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OCTOBER 1963 - JANUARY 1964
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AEC Research and Development Report

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M-3679 (33rd Ed.)

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SNAP 10A REACTOR PROGRESS REPORT

OCTOBER 1963 - JANUARY 1964

(Title Unclassified)

By

R. J. GIMERA
R. A. JOHNSON

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Frontispiece. SNAP 10A Reactor and Shield

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I. PROJECT OBJECTIVES

The overall objective of the SNAP 10A reactor project is to provide a reliable nuclear heat source for the SNAP 10A power system. Components must be developed and integrated into a system that can survive the launch environment imposed by an Atlas-Agena boost vehicle and subsequently operate successfully in the space environment. The design conditions which must be met are given in Section III.

All components must be subjected to a qualification testing program to demonstrate their capability to satisfy operational requirements, and the integrated reactor assembly must be subjected to a similar program. Complete SNAP 10A systems will also be tested. Reactor assemblies must be fabricated for these systems and the tests themselves must be followed and evaluated.

Project redirection late in the quarter was to cancel the flight test program. The immediate impact was to eliminate assembly of the FS-5 system, decrease the number of flight space parts, and curtail the remaining component qualification programs. Assembly of a system for nuclear ground test (S10-FS-1), one for nonnuclear ground test (S10-FSM-4), and two potential ground or flight tests (S10-FS-3 and 4) – was to be continued.

During this quarter, the ground test kit program to provide qualified drive mechanisms for ground tests was to be completed. The reactor-reflector assemblies for S10-FSM-4, FS-3, and FS-4 were to be completed and acceptance tested. A new system, S10-FSEM-2A, which will be used for system electrical engineering tests, was to be designed and parts were to be fabricated and ready for assembly.

All fuel elements for the complete SNAP 10A program were to be completed and ready for loading into complete systems.

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II. SUMMARY

A. GROUND TEST KITS

The ground test kits are used to provide reversible drum drive as well as scram capability for each of the four SNAP 10A reflector drums during fuel loading, NaK loading, and low power physics tests. Precision position sensors are provided within the kit for drum position feedback.

During early testing of the ground test kit, a number of failures occurred. Failures included inability to drive due to excessive friction, inability to scram due to failure of the clutch to release, and electrical shorting in the actuator. Many modifications were made to the kit during the quarter which appear to have raised the reliability of the kit to the required level. Special dry film lubricants were applied to all bearing surfaces, and over-constraint of shafts was eliminated by removing the outrigger bearing on the drive shaft and adding flexible couplings between pairs of bearings on the main kit shaft. The kit was simplified when it was found that the snubber ratchet pawls and their associated solenoids and limit switches were unnecessary and could be removed. The electromagnetic clutch armature was changed from a splined joint to a bellows flexure to assure clutch disengagement. The actuator electrical winding procedure was modified to improve insulation.

With these changes and numerous other minor changes, the testing program was reinitiated with very satisfactory results. Five ground test kits have successfully passed the acceptance test which now includes an operational test in the prescribed thermal-vacuum environment. One of the five kits successfully passed the full qualification test which represents 15 times the operational life expected for any kit.

Due to the problems encountered with the ground test kit, and especially those concerning the drive capability of the kit, it was decided that a modified flight drive system should be designed to operate the coarse control drums during the FS-1 nuclear ground test. Because of the considerable test data already available on the flight drive system, there was little question that it was a reliable mechanism. Since the primary method of shutdown on this ground test is outward driving of the control drums, it was of the utmost importance that the drive system reliability be very high. The use of this assembly eliminated

the ground test kit requirements for long-term endurance and radiation resistance and, since the ground test kits would no longer be used without scram capability, it reduced the safety consequences involved with a drive system failure.

This new coarse drum drive assembly was completely designed and all components are near completion of fabrication. A testing program was established for accepting and qualifying these assemblies, and the test setup, which involves use of the DRM reactor assembly, was prepared.

B. ENGINEERING

Shipping sleeve drop tests were performed which successfully demonstrated that the sleeve can maintain its integrity and prevent reactor criticality after the worst expected accident.

New analyses of reactor startup behavior were made for a number of different conditions which should bracket all anticipated situations in flight. A refined analysis on temperature drift during passive control was also performed as well as a study to determine the maximum power limitations on the reactor.

Grid plate materials were analyzed and a change was made from Hastelloy-C to Type 316 stainless steel to increase the negative temperature coefficient of the reactor.

Nuclear calibration and destructive tests of fuel elements were performed which provided reasonable correlation between the various methods of samarium content determination. A problem still exists in correlating calculated and experimental worths of the samarium at the periphery of the reactor core.

C. COMPONENT DEVELOPMENT

Most of the component development tests were continuations of long-term endurance tests. The components on these tests included control drum actuators, bearings, gears, and a position sensor demodulator. The test of the gears in an ultra-high vacuum was completed. The long-term tests on bearings included some in a poor vacuum to simulate ground test conditions.

The controller malfunctions which have been encountered on system tests were investigated and the magnitude of electromagnetic interferences to cause malfunctions was determined.

Five samples of different types of wiring were incorporated into high flux capsule No. 6 at BMI. This test was initiated due to the poor showing of the wire used in the reflector wiring harness in a previous radiation test. It is expected that testing of these samples under the thermal-vacuum-radiation environment will provide information for selection of wire to be used on flight systems.

D. QUALIFICATION

Significant progress was made during the quarter on the reactor component qualification program. Two actuator motors and two position sensors successfully completed their 90-day radiation environmental test in high flux capsule No. 5 at BMI. Two actuator motors successfully finished their qualification test series by completing 90 days of vacuum endurance at temperature while another two completed RFI tests and started their thermal vacuum endurance tests. Both position sensor demodulators and electronic temperature switches were received for testing. Two units of each component completed radiation qualification at the AI-STF. The temperature switches also completed their RFI qualification program. Limit switches and the wiring harness test units were delivered to BMI, and the high flux capsule No. 6 radiation test was started.

Four limit switches completed their qualification tests by finishing 90 days of thermal vacuum endurance. This leaves one switch still on endurance test. Both thermal cycle and shock and vibration test phases were completed on three sets of bearings during the quarter. These units are now in high-vacuum thermal endurance.

All 66 elements in the SNAP 10A fuel element qualification program successfully completed the scheduled test inputs which simulate prelaunch, launch, and startup environments and have accrued at least 90 days of thermal endurance testing. Nine of these elements have completed the full 1-year endurance program. Examination of the nine elements showed no significant change in cladding or fuel rod dimensions and no damage to the Solaramic hydrogen barrier. The decrease in fuel rod weight averaged 0.05 gm per fuel rod, which is equivalent to 1/5 of 1% of the original hydrogen.

E. FABRICATION

Several problems were encountered during the quarter which delayed the reactor assembly schedule. A failure of one motor brake during qualification was cause for recall of all motors from the field for reinspection and reacceptance testing. All limit switch mountings were reviewed and changes were incorporated to eliminate the limit switch malfunctions which have continued to occur on all systems.

Because of the radiation effect on wiring used on the reflector wiring harnesses, fabrication of replacement harnesses was initiated for all systems. Assuming the results from BMI capsule No. 6 will be satisfactory, a type of wire used elsewhere in the SNAP 10A system is being used for these harnesses.

Virtually all component acceptance testing was completed, including calibration of all of the platinum resistance temperature sensors in a NaK test loop.

All parts for the FSEM-2A operational reactor mockup were completed, and assembly was to start in early February.

Assembly of fuel elements for FS-3, -4, and -5 was completed. All of these elements have been acceptance tested and calibrated in a critical assembly.

The S10-FSM-4 reactor assembly was subjected to a repeat vibration acceptance test, and thermal-vacuum acceptance testing of the S10-FS-3 reactor assembly was completed. Due to the component problems, however, neither of the reflectors for these assemblies was delivered for integration into the complete system.

III. DESIGN DESCRIPTION

The SNAP 10A reactor consists of a core containing hydrided zirconium fuel elements enriched with U^{235} (Figure 1). The fuel elements are hydrided to an N_H of 6.35 (6.35×10^{22} at/cc) which is slightly less than the hydrogen concentration in cold water. The fuel elements are positioned and restrained in the core by upper and lower gridplates. The gridplates are supported by a fixed ring at the bottom and hold-down springs at the top. Beryllium side reflectors are used in the void space between the close-packed hexagonal fuel element array and the circular reactor vessel. The top reactor vessel head acts both as a vessel closure and restraining structure for the core hold-down springs.

The reactor vessel is surrounded by a beryllium structure which functions as the reflector (Figure 2). Four control drums which form a part of the reflector assembly provide both the fine and coarse control required for reactor operation. A lithium hydride (LiH) shield is positioned directly below the reactor vessel and is contained in a stainless-steel casing. In the SNAP 10A shield, a flexible mount is provided to support the LiH within the casing allowing for pre-launch thermal cycling of the system. Actuating devices, such as electrical motors and springs, and instrumentation, such as sensors and switches, are attached directly to the reflector assembly. Controlling elements, such as timers, the reactor controller, and demodulators for the control drum position sensors, are located in the SNAP 10A instrumentation compartment. A summary of important design parameters is given in Table I.

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Figure 1. SNAP 10A Reactor Core

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Figure 2. SNAP 10A Beryllium Reflector

TABLE 1
SNAP 10A REACTOR DESIGN SUMMARY

Operating Conditions		Total lifetime reactivity loss (\$)	-2.99
Reactor thermal power (kw) - nominal	34	Xenon equilibrium	-0.14
Net electrical power (watt) - nominal	500	Samarium burnout	+0.15
Operating life	1 yr	Temperature and power defect	-2.76
NaK outlet temperature (°F)	1010	Hydrogen loss	-0.05
NaK inlet temperature (°F)	900	Hydrogen redistribution	-0.13
NaK operating pressure (psia)	10	Burnup and fission product poisons	-0.06
Maximum fuel temperature (°F)	1085	Contingency	+0.31
Maximum cladding temperature (°F)	1050	Total control drum worth (\$) (r)	9.20
		Total shim capability (\$)	1.26
Reactor Design		Shield Parameters	
Fuel elements		Material	L ₁ H
Number	37	Dimensions	
Fuel alloy (wt% U in Zr)	10	Maximum diameter (in.)	21.08
Degree of hydriding NH (10 ²² atom/cm ³)	6.35	Minimum diameter (in.)	17.56
Cladding material	Hastelloy-N	Height (in.)	27.47
Fuel diameter (in.)	1.212	Shield Casing	
Cladding diameter (OD, in.)	1.25	Material	316 SS
Cladding thickness (in.)	0.015	Thickness (in.)	0.032
Active fuel length (in.)	12.25		
Internal reflectors		Integrated radiation doses below shield for 1 yr of full power operation (fast neutrons and gammas)	
Material	Be		
Cladding	None	Mating plane (NPU-Booster)	
Inlet plenum grid plate (lower)		Center of plane r = 0	1.5 x 10 ¹² nvt 6.2 x 10 ⁶ r
Material	316 SS		
Thickness (in.)	1/2 (sandwich construction)	Inner edge of instrumentation compartment (max)(r = 13-3/4 in.)	4.5 x 10 ¹² nvt 8.5 x 10 ⁶ r
Outlet plenum grid plate (upper)		Outer edge of instrumentation compartment (max)(r = 24-1/2 in.)	2.0 x 10 ¹⁴ nvt 9.2 x 10 ⁶ r
Material	316 SS	Reference plane (17-1/2 ft below core)	4.5 x 10 ¹¹ nvt
Thickness (in.)	1/8	Center of plane r = 0	1.5 x 10 ⁶ r
Core vessel		Outer edge of plane (max)(r = 30 in.)	1.9 x 10 ¹³ nvt 2.0 x 10 ⁶ r
Material	316 SS		
Internal diameter (in.)	8.875	Weight Summary	
Length (in.)	15.6	Reactor, core and vessel assembly (lb)	168
Wall thickness (in.)	0.032	Reflector-control assembly (lb)	106
Reflector Control Drums		Shield assembly (lb)	217
Number	4	Electronic equipment (lb)	8
Material	Be	Total nuclear system (lb)	499
Nominal thickness (in.)	2		
Nuclear Parameters			
Average core thermal flux (n/cm ² -sec)	1.9 x 10 ¹¹		
Mean fission energy (ev)	0.18		
Average isothermal temperature coefficient (°/°F)	-0.298		
Uranium loading (kg U ²³⁵)	4.75		
Effective delayed neutron fraction	0.008		
Mean prompt neutron lifetime (μ-sec)	6.5		
Burnable poison			
Material	Sm ₂ O ₃		
Prepoison reactivity worth (\$)	-1.60		
Initial cold excess reactivity (\$)	3.30		

One dollar = 0.008Δk/k

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IV. ENGINEERING

New analyses of reactor startup behavior were made, and shield and fuel element temperature calculations were refined. The reactor startup analyses were repeated for a number of different conditions which should bracket all anticipated situations in flight.

Engineering tests were performed on two components. Drop tests on the reactor shipping sleeves were completed successfully showing that the sleeve can maintain its integrity and prevent reactor criticality after the worst accident anticipated. Tests on the temperature actuated band release device (TABRD) were pursued to the point where the device could be set consistently on a simulated NaK line. Some problem still exists with the device in that actuation did not always occur with a temperature drop of less than 200°F. It is intended to work out this problem on the test fixture and then curtail all further work on the TABRD.

A refined analysis of SNAP 10A temperature drift during passive control was performed as well as a study to determine the maximum power limitations on the reactor.

Grid plate materials were analyzed and a change from Hastelloy-C to Type 316 stainless steel was made. 316 stainless steel will increase the negative temperature coefficient and minimize temperature drift during static control.

A. REACTOR STRUCTURE ENGINEERING

1. Objectives

The objective of this project is to ensure satisfactory structural performance of the SNAP 10A reactor under ground handling, ground testing, launch, and operational loads. To achieve this objective, the project performs design analyses and static, vibration, and creep tests of the basic reactor structure.

2. Progress

An ultimate load test was performed on the reactor vibration test assembly. Failure occurred at 13 g in the lateral direction in the "knee" of one of the in-plane support legs. During previously run static tests, the same type

of failure was observed at 21 g. Because the vibration test assembly had been subjected to a great number of cycles prior to destruction, a difference of this sort could be expected.

The planned drop test series on the reactor shipping sleeve was completed. The shipping sleeve was mounted on a dummy reactor and dropped along each of three critical axes from 15 ft onto concrete. During all tests the shipping sleeve remained attached to the dummy reactor. Post test inspection indicated all of the void compartments remained essentially intact and watertight. An additional test has been proposed to determine the effect of the NaK pump and converter structure on shipping sleeve performance. The test assembly has been modified for this purpose and the test will be conducted early next quarter.

B. REFLECTOR ENGINEERING

1. Objectives

During the past quarter, the primary objective of the SNAP 10A reflector engineering project has been the evaluation of component subassembly and complete system test data. Based on accumulated data, design changes have been recommended.

2. Progress

Several difficulties were encountered in testing the Temperature Actuated Band Release Device (TABRD) during the last quarter. The two main problem areas were: (a) sensing when the TABRD had armed without influencing the arming temperature, and (b) calibrating the TABRD so that the arming temperature is repeatable both with the deactivating spring installed and with the TABRD activated.

The initial switch installed on the TABRD sensed when the snap ring closed and armed the TABRD, but it drew enough heat away from the inner rod to lower the arming temperature about 75°F. A series of switches was tested before one was developed which was small enough not to influence the arming temperature and still rugged enough to reliably indicate that the snap ring had closed.

In the TABRD tests run with the deactivating spring installed, the set point (NaK line temperature of $925 \pm 25^\circ\text{F}$) was repeatable. However, when the

TABRD was activated and tested with the same setting, the arming temperature was over 1000°F. By precompression of the TABRD before calibration and installation of a stiffer deactivating spring, the increase in arming temperature was held to an acceptable value of 25°F.

In the first three tests of an activated TABRD, the notched stud broke when the inner rod temperature dropped 165 to 180°F. This drop compares favorably with the allowable temperature drop of 200°F. In the latest test, the inner rod temperature dropped 310°F before the notched stud broke. When this problem is resolved, the TABRD will be operational.

The rotor shaft on the position sensor froze up during qualification vibration test. When the position sensor was disassembled there was evidence of bearing damage. The loads transmitted to the bearings when the rotor shaft impacts the housing were analyzed by assuming that the kinetic energy of the shaft is absorbed in strain energy of the bearing material. The resulting maximum bearing stress on the projected area is on the order of 5000 psi, which is less than the allowable compressive stress of the material. The position sensor assembly will be inspected to determine if there are any high spots which could have caused localized stress concentrations.

C. SHIELD ENGINEERING

1. Objectives

The objective of this project is to ensure satisfactory structural and thermal performance of the SNAP 10A shield during ground handling, ground testing, launch, and orbital operation. To achieve this objective, the project performs structural and thermal analysis and static, vibration, and thermal tests of the SNAP 10A shield.

2. Progress

A new shield heat transfer code, TAP-3B, has been written. The number of nodes has been increased from 29 to 90 and expressions have been added for both thermal conductivity and heat capacity as functions of temperature.

Using the new code, refined temperatures have been obtained for both thermal test and flight system shields.

TABLE 2

CONDITIONS OF MAXIMUM SEVERITY ENCOUNTERED DURING FIRST TRANSIENT PULSE

	1	2	3	4	5	6	7	8	9
	Nominal Startup	Additional Drum Step	Rapid Drum Step	Rapid Drum Step	Slow Drum, Low Source	Slow Drum, High Source	Zero Initial Flow	Low (1/2 Nominal)	Low UA (1/2 Nominal)
Drum stepping period (sec)	150	150	50	100	300	300	150	150	150
Source strength (kw)	10^{-11}	10^{-11}	10^{-11}	10^{-11}	10^{-11}	10^{-8}	10^{-11}	10^{-11}	10^{-11}
Time to sensible heat (hr)	6.15	6.15	2.12	4.15	12.14	12.05	6.15	6.15	6.15
Excess Reactivity (β)	23.6	26.5	38.0	29.7	17.4	14.3	23.6	23.6	23.6
Peak power (kw)	40.3	56.2	127	63.5	21.1	14.4	43.8	64.2	49.1
Maximum fuel tem- perature ($^{\circ}\text{F}^*$)	475	600	778	586	356	256	632	615	717
Maximum outlet tem- perature ($^{\circ}\text{F}$)	366	420	550	435	286	246	466	450	635
Maximum rate of change of outlet temperature ($^{\circ}\text{F}/\text{sec}$)	6.3	9.2	16.8	9.5	3.3	1.9	10.4	10.6	8.9
Maximum flow rate (lb/min)	43.3	50.3	68.0	52.5	32.2	26.6	49.4	55.0	46.5
Maximum fuel stress (ksi)	1.09	1.55	2.64	1.34	-	-	1.75	1.74	-
Maximum clad stress (ksi)	15.5	19.7	33.3	21.7	-	-	27.9	22.2	25.0
Minimum barrier com- pressive stress (ksi)	-19.7	-18.3	-13.8	-17.7	-	-	-15.5	-17.5	-16.8
Minimum axial clear- ance (mil)	0.8	0.6	-1.0	0.6	-	-	0.6	0.6	0.48
			(Interference)						

*Hot channel (power generation rate 31% greater than core average).

D. THERMAL AND HYDRAULIC ENGINEERING

1. Objectives

The objective of this project is to conduct heat transfer and fluid flow analyses and tests to assure that the reactor core will withstand the thermal shock of orbital startup and is adequately cooled throughout the design life. Reentry analysis is performed to evaluate the behavior of the reactor during the orbital decay phase.

2. Progress

a. Startup Transients

The thermal performance of the SNAP 10A fuel elements during design orbital startup conditions were presented previously.* This study has been expanded to determine performance for several off-design conditions and for FS-1 ground test initial startup.

Table 2 shows the conditions of maximum severity obtained in the analysis of the first transient pulse in each of the following nine cases:

Case 1: Nominal design startup, \$0.236 excess reactivity

Case 2: One more control drum step than Case 1, producing 3¢ more reactivity

Case 3: Drum stepping rate at three times the nominal design rate

Case 4: Drum stepping rate 50% greater than nominal design rate

Case 5: Drum stepping rate at one-half of nominal design rate

Case 6: Drum stepping rate at one-half of design rate, source strength 1000 times the nominal case value

Case 7: Coolant flow is zero at start of transient; this situation could arise from failure of chemical batteries to supply pumping power before and during startup. The flow transient is initiated by conduction of heat through the coolant from the reactor to the pump throat

*NAA-SR-8994, SNAP 10A Reactor Quarterly Progress Report, July-September 1963

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Figure 4. FS-1 Startup, Effect of Source Strength on Outlet Transient

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Figure 3. FS-1 Startup, Effect of Source Strength on Power Transient

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Figure 5. FS-1 Startup, Effect of Source Strength on Flowrate Transient

Case 8: The value of the fuel temperature coefficient of reactivity is assumed to be one-half of the nominal

Case 9: The overall thermal conductance between fuel and coolant is assumed to be one-half of the nominal value.

The most important factor governing the startup transients is the amount of reactivity inserted in the reactor in the interval between the attainment of criticality and the generation of sensible heat. The effects of changes in control drum stepping rate and source strength are caused by changes in the excess reactivity at sensible heat.

The first preliminary startup test of the SNAP 10A FS-1 reactor is expected to be made with a fine control drum stepping period of 300 sec/step, which is twice the design stepping period. An analysis of the startup transient for this first test has been made for two reasons: (1) to define the conditions to be expected during this test, and (2) to furnish a check on the analytical technique employed to predict reactor startup transient behavior. Figures 3, 4, and 5 show the predicted power, outlet temperature, and flow transients with source strength as a parameter. The equivalent multiplied strength of the one-curie source to be used in the FS-1 startup has been estimated as 10^{-9} kw. The minimum possible source strength is approximately 10^{-11} kw. This arises from spontaneous fissions in the core and from (γ, n) reactions in the beryllium resulting from the decay of fission products produced in low-power tests of the reactor.

b. Steady-State Fuel Element Temperatures

The expected axial temperature distributions of SNAP 10A fuel elements under design operating conditions have been calculated. Figures 6 and 7 show the temperatures of elements in each of the six radial positions in the core; Figure 8 shows the temperatures for an average element. The temperatures shown are nominal values and do not include hot-channel effects, except that the flow distribution was assumed uniform, thus ascribing zero effectiveness to the inlet orifices. This assumption is conservative in that it results in higher temperatures for the high-powered elements than would be obtained with effective orifices. The surface temperatures shown in the figures are circumferential averages; the heat transfer coefficient used in the calculations is an average

Six Elements
R = 1.26 in.
(Relative Power = 1.25)

→

Six Elements
R = 2.18 in.
(Relative Power = 1.13)

←

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Figure 6. Temperatures of Fuel Elements in Central Position
and in Radial Positions of 2.18 and 1.26 Inches

Six Elements
 $R = 2.54$ in.
 (Relative Power = 1.07)

Six Elements
 $R = 3.78$ in.
 (Relative Power = 0.79)

Twelve Elements
 $R = 3.33$ in.
 (Relative Power = 0.90)

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Figure 7. Temperatures of Fuel Elements in Radial Positions of 2.54, 3.33, and 3.78 Inches

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Figure 8. Fuel Element Temperature
for an Average Element

circumferential value, including the effect of the cusp-shaped flow channels. Table 3 lists the design conditions applying to the figures.

E. NUCLEAR ANALYSIS

1. Objectives

The objectives of SNAP 10A nuclear analysis are to: (a) provide detailed reactivity information for the current reactor design, (b) provide reactivity predictions for future systems, and (c) perform nuclear hazards analyses for all phases of system handling and operation.

TABLE 3

SNAP 10A REACTOR DESIGN OPERATING CONDITIONS

Core thermal power	34.7 kw
Inlet temperature	899°F
Reactor coolant flow	4920 lb/hr
Average heat transfer coefficient	817 Btu/hr-ft ² -F
Axial local-to-average power ratio	1.47 cos (1.479 - 0.2413 Z) 0 ≤ Z ≤ 12.25 in.
Radial local-to-average power ratio	1.31 cos (0.244 r) 0 ≤ r ≤ 4.03 in.

2. Progress

Nuclear analysis of SNAP 10A temperature drift during the passive control period was completed using a more accurate model than has been used in the past. The new model includes power variations and their reactivity feedback effects. This model was programmed and was utilized in a study to determine the maximum power at which a SNAP 10A type core could be operated.

Various grid plate materials were studied and stainless steel grid plates were selected to replace Hastelloy-C. Stainless steel grid plates help to minimize the temperature drift during static control but increase the cold excess reactivity requirement due to a larger temperature defect.

The fuel element calibration program was continued this quarter with individual element reactivity measurements made in the SCA-4A critical assembly. The measurement of S10FS-3 samarium prepoison worth indicates possible uncertainties in the samarium content of the tubes or in the calculated initial worth of the samarium loading.

Several other studies were completed relating to reactor safety and long time operating characteristics.

3. General Nuclear Analyses

a. Improvement of Analytical Accuracy

Sixteen-group, H-Zr spectrum-weighted, neutron cross sections have been generated for nearly all the SNAP 10A reactor materials used in the SIZZLE code. A study of fission product burnup and fuel depletion will be made using SIZZLE as soon as H-Zr weighted (16) sixteen-group fission product cross sections can be generated.

Hydrogen leakage and redistribution continue to be the most unpredictable reactivity losses for the SNAP 10A reactors. Hydrogen redistribution produces the most important uncertainty for low-temperature operation. No major improvements have been made in the analysis of hydrogen redistribution during the past quarter. The HYTRAN model has been reexamined and seems to be theoretically correct. However, predictions of hydrogen redistribution made using the code does not appear to agree well with the available S2DR experimental data, particularly in prediction of the time constants associated with hydrogen redistribution. The model will be reexamined when S10FS-1 data become available.

b. Grid Plate Material Study

A comparison was completed of a low expansion alloy (Carpenter LE-42), Hastelloy-C, and 316 stainless steel for use as SNAP 10A grid plate materials. The study showed the effects of changing the grid plate material on: (1) the overall reactor temperature coefficient, (2) the operating level temperature

coefficient, (3) the temperature drift during static control, (4) the reactor start-up transient, and (5) the associated reflector weight penalty due to changing the temperature defect.

The conclusion reached in the study was that none of the materials was markedly superior to the others. A brief summary of results is shown in Table 4.

TABLE 4
SUMMARY OF GRID PLATE MATERIAL STUDY

Material	Results
Carpenter low expansion-42 (LE-42)	Low expansion coefficient below $\sim 700^{\circ}\text{F}$, nearly the same as HAC above 700°F . Lowest temperature defect. Highest power during startup transient.
Hastelloy C (HAC)	Temperature defect between LE-42 and 316-SS. S2DR operating experience. Small reduction in transient power peak.
316 stainless steel (316SS)	Highest temperature defect. Lowest transient power peak. Most effective for suppressing temperature swings during passive control period.

c. End of Life Shutdown Mechanism

A study of the mechanisms which would shut down the reactor was completed. The study assumed constant power and linear decay of flow to zero at the end of 5 yr. The results of the study are shown in Figure 9

d. Activation of René 41 Springs

A study was made to determine whether or not the activation of René 41 springs during Building 019 and Building 024 low power physics tests might present a handling problem during transport between buildings or during removal of ground test kits. The René springs (which contain 11 wt % cobalt-59) are utilized as grid plate holddown and reflector ejection springs. The activation was found to be negligible, as shown in Table 5.

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Figure 9. End-of-Life Temperature Drift

TABLE 5
ACTIVATION STUDY OF RENE' 41 SPRINGS

Location of René Alloy	Surface Dose in mrem/hr	
	Building 019*	Building 024*
Top grid plate holddown springs	0.0023	0.0033
Reflector ejection springs	0.0087	0.0125

*Maximum power ≈ 1.6 watts: Total power ≈ 45 watt-hours in Building 019 and ≈ 20 watt-hours in Building 024.

e. Source Strength for Typical Startup Conditions

The effective neutron source strengths for various startup conditions was calculated for use in transient analyses studies. The unmultiplied source strengths are shown in Table 6.

TABLE 6
UNMULTIPLIED SOURCE STRENGTH FOR
TYPICAL STARTUP CONDITIONS

Source of Neutrons	Unmultiplied Source Strength (watts)
Spontaneous fission	1×10^{-10}
External Pu-Be source	1×10^{-6} (per curie)
Space sources	$>1 \times 10^{-7}$

The resultant subcritical reactor power level may be obtained from the following equation:

$$P_s = \bar{S} \left(\frac{1}{1 - k_{\text{eff}}} \right)$$

where

P_s = subcritical power level

$\bar{S}$ = average source strength

k_{eff} = effective neutron multiplication factor.

4. S10FR-1 Analysis

a. System Changes

The decision has been made to replace the Hastelloy-C grid plates with 316 stainless steel grid plates in S10FR-1. The relatively high temperature coefficient of stainless steel reduces the temperature swing during statically controlled operation. The effect has been calculated and is shown in Figure 10.

Although it is not evident from the figure, the larger grid plate coefficient also results in a larger temperature defect of reactivity. The overall temperature coefficient has changed from 0.22 to 0.298¢/°F. The temperature defect associated with an 880°F temperature rise has therefore increased from \$1.94 to \$2.62. As a result the cold, clean excess reactivity of S10FS-1 must be increased from \$2.70 to \$3.38.

It has tentatively been decided to retain the one-shim reflector configuration (to permit shimming flexibility) and to add reactivity by adjusting the fuel loading. The three elements which were lowest in N_H (hydrogen content) will be replaced by higher N_H fuel, and the fuel loading will be shuffled to increase the effective N_H by moving higher N_H fuel to regions of greater importance. The Boomer code will be run to determine how much the stainless steel grid plates reduce the energy release during a nuclear accident.

b. Temperature-Time Behavior

The effect of power variations has been included in the calculations of temperature drift with time for S10FR-1. This rather tedious calculation was programmed and the code (LOAFER) will soon be published. The expected temperature drift versus time has been calculated both by hand and with the new code, and is shown in Figure 11.

5. S10FR-3, 4, and 5 Fuel Calibration

The SCA-4A critical assembly was employed for individual fuel element calibration of the S10FR-3, 4, and 5 fuel elements. The elements were clad in temporary cladding which contained unpoisoned ceramic barrier material. The worth of each element was then measured relative to SCA-4 element E-93. In addition, a random loading of 37 elements from each core loading was placed in the assembly and the excess reactivity was measured.

The individual rod measurements detected several elements which apparently did not have the hydrogen content indicated by the weight gain N_H determination method. These fuel rods were rejected on the basis of the nuclear measurements. The correlation between measured worth and weight gain N_H was excellent for the remainder of the rods.

The fuel rods were then removed from the temporary cladding tubes and reclad in permanent cladding which contained, nominally, 8.0 mg Sm_2O_3 /in. of tube. The finished elements were permeation tested, vibration and shock tested, re-permeation tested, and then returned to the critical assembly for final reactivity checks. The worth of more than 40 finished 10FS-3 elements has been measured relative to SCA-4 element E-93, and the excess reactivity of a random loading of thirty-seven 10FS-3 elements has been measured. The 10FS-4 and 10FS-5 fuel element measurements have not been completed.

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Figure 10. S10A Temperature Drift With and Without SS

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Figure 11. S10A Temperature Drift With Power Correction

The S10FS-3 individual element worth measurements were analyzed and it was determined that there was essentially no correlation between the measured, individual element, samarium worth, and the quoted samarium loading as determined by weight gain. It has not yet been determined whether the experimental uncertainties in the SCA-4A assembly, or uncertainties in the quoted samarium content, or both, result in this lack of correlation.

The difference between the excess reactivity of the 37 element random loadings with and without samarium represents the initial worth of the samarium prepoison loading. The measured worth of the 8.2 mg/in. (nominal average) Sm_2O_3 loading in S10FS-3 was $\$1.25 \pm 0.10$. The worth of this samarium loading has been calculated (using the DTK computer code) to be $\$1.60 \pm \sim 10\%$.

The lack of correlation between individual tube samarium worth and quoted samarium content, and the disagreement between calculated and measured total initial samarium worth, are being studied exhaustively at this time. Areas being investigated are: (a) accuracy of measurements made with the SCA-4A assembly; (b) the effect of open control drums on neutron energy spectrum, and the resulting effect on initial Sm worth; (c) the ability of the DTK code to calculate absorber worth as a function of radius; and (d) the accuracy of the weight gain method for determining samarium content.

6. High-Power, High-Temperature Limitations of the SNAP 10A Reactors

The S10FR-3, 4, and 5 reactors are capable of operating at much higher powers and temperatures than the current design point of 33 kw at 900°F inlet and 100°F core ΔT .

A parametric survey was completed using the new computer code mentioned in paragraph 4b. The code assumes a constant ΔT and considers all reactivity loss and gain mechanisms including changes in H_H due to hydrogen loss, changes in equilibrium xenon associated with power level changes, and power level changes as a function of the reactor outlet temperature to the fourth power.

The only power limitations assumed were that currently available fuel and reflectors would be used and the reflectors would be modified to permit operation with five shims.

The most stringent assumption made was that the reactor temperature drift during one year of statically-controlled operation must not exceed 60°F. The result of this analysis is shown in Figure 12.

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Figure 12. Nominal 60°F Drift Power-Temperature Limits

A second set of cases was run assuming fixed uncertainties in certain reactivity effects. The ground rule for this study was that the difference between the maximum temperature of the highest temperature case and the minimum temperature of the lowest temperature case (i.e., the temperature uncertainty band that exists prior to start of operation) must not exceed the limitations of 60 and 90°F. The results of this study are shown in Figure 13, and typical temperature uncertainty curves are shown in Figure 14. A TDR is being written which will present the complete results of this analysis.

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Figure 13. 60 and 90°F Swing Limits

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Figure 14. 50 kw - 60° Swing Case

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 Figure 15. Radiation Levels at Instrument Compartment,
 SNAP 10A - 33.5 kw

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 Figure 16. Nuclear Heating Rates
 Through SNAP 10A Shield

7. Control Drum Rebound

The possibility of a drum latch failure during a scram operation, accompanied by rebound of the coarse control drum, has been studied. It was shown that all drums would have to rebound simultaneously to at least the 70° position (135° = full out) in order for the reactor to attain a positive period. Rebound of this magnitude is considered an incredible accident.

F. SHIELDING ANALYSIS

Gamma dose rates and neutron fluxes, fast and thermal, were estimated at the location of the radiation detectors within the instrument compartment. These radiation levels are shown in Figure 15.

The internal heat generation within the SNAP 10A shield was computed. Heat is produced by the (n, α) reaction in lithium, the loss of neutron kinetic energy during slowing down, and the attenuation of gamma rays. The spatial variation of nuclear heat generation is shown in Figure 16.

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V. DEVELOPMENT

A. CONTROL COMPONENTS

1. Description

A group of components regulates reflector control drum rotation. The drum release actuators hold the control drums full-out during launch and release the drum when integral squibs are fired during startup. Springs on the coarse control drums rotate them full-in when the drums are released. All drums are mounted on shafts which rotate in high vacuum-high temperature bearings.

A controller regulates stepping of the fine control drums inward at regular intervals until the operating temperature is reached. A temperature switch in conjunction with the controller then regulates stepping of the drums to maintain a minimum reactor temperature during the active control period.

The drum actuators provide torques to turn the drums when energized from the controller. The actuator output torque is transmitted to the drum shaft through a pinion-gear-drive.

2. Progress

The control components development effort was concentrated upon the evaluation of weaknesses in the actuator, proof test of bearings and gears in high vacuum, performance mapping effects of system electrical interferences on the controller, preparation of a "universal" specification for purchase of squibs for both reactor and power conversion uses, and continuation of several temperature sensor and switch long-term tests to establish confidence.

a. Controller

The controller periodically provides a four-step sequence of power pulses to the control drum actuators to drive the control drums in and startup the reactor. The four steps are taken within 5 sec and this sequence is repeated every 150 sec as long as the reactor outlet temperature remains below the set point.

Additional electromagnetic interference testing was performed. Two main points of entry of interference into the controller were found: The temperature sensor input and the power input. It was observed that the temperature

sensor input is the more highly susceptible of the two. Previous testing had established the levels of interference that would cause malfunction so that this testing was concentrated upon methods that would prohibit the entrance of the interference levels into the controller.

It was found that reduction in length of wire between the controller and the temperature sensor switch was the most effective means of preventing noise from entering the temperature sensor input. Extensive testing was performed using a switch with only 6 in. of shielded twisted pair between it and the controller. No malfunctions were recorded over 2400 timing cycles. A circuit which will modify the system to incorporate this change has been proposed.

Two other means of preventing the entry of noise into the temperature sensor input were tested. The first was the addition of a filter capacitor across the leads at the controller. This addition proved effective in the attenuation of pulses on the leads. The second system tested was merely that of changing the present wiring system to all shielded, twisted pairs. This change seemed to help but was not 100% effective.

Attenuation of transient noise on the power lines can be accomplished only by the use of filters. The addition of simple bypass capacitors to the lines was tested and was somewhat effective. Grounding the neutral lines to the controller case also proved an effective interference control. Specification of the exact filtering to be used depends upon the nature and magnitude of transient noise to be encountered.

All radiation testing of controller components and of controllers was completed. The results of all testing is herein summarized. The first testing to be done was in the Battelle Memorial Institute (BMIR) reactor. Low flux capsule LF-1 provided information on the logic transistor, 2N744, and low flux capsule LF-2 provided information on the remainder of the controller components. Testing in the shield test reactor (STR) provided information on the 2N744, the 2N1072, and the logic modules as well as on two complete controllers.

Table 7 summarizes the results of all radiation testing applicable to the startup controller.

TABLE 7
SUMMARY OF RADIATION TESTING RESULTS APPLICABLE
TO STARTUP CONTROLLER

Capsule	Component	Dose	Comments
LF 1	2N744 Si transistor	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Gain vs nvt curves obtained Showed useable gain (>10) at 10^{14} nvt
LF 2	2N1072 Si transistor	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Gain and leakage current vs nvt curves obtained. Showed useable gain (>3) at 8×10^{13} nvt
LF 2	PS760 Si diode	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Forward voltage drop vs nvt curves obtained. V_f less than 1 volt at 10^{14} nvt
LF 2	1N2032 Zener diode	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Zener voltage vs nvt curves obtained. No appreciable change at 10^{15} nvt
LF 2	019-M Power diode	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Forward voltage and reverse current vs nvt curves obtained. $V_f = 3$ at 10^{13} nvt and 12 at 10^{14} nvt
LF 2	TM 1/4 Si sensistor	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Resistance vs nvt curves obtained. No change at 10^{14} nvt
LF 2	Capacitor 20 μ -farad tantalum foil	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Capacitance decreasing at 10^{13} nvt. Leakage current increasing
LF 2	Capacitor 6.8 μ -farad tantalum foil	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Capacitance fairly constant at 10^{14} nvt. Leakage current in- creasing at 10^{12} nvt
LF 2	Capacitor 0.1 μ -farad metallized mylar	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Capacitance constant at 10^{14} nvt. Leakage increasing at 10^{12} nvt
LF 2	Capacitor 0.47 μ -farad ceramic	2×10^{15} nvt $E > 0.1$ Mev 4.7×10^7 r	Capacitance fairly constant at 10^{14} nvt. Leakage increasing at 10^{12} nvt
STR 1	Logic modules	4.5×10^{13} nvt $E > 0.1$ Mev	No significant change in operation
STR 2	2N744 2N743 2N1072 Si transistors	0.4×10^{13} nvt $E > 0.1$ Mev 2×10^7 r	Demonstrated feasibility of gamma predosing
STR 3	Controller S/N 4 Nonflight	4.9×10^{13} nvt $E > 0.1$ Mev	Time delay periods remained within specification limits. Faulty sequences were observed at 2.6×10^{13} nvt. Installation of a 1500 μ -farad capacitor (as in flight designs) restored normal operation
STR 5	Controller S/N 4 Nonflight	1.1×10^{14} nvt $E > 0.1$ Mev	Additional dose of 6×10^{13} nvt After a total dose of 8×10^{13} nvt controller would not operate below 120°F. At 1.1×10^{14} nvt, temperature had to be held at 150°F to attain nor- mal operation
STR 9	Controller S/N 12 Flight	3×10^{13} nvt $E > 0.1$ Mev 2×10^7 r	Qualification test. Normal operation at 120°F base temperature
STR 11	Controller S/N 12 Flight	8×10^{13} nvt $E > 0.1$ Mev 2×10^7 r	Temperature dependence shown. At 6.8×10^{13} nvt minimum tem- perature 141°F. At 7.8×10^{13} nvt minimum temperature 180°F

b. Temperature Sensor Switch

The backup design temperature sensing system was made the reference design due to the inability of the thermomechanical switch to successfully complete design verification testing. Both components of the backup design — resistance temperature detector (RTD) and the magnetic amplifier switch — had successfully completed design verification testing and all units had been delivered. These units are now undergoing acceptance testing.

TABLE 8
SUMMARY OF EXPERIMENTAL TEST RESULTS

Type	Quantity	Test	Results
Thermomechanical switch	4	Thermal cycling, shock, vibration and acceleration	Erratic switching, adjustment defects, large shifts through shock, vibration, and acceleration
RTD (sensor)	2	Thermal endurance (in	No. 1
Thermomechanical switch	4	Thermal cycling, shock, vibration and acceleration	Erratic switching, adjustment defects, large shifts through shock, vibration, and acceleration
RTD (sensor)	2	Thermal endurance (in air): No. 103:2300 hr at 1000°F + 12 thermal cycles No. 109:1750 hr at 1000°F	No. 103, No detectable drift greater than calibration uncertainty ($\pm 1^\circ\text{F}$) No. 109: No detectable drift
RTD	3	Qualification level shock, vibration, and acceleration	No detectable shift
Electronic switch	2	240 hr continuous operation	No. 1003, Stability $\pm 0.1^\circ\text{F}$ No. 1017, stability: $\pm 0.5^\circ\text{F}$
Electronic switch	2	Temperature cycles (0-140°F in air)	No. 1003, equivalent switch point variation: $\pm 0.7^\circ\text{F}$ No permanent set point change No. 1017, equivalent switch point variation: $\pm 0.1^\circ\text{F}$ No permanent set point change (See Figures 17 and 18a, and b)
Electronic switch	2	Gamma predose ($2.3 \times 10^7\text{r}$)	Unit 1: Maximum dosing band = 0.3°F Maximum opening band = 0.2°F Hysteresis $\approx 0.6^\circ\text{F}$ No apparent drift trend Unit 2: Maximum dosing band = 0.62°F Maximum opening band = 0.7°F Hysteresis $\approx 0.4^\circ\text{F}$ (See Figures 10a, and b)
Electronic switch	2	Qualification neutron irradiation ($3 \times 10^{13}\text{ nvt}$)	No malfunctions. Operated within specification.

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Figure 17. Switch Point (Simulated Sensor Resistance) vs Elec-
tronic Switch Temperature

The present reference design utilizes a platinum resistance element as the temperature sensitive branch of a Siemens (3-wire) resistance bridge. The output of the bridge is fed to an amplifier and any off-null signal is amplified to produce a change of state of an output relay.

Time Constant

A NaK loop was used to obtain data on system time constant and repeatability. The electronic system time constant was approximately 3 min when the NaK loop test section was evacuated to 1.5×10^{-4} mm-Hg. Testing in a NaK filled pot at atmospheric pressure showed a time constant of approximately 2 min. The reduction in time constant observed in the latter experiment is attributed to the air in the switch well and the added heat transfer by gas conduction from the well to the sensor. It was analytically determined that the outlet coolant temperature would return to below 1020°F before the end of the system active control mode with a time constant as long as 4.3 min. The resulting maximum temperature of the outlet coolant would be approximately 1033°F for this 4.3-min time constant. It was, therefore, concluded that the 3-min time constant is acceptable.

Installation and Removal

Limited testing has shown the system to repeat within 3°F through removal and reinstallation of the sensor. Tests are continuing.

Testing

The results of all testing performed during the quarter is summarized in Table 8 and shown in Figures 17, 18a and b, and 19a and b.

Electronic Switch Thermal Cycling

The graphs of the response of the electronic switches to thermal cycling, Figures 17, 18a and b, were generated in the following manner: thermocouples were mounted to the switch housings and the switches were placed in an oven and temperature-cycled as indicated in the figures. Switch point data were taken at 0 and 140°F at which temperatures the switches were allowed to remain for 1/2-hr before recording of data. The RTD resistance was simulated by a decade resistance box.

2-18-64

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Figure 18a. Switch Point (Simulated Sensor Resistance) vs Electronic Switch Temperature

2-24-64

7635-0133

Figure 18b. Switch Point (Simulated Sensor Resistance) vs Switch Temperature After Shock, Vibration, and Acceleration

2-19-64

7635-0134-1

a. Unit 1

2-18-64

7635-0134-2

b. Unit 2

Figure 19. Gamma Radiation Test

c. Drum Actuator

The activity in this task was concerned with testing of system-built flight actuators. Actuator D10-A-1 is being tested in temperature and vacuum. By November 20, this motor had accumulated 2400 hr of environmental testing, at 800°F average coil temperature, (excluding I^2R heating), and a vacuum of 2×10^{-7} mm-Hg. The torque output and insulation resistance has increased in some cases during the test life. The values are given in Table 9.

TABLE 9
ACTUATOR D10-A-1 TESTED IN TEMPERATURE AND VACUUM

	0 Hr	2400 Hr	Safety Factor 2400 Hr
Insulation Resistance:			
Stator			
at 50 v dc	192 K	217 K	108
Brake	172 K	62.5 K	64
Torque Output:			
CW at 28 v dc	23.2 in.-oz	28.8 in.-oz	2.4
CCW at 28 v dc	23.2 in.-oz	27.2 in.-oz	2.2

Test vacuum and temperature are reached at zero hour. The insulation resistance safety factors are based on a minimum allowable insulation resistance, R_i , defined as follows:

$$\frac{R_i}{R_w} = \frac{100}{1}$$

Where R_w is the coil winding resistance, the torque safety factors are based on a minimum allowable torque of 12 in.-oz.

Comparison of actuator D10-A-1 to the early development actuator (AI-B30-8P), which was tested for over 10,000 hr, shows very favorable results considering that the environmental conditions in the current test are more stringent than those of the AI-B30-8P actuator tests. The temperatures and vacuum are somewhat higher for the current test. A comparison is shown in Table 10. Figure 20 shows actuator D10-A-1.

TABLE 10
COMPARISON OF TEST CONDITIONS, ACTUATORS AI-B30-8
AND D10-A-1

	Vacuum (mm Hg)	Hottest Spot (° F)	Average Coil Temperature (° F)
AI-B30-8P	5×10^{-5}	840	600
D10-A-1	2×10^{-7}	1030	800

Figure 20. Actuator D10-A-1

Humidity Test

The first of the series of humidity tests (Figure 21) has been completed. The test was started on November 12, 1963 and completed on December 12, 1963. The purpose of these tests is to attempt to obtain sufficient data to evaluate the effects of humidity on actuators, so that these effects can be explained if these conditions are encountered in the field.

11-7-63

7568-55406

Figure 21. SNAP 10A Actuator
Humidity Test

The general description of the test is as follows. The test was performed at the five different dry bulb temperature of 40, 70, 100, 130, and 160°F.

At each of these temperatures relative humidity (RH) levels were 25, 50, 75, and 100% RH.

Each level of humidity reading was run for a period of 1-day. During this time, insulation resistance was monitored and, while the actuator was subjected to humidity environment, an attempt was made to dry out the actuator by impressing 6 watts through its windings. The insulation resistance was monitored. Significant observations made during the test are described on the following page.

At 40°F the readings were as follows:

RH (%)	Insulation Resistance (meg)
25	1000
50	200
75	67
100	500

A 2-hr dry time failed to increase the insulation resistance except at the 75% RH point. At this point, the insulation resistance rose to 135 meg.

The data at 70°F is as follows:

RH (%)	Insulation Resistance
25	500 meg
50	29.4 meg
75	278 K ohm
100	179 K ohm

A 2-hr dry time showed no effect at 25% humidity but was quite effective at the other 3 points, increasing the insulation resistance by as much as a factor of 10.

The data at 100°F is as follows:

RH (%)	Insulation Resistance
25	1000 meg
50	20.8 meg
75	2.78 meg
100	35.7 K ohm

The 2-hr dry attempt was again effective only at 50, 75, and 100% relative humidity. The effect of drying at this point was as pronounced as it was in the 70°F temperature test.

The data at 130°F test is as follows:

RH (%)	Insulation Resistance
25	1000 meg
50	8.3 meg
75	6.25 K ohm
100	13.5 K ohm

The effect of drying the actuator was less pronounced at this temperature than in the previous ones varying from a factor of 2 to a factor of 6.

The data at 160°F is as follows:

<u>RH</u> <u>(%)</u>	<u>Insulation Resistance</u>
25	1000 meg
50	1.14 meg
75	41.6 K ohm
100	926 ohm

The effect of drying the actuator was less pronounced in all these tests in the 160°F range and could be considered almost insignificant. The room ambient temperature conditions readings of the actuator were the same before and after testing, approximately 1000 meg.

Conclusions

No final conclusions can be drawn as a result of one test. However, some implications and observations are listed below.

- 1) The upper limits of testing were far more severe than is expected to be encountered.
- 2) Except for the 160°F test, the actuator can be expected to operate normally under the imposed relative conditions. It is indicated that a drying cycle is not really necessary, although it was effective.
- 3) The actuator can be "dried" appreciably in most cases under humidity conditions. (Dried is a relative term indicating that the insulation resistance can be increased.)
- 4) At certain temperatures it is not the 100% relative humidity condition which is most severe but a value somewhere between 50 and 100%. This value was indicated to be near 75%. The exact point is not known.
- 5) The humidity test data is not in agreement with the general results found when testing actuators at room ambient conditions. In general, testing of actuators at room ambient conditions on "moist" days shows lower insulation resistances than were encountered in this test at the saturated conditions.

- 6) In order to arrive at any more definite conclusions than the foregoing, considerably more testing will have to be done.
- 7) It is not reasonable to assume with certainty that the humidity conditions in the field will be the same as the test conditions. That is, the test conditions were performed in a controlled chamber. This means that the actuator was effected by essentially pure water, whereas, in the field, it is not reasonable to assume that the humidity condition will be pure water but rather some combination of impurities.

d. Reflector Drive Components

Two major areas of development are now active on the SNAP 10A drive system: (1) 90-day performance check tests of the control drum bearings and 90-day performance check tests of the actuator motor/gear drive assembly under ultra-high vacuum (ion pumped) conditions, and (2) performance mapping of the drive system parts under ground test conditions to determine allowable operating life.

Reflector Bearings

Bearing developmental effort primarily directed toward space operation through ground test maximum life compatible with space design materials, if possible, is also an objective. The reflector drum bearings have been chosen for development of the technology for all control system bearings because they are representative of, or are more complex than, the other bearings used in the actuators, position sensors, etc.

A SNAP 10A reference design reflector drum bearing set is under test in ultra-high vacuum conditions at design temperature. The materials used in this design are:

Shafts - Titanium (6Al-4V) with flame sprayed aluminum oxide coating and molydisulfide (X-15) dry lubricant

Journal and thrust surfaces - Titanium carbide ceremet (Kennametal K-162B)

Self-aligning ball - Titanium carbide ceremet (Kennametal K-162B)

Self-aligning socket - Titanium with flame sprayed aluminum oxide coating and molydisulfide (X-15) dry lubricant.

The steady state test conditions were vacuum of 7×10^{-9} mm Hg, and temperature of 600°F. The starting friction torque remained below the design maximum of 2.5 in.-lb during the initial 5 days of testing. This bearing set was rotated in small angular rotational steps for the first five days and is now under a 90-day dwell to evaluate the possibility of self-welding after long periods of no control activity. The complete results of this test will be presented upon completion of the post 90-day operation. The performance thus far indicates no problem in operation of the SNAP 10A drive bearings at 600°F and pressures down to 7×10^{-9} mm Hg.

Gear Drive

The first ultra-high vacuum performance test of the SNAP 10A gear drive system is nearing completion. The objective of this test is to evaluate the operating characteristics of the drive system and to investigate the self-welding possibility and wear resistance of the X-15 dry film lubricant utilized on the SNAP 10A reference design Haynes Stellite 6B pinion and the titanium (6Al-4V) gear.

The performance test incorporates a 5-day operational phase, a minimum of a 90-day dwell and a final 5-day operational phase. Pressure in the vacuum system has remained in the 10^{-9} mm Hg decade with the gears operating at 700°F and the actuator at 500°F, with pressures in the 10^{-10} mm Hg decade at startup ambient temperature.

The initial 5-day operational test phase, consisting of intermittent stepping of the simulated control drum, was completed with no excessive friction noted. During the dwell phase, readings of coil resistance and insulation resistance have indicated no change in electromagnetic characteristics of the actuator. After the dwell phase, the actuator will be stepped, and the torque required to actuate will be compared to predwell values.

No ground test vacuum tests on the drive system parts have been conducted to date, but test equipment is being assembled for these tests.

e. Cable Harness

The objective of this program is to develop an integrated cable harness which will be used to transmit power from the control drum actuator to the control components and to transmit signals from the diagnostic components to the

instrument compartment. This developmental activity includes the development and evaluation of cable material and electrical connector devices as well as the techniques of terminating the cable and joining the cable to the connector.

A 6-ft sample of epoxy-sized cable, the reference design material for SNAP 10A, was tested in high flux capsule 5 at BMI at 700°F and 10^{-5} mm Hg. The integrated neutron and gamma flux were $\sim 3.8 \times 10^{18}$ nvt (>0.1 Mev) and 6.3×10^9 r, respectively. The effect of this combined environment on the cable material is seen in Figure 22. The insulation resistance from conductor to

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Figure 22. The Degradation of Insulation Resistance in Epoxy-Sized Cable Under Neutron and Gamma Irradiation at 700°F and 10^{-5} mm Hg

shield was 100 meg at the beginning of the test and this measurement decreased at an almost constant rate to 4000 ohm at the end of 2500 hr. The relatively flat portion of the curve occurred from 970 to 1117 hr while the radiation capsule was removed from the core position with temperature and pressure maintained constant. The dominant effect of radiation on the degradation of the electrical insulation of this cable sample is due primarily to the presence of the epoxy binder. However, removal of this organic material by baking the cable out in air prior to use renders the Fiberglas insulation very weak and makes cable harness fabrication virtually impossible.

The cable samples listed below are currently being tested in high flux capsule 6 at BMI at 700°F and 10^{-5} mm Hg.

Science Systems epoxy-sized unbaked

Science Systems epoxy-sized baked

American Super Temp-Pyrad 1000

American Super Temp-Pyrad 1000 with Foster Seal applied to the terminations to prevent fraying

Santa Fe Textiles - 5-944 - silicone sized - baked out.

On the basis of this test, a recommendation will be made of the best cable material currently available for SNAP 10A systems.

f. Drum Release Actuator

The drum release actuator is a pyrotechnic squib-fired pin-puller which releases the drums prior to reactor startup. Inadvertent drum release is prohibited by a lock wire preventing pin movement. Operational reliability is enhanced by employment of two squibs, since the firing of either squib will generate enough force to shear the lock wire and pull the pin. The pin, once pulled, is prevented from bouncing and relocking the drum by a pin retaining mechanism within the actuator body. Development of the drum release actuator is complete and tests have confirmed the success of this design.

The squib is a small pyrotechnic explosive capsule capable of firing upon application of 28 volts. As had been previously reported,* the McCormick Selph M-130 Squib was modified by changing the cadmium plating to nickel plating. With this change the squib is now designated as the McCormick Selph M-130 Mod 4 Squib. In order to embrace this change and also include the latest SNAP 10A environmental conditions, a new squib specification has been drafted. The previously conducted developmental test program on M-130 squibs will be extended to the M-130 Mod 4 squibs and will cover the requirements given in this latest specification.

As a backup for M-130 squibs, one test firing has been accomplished with a PC10 squib which was fired in a completely assembled drum release actuator. The assembly was exposed for 10 min to a 500°F temperature and

*NAA-SR-7494, SNAP 2/10A "Reactor Quarterly Progress Report," April-June 1963

then fired. Pressure developed was in the range of 600 to 7000 psi, and inspection revealed that no damage to the actuator housing has occurred. In a further test the PC10 squib was exposed to 250°F for 48 hr prior to firing. Firing was conducted at 28 volts and 5 amp. A pressure of 2000 psi was developed with a delay time of 15 msec.

B. SAFETY COMPONENTS

1. Summary

The effort on safety components was expended on developing confidence in the TABRD by testing shear bolts, providing support of production in EABRD manufacture, and evaluating timer failures so that details of manufacture and assembly of future units would be improved.

2. Progress

a. Temperature Actuated Band Release Device (TABRD)

The TABRD is a rod and tube device that is operated by sensing a temperature drop in the NaK outlet pipe and exerting a tensile load within itself to rupture a notched bolt and thereby release the reflector band.

Tests were started on the notched bolts to establish reliability against inadvertent failure in shear due to the 180-lb band load. Shear tests are being conducted on 25 bolts to establish level and mode of failure; it is expected that shear rupture will be at ~630-lb load. Tests are also being conducted to determine the repeatability of this device to arm at the required temperature of $925 \pm 25^\circ\text{F}$. The present test results indicate a rather wide range of arming temperatures so that additional investigation into the details of this device is now being performed.

Tests were conducted to determine the ΔT required to rupture the bolts. These tests were not conclusive as a rather large temperature variation was noted from one test to another, i. e., 410°F minimum to 670°F maximum. Normally, as shown by analysis, a 300°F ΔT is sufficient to rupture this type bolt. Inspection of the test specimens indicated that part of the variation in the temperature needed for bolt rupture may have been due to a worn condition of the threads holding the rod to the housing. This condition would necessitate a larger difference in temperature to apply the required strain on the bolt. Further investigation of this particular point is being made to establish the necessary parameters for successful operation of the TABRD.

b. Electrically Actuated Band Release Device (EABRD)

This component is a fusible link device in series with the other parts comprising the reflector retaining band. Upon an electrical command, a heater inside this device melts a brazed joint, which normally holds its two major parts together, allowing the retaining band to part.

Structural testing and metallurgical examination of a quantity of EABRD assemblies made of 17-7 PH stainless steel has shown very unreliable welds in the female housing. Due to the difference in thickness of the metal being joined at the weld, a great deal of stress corrosion cracking occurred. See Figure 23.

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Figure 23. EABRD Stress-Rupture of 17-7PH EABRD at 800°F

To solve this problem, a new EABRD design was adopted using Rene 41 bar stock instead of 17-PH stainless steel tubing. This new design has two distinct improvements over the old design, as it (1) eliminates the weld joint, and (2) provides a positive means of controlling the braze joint clearance with the use of dimples in the female housing.

Development effort on the heater design was limited to publication of a specification for encapsulating the heater coil. Details of the heater design are shown in Figure 24.

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Figure 24. Heater, Electrically Operated Shutdown Actuator

c. Timer

The timer is required to provide two functions at the end of the system's life. A 1-min time base is provided which times out from the instant of receipt of a malfunction signal. It resets immediately should the malfunction signal disappear before the end of 1-min. Once the 1-min time base has timed out, the 1-hr time base is initiated. The 1-hr time interval serves as delay period for the acquisition of failure data. When this time base times out, a contact closure is made which initiates reflector ejection.

Two timers completed 90-day endurance tests. One timer was subjected to an accelerated life test, where it was cycled through its two time bases twice every 6-hr. Test conditions were 140°F and 1×10^{-6} mm Hg. The timer completed 860 cycles during 2580 hr of testing with no malfunctions. Variance in the time bases was less than 1%. The second timer was placed on a "soak" test where it was maintained, with no power applied, at 1×10^{-5} mm Hg or less for 90-days. After the soaking period, the timer was operated and no degradation in performance was noted.

Six additional timers were analyzed and examined for design or quality control deficiencies. Figure 25 shows a partially disassembled timer.

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7623-55295

Figure 25. Reflector Ejection Delay Timer

Several cases of poor workmanship were noted including such things as solder splashes, split wire insulation, improperly adjusted clutches and relays, gears not staked, and faulty motor connections. These deficiencies were called to the attention of the vendor and a more strict source inspection procedure was set up.

One basic design deficiency was discovered. It was found that the carbon brushes were wearing very rapidly and that carbon material was building up excessively in the slots between the commutator bars. This excessive build-up is shown in Figure 26. The cause was traced to an improper selection of brush material for use in the dry inert atmosphere which is sealed into the timer. Consultations were held with a brush manufacturer regarding selection of a proper brush material.

Figure 26. Timer Commutator Showing Heavy Carbon Deposits in Slots

C. DIAGNOSTIC COMPONENTS

1. Summary

The position sensor qualification failures were evaluated and methods of mounting limit switches to prevent cracking of the cases were devised.

2. Progress

a. Drum Position Sensor

Following failures of a position sensor in qualification vibration and shock, an attempt was made to isolate mounting fixture effects by subjecting another sensor to vibration and shock. In this test the sensor was mounted directly to the test table with no shaft coupling attached. Bench measurements of shaft torque at room temperature were made before and after the test. Results are summarized in Figure 27. Since only eight cycles are required through the qualification test series or normal usage on a flight system, this test was not considered a failure. Both sensors are being disassembled for examination of the bearings to determine the mode of failure.

Two sensors have completed 90-days irradiation in vacuum without failure. The units operated within specification throughout the test.

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Figure 27. Relationship Between Shaft Input Torque and Number of Revolutions from Test for Position Sensor S/N 1017

b. Position Sensor Demodulator

Since some variation in signal from the drum position sensing channel had been reported from the FSM-1 system tests, a demodulator connected to a position sensor was placed on long-term drift test. On this test it has now operated for 250 hr, at temperatures of 0 to 140°F. The maximum drift of output signal at a specific temperature was approximately 30 mv, or 0.6% of full scale. This test indicates insignificant drift of the sensing system. A test plan was written covering measurements on the various portions of the FSM-1 sensing channel, including the system wiring and power supply connections, to isolate the causes of the reported drift on FSM-1.

c. Limit Switch

Failures of limit switches during installation on the reflector assembly and system test have been analyzed, and found to be caused by (1) excessive stresses imposed on the switch case by the present mounting method, and (2) the brittle nature of case and plunger material (Supramica 560). Based on design studies and mounting tests the course of action listed below was adopted to eliminate breakage. (See Figure 28.)

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Figure 28. Modifications to Limit Switch to Eliminate Breakage

- 1) Notching of the case cover corners to remove weak areas. Installation of high-strength alumina bushings in the notched areas. The mounting screws will pass through these bushings.
- 2) Addition of a 1/16-in. thick metal plate, with fiberglass cloth between the plate and the switch, to distribute mounting screw stresses.
- 3) Replacement of the Supramica plungers with high-strength alumina parts. Fabrication of parts for proof-test has started.

D. SHIELD

Shield development is complete and a report summarizing this work is being prepared.

E. MATERIALS APPLICATION

1. Summary

The objectives of the component materials study are to evaluate, test, and recommend materials combinations for use in various components throughout the system. Techniques are being developed to apply electrical insulation to stepper motor field coils and for application processes of dry film lubricants to bearing surfaces of various configurations. Materials combinations are being tested for their ability to not self-weld at elevated temperatures.

a. Ground Test Kit Development

Development work on the ground test scram kit has resulted in several material changes that have improved the drive mechanism operation. The original drive motor bearings, Inconel-X shaft and thrust plate against carbon-graphite bushings, have been replaced with Al_2O_3 plated thrust plates and bonded dry film coatings on the metal shaft. This change eliminates any metal to carbon-graphite bearing material combination and greatly reduces motor friction. The gear train has been improved by replacing the 300 series stainless steel worm wheel with a wheel made of 440-C, heat-treated to R_c 58. Both the worm and worm wheel have been coated with a bonded dry film lubricant (molybdenum disulfide-sodium silicate suspension).

Due to the excellent improvement of motor and drive train performance with the dry film coatings, all bearing surfaces in the kit assembly will be dry film coated during the next test.

Two evaporation tests were conducted on APL grease. These tests were conducted in order to determine the feasibility of this grease for use in vacuum at 250°F. The results are summarized in Table 11.

TABLE 11
TEST RESULTS OF APL GREASE

Test	Weight of Sample (gm)	Weight Loss (gm)	Weight Loss (%)	Temperature (°F)	Time in Test
1*	0.3126	0.0397	12.7	250	1 day
2†	0.0010	0.0007	70.0	250	1 week

*Vacuum was 16 μ

†Vacuum was 27 μ

Condensation of an oil or grease film on the furnace window occurred in each test. This condensation could have come from the grease and/or the pumping system. There is no way to determine which source caused the film. In the second test a stainless steel plate was placed beside the grease sample. At the end of the test there was no trace of grease on the steel.

Although the results of these tests were not quantitatively comparable, they did show that in each case the grease evaporated at too high a rate for use in this system.

b. Design and Fabrication Support

Brake Materials

The reference design brake materials for the SNAP 10A actuator were evaluated for the extent of self-welding adhesion that might take place during the expected 90-day dwell during the system mission.

The materials of the first test were chromium plating vs chromium plating run at 700°F and 2×10^{-7} mm Hg. The samples were loaded together at 60 psi for three days. An adhesion check was then made and the samples were separated for 90 days. At the end of the 90-day period they were loaded together for three days. A final adhesion measurement was made after the

three-day dwell. The first adhesion value was 0.4 psi and the second measurement showed that the adhesion was less than 0.4 psi. The next two tests evaluated Al_2O_3 vs chromium plating.

Both these tests were conducted at 700°F for approximately 2300 hr in a vacuum of 5×10^{-8} mm Hg. In each case, the samples were loaded to 60 psi. The adhesion values were 0.4 and 1.30 psi.

These three tests show that the materials used as braking surfaces in the actuator can be subjected to 90-day dwells without any significant self-welding occurring.

Copper Deposits in Actuators

A stator from actuator life test (AI-B30-8P) was expanded for areas of copper diffusion or migration. The stator was considered to be the source of the copper that was found on the interior surfaces of the actuator.

The stator was disassembled for inspection and various pieces of material were analyzed by x-ray emission tests. Elemental copper was found on various surfaces within the stator including the PBX, mica, MyKroy, and relay 5.

The only possible source of copper is the coil wire in the stator. If copper migrated to various surface points on the stator, it had to vaporize before it could be plated onto the interior surfaces of the actuator. The maximum reported temperature during the life test was 1000°F. This temperature was held for approximately 1000 hr. The estimated weight of the copper deposits was approximately 0.3 gm. At 1000°F it would require 1.3×10^{10} hr for this amount to evaporate. The temperature would have to exceed 1300°F for this amount of copper to evaporate in 10,000 hr.

Conclusions from this investigation are:

- 1) The source of the copper was the wire in the stator
- 2) The mechanism of migration cannot be precisely determined
- 3) There were other conditions (i. e., excessive temperatures) which were not observed or recorded during the test. These conditions are probably responsible for the copper deposits.

Core Vessel Discoloration

The results of the investigation on core vessel discoloration indicate that discoloration is to be expected for any stainless steel in contact with oxygen above 600°F. In even stabilized grades of stainless steel prolonged exposure above 800°F causes carbide precipitation which lowers the oxidation resistance of the alloys and renders them sensitive to pitting corrosion in the presence of moisture and/or halogen ions. It is recommended that surface protection plating and coating be evaluated as a corrosion barrier during and after ground qualification tests.

Electrically Actuated Band Release Device

A metallurgical analysis was made on the design concept employing 17-7 PH in the EABRD. Although reliable brazing techniques were developed, the extreme difficulties in welding 17-7 PH and poor tubing corrosion resistance of finished assemblies made this design unsatisfactory.

A backup design utilizing Rene' 41 machined components is being fabricated and appears to eliminate all of the previous difficulties. Joint clearances are preset prior to brazing and the Rene' 41 appears to have superior resistance to intergranular corrosion. Figure 29 shows the annealed and aged structure of Rene' 41. The grains are equi-axed and no evidence of corrosion was found. The curved portion of the tube wall serves to position the mating surfaces and set the joint clearances.

Figure 29. Section of Annealed and Aged Rene' 41 EABRD Member Showing Recrystallized Structure and Positioning Dimple

100X

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BLANK

VI. QUALIFICATION

A. CONTROL COMPONENTS

1. Mechanical Components

a. Bearings

Three sets of SNAP 10A control drum bearings were coated with a molybdenum disulfide dry film lubricant and subjected to qualification level thermal cycle, shock, vibration, and acceleration tests. These tests were performed to demonstrate the ability of the bearings to withstand the environmental conditions they will experience prior to and during launch and flight to orbit.

The bearings showed no effects from the thermal cycle tests. After the scheduled shock, vibration, and acceleration (SVA) testing the lower bearings were tight on the alignment movement. In order to provide additional information, a second series of SVA qualification tests were run. These tests doubled the required rotation torque with a maximum value of about 32 in.-oz. (maximum allowable, 40 in.-oz.) and increased the required alignment torques. However, of 36 alignment measurements only one (12.8 in.-lb) exceeded the 12 in.-lb maximum allowable torque established in the performance criteria. Post test inspections showed that the lubricant was transferred from the socket to the ball on all bearings. Bearing responses to the first SVA tests were normal. However, the responses during the second series of tests were in excess of 100 g, indicating an increase in clearances due to the vibration.

The test sequence was as follows: Per the prescribed process specification, the dry film lubricant was applied to the bearing races, the shaft thrust shoulder, the portion of the shaft on which the bearing rotates, and the bearing face of the spacer. The bearings were weighed, assembled in the thermal cycle and endurance test fixture, installed in an ultra high vacuum chamber, and rotation measurements were taken (Table 12, Column A). Ten 4-hr thermal cycles were completed from 30 to 700°F and back to 30°F with a maximum temperature ramp of 10°F/min. Rotational torque measurements were taken at frequent intervals during each thermal cycle and before removal from the fixture (Table 12, Column B). No apparent damage was caused by the thermal cycle tests. No significant changes were noted in rotational torque measurements. A slight net loss of weight was detected and slight traces of lubricant transfer were observed on each bearing.

TABLE 12
BEARING ROTATION TORQUE MEASUREMENTS
(in.-oz)

Bearing Set No.	Condition*	Torque					
		Clockwise			Counterclockwise		
		Breakaway	Average	Running	Breakaway	Average	Running
1	A	-	13	8	-	12	8
	B	9.5 11.5 16.5	12.5	10	13 12.5 16	14	12
	C	21 20 23	21.5	15	24 25 26	25	16
	D	32 27 19	26	18	29 22 26	26	17.5
2	A	-	12	9	-	11	8
	B	8 7.5 12	9	8	8 7.5 8	8	6
	C	18 16 20	18	13	22 20 16	19	14
	D	29 21 27	26	15	31 28 32	30	16
3	A	-	12	8	-	12	7
	B	11.5 9.5 10.5	10.5	7	9 8.5 8.5	8.5	6.5
	C	25 18 20	21	16	24 26 29	26	19
	D	27 21 23	24	16	28 23 27	26	19.5

*Condition

A = Prethermal cycle
B = Postthermal cycle
C = Post first SVA
D = Post second SVA

The shock, vibration, and acceleration tests were conducted by the environmental test unit at Santa Susana. The control drum weight simulator and one set of bearings were installed in a rigid aluminum fixture which was mounted on the shaker table for shock and vibration, and then on the centrifuge for acceleration tests. The bearings were not disturbed in the fixture throughout these tests. Upon completion, the bearings were removed from the fixture and stored in a plastic bag with desiccant; the next set of bearings was installed and the above process repeated. When the second shock, vibration, and acceleration test series was conducted, the only variation to the above procedure was the added measurement of the alignment torque before removal of the bearings from the fixture. Upon completion of the tests, a resonance search of the test fixture was conducted. Resonance frequencies were found at 290 and 2000 cps.

When they were not being tested, the bearings were stored with a desiccant in plastic bags. During the shock and vibration tests the relative humidity ranged from less than 20 to 53%.

Two accelerometers were used — one to monitor input to the shaker table and the other to monitor bearing response which was recorded on an X-Y plotter. During the first series of tests the maximum bearing response was 30 g at 1200 cps and 7.5 g input and the normal response was less than 15 g. When the bearings were removed from the fixture, the upper bearings could be freely moved on the alignment movement. However, two lower bearings were tight for manual manipulation and the third was somewhat tight. Traces of dislodged lubricant were noted on both the upper and lower bearings. The bearings were disassembled for examination. Considerable transfer of lubricant between the race and the ball was apparent.

The bearings were weighed, reassembled, and weighed again. The bearings were remounted in the shock and vibration test fixture and the alignment torques measured (Table 13). The bearings were then installed in the thermal cycle test fixture and rotation torques measured (Table 12, Column C). The rotational torques had increased by a factor of two but were still within limits. No alignment torque requirements had been specified for this series of tests; therefore, no pretest measurements are available for comparison. Particles of lubricant were dislodged with each movement. At this time a maximum of 12 in.-lb was established as the rotation torque limit.

TABLE 13

BEARING ALIGNMENT TORQUE READINGS BEFORE
SECOND SHOCK, VIBRATION, AND ACCELERATION
(in.-lb)

Bearing No.	Bearing Designation	Starting Measurement		Rotated 60°		Rotated 120°	
		CW	CCW	CW	CCW	CW	CCW
1	Lower	5.25	2.4	1.3	0.3	0.45	0.85
2	Lower	1.5	1.25	0.75	0.90	1.2	1.1
3	Lower	3.5	2.0	0.8	0.6	0.8	0.8

The second shock, vibration, and acceleration tests caused an additional increase in rotational torque (Table 12, Column D) and a substantial increase in the alignment torque (Table 14). It will also be noted that these torque readings remained high with successive measurements whereas they had progressively diminished after the first tests. Only one reading exceeded the 12 in. lb maximum.

TABLE 14

BEARING ALIGNMENT TORQUE READINGS AFTER
SECOND SHOCK, VIBRATION, AND ACCELERATION
(in.-lb)

Bearing No.	Bearing Designation	Starting Measurement		Rotated 60°		Rotated 120°	
		CW	CCW	CW	CCW	CW	CCW
1	Lower	12.8	11.2	8.1	7.5	11.2	11.9
2	Lower	10.0	9.4	8.8	8.1	8.8	11.0
3	Lower	8.1	7.5	9.4	10.2	11.9	10.6

A slight weight loss occurred following each test and lubricant particles were visible following alignment torque measurements. The higher torque value did not impair functional operation and, as there are no criteria available for evaluating the weight loss and lubricant transfer effects, the qualification test program is continuing. Endurance tests are underway and completion of 90 days at temperature and high vacuum is expected early in April 1964.

b. Control Drum Drive System

A purchase order was issued for the test chamber. Delivery of this ultra-high vacuum chamber is currently scheduled March 1, 1964, but the AEC is working with AI to effect an improvement in this delivery schedule. The ultra-high vacuum system includes an electron beam titanium evaporation system and a 400 l/sec ion pump to give a clean vacuum of 10^{-9} mm Hg, or better, with the fixture and components in place at a temperature of 700°F.

Fabrication of the simulated SNAP stationary reflector is 90% complete. A flight hardware drum will be used for the movable drum (to be mounted in the reflector) thus giving heat transfer characteristics which are more reliable than previous characteristics.

With the exception of the stepper motor and position sensor, flight hardware that has been received includes all parts necessary to assemble the test unit. These two items are expected in the near future.

Instrumentation is 75% received and is 85% assembled. The balance of the instrumentation not received includes the silicon-controlled rectifiers for heater output control. The delivery of these items is awaiting approval by the Los Angeles City Electrical Code Department but no delay in the program is expected.

2. Electrical Components

a. Control Drum Actuator

The seven control drum actuators supplied for qualification tests were subjected to their respective tests in the qualification test sequence. Serial No. 2822 and 2823 were installed in a high flux capsule in the BMI reactor on September 18, 1963. These two units were subjected to a neutron and gamma dose rate test similar to the radiation dose rate expected for the SNAP 10A reactor during operation. The test was run for eight reactor cycles (approximately 96 days) with removal from the reactor on January 6, 1964. Data were taken at frequent intervals throughout the test. Although the data have not been reduced, preliminary analysis of the test results indicates both units performed satisfactorily.

Serial No. 2824 and 2825 were placed in the thermal vacuum endurance tests. No. 2824 satisfactorily completed the qualification program. Serial No. 2825 experienced a brake failure after having completed 200 hr of endurance

testing. The unit was removed from the test equipment and returned to project for analysis.

Serial No. 2826 satisfactorily completed all its assigned qualification tests. Serial No. 2827 and 2828 have successfully completed the test sequence through radio frequency interference tests. These two units are currently in the 90-day thermal-vacuum endurance phase with completion expected early in March.

b. Temperature Sensor and Switch

The qualification test procedure for the electronic temperature sensor switch was completed and released. The design, fabrication, and setup of the test fixtures and test apparatus were completed. Four switches, Serial No. 1011, 1012, 1014, and 1015 were received for qualification testing. All units were given performance record tests and tested within specification. Serial No. 1011 and 1012 were assigned for radiation testing and completed this test phase with no malfunctions.

Serial No. 1014 and 1015 have completed radio frequency interference tests and are currently in the thermal cycle test phase.

Preparation of the qualification test procedure for the platinum resistance sensor is in process. The design, fabrication, and checkout of the radiation test fixtures were completed. Four sensors, Serial No. 107, 119, 108, and 116, were received for testing. Serial No. 107 and 119 were assembled in the radiation fixture and are currently being prepared for shipment to BMI to be included in the forthcoming high flux Capsule 7 irradiations.

The fabrication of the ultra-high vacuum systems and all related test apparatus was completed. Purchase orders were issued for data acquisition and recording equipment.

c. Startup Controller

Controllers Serial No. 8 and 13 completed the 90-day thermal-vacuum endurance tests. Although these units are very sensitive to stray electrical pulses, their operation and performance appear satisfactory when they are properly shielded. Currently, the test data are being reduced and the qualification test report is being prepared.

d. Cable and Connectors

The two representative cable harnesses, Serial No. 002 and 003, were assembled in HF Capsule 6 at BMI. The irradiation test of these components is scheduled to start January 22. The test will be a total dose test and will last three reactor cycles, approximately 6 wk. Harnesses Serial No. 001 and 004 successfully completed performance record and thermal cycle tests, and are currently undergoing shock, vibration, and acceleration tests. No further testing on these components is planned.

B. SAFETY COMPONENTS

1. Mechanical Components

a. Electrically Actuated Band Release Device

The following activities associated with qualification tests of six EABRD's were completed. Shop fabrication of the following test fixtures was completed:

- 1) Shock, vibration, and acceleration fixture, shown in Figure 30.
- 2) Bake out oven. This oven was designed to the bake out test fixture, as shown in Figure 31, for endurance testing under ultra-high vacuum.
- 3) Shop fabrication of all test fixtures for these tests has now been completed. Additional fabrication is still required in the lab.

A three-mode temperature controller was delivered which now makes possible more accurate temperature response control during automatic temperature cycling. The unit was assembled and checked out with liquid nitrogen used as the cooling medium. The checkout indicated an accurate linear temperature ramp response. The best results were obtained when the test fixture heater turned on whenever the indicated temperature was below the set point at any time during the thermal cycle. Also the liquid nitrogen was programmed to turn on when the indicated temperature was above the set point during the down ramp and low-temperature hold periods of the thermal cycle.

Two development type EABRD's were received and were used for partial equipment checkout and to acquaint technicians with proper test procedures. Figure 32 shows one EABRD mounted in a tension test fixture during a checkout performance record test.

1-9-64

7623-55298

Figure 30. EABRD Shock, Vibration,
and Acceleration Test Fixture

9-13-63

7622-1821

Figure 31. EABRD Endurance Test Fixture

Figure 32. EABRD Tension Test

1-9-64

7623-55301

The following EABRD reliability proposals were prepared:

- 1) A proposal for testing of 135 EABRD's to establish the probability of inadvertent EABRD separation due to environmental conditions during launch, ascent, and flight to orbit. Included in the proposal are detailed descriptions of the budget, time schedule, equipment, controls, and instrumentation for the tests. The type of tests and test conditions are to be similar to the 40 EABRD reliability tests. The test program is to be completed in 12 mo. Test firings were not planned.
- 2) A proposal for reliability testing of 40 EABRD's. The proposal consisted of a detailed description of the tests, a detailed cost estimate, a time schedule, sketches of the equipment, test fixtures, and control circuits required. It is planned to run screening tests on 10 EABRD's to determine the correct test parameters for the remaining 30. The tests are designed to produce short time failures under accelerated test conditions in order to determine the reliability under long time flight conditions. The

specific type of failure to be analyzed is mechanical separation of the EABRD which allows the reflector retaining band to separate. The tests suggested are: thermal cycle, shock, vibration, acceleration, and endurance under vacuum. These tests are to be run at different temperatures and at different simulated band loads. The test schedule is to be completed in 6 mo. Firing of the EABRD's is not planned.

Approval was received for the 40 EABRD reliability tests and the action enumerated below was initiated to start the program:

- 1) Three belljars were ordered and received.
- 2) Belljar base plates were designed, ordered, bids were reviewed, and the order let.
- 3) A two-belljar manifold was reworked, assembled to a 6-in. oil diffusion pump vacuum system, and checked out.
- 4) A blankoff flange was modified to mount a belljar to an existing 1200 l/sec ion pump.
- 5) The instrumentation and control consoles were designed and partially assembled.
- 6) EABRD belljar test fixtures were designed.
- 7) Additional material required, equipment, and temperature recorder conversion kits were ordered.

b. Temperature Actuated Band Release Device

TABRD qualification testing included equipment shakedown tests and component actuation repeatability tests.

The thermal cycle test fixture was received, cleaned, and assembled on the vacuum chamber (Figures 33 a, b, c). Test runs indicated that vacuum pressures in the 10^{-9} mm Hg range were readily obtainable. Shakedown of the instrumentation and heaters led to minor modification and changes. To increase the heatup rates, stainless steel foil was wrapped around the thermal cycle fixture to insulate and reflect the heat back into the unit (Figure 33a).

In order to develop operational characteristics, four repeatability tests were run using a TABRD supplied by the Component Development Section. For

12-30-63

7623-55287

a. TABRD Assembly

12-30-63

7623-55288

b. Prior to Flange Assembly

12-30-63

7623-55289

c. Thermal Cycle Fixture
One TABRD in Place

Figure 33. TABRD Thermal Cycle Test Fixture

these tests a special snap ring arming sensor switch was developed and successfully used. The test information and data have been turned over to Component Development for further analysis. The pressure in the 20-in. vacuum chamber during the tests ranged from 10^{-7} to 10^{-8} mm Hg.

The thermal cycle fixture was modified to permit more convenient mounting and dismounting of the TABRD units. The shock, vibration, and acceleration fixture was similarly modified. The modification allows transfer of the TABRD units from the thermal cycle fixture to the shock, vibration, and acceleration fixture without disassembly of the TABRD.

2. Electrical Components

a. Reflector Ejection Delay Timer

Four timers, Serial No. A4784, A4785, A4788, and A4789, were received for qualification testing. One of the units, A4789, did not meet specifications on the initial performance record tests. The remaining three units performed satisfactorily, and Serial No. A4784 and A4785 completed the radiation tests to the component qualification levels without malfunction. Serial No. A4788 was recalled for quality control action and no further testing was performed. No further testing is planned on this component.

C. DIAGNOSTIC COMPONENTS

1. Limit Switches

Limit switches Serial No. 101, 102, 107, and 117 successfully completed the 90-day thermal-vacuum endurance tests. The case of Serial No. 106 was broken, while being set up for radio frequency interference testing, and was unusable. This switch was replaced by Serial No. 097. Serial No. 097 and 103 were tested for radio frequency interference (RFI). Preliminary analysis of the RFI data indicates that these units do not conform to MIL-I-26600. Serial No. 103 is currently undergoing thermal-vacuum endurance test. Serial No. 104 and 105 were installed in HF Capsule 6 at BMI and will be subjected to a total dose radiation test, with reactor startup scheduled for January 22. The test will run for three reactor cycles or approximately 6 wk.

2. Position Sensor

The qualification test procedure was revised to comply with the updated equipment specification. Sensors Serial No. 1009 and 1010 completed the

radiation test phase at BMI with no apparent malfunctions. The test was performed in conjunction with the control drum actuators in HF Capsule 5. This was a dose rate test similar to the expected dose rates the component will receive from the SNAP 10A reactor and was conducted at 500°F in a vacuum of 1×10^{-5} mm Hg. Serial No. 1011 was received and required excessive input shaft torque in the initial performance record test. This unit was returned for adjustment or repair. Serial No. 1012 was acceptable and completed performance record and thermal cycle tests. The input torque required became excessive during vibration testing so that this unit was also returned to project for disposition. Replacement sensors have not as yet been received for further testing.

3. Position Sensor Demodulators

Demodulators Serial No. 06 and 08 were received and subjected to performance record, operation, and regulation tests. No discrepancies were detected. These two units were subjected to gamma predosing and are currently being prepared for neutron irradiations at STIR. The qualification test procedure was revised to concur with the latest revisions to the equipment specification.

D. SHIELD

As the scheduled test program had already been completed, no tests were conducted during this quarter. All reports on the SNAP 10A shield thermal-vacuum tests and shock and vibration tests have been completed and are being published.

E. FUEL

All 66 elements in the SNAP 10A fuel element qualification program have completed the scheduled test inputs of thermal cycling, shock and vibration, and ramp heating, and have accrued at least 90 days of thermal endurance testing (1100°F isothermal). Single-element reliability of successfully completing 90 days operation is now 0.989, and full-core reliability (37 elements) is 0.674 (both at 50% confidence).

Nine elements completed the 1-yr, 1100°F thermal endurance program and were removed from the endurance furnaces. The remaining 57 elements continued on test. Premutation test results continued to show no increase in fuel element permeation rate.

Examination of the nine elements that completed the 1-yr endurance showed no significant change in cladding or fuel rod dimensions, and no damage, apparent to the naked eye, to the Solaramic hydrogen barrier. The decrease in fuel rod weight, if assumed to be all due to hydrogen, was found to correspond to the hydrogen loss estimated from integrated permeation measurements during the year. The actual loss averaged 0.05 gm per fuel rod, which is equivalent to 1/5 of 1% of the original hydrogen.

Study of the permeation rates of all 66 elements shows decreasing rates during the first 500 hr of 1100°F endurance testing for the high- and medium-carbon elements. This decrease may be due to improvement of the hydrogen barrier "aging" or hydrogen outgassing from the cladding. The minimal weight loss in the nine elements noted above shows that the decreasing rates were not due to decreasing hydrogen pressures resulting from high hydrogen losses.

VII. REACTOR SYSTEM FABRICATION

Several problems encountered during the quarter delayed the fabrication schedule. Most of the problems involved electrical components. A brake in one of the control drum actuators failed during qualification testing and all actuators were recalled from the field for reinspection and reacceptance testing. Limit switches undergoing system tests presented problems which required intensive review. The limit switch mountings on all systems were modified to incorporate changes which should greatly increase the reliability of the switch readings. Delivery of assemblies was postponed until completion of work on both the brake and limit switch problem areas.

Results of radiation testing at BMI indicated that the wiring used in the reflector wiring harnesses was not acceptable. Carbonization of epoxy sizing in the wiring caused excessive degradation in insulation resistance. New wiring harnesses were started for FS-1 and all subsequent systems and these replacement harnesses will be installed on the reactors whenever they become available. The reactor deliveries were not delayed due to the wiring harness.

To achieve an increased negative reactivity coefficient, the grid plate material for all systems was changed from Hastelloy-C to Type 316 stainless steel. Plates for FS-1 were on hand and fabrication for plates for subsequent systems was initiated.

A NaK loop was made operational for acceptance test and calibration of platinum resistance sensors for all flight systems. Significant engineering experience was gained from this series of tests.

Program redirection was received late in the quarter to stop all assembly on FS-5. The components originally assigned to this system will be used as spares, where necessary. The beryllium parts have already been reassigned to FSEM-2A.

All FSEM-2A system parts which will be used for electrical engineering tests were completed. In many cases, these parts were obtained from previous test assemblies. Problems with the magnesium blocks originally intended for this system resulted in assignment of the FS-5 beryllium parts to the assembly.

Refinements applied to Sm_2O_3 determinations for the FS-3, -4, and -5 cores were applied to a review of the Sm_2O_3 values reported for the FS-1 core. The method used to determine samarium for the FS-3, -4, and -5 cores was based on correlations of destructive analyses of selected tubes with the weight of poison added during the coating process. With this method, the Sm_2O_3 content of the FS-1 core was determined as $3.25 \text{ gm} \pm 0.01 \text{ gm}$ at the 95% probability level. No significant difference was found between the originally reported samarium content, taken from end sample analysis, and the later samarium content determined from coating weight gain. Therefore, the average of the two methods, $3.19 \text{ gm} (\pm 0.02 \text{ gm at the 95% probability level})$ is now considered to be the best estimate of the Sm_2O_3 content of the FS-1 core.

Fabrication of the fuel elements for the FS-3 core was completed. Eighty-five percent of all assemblies had leak rates below 0.50 cc/hr per element at 1200°F isothermal. The proposed maximum leak rate of 0.50 cc/hr can apparently be attained with some decrease in the assembly yield. New processing controls were developed to correlate the total samarium in the tube, as determined by destructive sampling, with the weight of coating applied to the tube. With these new controls, it appears feasible to fabricate core loadings with total samarium content within the proposed limit of $\pm 5\%$ of nominal. For the FS-3 core, the total Sm_2O_3 is $3.72 \pm 0.04 \text{ gm}$ at the 95% confidence level.

Assembly of fuel elements for the FS-4 and FS-5 cores was completed. Almost 90% of the assembled elements exhibited permeation rates lower than the proposed specification limit of 0.50 cc/hr per element at 1200°F isothermal. The preliminary samarium content of the cores is $3.59 \pm 0.05 \text{ gm}$ for both the FS-4 and FS-5 cores (at the 95% confidence level). It appears that total samarium for each core will be well within the proposed limits of $\pm 5\%$ of nominal.

A. FS-1

1. Reactor Structure

To achieve an increased negative reactivity coefficient a decision was made to change grid plate material from Hastelloy-C to Type 316 stainless steel. One set of stainless steel plates was available and these were fully inspected and certified for use on FS-1.

2. Electrical Equipment

The electrical equipment for the FS-1 system was completed and delivered prior to this report period except for the electrically actuated band release device (EABRD).

During the quarter various problems were encountered in fabrication of the EABRD bodies from 17-7 Ph steel tubing. The problems included difficulty in obtaining satisfactory welds, susceptibility to corrosion during fabrication, and indications that the material could become overaged during the brazing cycle. A complete review of the design was made and it was established that a redesign was warranted.

In the new design, which was completed, the material for the bodies was changed to Rene-41. The part which previously required welding was redesigned to be completely machined from one piece of bar stock, and spacing dimples were added to the female body to control the thickness of the braze material between the two parts.

Fabrication of the new parts was initiated. These parts will be used on FS-1 as the ultimate shutdown device and for a testing program to demonstrate their adequacy.

Examination of a control drum actuator brake coil which failed in qualification test revealed a crushed coil bobbin which could have caused or contributed to the failure. The actuators from FS-1 and subsequent systems were recalled and checked to verify that the same condition did not exist in other actuators and to perform a brake temperature rise rate test to detect any weaknesses in the brake coil windings. This work was successfully completed.

Preliminary results from the BMI radiation tests indicated that the wiring originally used in the reactor wiring harnesses would degrade at an unacceptable rate in radiation. This is due to carbonization of the epoxy sizing used on the glass insulation fiber. Five samples of wire were obtained for testing in the next BMI capsule, HF-6, to determine which type of wire is acceptable. Based on earlier nonnuclear high-temperature tests, and in anticipation of satisfactory results in early February from BMI, fabrication of a new FS-1 wiring harness was initiated using American Super-Temp wire. This harness will replace the existing one after the reactor has been integrated into the FS-1 system.

3. Fuel

Refinements applied to Sm_2O_3 determinations for the FS-3, -4, and -5 cores were applied to a review of the Sm_2O_3 values reported for the FS-1 core.

The reported FS-1 samarium was based on correlation of destructive analyses of selected cladding tubes with analyses of end samples of all tubes. Six tubes selected for destructive analysis were sectioned; five sections, each 1/2-in. in width, were taken from each tube at equal intervals along its length. The samarium oxide in each section was determined by chemical analyses, and a regression analysis was performed to relate the samarium analysis to the sample position in the tube. It was found that the samarium content of the sections showed a consistent decrease down the length of the tube, with the highest samarium content at the open end. This distribution resulted from the coating process that gave a uniformly tapered coating along the length of the tube. The taper permitted a statistically accurate correlation to be made between the total samarium in the tube and the samarium in the section cut from the open end of the tube. This end sample section was therefore cut from each tube and analyzed. The tube's total samarium content was then determined by comparison of this end sample analysis with the previously established correlation between end sample and total samarium. The total Sm_2O_3 for the 37-element core was reported by this method as 3.13 ± 0.07 gm at the 95% probability level.

The method used to determine samarium for the FS-3, -4, and -5 cores was based on correlations of destructive analyses of selected tubes with the weight of poison added during the coating process. This change was made when it was determined that the coating process had changed after FS-1 fabrication and did not produce a uniformly tapered coating. The FS-1 fabrication history was searched and the correlation between chemical analysis of the six tubes and destructively sampled poison coating weight gain was established. The Sm_2O_3 content of the core, determined this way, was 3.25 ± 0.01 gm at the 95% probability level.

No significant difference was found between the originally reported samarium content, taken from end sample analysis, and the later samarium content, determined from coating weight gain. Therefore, the average of the two methods, 3.19 ± 0.02 gm at the 95% probability level is now considered the best estimate of the Sm_2O_3 content of the FS-1 core. The fuel element

specification calls for 3.63 ± 0.36 gm of Sm_2O_3 per core, so the total Sm_2O_3 is slightly below the lower limit (3.27 gm) of the specification.

B. FSM-4

1. Reflector

Component parts required to improve heat transfer to the TABRD inner tension rod were completed. This completed all parts required for the device and procedures were nearly established for installing and setting it. In January, the decision was made to suspend qualification of the TABRD, so FSM-4 and subsequent systems will be delivered with the device installed, but not active. To decrease the possibility of premature failure, the stud holding the band will not be notched.

The graphite bushings in the position sensor supports were replaced with dry-film coated titanium bushings.

Numerous installation and removal requirements of the void filler blocks, coupled with bolt seizure problems, necessitated the removal of self-locking fastener inserts from all locations where the void filler blocks attach.

The limit switch mountings were modified to decrease the breakage of the brittle case material and to alleviate the problem of the shift of the switches out of adjustment. The major change incorporated was the use of fiberglass pads on either side of the switches sandwiched between metal plates. Counter-sinking of the attachment screws also provided more positive support.

2. Electrical Equipment

Except for the EABRD and replacement of the reflector wiring harness (Section VII-A-1), all electrical work for the FSM-4 system is complete. Fabrication of the replacement harness will be completed after review of radiation data from BMI. The harness will then replace the existing harness after the reactor has been integrated with the FSM-4 system.

In the fit-up test of a nuclear power unit (NPU) heat shield on the FSEM-3 system, it was established that additional clearance is required between the heat-shield ejector bracket and the reactor-NPU interface connectors, to ensure heat shield ejection. The additional clearance has been obtained by designing a

new curved connector backshell for these interface connectors. The curved backshells will be used on all of the new harnesses.

3. Assembly and Acceptance

The wiring harness on this assembly was reworked and reinstalled after the thermal vacuum and vibration acceptance tests. Following installation, the vibration acceptance test was repeated and a performance record of the system was made. All components were satisfactory except six limit switches which shifted out of adjustment and gave improper readings.

These continuing problems with limit switches were cause for an intensive review of the limit switch mounting methods. This review was completed during the quarter, the switches on FSM-4 were modified, and the assembly was almost ready for delivery at the end of January.

C. FSEM-2A

1. Reflector Mockup

FSEM-2A is to be a system mockup to evaluate the electrical flight hardware. The reflector on this system will be assembled with magnesium drums and blocks previously used on a safety test; and a tooling vessel, no longer needed, will be used for the basic structure. Upper and lower reflector brackets, upper adjusting brackets, and hinges were appropriated from the safety test hardware. Squib actuators were obtained from a previous qualification test. Gear segments and pinions were obtained from a stock of gears on which a nitriding process had been tried. New parts made were the upper reflector drive brackets, drum shafts, drum lock brackets, eccentric hinge pins, and reflector band splice. New drawings were necessary for reworking the magnesium blocks and drums, upper and lower reflector brackets, and for the changes necessary to the wiring installation, reflector assembly, and main assembly. Reproductions of previous drawings were used for these new drawings wherever possible.

After checking into the vapor pressure of magnesium, it was decided to electroless nickel plate the blocks and drums so that excessive outgassing of the magnesium alloy would not occur during thermal-vacuum tests. Samples of the magnesium alloy, after nickel plating, were obtained and tests were made to gain information on this outgassing problem. The plating on the samples kept

the outgassing at a safe minimum at temperatures of 100 to 200°F above that to which the reflector would be subjected. After the magnesium parts were removed from the heat treat, which was necessary to stabilize the magnesium, a large number of cracks became visible in the blocks. Evidently, the stress relief had brought out cracks which had been sustained during the safety drop test. A decision was therefore made in late January to use the beryllium flight blocks and drums previously assigned to FS-5. Assembly drawings and other changes will be made to reflect this latest decision. At the end of the quarter all parts were available for the assembly.

2. Electrical Equipment

Updating of the FSEM-2 system to FSEM-2A involves fabrication of new reflector wiring harnesses and procurement of new control drum position sensors for the reflector mockup. The wiring harnesses were completed during the quarter and the position sensors were delivered, though acceptance testing was not completed. A replacement harness will be fabricated for this system during the coming quarter to make the electrical system identical to that on a flight system.

3. Assembly and Acceptance

All components for FSEM-2A were accumulated in the assembly area. Work on this assembly was to be initiated on February 1.

D. FS-3

1. Reactor Structure

An order was placed for five sets of Type 316 stainless steel grid plates. These grid plates will be used in all SNAP 10A flight prototype reactor assemblies in place of the previously specified Hastelloy-C plates. An improved negative reactivity coefficient will be realized as a result of this change.

2. Shield

This shield was delivered following final assembly in Oak Ridge in September 1963. Radiographic and visual examination indicated such a low-quality closure weld that the assembly was returned to Oak Ridge for rework. Later it was decided to reassemble the lithium hydride shield into a new casing rather than to repair the old casing. The spare casing was shipped in late

December. It is anticipated that this unit should be completed and returned by early March. The FR-4 shield, which is identical in design, will be substituted and used in the FS-3 system.

3. Reflector

All of the modifications described for the FSM-4 reflector (Section VII-B-1) were also made on the FS-3 reflector.

4. Electrical Equipment

All electrical components were complete for FS-3 except for the EABRD and a replacement wiring harness. The status of the EABRD is described in Section VII-A-2. Materials are on hand and fabrication of a replacement harness was started, although the harness will not be installed until after the reactor is integrated with the power conversion system.

5. Assembly and Acceptance

The FS-3 thermal vacuum test was substantially completed as planned. The only failures noted were a small drift in the output of the two demodulators and limit switch setting. In one case, this demodulator drift stayed within specification limits; the other drift was slightly over specification. This problem was later rectified after its origin was traced to poor grounding of the instrument case. The limit switch malfunctions were mainly in the excessively tight tolerances on the fine control drum switches. The design changes made on limit switch mountings should eliminate this problem.

During this test, a fairly complete set of photographs was obtained of the reflector-vessel dimensional changes at hinges and brackets. Due to a variety of instrument problems, the data were not as precise as expected, but all dimensional changes appeared to occur in the direction anticipated and were of the correct order of magnitude. This test was run in "real" time using a tooling controller and a simulated NaK pump, simulated NaK lines, etc. The major variation from real operation was involved in running the fine control drums out far enough and long enough to check the reflector-vessel clearances. This was done once at near the maximum reflector-vessel ΔT and several times as the system approached equilibrium. While precise measurements could not be taken, the gap appeared to be near the design values and in no case did there appear to be any danger of contact.

Due to the brake failure during qualification testing, the motors from the assembly were removed and inspected, and the limit switches were modified to incorporate the changes in mountings. The assembly was prepared for the vibration acceptance test which is the final operation before delivery for integration into the FS-3 system.

A NaK loop, which simulated the SNAP 10A reactor outlet lines, was completed and was used for acceptance testing and calibration of the platinum temperature sensors. These sensors, with their associated electronic switch, control the reactor outlet temperature. The calibration techniques were successfully established and all sensors for flight system use were tested and ready for installation. While testing in the NaK loop, several problems were encountered and satisfactorily solved. As this test was the first of the sensor in an installation similar to the flight system, much was learned about sensor operating characteristics and about the expected performance of the complete reactor control system.

6. Fuel

Fabrication of the fuel elements for the FS-3 core was completed. Forty-eight elements were delivered, 40 of standard N_H and 8 low N_H . Only four elements required waiver action to accept minor dimensional discrepancies. The balance of the core loading met all drawing and specification requirements. Summaries of permeation rates and Sm_2O_3 content are shown in Figures 34 and 35. The N_H is given in Figure 36.

Two proposed specification changes were evaluated during FS-3 fabrication. One change was to lower the maximum acceptable leak rate from 0.8 cc/hr-element at 1200°F isothermal to 0.5 cc/hr. The other was to tighten the tolerance on total amount of Sm_2O_3 in a core from $\pm 10\%$ of the nominal 3.63 gm to $\pm 5\%$.

With one exception, element assembly procedures were unchanged from FS-1 procedural methods. There was an added requirement for an internal atmosphere of at least 15 mm of helium in the element. The helium is to serve as a heat transfer medium between the fuel rod and the cladding during the reactor startup, before the fuel heated up and generated a hydrogen atmosphere. The assembly atmosphere within FS-1 elements was about 250 μ of helium.

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Figure 34. SNAP 10A FS-3 Histogram of Hydrogen Leak Rates at 1200°F Isothermal (40 Standard N_H Fuel Elements)

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Figure 35. SNAP 10A FS-3 Histogram of Sm_2O_3 Content (mg/Element) (40 Standard N_H Fuel Elements)

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Figure 36. SNAP 10A FS-3 Histogram of N_H Values (40 Standard N_H Fuel Elements)

No difficulties were encountered in adopting this change. The permeation rates of the elements assembled for FS-3 (Figure 34) can be summarized as follows:

$$98\% \leq 0.80 \text{ cc/hr at } 1200^\circ\text{F isothermal}$$

$$85\% \leq 0.50 \text{ cc/hr at } 1200^\circ\text{F isothermal}$$

It can be concluded that the proposed maximum leak rate of 0.50 cc/hr can be attained at the expense of a nominal decrease in the acceptance yield.

Considerable efforts were devoted to control of the process of application of the Sm_2O_3 to the tubing, and to improvement of the accuracy of measuring the total Sm_2O_3 applied to each tube. The application process was modified to eliminate the uniform taper in coating thickness and, therefore, the uniform change in samarium content that was present in the FS-1 elements. As a result of the process modification, the distribution of Sm_2O_3 down the length of the tube in the FS-3 elements was more random than the Sm_2O_3 distribution in FS-1 elements. The result of the random distribution was that the end sample determination of samarium content used for the FS-1 elements was no longer valid.

A new method was developed to estimate the total samarium of each cladding tube. This method establishes a correlation between the weight of Sm_2O_3 added during the coating process and the destructive analysis of representative tubes. Four tubes are selected at random from each lot of 40 tubes coated as a group. These four tubes are then sectioned. Five 1/2-in.-wide sections are cut from the 12-1/4-in. length of the tube that is opposite the fuel rod. The Sm_2O_3 in each section is determined by chemical analysis, and a regression analysis is performed correlating the total samarium in the tube, as determined by this chemical analysis, with the weight of coating containing poison that was recorded when the tube was coated. The total samarium in each of the 36 coated tubes remaining in the original lot of 40 is then determined from its recorded poison-coat weight and the established regression line.

This technique was used prior to the coating of FS-3 cladding tubes to establish and verify processing parameters. Process controls were instituted to control the total poison coat weight within ± 0.2 gm. The modified processing and reporting techniques have proven effective in maintaining close control over

Sm_2O_3 contents of cladding tubes. It appears feasible to fabricate core loadings with total samarium content within the proposed limit, $\pm 5\%$ of nominal at the 95% confidence level.

In the 12-1/4-in. of coated tube that is opposite the fuel rod, the Sm_2O_3 content of the FS-3 elements, as estimated by the poison-coat weight method, ranges from a minimum of 93.1 mg/element to a maximum of 100.6 mg/element. For the 37-element core, the total Sm_2O_3 is 3.72 ± 0.04 gm at the 95% probability level.

E. FS-4

1. Reactor Structure

Stainless steel grid plates are being fabricated for this system as described in Section VII-D-1.

2. Shield

Outgassing potential determination of this shield was completed in mid-November. Radiographic inspection performed in Oak Ridge revealed one large tungsten inclusion in the closure weld. This inclusion will be removed and the general area repaired in Oak Ridge. By early February, this rework should be completed and the assembly returned and used in place of the FR-3 shield.

3. Reflector

In addition to the modifications described for the FSM-4 reflector (Section VII-B-1), the control drum bearing support brackets for FS-4 were reworked to permit installation of the bearing sockets. At assembly, it was seen that the bore was tapered and undersized at the bottom.

4. Electrical Equipment

An EABRD and a replacement wiring harness are being fabricated for this reactor. No delay due to the lack of these components is anticipated, however, in completion of the assembly as the assembly and testing will continue with the original harness.

5. Assembly and Acceptance

The assembly of FS-4 proceeded at a low level during the month of January. All parts for the assembly are available and the effort is currently being increased.

Acceptance testing of all components, including the temperature sensors and electronic temperature switches, was completed.

6. Fuel

Assembly of fuel elements for the FS-4 and FS-5 cores was completed during the period. All elements have completed the assembly permeation test and almost 90% of them had permeation rates lower than the proposed specification limit of 0.50 cc/hr-element at 1200°F isothermal. About 40 elements have completed permeation testing after acceptance level vibration testing. Three of these elements have been rejected because of leak rate increases (caused by the vibration testing) in the range of 0.20 to 0.25 cc/hr. The rejected elements had been subjected to special criticality tests and the increased leak rates are thought to be caused by handling damage. Historically, appreciable increase in leak rate after vibration testing occurs in less than 1% of the elements tested.

There were no changes in element fabrication methods from FS-3 to FS-4 and -5. The methods for Sm_2O_3 process control and content determination were the same as those developed for FS-3. The preliminary samarium content of the FS-4 and -5 cores is summarized in Table 15. The data is based upon a tentative assignment of fuel elements to cores since all elements have not completed final permeation testing. It appears that total Sm_2O_3 for each core will be well within the proposed specification limits of 3.63 ± 0.18 gm, $\pm 5\%$ of nominal.

F. FS-5

1. Shield

Fabrication of all component parts has been completed. Trial fit-up of the casing and internal support structure has been accomplished. These components were shipped in mid-January to Oak Ridge for shield assembly.

2. Assembly and Acceptance

Redirection was received late in the quarter which stopped all assembly work on FS-5. Because of this, the parts are being accumulated and stored as a kit. No assembly or acceptance testing was accomplished and none is planned in the future.

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Figure 37. S10A Ground Test Kit Modifications

TABLE 15

PRELIMINARY SAMARIUM CONTENT OF FS-4 AND -5 CORES

	FS-4	FS-5
Total Sm_2O_3 content (gm per 37-element core)	3.594 ± 0.054 at 0.95 probability level	3.595 ± 0.055 at 0.95 probability level
	3.594 ± 0.073 at 0.99 probability level	3.595 ± 0.074 at 0.99 probability level
Total Sm_2O_3 content (mg/in. average per 37-element core)	7.93 ± 0.11 at 0.95 probability level	7.94 ± 0.11 at 0.95 probability level
	7.93 ± 0.15 at 0.99 probability level	7.94 ± 0.15 at 0.99 probability level

3. Fuel

Fuel fabrication efforts for FS-5 are proceeding with FS-4 efforts and are described in Section VII-E-6.

G. AEROSPACE GROUND EQUIPMENT

1. Ground Test Kit

The ground test kits are used to provide reversible drum drive as well as scram capability for each of the four SNAP 10A reflector drums. These kits replace the flight drum drives for fuel loading, NaK loading, and physics tests. Precision position sensors are provided within the kit for drum position feedback.

a. Component DescriptionController

The ground test kit controller provides 330 programmed sets of pulses per minute to drive the kit actuators. Each set of pulses drives the actuator 7.2° which in turn drives the drum through an 80:1 transmission ratio for a drum speed of $1/2^\circ$ per sec. Drum drive direction is reversible.

Ground Test Kit

The coarse drum and fine drum drive ground test kits are different only in scram direction and mounting bracketry. A sectioned isometric view of the fine drum drive kit is shown in Figure 37.

The actuator drives an 80:1 worm transmission which is engaged to the main shaft by an electromagnetic clutch. A pair of clock power springs are attached to the main shaft and wind up as the drum is driven in. Energy is thereby stored to scram the drum when the clutch is deenergized. A pair of snubber springs and cams cushion the impact of the scrambling system. The lower drive shaft is designed with a torsional spring rate which cushions scram impact loads reflected to the reactor drum spline. A solenoid, when deenergized, inserts a rebound stop into a main drive shaft cam which prevents drum rebound beyond 100° from drum full-in position.

An inner coaxial shaft connected rigidly to the main shaft drives the position sensor head. The position sensor head incorporates a selysn pickup and a potentiometer pickup for two separate outputs.

Two limit switches are operated by the main shaft cams. One switch indicates drum full-in position and one indicates 100° drum out position.

b. Kit and Controller Modifications

During testing of the ground test kit, a number of failures occurred. Failure diagnosis indicated excessive friction existed throughout the kit from improper bearing materials, over constrained shafts and assembly misalignment. Several scram failures occurred when the magnetic clutch armature did not release after collapsing the magnetic field. There were also electrical failures in the actuator and in the special controller used to drive these actuators. A detailed review of the complete ground test kit and controller design was initiated to investigate the problem areas. It was determined that major modifications were necessary to assure successful operation. These modifications have been incorporated into the kits and may be detailed as follows:

- 1) A special dry film lubricant capable of withstanding the environmental conditions of vacuum, temperature, and irradiation was added to all bearing surfaces, including the scram springs.
- 2) The actuator bearings were redesigned to reduce friction and overconstraint was eliminated by removal of the outrigger bearing. The mounting of the actuator to the kit was changed to facilitate assembly.

- 3) The addition of a flexible coupling between the kit drive shaft and the position sensor reduced shaft constraintment.
- 4) The kit drive shaft was redesigned with tolerance for both parallel and angular misalignment between the kit and the reactor assembly.
- 5) An alignment sleeve was added to provide a pilot fit and assure proper location of the kit to the reactor assembly.
- 6) A special mounting pin was added to allow assembly of the kit on the reactor without damage to the kit.
- 7) A thrust spacer was added to the top of the drive shaft to assure proper axial adjustment of the scram assembly.
- 8) The snubber ratchet pawls and their associated solenoids and limit switches were unnecessary and were subsequently removed.
- 9) The electromagnetic clutch armature was redesigned from a sliding joint to a bellows flexure to assure clutch disengagement when the magnetic field is cut.
- 10) The electromagnetic clutch field was redesigned to optimize the magnetic field air gap.
- 11) The scram springs were redesigned to a dual spring system with lubricated spacers to prevent cocking, nesting, or binding of the springs.
- 12) The actuator electrical winding procedure was modified to improve insulation. (It should be noted that although the actuators used on the ground test kit are similar to the flight actuators, the greater torque requirements of the ground test kit drive mechanism necessitated modifications that sacrificed motor insulation in favor of increased motor windings.)
- 13) The rebound stop engagement pawl was modified to ensure positive engagement of the pawl with the cam and prevent scram rebound.
- 14) Inspection holes were added to the main support tube to allow visual inspection of the drive shaft axial alignment.

In addition to the modifications to the kit itself, several changes have been made to the kit controller. These are outlined as follows:

- 1) The logic scheme was revised so the timing cam operates continuously rather than intermittently.
- 2) The cam contours were modified to reduce the cam loads.
- 3) Voltage spike suppressors were added to both the controller and the actuator to prevent instantaneous overload.

c. Acceptance Test

After assembly, each kit must pass a series of electrical and mechanical tests to determine the acceptability of the unit. Fixed limits are held on all electrical parameters and torque measurements. The kit is subjected to a series of 10 scrams under room ambient conditions. Ten more scram tests are conducted in vacuum to ensure proper operation in the prescribed environment. After the vacuum checkout the electrical and mechanical tests are repeated to confirm that the kit's operation is consistent and within specification limits. Two ground test kits have successfully been acceptance tested.

d. Ground Test Kit Qualification Test

Two kits are subjected to qualification tests that represent 15 kit operation lives and include a total of 1200 scrams for each kit. The qualification testing follows a sequence of electromechanical performance record tests before and after performance testing in vacuum and air. The qualification and acceptance tests yield direct correlation for substantiation of the acceptance test for each delivered kit. One kit has successfully completed two-thirds of the qualification testing.

2. Coarse Drum Drive Assemblies

As problems were encountered with the ground test kits during the previous quarter, it was decided to design a modified flight drive system for the coarse control drums to be used during the FS-1 power tests. This design was necessary to ensure a reliable drive system, which is the primary shutdown mechanism for FS-1, on a schedule compatible with the system test. This schedule did not allow significant development time. With this change, the ground test kit itself was relieved of the radiation and long-term endurance

requirements and of the requirement for a very reliable drive system. Though the ground test kit drive system is expected to be reliable, its failure will not constitute a safety problem as it will never be used without the scram capability.

All test experience to date indicates that a flight drive is very reliable and can be adapted to the FS-1 coarse control drums without problems. The original intention had been to modify the ground test kits by elimination of the clutch and scram capability, using only the ground test kit drive system for the coarse control drums on FS-1. During this quarter, a drive assembly consisting of a flight stepper motor and gear train was designed, fabrication was started, and a testing program initiated. A flight-type position sensor will be mounted on the assembly as will IN and OUT limit switches.

To ensure reliability, all materials used in the assembly are to be the same as those used in the flight drive system. All test data to date, including the DRM test, BMI tests, and component qualification tests, are directly applicable to the assembly. Information on these tests is being collected to support qualification of the drive.

By the end of the quarter, the motors, position sensors and demodulators were all assigned for these assemblies and fabrication of the gears and bracketry was near completion. Preparations for the test program which will be performed using the DRM reactor were sufficiently advanced to allow start of testing in mid-February.

As the coarse drum drive assemblies can operate with a faster than normal stepping rate, a series of special tests of control drum actuators was initiated to verify their ability to operate in this mode. Two actuators, Serial No. 2830 and 2831, were received and have been subjected to accelerated operation tests.

Actuator No. 2830 has completed 30 cycles consisting of 10 min continuous operation and 50 min cooling under the following conditions:

Input voltage	18 vdc
Environmental conditions	ambient
Stepping rate	4 motor pulses/sec

Actuator No. 2831 completed 80 cycles of 44 min continuous operation and then was cooled until the brake case was approximately 100°F. This test was performed under the following conditions:

Input voltage	18 vdc
Environmental conditions	ambient
Stepping rate	1 motor pulse/sec

Fixture fabrication and vacuum system checkout for testing of both actuators under other environmental conditions is in progress.

VIII. REACTOR SYSTEM TEST (10 DRM)

The S10 DRM reactor tests were performed to develop and qualify the SNAP 10A reactor system using components developed by Component Development. The objective of the program was to confirm the analyses conducted by Reactor Engineering and to verify the integrity of the reactor system design.

Work during this quarter consisted of post-mortem examination of the reactor assembly and the preparation for additional follow-on testing. The post-mortem examination has been completed and the report covering this work is being written. Three major problems were uncovered and are described below.

During the performance record check, after completion of the 90-day endurance test, the Z stepper motor brake failed to release properly. However, the motor still had the capability of driving the drum. The stepper motor was disassembled during the post-mortem examination and the flexible coupling connecting the brake disk to the shaft had stiffened limiting the disk movement and thus lowering the braking efficiency. A new type flexure that cannot stiffen is now used in the reference design.

Torque measurements of several of the reflector drum bearings were found to be high. Upon disassembly, impurities that appeared to be burned lint or dirt were discovered in the affected bearings. In one case a metal chip had scored the bearing and shaft so that the shaft could not turn in the bearings. In this case the ball was turning in its housing. Pretest inspection and checkout had not revealed these faults.

Two broken leads were found during the post-mortem examination of the wiring harness. One was connected to a coarse drum release squib and the other to a fine drum release squib. Both leads were normal during the pretest performance record check. The squibs fired normally at the initiation of the test and so it is thought that the leads were broken during post-test handling.

It should be noted that in no case had these discrepancies caused the reactor assembly to malfunction.

In analyzing the results of the DRM Tests two questions were raised: "How accurate were the recorded temperatures?" and "How much would nuclear heating affect these temperatures?".

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The reflector temperatures recorded were measured by placement of sheathed floating junction thermocouples spring-loaded against the reflector and then shielded to minimize radiation losses. A better method would have been to immerse the thermocouples in the beryllium since, to simulate the effects of nuclear heating, electric heating elements would have to be imbedded in the beryllium. However, holes could not be drilled originally as it would have weakened the reflectors and could have caused failure during the shock and vibration tests.

Since no new vibration tests are planned for the S10 reactor assembly, holes have been drilled and thermocouples and heating elements have been prepared for a follow-on test to validate previous temperature profiles. This test will be performed in conjunction with qualification of the coarse drum drive assemblies (Section VII-G-3-b).

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