time was logged at a pressure of $10^{-4}/10^{-5}$ Torr and a power input of ~8 kwe. The data are presented in Figure 99. Included are data showing resistance change as a function of time and system pressure.

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Figure 99. SNAP 10A Radiant Heater Performance

Performance mapping was conducted during heater operation at 10^{-2} Torr system pressure. This covered a range of NaK flowrates from 4 to 8 gpm and power input from 7 to 8 kwe. Heater efficiency averaged 92% over these ranges. An increase in ribbon element resistance, 0.97 to 1.82 ohm, also was noted during this period of operation. This increase amounted to an average of 0.7%/hr as compared to the 0.2% anticipated on the basis of previously reported radiant heater tests. At present, the heater is being operated

at $10^{-4}/10^{-5}$ Torr system pressure to effect cleaning of the tantalum ribbon elements. To date, this has lowered the ribbon element resistance to 1.17 from 1.82 ohm. The heater has experienced three thermal cycles. Additional thermal cycles also will be imposed upon the heater to meet the requirement of 10 cycles. Higher power operation also will be performed.

The insulation value of the beryllium insulators has been satisfactory and has been measured at ~ 3500 ohm. An exact measurement of this resistance to ground is difficult because of the rectifying effect of both tantalum and beryllium. This yields a leakage current across the insulators of 35 ma. The resistance measurement with reversed polarity is $\sim 100,000$ ohm. Test data for this heater is presented in Table 14.

TABLE 14

TANTALUM-RIBBON RADIANT-HEATER QUALIFICATION DATA

Total operating time (hr)	~ 2	118	286
Ribbon temperature ($^{\circ}\text{F}$)	3120	3080	3040
NaK inlet temperature ($^{\circ}\text{F}$)	999	958	981
NaK outlet temperature ($^{\circ}\text{F}$)	1051	1008	1021
Outer shield temperature ($^{\circ}\text{F}$)		850	850
Chamber pressure (Torr)	$\sim 5 \times 10^{-4}$	1.1×10^{-2}	1×10^{-4}
NaK flow (gpm)	6.05	6.05	8.0
Element voltage (rms)	87	118	95
Element current (amp)	90	65	81
Power input (kwe)	7.85	7.65	7.75
Thermal transfer (kwt)	7.21	7.05	7.36
Heater efficiency (%)	92	92	95
Heater resistance (ohm)	0.97	1.82	1.17

Operation of the heater at a system pressure of 10^{-2} Torr was begun after ~ 2 hr at a system pressure of $\sim 5 \times 10^{-4}$ Torr to complete outgassing of the unit.

To improve heater efficiency to the 93% required level, a gold-coated dual-layer insulation blanket is being designed. This blanket will be applied to the unit externally; it will be tested during the qualification test of the second developmental heater unit.

G. NaK LOADING CART

1. Introduction

The NaK loading cart was designed and fabricated for the purpose of loading the NPU with clean NaK coolant and to provide the capability of hot flush and circulation of the NaK coolant at elevated temperatures through the NPU, NaK loading cart, and the connecting piping. NaK oxides, hydrides, and other contaminants are removed from the NaK coolant by filtration and cold-trapping within the cart. Removal of these contaminants is required to prevent formation of deposits on the internal surfaces of the piping and component parts. These deposits can result in a reduction in NaK coolant flow, reduction in heat transfer, and accelerated system corrosion. The NaK cart and its instrument cart have the capabilities of monitoring the oxide content, NaK flowrate, system pressure, and temperature during operation. The NaK loading cart is illustrated in Figure 100 and shown schematically in Figure 101.

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Figure 100. NaK Loading Cart

2. Technical Accomplishments

Following the cleanup and loading of FSM-1, the NaK loading cart was modified to incorporate a pressure control system with the capability of automatically maintaining a preset pressure during NaK heatup and subsequent

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Figure 101. NaK Loading Cart Flow Schematic

system loading. The change required the addition of a pressure sensor attached to the vacuum manifold, a solenoid valve controlled by a sensor and placed in the vacuum supply line, a needle valve placed adjacent to the solenoid valve to adjust response time, a bypass line, and two shutoff valves. Concurrent with these modifications of the NaK loading cart, several additional product improvement changes were made. These changes are as follows:

- a) A new, higher-capacity cold trap was added to increase the rate of oxide removal from the NaK charge.
- b) A second 1-ton refrigeration unit was added to the NaK loading cart to maintain temperature control of the higher-capacity cold trap, independent of the plugging meter operation.
- c) A back-pressure regulator was placed in the common refrigeration suction line of the three plugging meters to provide an adjustable temperature control system. The control will enable the operator to determine the change in plugging temperature associated with the progress of the NaK cleanup.
- d) The high inlet standpipe located in the fill tank was removed to prevent the hot inlet NaK from absorbing the argon cover gas. This gas entrainment resulted in cavitation of the pump and loss of NaK flow.
- e) The expansion valves and associated power bulbs of the plugging meter's refrigeration system were relocated to prevent damage during hot flushing of the plugging meters following a plugging check.
- f) A 0 to 50°F readout range was provided on the plugging-meter temperature recorder in place of the factory-furnished 0 to 500°F range to permit a more accurate readout of the plugging temperature.
- g) The gas and NaK systems are separated in several places within the NaK loading cart by means of stainless-steel, bellows-sealed shutoff valves. Isolation valve (V105) exhibited slight leakage and was removed from the system. The line on the gas side of the valve was cut and capped. A backup shutoff valve (V124) was added

in series with valves V102 and V119 to provide better isolation of this circuit.

- h) The solid-conductor interconnecting cable used between the instrument cart and the NaK cart was replaced by a stranded-conductor cable to provide a more trouble-free electrical system. Extension sleeves were added to the connectors to carry the cable bending load well away from the pins.
- i) A larger vacuum manifold was designed and installed in the system to provide a more stable vacuum system.
- j) The vacuum pump was relocated so that the oil level could be monitored and the unit serviced without requiring removal of the unit from the cart. An oil trap was designed, fabricated, and installed in the suction side of the pump to prevent vacuum pump oil from back-filling into the lines of the gas system in the event of a power failure.

Following the above modifications, the cart was serviced for the next system loading use by replacing the NaK filter, inspecting and cleaning all gas lines, and inspecting and replacing all leaking valves or valve seats.

VII. SUPPORTING OPERATIONS

A. ACCEPTANCE TESTING

1. Facility Activation

The facility was prepared for FS-1 Acceptance Testing. Facility systems have been tested and the operations crews have had a refresher training course. The facility instrumentation calibration was initiated and is near completion.

The revised Operations Manual has been prepared in draft form and is ready for Safeguards Committee review.

To ensure facility readiness, several tests were run to document the condition of the vacuum and supporting systems. The vacuum chamber was tested for in-leakage and out-leakage. The in-leakage test is conducted with the vacuum chamber at 10^{-2} mm Hg pressure or less. The chamber is pumped down until the in-leakage plus outgassing nearly equals the vacuum pumping capacity, as indicated by a steady vacuum being maintained while the chamber is continuously being evacuated. At this time, the vacuum isolation valves are closed and the pressure is allowed to rise. A total of outgassing plus in-leakage of 0.35 std cc/sec is allowable. A leak rate of 0.227 std cc/sec was measured. No attempt is made to separate in-leakage from outgassing.

The out-leakage test is conducted with the vacuum chamber at 26 psig and the vacuum isolation valves closed. An allowable leak rate of 2.7 psig in 8 hr is allowable. A leak rate of less than 0.6 psig per 8 hr was measured. The vacuum pumping system was He leak-checked with a sensitivity of 10^{-5} std cc/sec. All detectable leaks were repaired. The vacuum-chamber cooling water flow was measured under several typical valving configurations to determine reference flowrates for future operations.

The facility instrumentation calibration was started. Problems with the data-logger digital voltmeter have suspended these operations temporarily.

The nuclear channels will be operationally checked with the FS-1 power system prior to fuel loading and compared with discriminator curves run last summer.

The ground-test drum drive kits for use on FS-1 were received this quarter. The Compact Reactor Safety Panel has reviewed the acceptance and

qualification test data for these kits and has approved their use for SNAP 10A Acceptance Test operations. These data have been transmitted to the Atomic Energy Commission. At this time, authorization to load fuel and to perform subsequent low-power physics tests on SNAP 10A Ground Nuclear Qualification and Flight Systems is pending AEC approval.

VIII. FLIGHT TEST

A. GSE AND HANDLING OPERATIONS

Flight system launch support begins with a definition of the shipping, handling, testing, and operating activities to be performed. After these activities are established, the equipment required to accomplish these actions is developed and fabricated. This ground support equipment falls into two classifications: Electrical and Mechanical Aerospace Ground Equipment (AGE). Progress on each is as follows:

1. Electrical Aerospace Ground Equipment

a. System Test Sets, Models TSM-1 and TSM-2

Engineering design effort on model TSM-1 was temporarily phased out at a logical stopping point. Fabrication of TSM-2 to be used in checkout of the flight systems in the Acceptance Test Facility has progressed to the point where all the components are mounted in the racks and the interconnecting wiring is essentially completed. Initial checkout of this unit revealed design problems that are being resolved by further development work.

b. Payload Monitor and Control Console

Technical requirements for the payload console have been agreed upon, but no hardware changes to existing payload console panels have been started. Work on these panel modifications will not begin until several months prior to the launch date.

c. Shipping Monitoring Equipment, SME-1

Design effort on this equipment was temporarily halted.

2. Mechanical Aerospace Ground Equipment

a. AGE Item 17a, Reflector Installation Fixture

A procedures drawing that shows the methods to be used in installing and using the reflector installation fixture with the SNAP 10A Unit was completed and released.

b. AGE Item 30a, Tilt Sling

Drawings showing details of the counterbalance structure for the tilt sling have been released. The counterbalance structure was added to the tilt sling to better position the sling over the load.

c. Reflector Scram Mechanism

An air-operated reflector scram mechanism was developed and tested at system operating temperature. Design changes suggested as a result of the test were not made. Further developmental work will await the testing results of the ground test kits for which the scram mechanism is a backup.

d. AGE Item 33a, Center-of-Gravity Locating Equipment

The first of these units was assembled. Checkout of the unit was not completed. This and the other AGE items have been placed in temporary storage.

3. Handling Operations

Checkout of the AGE, by using this equipment in moving test systems, continued at the Santa Susana Field Laboratories. These system moves continued to provide training for personnel who will use this equipment at the launch site.

B. LAUNCH OPERATIONS

The objective of Flight Test Group is to safely transport the SNAP 10A Unit to Vandenberg Air Force Base, integrate the subassemblies into the flight configuration, test subsystems and the total SNAP 10A Unit for flight readiness, transport the SNAP 10A Unit to the launch complex, perform coordinated testing with launch vehicles and launch complex systems, and monitor and control the SNAP 10A Unit during launch countdown. In meeting this objective, it will be necessary to establish shipping procedures, equipment and operating manuals, and safeguards reports covering this activity and to obtain the required approvals from the reviewing agencies. These documents also will include emergency procedures covering all credible eventualities.

The current status of the documentation and other activities required in preparation for meeting this objective is discussed below.

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1. SNAP Prelaunch Test Facility (SPTF) Activation

Planning for the activation of this facility for preflight operations is continuing. This includes establishing the requirements for furniture, machine tools, hand tools, storage space for spare parts, and other necessary equipment.

2. Reports, Procedures, and Specifications

a. Prelaunch Test Facility Safeguards Report

The Prelaunch Test Facility Safeguards Report was approved, printed, and distributed. Copies were sent to the AEC for their review and approval.

b. SNAP Prelaunch Test Facility Operations Manual

Further revision to this manual has ceased. A major portion of this manual covers test operations using the test sets. More meaningful progress in writing of this manual will be made after observing the actual usage of the test set in conjunction with tests on Test System FSEM-2A.

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