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TEST SUMMARY OF THE SNAP 8
DEVELOPMENT REACTOR MOCKUP-1
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AEC Research and Development Report

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M-3679 (48th Ed.)

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Edited

By

W. J. KURZEKA

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CONTENTS

	Page
Abstract	6
I. Introduction	7
II. Design Description	11
A. Core Assembly	11
B. Reflector Assembly	17
1. Support Structure	17
2. Reflector	19
3. Drum Bearings	19
4. Actuator, Gears, and Coupling	21
5. Spring Drives and Snubbers	25
6. Limit Switches and Position Sensors	25
7. Drum Lock-Out Devices	29
8. Reactor Shutdown Devices	31
9. Ejection Initiators	33
10. Wiring Harness	35
C. Shield Assembly	35
D. Electric and Electronic Controls	38
1. Startup Programmer	39
2. Controller	39
3. Relay Box	41
III. Testing Program	43
A. Standard Performance Record Test	43
B. Initial Survey for Shock and Vibration Testing	45
C. Startup Reliability Test	51
D. Hot Performance Record Test	55
E. Launch Environmental Test	57
F. Final Startup Reliability Test	59
G. Tests Planned But Not Run	59
IV. Summary and Conclusions	63

TABLES

	Page
1. S8DRM-1 Vibration Characteristics	48
2. Startup Reliability Test	52
3. Squib Induced Shock Levels	55
4. Upper Heat Simulator Temperature Profile	56
5. Component Temperatures at Steady-State	56
6. S8DRM-1 Launch Vibration and Shock Environment	58
7. Final Startup Reliability Test	60
8. Squib Firing Shock Data	62

FIGURES

1. SNAP 8 Development Reactor Mockup-1	10
2. SNAP 8 Nuclear System	12
3. Core Assembly Components	13
4. Shield-Core Vessel Quick Disconnect	14
5. Reflector Assembly (upper view)	16
6. Reflector Parts	18
7. S8DRM-1 Drum Bearings	20
8. View at Bottom of Reflector Assembly	22
9. Electric Actuator Drive System	23
10. Exploded View of the Electric Actuator	24
11. Reflector Assembly (lower view)	26
12. S8DRM-1 Limit Switch	27
13. S8DRM-1 Rotary Position Sensor	28
14. S8DRM-1 Rotary Position Sensor (cross section)	28
15. Reflector Assembly With Key Latch	30
16. Reflector Holding Band Components	32
17. Electrically Actuated Band Release Device	34
18. Thermally Actuated Band Release Device	34
19. Schematic Showing the Technique of Terminating Cable Conductors	36

FIGURES

	Page
20. S8DRM-1 Shield and Casting Hardware	37
21. SNAP 8 Controller Block Diagram	40
22. S8DRM-1 Relay Box	42
23. SNAP 8 Developmental Reactor Mockup-1 Environmental Test . . .	44
24. Reactor Vibration Test	46
25. S8DRM-1 Vibration Schematic	47
26. Reactor Assembly With Protective Test	50
27. Vacuum Chamber	54
28. Reactor Core Heat Simulator	54

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ABSTRACT

This report describes the design, fabrication, and testing of the SNAP 8 Development Reactor Mockup-1 by Atomics International (AI). The program objectives and design requirements are stated. The components and assembly are shown in photographs and described functionally. Several test phases including shock and vibration testing and operations at high temperature in a vacuum chamber are described. The program met all objectives before termination of the program in July of 1965.

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I. INTRODUCTION

The SNAP 8 Developmental Reactor Mockup-1 (S8DRM-1) represents the initial concept of a SNAP 8 flight system reactor. The design evolved from earlier SNAP reactor concepts (i. e., SNAP 10 and SNAP 2). Both the basic configuration and the initial component design represent a more sophisticated approach toward a high power reactor capable of unattended operation over a 10,000-hr period. The design criteria for the S8DRM-1 are based upon the preliminary performance specification for the SNAP 8 Flight Reactor. Basically, these can be summarized as requirements to provide a reactor capable of producing 600 kw, 1300°F outlet coolant temperature, and 10,000 hr of unattended operation in a space environment.

The main objectives of the S8DRM-1 program are to:

- 1) Assist the development program in the design of flight qualified systems and components
- 2) Test the adequacy of fabrication techniques to provide flight qualified systems and components
- 3) Demonstrate the capability of assembling all individual systems and to assemble all systems to form the nuclear system
- 4) Demonstrate that systems and components can operate satisfactorily before, during, and after simulated environmental conditions
- 5) Demonstrate that systems and components can withstand simulated space and thermal environmental conditions over the reactor life.

To achieve these objectives and relate the information to a flight system, the S8DRM-1 design was based on the concept of a flight system as it existed in 1962. The original intent was to duplicate the flight system as closely as was practical with certain modifications to account for the fact that the S8DRM-1 was a nonnuclear, electrically heated device which would be subjected to extensive testing and handling.

The performance characteristics required of the S8DRM-1 are:

- 1) A design configuration will be provided based on a flight type nuclear system with the necessary structure, control system, safety and shutdown features, diagnostic components, and radiation shield.

2) The complete configuration must withstand testing to simulate a flight life sequence; this will include normal handling, cold and hot preflight check-outs, launch environment, orbital startup, and orbital life of 10,000 hr.

3) The assembly will meet the performance requirement when operated with a 15-kw electric core heater, heaters in the NaK pipes to simulate the NaK pipe temperature, and a heater below the shield to simulate the heat received from the power conversion system. The pressure for simulated prelaunch testing must be $<10^{-3}$ torr, and for simulated orbital testing it must be $<10^{-6}$ torr. The temperatures maintained by the heaters must correspond to a nominal 1300°F NaK outlet and 1100°F NaK inlet temperature to the reactor core.

4) Using the above criteria for thermal analysis, plus criteria for the nuclear heating effects, the component design temperatures were defined as follows:

Component	Maximum Temperature (°F)
Core Assembly (exclusive of fuel elements)	1400
Reflector Support Structure	1200
Reflector	1150
Drum Bearings	1000
Actuator	1050
Gears	1050
Limit Switches	975
Position Sensors	1000
Drum Release Actuator Squib	250
Temperature Actuated Band Release Device	1300
Electrically Actuated Band Release Device	800
Ejection Springs	1100
Wiring Harness	1200
Radiation Shield	
LiH	975
Structure	1150
Programmer	Room Ambient
Controller	Room Ambient
Relay Box	Room Ambient
Key Latch	Room Ambient
Squibs	Room Ambient

5) The radiation shield is required to limit the total integrated radiation from a 300-kwt reactor to 5×10^{12} nvt fast neutrons and 9×10^6 rads (carbon) for gammas over an 8-ft-diameter payload surface located 15 ft from the center of the reactor core.

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6) The assembly must withstand the vibration and shock levels specified in Table 6.

This report describes the design, fabrication, and operation of the components and the assembly. It also describes the testing program conducted and the design changes or refinements indicated as a result of the program.

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Figure 1. SNAP 8 Development Reactor Mockup-1

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II. DESIGN DESCRIPTION

The S8DRM-1 is shown photographically in Figure 1 and a conceptual drawing is shown in Figure 2. It is composed of a core assembly, reflector assembly, shield assembly, and protective cover assembly shown in Figure 1 (without cover) and electronic components consisting of a controller, startup programmer, and relay box. All major components were designed and developed at AI under contract with the Atomic Energy Commission (AEC).

A. CORE ASSEMBLY

The core assembly components are shown in Figure 3. The reactor core vessel is a cylinder of Type 316 stainless steel with an OD of 9.21 in. and a wall thickness of 0.105 in. The overall length is approximately 21.5 in. The vessel has a reversed dished inlet head at the base, a torispherical outlet head at the top, flued elliptical inlet nozzle located in the cylindrical portion of the inlet heat plenum, and an outlet nozzle located in the center of the torispherical head.

The core vessel was fabricated as a forged billet and then rough machined to shape. The forging was ultrasonically tested to insure crack free material. The reflector support brackets and the inlet nozzle were welded to the lower head. The entire assembly was then machined to final dimensions.

The lower head was similarly fabricated (machined from a forged billet) and then welded to the vessel. Complete inspection of the weld was performed through the mediums of radiography, dye penetrant, and helium leak check.

The lower grid plate was designed to accommodate 211 fuel elements plus internal reflectors. The 0.250-in.-diameter fuel element holes were held to a locational tolerance of ± 0.001 in. based on rectangular coordinates. The grid plate rests in the lower portion of the core vessel and is bolted in place. Hastelloy C, 0.438 in. thick, was chosen as the material to be used for the lower grid plate based on thermal expansion considerations which would exist in a nuclear reactor.

The upper grid plate was fabricated from Type 316 stainless steel. The design was based on a particular orientation with respect to the lower grid

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Figure 2. SNAP 8 Nuclear System

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12

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Figure 3. Core Assembly Components

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Figure 4. Shield-Core Vessel Quick Disconnect

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14

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plate. Again, the upper grid plate contains sufficient holes to accommodate the locating pins at the top of the fuel elements. There is a gap of approximately 0.060 in. between the top of the fuel elements and the lower surface of the upper grid plate to permit thermal expansion in an operating reactor. The upper grid plate fits inside the core vessel and rests on a ledge machined on the vessel wall.

The upper head is torispherical in shape with the outlet nozzle in the center of the head. The rim of the upper head was designed to be inserted in the core vessel with the lower portion resting against the top surface of the upper grid plate, thereby locking the latter in position. The top edge of the rim was designed to be welded to the upper edge of the core vessel in a standing lip configuration. This was based on the concept of a flight system which would require that the standing lip burn off during reentry to the earth's atmosphere. The core internals, including the fuel elements, would be ejected and destroyed. The upper head was not welded to the core vessel on the S8DRM-1 but, rather, was clamped into position. This permitted interchange of fuel elements and heaters used during various portions of the test program.

The upper head was fabricated from a Type 316 stainless steel forging. The part was rough machined prior to welding the support ribs into position. The entire assembly was stress relieved and machined to final dimensions.

To attain substantial conformity to a flight type core during shock and vibration, 211 dummy fuel elements were fabricated from stainless steel. These elements are duplicates of the proposed enriched uranium fuel elements in terms of external configuration and mass. Their primary use is in conjunction with shock and vibration tests.

Part of the flight system safety requirements called for separation of the core vessel from the neutron shield during reentry. This was accomplished by using a quick disconnect V clamp to attach the core to the neutron shield (Figure 4). Both the core vessel and the neutron shield have mating V flanges. Two quick disconnect latching mechanisms are provided and clamp tension adjustments are made with a T bolt. Each of the disconnect latches is attached to a reflector half through flexible cables. When the reflector half is ejected under spring load, the latch is opened and the core vessel is freed from the

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16

Figure 5. Reflector Assembly (upper view)

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neutron shield thus permitting separation of these items. The latch springs open after 10° movement with a 25-lb pull on the cable.

The clamp was fabricated from Inconel X; a backing strap of the same material was welded to the v-shaped section to provide additional rigidity. The interior of the clamp as well as all moving parts were coated with a dry film lubricant.

B. REFLECTOR ASSEMBLY

Figure 5 shows the reflector assembly. In a flight system, reactor control would be based on a beryllium reflector. On the S8DRM-1, the beryllium reflector is supported on an Inconel X plate which, in turn, is supported on the lower head of the core vessel. The reflector is divided into halves; each half contains movable beryllium control drums plus a fixed segment such that when the control drums are in the most reactive position (facing the core) the core is surrounded by a nominal 3-in.-thick beryllium cylinder approximately 16.25 in. long.

The reactivity characteristics of the reflector were based on a flight system containing 211 enriched uranium hydride fuel elements. Three of the six control drums are designated as snap-in drums which, upon command, are spring-driven and locked in a position facing the core. In this situation, the shutdown margin is \$1.30. Active control takes place through the medium of the remaining three control drums which are alternately driven towards the core by bi-directional motors under a preset program.

1. Support Structure

The reflector support structure was designed as an Inconel X welded assembly divided in two parts (Figure 6). Each half supports its half of the beryllium reflector and transmits all loads to the brackets attached to the core vessel lower head. The junction between the support structure and the core vessel brackets is in the form of a pivot joint. This allows the reflector half to rotate away from the core vessel and forms the primary system for scrambling the reactor through reflector ejection. This process is aided by a series of springs installed between the reflector support structure and the neutron shield.

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18

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Figure 6. Reflector Parts

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The upper surface of the reflector support structure contains mounting pads which are designated as the reference surface. The beryllium reflector is bolted to this surface and all critical points on the support structure are machined with reference to this surface.

In addition to supporting the fixed beryllium, the support structure also provides the housings for the control drum lower bearings and mounting surfaces for the position sensors.

2. Reflector

The fixed beryllium reflector was designed as a cylinder with a nominal 3-in. thickness. Three cavities are provided in each reflector half to accommodate the control drums so when all drums are facing the core, the latter is completely surrounded by beryllium (Figure 6).

The fixed reflector is bolted to the lower support structure. To prevent excessive loads on the threads tapped in the beryllium, threaded steel inserts were installed. All holes in the beryllium were flat-bottomed drilled to avoid stress concentrations.

The raw beryllium material is a controlled grade which limits the percentage of impurities. The material was hot pressed to approximate shape, stress relieved, and then machined to final dimension. A black anodize coating with a thermal emissivity greater than 0.7 was applied to all surfaces.

The rotating control drums were designed and fabricated in a manner similar to that of the fixed reflector. The drums were carefully contoured to provide a 0.060-in. clearance between the drum and its cavity in the fixed reflector. The back surface of each control drum is flat and provides the mounting face for beryllium plates or shims which vary the reflectivity when bolted to the drum.

3. Drum Bearings*

Each control drum has a set of bearings which were designed to provide precision clearances for control accuracy, self-alignment through ball joints, lubrication for antiself-welding and low friction, and structural support of the drums during all operating conditions. The bearing parts are shown in

*L. G. Kellogg, "SNAP Reactor Control Drum Drive," NAA-SR-9615 (CRD) (August 24, 1964)

Figure 7. S8DRM-1 Drum Bearings

Figure 7. Lubrication is provided by the carbon graphite bushing and by molydisulphide on aluminum oxide coated surfaces. The parts are inserted into the bearing brackets and adjusted for clearances of a few ten-thousandths of an inch during assembly of the reflector drums (Figures 5, 6, and 8).

4. Actuator, Gears, and Coupling^{*}

Three of the control drums are driven by an electric actuator through a one-stage gear reduction and flexible coupling to the drum bearing shaft (Figure 9). The actuator is a variable reluctance stepping motor^{*} with four separately energized windings and operates on 28 vdc. Energization of each phase in sequence causes a shaft rotation of 1.8° . For S8DRM-1 operation, a four pulse sequence is used resulting in a 7.2° overall step of the shaft. The output pinion drives a gear to reduce drum rotation by a factor of 13.8 which results in 0.52° rotation of the central drum per each four pulse sequence. A minimum of 15 lb-in. of torque is transmitted to the control drum shaft.

The actuator assembly is shown in Figure 10. The brake is engaged, when no electric power is applied, to hold the rotor-gears-drum drive chain in a given position. During stepping operation, one stator coil is energized first, the brake is energized to release the rotor, the other stator coils are energized in sequence, the brake is deenergized, and finally the fourth coil is deenergized. The overlap of brake and stator coils operation assures that the rotor is held by a force at all times.

Since the actuator is required to operate at 1000°F , an AI developed ceramic insulation was applied to the coils. A wet winding process in which the wire is drawn through a slurry of the ceramic was used to wind the coils. This was followed by vacuum and heat curing. The bearing material combinations are the same as used for control drum bearings. The brake faces are an aluminum oxide coating vs chromium plating to prevent contact welding of the surfaces during long periods of time at high temperature under the spring force. The spring is made from René 41 wire.

The gears were fabricated from Inconel X and were coated with a dry-film lubricant. The large spur gear shaft was supported by a carbon compound bushing inserted in the lower end bell of the actuator. A bellows-type coupling

^{*}S. Giles and S. Marcus, "SNAP 8 Critical Drum Actuators," NAA-SR-9645 (December 15, 1964)

Figure 8. View at Bottom of Reflector Assembly

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22

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23

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Figure 9. Electric Actuator Drive System

NAA-SR-12300

24

Figure 10. Exploded View of the Electric Actuator

connected the other end of the shaft to the control drum upper shaft to accommodate misalignment between the actuator and the control drum due to differential thermal growth.

5. Spring Drives and Snubbers

As previously noted, three of the six control drums are spring driven. Three spring-loaded actuators are located on the stationary reflector above three startup control drums (Figure 5). A torsion spring located within the actuator housing is torqued to 16 in.-lb while the drum is in the full-out position. When the squib actuator is energized and the pin is driven from the bottom of the control drum, the latter immediately rotates towards the core.

Both the spring housing and the torsion spring were fabricated from Inconel X. This high temperature spring material was used because the device would be required to operate a number of times on the S8DRM-1 after it had been subjected to thermal testing.

At the end of its travel, the snap-in drum must be in a position facing the core vessel. A combined snubber and latch assembly was provided for each of the snap-in drums to absorb the momentum of the drum as it approaches its final position and to lock it in place (Figure 11). As the drum rotates, an arm mounted on the drum contacts a spring-loaded plunger which is part of the snubber assembly. The latching mechanism is based on a cantilever spring-type jaw. The arm is driven into the latch jaw where it contacts a rebound plunger and spring and the drum is firmly fixed with a minimum of rebound. The snubber assembly is mounted on the reflector support structure. The plunger travel is regulated by changing the spring preload through the use of a threaded plug. Once the optimum setting has been attained, the plug is locked in place.

Friction throughout the snubber assembly was minimized by an application of a dry film lubricant, a form of MoS_2 , which is used rather extensively throughout S8DRM-1.

6. Limit Switches and Position Sensors

Limit switches were mounted on the reflector support structure to indicate particular positions of the control drums. Each snap-in drum actuates an

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26

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Figure 11. Reflector Assembly (lower view)

individual switch which indicates on the test console that the drum has fully rotated and now faces the core. One active control drum is monitored by two switches which indicate positions of 86.5 and 74° from full in, respectively. At these positions, the control drum stepping rate changes. The limit switches are purely diagnostic and do not provide a control function, since the change in stepping rate is preprogrammed and is time dependent.

The particular limit switches are commercial items appropriate for high temperature use. Some modification was made at AI. In particular, the switches were disassembled and all surfaces which would be subjected to rubbing were coated with a dry film lubricant (Figure 12).

The position of each of the active control drums was constantly monitored by a position sensor mounted on the reflector support structure. The control drum shaft was connected through a bellows coupling to the position sensor shaft. Basically, the latter is a rotary differential transformer which generates a signal through a change in reluctance as the shaft is rotated (Figures 13 and 14). The design was based on the technology developed for the SNAP 10A sensor, with design refinements to minimize sensitivity to temperature and improve

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Figure 12. S8DRM-1 Limit Switch

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Figure 13. S8DRM-1 Rotary Position Sensor

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Figure 14. S8DRM-1 Rotary Position Sensor
(cross section)

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28

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bearing design. The null point is set midway between the full-in and full-out control drum positions. Any change generates a signal which is passed through a demodulator thus converting the 400 cps sensor output to a dc voltage. The position sensor is capable of a resolution better than 10 min of arc with a frictional torque of less than 1 oz-in.

7. Drum Lock-Out Devices

The normal position for all control drums in the shutdown state is 154° of rotation away from the full-in position. This is the position during launch and is maintained for personnel safety at all times when the reflector assembly is mounted on a core loaded with fuel. When the reflector assembly is mounted on a loaded core, a key operated latch mechanism is installed. As seen in Figure 15, this is a scissors mechanism that is installed on a mounting slide-way between two control drums at four locations. When mounted, a key is turned and the handle is rotated to extend linkages of the scissors into slots on the adjacent drum which is rotated to the full-out position. This prevents drum rotation. An interlocking mechanism prevents removal of the latch until squib actuated pins are in place at the base of each drum. The latch can, however, be rotated a few degrees to a test position where the scissors linkage is in a wide slot section on the electrically driven control drums. This test position allows operation of the actuators to move the drum through a few degrees to verify performance.

In a typical launch operation, squibs are installed in the squib-fired actuators just before launch. The squib-actuated pins become inserted into a hole in the base of each drum, the interlock with the key operated latch is then deactivated, and the key latch assembly is removed. The squib-actuated pins remain in place during launch to restrain the drums against shock and vibration. When it is desired to start the reactor in orbit, a ground command is sent to the space vehicle to cause ignition of the squibs (two in each location for redundancy). The explosive gas generated acts on a piston within the squib actuator and effects pulling of the pin from the central drum (Figure 8).

The squib actuator was designed with a ball lock configuration which prevents accidental release of the pin. It is necessary for the ball retainer to be actuated through gas pressure to move the locking pin. The various parts were fabricated from a titanium alloy to minimize weight and still retain high strength.

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Figure 15. Reflector Assembly With Key Latch

8. Reactor Shutdown Devices

The basic reactor safety mechanism for a SNAP 8 flight system is predicated on reflector ejection. This technique has been incorporated on the S8DRM-1. In addition, an explosive charge may be provided to destroy the reactor upon ground command. This latter device would find primary use from the time prior to launch until just before a nuclear startup in orbit. A mass mockup of the explosive charge, fabricated of aluminum, was attached to the S8DRM-1 (Figure 11). It surrounds the base of the core and the attachment points are on the neutron shield casing. The mockup is in the shape of a C and is split. In a flight system, this shape would contain an explosive and the device would be capable of being ejected on command. The mockup does not contain this explosive feature.

The initial concept of a flight system required that the reactor be destroyed upon reentry to the earth's atmosphere. Since both the neutron shield and the beryllium reflectors constitute large heat sinks, it was considered mandatory that these items be separated from the reactor core and that the latter burn completely during the reentry process. These were primary considerations in the design of the safety system and were incorporated in S8DRM-1.

The reflector ejection system is powered by a set of springs with a 360-lb load to each reflector half (Figure 11). The springs are confined in a compressed position between the bottom of the reflector support structure and the top of the neutron shield. When the steel band is removed from the top of the reflector halves, they rotate away from the core on the pivots located at the bottom of the core vessel. The springs provide the force. After 15° of rotation, the pivots become free and the reflector halves are ejected in an outward and upward direction.

The springs were manufactured from René'41, a nickel base alloy. Design and fabrication techniques involved considerations of stress levels and creep rate over a 10,000-hr period at temperatures exceeding 1000°F. After being subjected to this environment, the spring must retain the capability to impart sufficient force to the reflectors to result in successful ejection. Processing of the springs included heat treatment after forming to raise the allowable stress level.

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Figure 16. Reflector Holding Band Components

9. Ejection Initiators

The reflector halves are held together at their upper edges by a steel band (Figure 5). The reflector is constrained in this manner until the band is released for reflector ejection. Provisions are made in the S8DRM-1 design for initiating ejection by an electrical signal, by a sizable drop in coolant temperature, or by thermal weakening of the band during reentry.

This steel band (Figures 5 and 16), known as the reentry band, is 0.036-in.-thick by 0.625-in.-wide, Type 316 stainless steel. At two points in the band, spring loaded mechanisms are attached which maintain band tension and also allow for thermal expansion of the reflector without creating excessive stress levels in the band material. Ceramic standoffs, attached to the reflector, provide nonself-weld mounting surfaces or contact points for the band. Calculations showed that the band must be loaded to a definite value to hold the reflector halves in contact during launch shocks and vibrations. A T bolt fastener is used to adjust tension. In addition to holding the reflector halves together, the band is sized to weaken and break early during reentry, thus initiating reflector ejection.

The electrically actuated band release device (EABRD) was designed to cause the band to separate upon command (Figure 17). The device consists of a thin wall Rene' 41 tube with a small heating element inside it. When a signal is sent by ground control, the heater is energized and develops sufficient heat to weaken the tube resulting in rupture of tube and reflector ejection. A prototype of the EABRD (less the heating element) was used on the S8DRM-1.

The other mechanism which could be used to break the band was the thermally actuated band release device (TABRD) shown in Figure 18. A short ceramic cylinder containing a circumferential notch is installed in the band. The ends of the ceramic cylinder are threaded and mate with tapped fittings which are welded to the band. The draw bar of the TABRD hooks onto the ceramic cylinder in the area of the notch. The body of the TABRD is mounted to the NaK outlet pipe. The operation of the device is based on differential thermal expansion. The draw bar portion of the TABRD expands relative to the outer body as the NaK outlet temperature in a flight system increases from startup through steady state conditions. A ratcheting feature prevents force loading of the

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Figure 17. Electrically Actuated Band Release Device (EABRD)

Figure 18. Thermally Actuated Band Release Device (TABRD)

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ceramic bolt during heatup. This represents the arming phase. If, for some reason, the NaK outlet temperature falls appreciably, the draw bar contracts relative to the body, fails the notched ceramic cylinder, and initiates reflector ejection. This device was used on the S8DRM-1 but was rendered inoperative to avoid reentry band separation during thermal testing.

10. Wiring Harness

The S8DRM-1 cable harness and its associated connectors provide the connecting link between the power source and the receiving units such as the control drum actuators and the squib actuators. In addition, the cable harness transmits signals from the limit switches and the control drum position sensors. The major portion of the cable harness starts at a series of connectors located at the bottom of the neutron shield and runs along the conical shield surface (Figure 1). Another series of connectors are located on brackets at the top of the shield. From this point, the harness is divided into two parts; each part being routed along a reflector half. The termination points are at the individual components which must receive power or transmit signals.

The materials and fabrication techniques used on the wiring harness are shown in Figure 19. The wire end terminals were slipped onto the connector back pin and resistance welded in place. Finally, the harness was baked at 800°F for 3 hr in an air oven to remove the silicone sizing by oxidation.

C. SHIELD ASSEMBLY*

The S8DRM-1 neutron shield was based on a 300-kwt reactor. The function of the neutron shield is to reduce radiation from the reactor to a level which can be tolerated by other components of the system and the payload. The assumed payload configuration was an 8-ft-diameter circle located 15 ft from the reactor. The specified maximum doses are 5×10^{12} nvt for neutrons and 9×10^6 rads gamma at the end of a 10,000-hr life. The primary shielding materials are lithium hydride (LiH) for neutron attenuation and tungsten for gamma attenuation (Figure 2).

*F. H. Welch, "Lithium Hydride Technology II, Fabrication of Shadow Shields for SNAP Applications," NAA-SR-9400, Vol II (CRD) (September 30, 1965)

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Figure 19. Schematic Showing the Technique of Terminating Cable Conductors

In a flight system, the shield would be built as a two-region device. A layer of Li^7H would be used close to the core because of its low heat generation and the balance of the shield would be natural LiH . This arrangement would reduce the peak temperatures encountered. In the S8DRM-1, both regions contain natural LiH , since the fabrication technique was able to be demonstrated at reduced cost.

The shield was designed with a conical shape approximately 28 in. long (Figure 20). The top diameter is 31.8 in. and the bottom diameter 40.4 in. An inner bulkhead, approximately 10 in. below the top of the shield, separates the two LiH regions. A LiH stabilizing structure was designed for installation in the shield casing. This controls the cracking normally associated with LiH . The shield casing material selected was Type 347 stainless steel based on welding data and compatibility with the LiH .

The basic design concepts were predicated on a unique production technique of filling the shield with the granulated LiH and then subjecting the filled shield to a high temperature which would melt the granulated LiH . This operation was done with the shield in an inverted position (Figure 20). A reservoir, located above the filling surface, also held the granular LiH . The reservoir was made

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Figure 20. S8DRM-1 Shield and Casting Hardware

NAA-SR-12300

37

~~CONFIDENTIAL~~

in concentric portions with concentric fill tubes. The inner tube and reservoir were connected to one region while the annular reservoir and tube were connected to the second region.

The shield casing and casting hardware were placed in a retort which was evacuated, backfilled with purified H_2 to 850 mm Hg pressure, and heated for approximately 30 hr to melt the charge. The casting was cooled by raising the furnace in 2-in. increments to provide cooling from the bottom upwards during a 97-hr cooling period.

After casting, the conical surface of the shield was coated with chrome oxide to provide a high emissivity coating for more effective cooling of the shield in vacuum. This material was applied by the plasma spray process to a thickness of 0.003 to 0.005 in. (see Figure 1).

D. ELECTRIC AND ELECTRONIC CONTROLS

In a flight system, a programmer would provide signals to various equipment during the startup sequence. A relay box would receive inputs from the programmer and other command circuits and then close the power relays to various squibs and other actuating devices. A controller would receive inputs from sensing devices such as temperature sensors and switch power to the control drum actuators.

The automatic startup sequence devised for the S8DRM-1 is listed below:

<u>Time</u>	<u>Event</u>
0	Automatic startup switch is closed.
15 sec	The reactor destruct explosive charge is ejected.
30 sec	All squibs are fired. The snap-in control drums lock in position facing the core.
1 min	Squib voltage is removed.
1.5 min	The three control drums start stepping toward the core at a rate of 50 steps/min.
9.14 min	The control drum monitored by limit switches reaches 86.5° from the full-in position. The first limit switch is closed. The stepping rate changes to 1.5 steps/min.
48.1 min	The control drum actuates the second limit switch at 74.5° from the full-in position. The stepping rate changes to 2 steps/min.

1. Startup Programmer

The startup programmer provides an automatic reactor startup sequence. It provides discrete, timed, switch closures over a 2-hr period to automatically sequence the events required for reactor startup. The three basic building blocks are a stable time base oscillator, a frequency divider network, and an output circuit. A series of breadboard circuits utilizing magnetic core-transistor oscillators, incremental magnetic core pulse dividers, and relay driver stages were designed, built, and evaluated for performance. From the most promising circuits, the S8DRM-1 programmer was designed and built. The unit was rack mounted in a console external to the reactor. Additional circuitry was provided to allow resetting of the programmer plus manual overriding in certain areas of the sequence.

2. Controller

Normally, the controller would receive inputs from various sensing devices and, in turn, provide power to the control drum actuators. In a nuclear system, the controller would be required to provide a sequence of step outputs to an actuator as long as an input signal indicated that the coolant temperature was outside the control temperature dead band. It would also be required to provide a sequence among the three control drum actuators so that the drums would always remain symmetrically located. Necessarily then, the controller in a flight system must use radiation hardened components to satisfy the requirements for long-term active control. A controller block diagram is shown in Figure 21. Since the S8DRM-1 was designed as a nonnuclear test device and reactor core heat would be provided by electrical heaters, plus the fact that many of the operational tests were to be performed at ambient conditions, it was decided that the particular controller to be used should operate on a time base rather than on a temperature sensing device. Further, the control drum limit switches, though normally signaling a change in the stepping rate, would not be the exclusive mechanism involved. Again, the real time base would provide the change in stepping rate.

The inability of vendors to provide thoroughly tested, radiation hardened components necessitated the use of more conventional electronic parts.

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Figure 21. SNAP 8 Controller Block Diagram

An irradiation program was underway at AI, but significant results were to be obtained too late for the S8DRM-1 program. Therefore, the controller was made into a rack mounted console.

3. Relay Box

The relay box contains the power switching relays which receive input signals from the startup programmer and other command circuits and then closes the power relays to various squibs and other actuating devices (Figure 22). The primary purpose of the relay box is to fire the squibs thus freeing the control drums and allowing them to rotate. In addition, on a flight system, the relay box would energize the squib which would eject the explosive charge located at the base of the reactor.

The relay box contains 12 fusistors — a combined fuse-resistor with a resistance of less than 0.5 ohms. In a flight system, the power to fire the squibs would be supplied by a battery. To prevent excessive current drain in the event that a squib failed to fire within a prescribed period, the fusistor would blow-out thereby opening the circuit.

Since the relay box operates only during startup of the reactor, it is not subject to high temperature, irradiation doses, or the long-term vacuum environments. It was, therefore, not subject to temperature and vacuum conditions during the S8DRM-1 testing.

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NAA-SR-12300
42

~~CONFIDENTIAL~~

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Figure 22. S8DRM-1 Relay Box

III. TESTING PROGRAM

The S8DRM-1 is a flight prototype system without live fuel elements which was used to test the design for flight application. As this system was the first attempt to test the SNAP 8 nuclear system, some failures were not unexpected. Failed components were redesigned, where necessary, for the next test program and the S8DS system (as applicable).

The main objectives of the test program were to: (1) assist the development program in the design of a flight qualified system and components; (2) test the adequacy of fabrication techniques to provide flight qualified systems and components; (3) demonstrate that systems and components can operate satisfactorily before, during, and after simulated flight environmental conditions; and (4) demonstrate that systems and components can withstand simulated long-term environmental conditions.

The formal test program for the S8DRM-1 is outlined in the block diagram of Figure 23. The program was described in detail in seven test procedures used to conduct the tests; and the results of these tests, in chronological order, are described below.

A. STANDARD PERFORMANCE RECORD TEST

The purpose of this test was to check critical dimensions and the operation of the S8DRM-1 system at ambient conditions. Hundreds of data points on the mechanical and electrical performance of control, safety, and diagnostic components were monitored. This procedure was used to check the assembly after each major test to assess the effect of that test and to define the condition of the assembly prior to the next test in the sequence.

The first scheduled performance record test for the S8DRM-1 was performed in the shock and vibration laboratory, since the first major testing for the S8DRM-1 was to be low level shock and vibration. The assembly of the various major subassemblies on the vibration fixture showed an interference of the reentry band with adjacent hardware and a brittleness in the lava insulation used with the reentry bands. Development of the EABRD and TABRD safety devices had not matured to the point for providing flight type devices so mockup parts were installed.

CONFIDENTIAL

NAA-SR-12300
44

CONFIDENTIAL

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Figure 23. SNAP 8 Developmental Reactor Mockup-1 Environmental Test

The system met almost all the performance record requirements; but wiring harness, controller, and spring drive deficiencies were noted. The harness showed inadequate insulation at the connector pins and poor weld connections to the connector pins. A transistor in the controller failed and the design was improved. Also, improper phase-excitation of actuator coils necessitated controller modification. The springs for the snap-in drums did not meet the requirements but were used in the testing to prevent a delay in the program. All other performance record requirements were met.

B. INITIAL SURVEY FOR SHOCK AND VIBRATION TESTING

The purpose of this test was to verify analytical data concerning low level amplification factors and resonant frequencies. The results of this test revealed that it was necessary to replace some S8DRM-1 components prior to proceeding with the more severe conditions of the launch environment test. This constituted the first series of shock and vibration tests on the S8DRM-1 and was conducted in two phases: Phase 1 was a survey of the reactor assembly and Phase 2 was a survey of the assembled reactor and shield assembly. The first low level surveys were conducted to detect resonant frequencies and structure responses and, in particular, to determine the response of the vibration limiter control channels. Figure 24 shows the reactor assembly mounted on the shaker table. Once the basic structural dynamics of the reactor were established, test runs were made in each of the three axes (Figure 25). The procedure was repeated in all axes for both Phase 1 and Phase 2 of the test program.

The vibration inputs were performed at a constant octave at a sweep rate requiring 25 min from 12 to 2000 cps as follows:

Sequence Order	Direction	Input (g)	Frequency (cps)
1	Longitudinal axis	0.25	12 to 2000
2	Longitudinal axis	1.0	12 to 500
3	Lateral axes	0.25	12 to 2000
4	Lateral axes	1.0	12 to 500

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Figure 24. Reactor Vibration Test

NAA-SR-12300

46

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Figure 25. S8DRM-1 Vibration Schematic

The shock inputs for both phases were:

Axis	Input (g half sine)	Duration (msec)
+X	5	6
+X	10	6
-X	1	6
-X	2	6
+Y, +Z	3	10

As a result of the two test phases the following information was obtained: (1) dynamic response of the reactor mockup due to a specified harmonic input both with and without a reactor-shield interface, (2) the ability to predict damage which might result from high level tests and make needed corrections and, (3) some indication of the probable behavior of future systems of a similar configuration.

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TABLE 1
S8DRM-1 VIBRATION CHARACTERISTICS

Part	Response to 1-g Input		Expected Maximum Response		Allowable g	
	X	Y(Z)	X	Y(Z)	X	Y(Z)
Vessel Wall	4.5	6.5	16	16	100	55
Grid Plate	4.5		34		45	
V Band Clamp	4.5	6.5	16	16	95	18
Control Drum Drive Bracket	4	13	14	33	100	100
Scram Pivot Bracket	4.5	6.5	16	16	23	100
Reflector Support Bracket	4.5	6.5	16	16	100	100
Bearing Housing	7	8.75	24.5	22		100
Actuator Bracket	3.8	7	13	17	100	100
Actuator Cable	5.5	14	19	35	100	33
Reflector Support Structure	4	13	14	33	100	100
Reentry Band	14.5	47	51	117		

Table 1 is a summary of low level vibration results and includes an extrapolation to show "Expected Maximum Response" under full launch vibration along with the calculated allowable g at many points on the assembly. The table illustrates how useful the survey levels of vibration are as a dynamic analysis tool.

Following the first phase of the shock and vibration tests, a partial performance record test including a dimensional verification of the critical clearances between the reflector and the core vessel was conducted, but no significant change was observed. During a physical examination of the assembly the following discrepancies were noted:

- 1) Two of the special bolts that hold down the bottom grid plate in the core vessel vibrated loose.

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- 2) Two of the V band clamp bolts had loosened which caused the clamp itself to loosen.
- 3) The ground safety keylock interlocks loosened and snapped into a test position.
- 4) Actuator hold-down screw loosened and fell off (design did not call for safety wiring the screw).
- 5) Several wire harness hold-down clamps failed. (Marginal design necessitates new type of clamp for future harnesses.)

The reactor was then disassembled for the purpose of dye penetrant checking, helium leak checking, and radiographing the core vessel and separation band welds. The welds were all satisfactory. The inlet NaK line was positioned on the S8DRM-1 assembly and welded into place followed by reassembly of the reactor and reflector on the shield.

During the Performance Record Test that followed reassembly of the reactor for the second phase of shock and vibration, erratic winding resistance readings were observed for the control drum No. 5 actuator. The problem was corrected by increasing the wire and pin fiberglass insulation sleeving inside the connector backshell. Also the neutron shield wiring harness insulation resistance was found to be below specified values and was attributed to high humidity in the test building. To verify the effect of humidity, a portion of the neutron shield wiring harness was removed from the shield and baked-out in an oven for 5 hr at 300°F. The insulation resistance changed from 0.5 megohms to as high as 35,000 megohms after bake but fell to 130 megohms in 15 hr when exposed to room humidity. The entire assembly was, therefore, installed in a plastic tent and heated air was ducted through the tent (Figure 26). The resistance increased to acceptable levels.

The Phase 2 Shock and Vibration Test was conducted and the assembly was moved to the vacuum chamber laboratory where it was dehumidified overnight in a vacuum chamber and given a Performance Record Test. All performance was met except that one drum stopped stepping at 90° from full-in. The small clearance in the bearing had packed with dry film lubricant during vibration and had bound up. It was loosened for further testing and larger clearances were incorporated in a new bearing design. Finally, the reactor was disassembled and weld areas were dye penetrant or helium leak checked as before with satisfactory results.

Figure 26. Reactor Assembly With Protective Tent

NAA-SR-12300

50

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C. STARTUP RELIABILITY TEST

The purpose of this test was to determine the startup reliability of the S8DRM-1. The startup sequence was repeated nine times, firing the lockout squibs each time and operating the control system through a simulated reactor startup. At the end of every three firings of the lockout squibs, a Standard Performance Record Test was conducted. Measurements of the shock imparted to components during squib firing were recorded.

This test was the first Startup Reliability Test to be performed on the S8DRM-1 system and the results of this series of automatic startups are shown in Table 2. It will be noted that a partial Performance Record Test was conducted after sequences 3 and 6. All sequences simulated a successful startup of the reactor although malfunctions of some components were noted.

Evaluation of the squib shock on fuel element ceramic coatings was done by installing some natural uranium fuel elements in the core and conducting separate hydrogen permeation tests on the elements after the test.*

In addition to monitoring the startup functions, shock levels resulting from squib firings were recorded as shown in Table 3. Accelerometers were mounted to the grid plates, two fuel elements, and two various other components to measure the shock input to the components. The difference between the response data recorded during the first two startup sequences was thought to be variation in the pressure generated by each igniter and variation in the mechanical properties of the squib housing energy absorber. Measurement of shock input was rescheduled for the next Startup Reliability Test conducted during March 1965.

Data from Channel 5, which was the transducer mounted on the squib housing, is questionable as this transducer was blown off of the housing each time the squib was fired. The pulse shown for this channel was a sharp 2 msec spike experienced by the transducer after the initial shock. The typical shock pulse duration on the other channels was 4 to 6 msec.

*J. Whitlock, "Testing S8DRM-1 Fuel Elements, (Interim Report)," NAA-SR-10500 (SRD) (June 23, 1965)

TABLE 2
STARTUP RELIABILITY TEST
(Sheet 1 of 2)

Subject	Results	Cause of Failure	Apparent Effect the Failure Would Have on Orbital Startup
Startup Sequence No. 1	System functioned satisfactorily with three exceptions: 1. Two startup drum limit switches did not function correctly. 2. Position sensor did not function correctly. 3. One squib igniter did not fire.	1. Incorrect mechanical positioning of one switch. The other switch apparently had molykote inside the switch causing the switch to become inoperative. 2. The sensor was out of calibration. 3. Squib connector had a faulty connection.	1. <u>Successful Startup</u> . The switches are for an indication of full-in position of startup drums only. They serve a diagnostic purpose only. 2. <u>Successful Startup</u> . The position sensor delivers specific control drum information only. 3. <u>Successful Startup</u> . Each drum lock release actuator contains redundant squib igniter (it only requires the firing of one squib to operate this actuator).
Startup Sequence No. 2	Entire system functioned satisfactorily.		
Startup Sequence No. 3	Entire system functioned satisfactorily.		
(Partial Performance Record Test)	Entire system functioned satisfactorily.		
Startup Sequence No. 4	Entire system functioned satisfactorily.		
Startup Sequence No. 5	Entire system functioned satisfactorily.		
Startup Sequence No. 6	Entire system functioned satisfactorily.		
(Partial Performance Record Test)	Entire system functioned satisfactorily.		

CONFIDENTIAL

NAA-SR-12300
52

CONFIDENTIAL

TABLE 2
STARTUP RELIABILITY TEST
(Sheet 2 of 2)

Subject	Results	Cause of Failure	Apparent Effect the Failure Would Have on Orbital Startup
Startup Sequence No. 7	System functioned satisfactorily with three exceptions: 1. Controller gave indication of reactor operation during initial checkout. 2. One limit switch failed to function. 3. One squib igniter did not fire.	1. Reset circuit in programmer apparently did not function. 2. Apparently loose caked moly-kote caused switch to malfunction. Switch was removed after Test No. 9 and sent for analysis. 3. Four-ohm fusistor in the relay box failed causing loss of power to igniter circuit.	1. <u>Successful Startup</u> . This malfunction observed during checkout of system and prior to initiation of startup. 2. <u>Successful Startup</u> . This switch indicates full-in position of startup drums and serves a diagnostic function only. 3. <u>Successful Startup</u> . Each drum lock release actuator contains redundant squib igniters (it only requires the firing of one squib to operate this actuator).
Startup Sequence No. 8	Entire system functioned satisfactorily.		
Startup Sequence No. 9	Satisfactory operation for 79 min.	Failure of a resistor in the Visicorder gave an erroneous indication of a problem in one of the actuators.	<u>Successful Startup</u> . This malfunction was in the diagnostic instrumentation and in no way jeopardized the reactor startup. The test was terminated only because of an apparent problem.
Startup Sequence No. 9	Entire system functioned satisfactorily. This test was rerun due to the premature shutdown mentioned above.		
Performance Record Test	System performed satisfactorily except for the following: Control drum 1 stopped its inward stepping at approximately 70° from full-in position.	Cause was not determined. The system checked out satisfactorily after the malfunction.	This test is not a part of a startup sequence. It is expected the reactor would go critical with the drum at this position. However, the life expectancy of 10,000 hr would be shortened due to this failure.

NAA-SR-12300

53

CONFIDENTIAL

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Figure 27. Vacuum Chamber

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Figure 28. Reactor Core Heat Simulator

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54

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TABLE 3
SQUIB INDUCED SHOCK LEVELS

Channel	Description	Response (g)	
		Test No. 1	Test No. 2
1	Center fuel rod	No signal	No signal
2	Fuel rod, 2 holes from grid plate center toward +Y axis	5.0	1.1
3	Upper grid plate	2.0	1.2
4	Lower grid plate	2.0	1.0
5	-Z Axis (drum squib housing)	280.0	120.0
6	Position Sensor, Control Drum No. 1	28.0	24.0
7	Wire Harness Connector	4.0	4.0
8	Position Sensor, Control Drum No. 3	20.0	36.0
9	Center of Gravity, Control Drum No. 1	24.0	10.0
10	Center of Gravity, Control Drum No. 4	12.0	20.0
11	Spring Housing	20.0	20.0
12	Stepper Motor No. 3	16.0	16.0

D. HOT PERFORMANCE RECORD TEST

The objective of this test was to run the reactor at operating temperatures and vacuum prior to the Launch Environmental Test and to accumulate data on temperature gradients throughout the assembly. The test was run in a vacuum chamber (Figure 27) with a heater assembly (Figure 28) inserted in the core.

The assembly was heated up at the rate of 100°F/hr and was subjected to temperatures as shown in Table 4 at steady state. Column 2 denotes the temperature profile required per the test procedure criteria. Column 3 denotes the actual temperatures attained during the test. The deviation is attributed to failure of two out of the five heaters (Zone 1 and Zone 5) located in the upper heat simulator. The test was continued with the remaining three heaters. The vacuum chamber attained an equivalent steady-state pressure of 2×10^{-5} torr (as required by the procedure) The reactor startup sequence was initiated after attaining steady-state pressure and temperature. Table 5 shows the steady

TABLE 4
UPPER HEAT SIMULATOR TEMPERATURE
PROFILE

Core Vessel Zone	Temperature Requirements Per Test Procedure* (°F)	Actual Temperatures Attained During Test (°F)
1 (Top)	1280	975
2	1240	1320
3	1200	1190
4	1160	1162
5 (Bottom)	1120	960

*These temperatures simulate calculated reactor operating conditions.

TABLE 5
COMPONENT TEMPERATURES
AT STEADY STATE*

Component	Temperature (°F)
Reflector Support Structure	478
Reflector (fixed)	560
Control Drum (in full-out position)	399
Drum Bearings	469
Actuator	429
Ejection Springs	598
Position Sensor	444

*Drums were in the full-out position with actual core surface temperatures as in Table 4, Column 3.

state temperature of same components. The startup sequence simulated an orbital startup with the exception of the firing of squib igniters and a reduced heatup rate. The squib igniter firings had been accomplished previously at atmospheric pressure and ambient temperatures to reduce vacuum chamber contamination by the products of explosion.

The entire reactor system operation was satisfactory, without exception, during all phases of the test. The temperature profile data was sent to the Analysis Group for evaluation for the S8DR Program.

Subsequent to the Hot Performance Record Test, a Standard Performance Record Test was conducted at atmospheric pressure and ambient temperatures. The data from this test when compared with data from previous Performance Record Tests indicated no apparent damage to the reactor system was incurred during the thermal-vacuum test.

E. LAUNCH ENVIRONMENTAL TEST

The entire system (reactor and neutron shield) was subjected to this environment for purposes of determining component amplification factors, verifying component design related to shock and vibration characteristics, testing the adequacy of design of integrated components under a shock and vibration environment, and determining the ability of the integrated system to withstand this test environment. The information was utilized in the design of subsequent SNAP 8 components and systems.

This test was the final shock and vibration test performed on the S8DRM-1 reactor-shield assembly. No Performance Record Test was conducted in the vibration laboratory due to the high humidity within the building so the Performance Record Test following the Hot Test was used as the reference base.

The nuclear system was mounted to the shaker table and subjected to the shock and vibration environments noted in Table 6. The S8DRM-1 design was predicated on use of an Atlas-Centaur Launch Vehicle. The shock and vibration levels were subsequently revised to the NASA-417-2 specification. Testing to these revised levels was to be conducted during FY 1966 but due to termination of the S8DRM-1 project the test was not performed.

TABLE 6
S8DRM-1 LAUNCH VIBRATION AND SHOCK ENVIRONMENT

Vibration Test		
Direction	Magnitude	Frequency (cps)
Longitudinal (X) Axis	0.5 g	12 to 700
Longitudinal (X) Axis	1.0 g	12 to 700
Lateral (Y and Z) Axes	0.5 g	12 to 700
Lateral (Y and Z) Axes	1.0 g	12 to 700
Longitudinal (X) Axis	1/2-in. double amplitude	5 to 12
	3.5 g	12 to 400
	7.5 g	400 to 3000
Lateral (Y and Z Axes)	1/2-in. double amplitude	5 to 10
	2.5 g	10 to 250
	5.0 g	250 to 400
	7.5 g	400 to 3000

Shock Test		
Axis	Magnitude (g, half sine wave)	Duration (msec)
Longitudinal (+X)	10	6
Longitudinal (-X)	4	6
Lateral (Y and Z), ($\pm$ g)	6	10

The assembly withstood the vibration in that no major redesign of basic structure or component mounting structure was indicated. Several lesser failures were noted which could be remedied by minor redesign or design refinements. Three limit switches broke in the weld between the tubular section and case. Two bellows couplings on the control drum drives failed in the bellows leaf welds. A welded stud in the NaK inlet pipe broke off. Three reflector-to-core ceramic positioning standoffs cracked and broke off. The V band reactor-to-shield clamp loosened and turned (the lack of a positive device to prevent rotation of the core vessel was noted during inspection of the clamp). And finally, a powdering of

the circular shim cloth used between the tungsten gamma shield and the hydride shield was observed. The dummy fuel elements were evaluated by the Material Department and were found to show no damage.*

F. FINAL STARTUP RELIABILITY TEST

This test was the final startup reliability test to be performed on the S8DRM-1 system. The results of this series of automatic startups are shown in Table 7. Table 8 is a compilation of squib firing shock data recorded during the Startup Reliability Test. Accelerometers were mounted in 11 locations on the reactor to measure the shock input to various components as a result of squib firings. Data from Channel 7, which was the transducer mounted on the squib housing, is questionable. This transducer was blown off of the housing each time the squib was fired; therefore, the data recorded for this channel during Sequences 1 and 2 is considered unreliable. Several other channels show a lack of data during firings which indicates these channels did not record during a particular firing. The shock data from this test is now available to predict squib firing shock effects on subsequent reactor assembly designs.

G. TESTS PLANNED BUT NOT RUN

Originally another Hot Performance Record Test was planned, to be followed by an Orbital Environmental Test which would more accurately duplicate the environment in orbit by simulating the heat below the shield, the NaK piping heat, and the space background temperature in addition to the core vessel heat. The final test was to have been an Orbital Environmental Life Test for 10,000 hr at lower than 10^{-6} torr pressure with the heat sources simulated and with a liquid nitrogen cooled shroud surrounding the assembly. These portions of the test program were not run when the S8DRM-1 project was terminated by the AEC in April 1965.

*NAA-SR-10500, "Testing S8DRM-1 Fuel Elements," J. Whitlock (SRD)
(June 23, 1965)

TABLE 7
FINAL STARTUP RELIABILITY TEST
(Sheet 1 of 2)

Test	Results	Cause of Failure	Apparent Effect the Failure Would Have on Orbital Startup
Startup Sequence No. 1	Entire system functioned satisfactorily with no exceptions		
Startup Sequence No. 2	<p>1. Test was terminated after 48 min due to a controller malfunction.</p> <p>2. Test was rerun. The system performed satisfactorily with the exception that one squib igniter did not fire.</p>	<p>1. The controller is not a flight type but only of "breadboard" design. It was inadvertently triggered by some electromagnetic interference (EMI) in the building.</p> <p>2. Squib connector had a faulty connection.</p>	<p>1. <u>Failure to start up.</u> The controller used in a flight reactor would be designed to eliminate EMI.</p> <p>2. <u>Successful startup.</u> Each drum lock release actuator contains redundant squib igniters. (It only requires the firing of one squib to operate the actuator.)</p>
Startup Sequence No. 3	<p>System functioned satisfactorily with two exceptions:</p> <p>1. One squib igniter did not fire.</p> <p>2. One startup drum did not latch in the full-in position.</p>	<p>1. Trouble shooting after Test No. 5 revealed relay box fusistor failure (see below).</p> <p>2. Lower drum support bearing caused excessive drag on drum. The exact cause of bearing failure is to be determined during installation of new bearings at a later date.</p>	<p>1. <u>Successful startup.</u> Each drum lock release actuator contains redundant squib igniters.</p> <p>2. <u>Successful startup.</u> Startup drum did not latch in the full in position; however, the bearing drag was sufficient to secure the drum at a position approximately 98% full-in (this is adequate for startup).</p>
Performance Record Test No. 1	Entire system functioned satisfactorily with no exceptions.		
Startup Sequence No. 4	System functioned satisfactorily with the exception that one squib igniter did not fire.	Trouble shooting after Test No. 5 revealed relay box fusistor failure (see below).	<u>Successful startup.</u> Each drum lock release actuator contains redundant squib igniter.
Startup Sequence No. 5	System functioned satisfactorily with the exception that two squib igniters did not fire (not located on same drum lock release actuator).	Three of the four ohm fusistors, in the relay box failed causing loss of power to the igniter circuit.	<u>Successful startup.</u> Each drum lock release actuator contains redundant squib igniters.
Startup Sequence No. 6	Entire system functioned satisfactorily with no exceptions.		
Performance Record Test No. 2	Entire system functioned satisfactorily with no exceptions.		

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NAA-SR-12300
60

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TABLE 7
FINAL STARTUP RELIABILITY TEST
(Sheet 2 of 2)

Test	Results	Cause of Failure	Apparent Effect the Failure Would Have on Orbital Startup
Startup Sequence No. 7	System performed satisfactorily with the exception that limit switch B did not operate as required.	Looseness of switch housing relative to switch body. The switch design is inadequate and is not to be used on subsequent reactor systems.	Successful startup. An automatic switching device is built into the programmer system to override a failure of limit switch A or B which are diagnostic components.
Startup Sequence No. 8	Entire system functioned satisfactorily with no exceptions.		
Startup Sequence No. 9	System functioned satisfactorily for 105 min. The controller malfunctioned at this time necessitating a premature shutdown.	The cause of this malfunction remains to be determined.	Failure to start up. This controller is not of flight design.
Performance Record Test No. 3	Entire system functioned satisfactorily with no exceptions.		

NAA-SR-12300

61

CONFIDENTIAL

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TABLE 8
SQUIB FIRING SHOCK DATA

Startup Test Sequence	Data	Channel Number and Location										
		Actuator Between +Y and -Z Axis	Actuator Between +Y and -Z Axis	Actuator +Z Axis	Control Drum 1 Between -Y and -Z Axis	Startup Drum 6 Between -Y and +Z Axis	Spring Housing Between -Y and +Z Axis	Squib Actuator Right of -Z Axis	Position Sensor 3 Between +Y and -Z Axis	Position Sensor 1 Between -Y and -Z Axis	Position Sensor 5 +Z Axis	Wire Harness Connector Right of +Y Axis
		1	2	3	4	5	6	7	8	9	10	11
1	Shock (Peak G) Dwell (msec)	43 7.0	39 7.3	45 6.0	21 4.5	23 6.0	12 7.0	180 2.5	17 1.0	30 5.0	42 11.0	11 12
2	Shock (Peak G) Dwell (msec)	116 5.0	80 4.5	50 4.0	36 3.0	60 4.0	16 30	- -	80 2.0	76 3.0	110 1.0	24 6.0
2 (rerun)	Shock (Peak G) Dwell (msec)	80 6.5	76 7.0	60 2.0	40 4.0	38 4.0	- -	60 2.0	100 0.5	70 3.0	100 3.5	24 7.0
3	Shock (Peak G) Dwell (msec)	27 4.5	27 6.0	15 2.5	6 3.0	12 4.0	- -	- -	18 1.0	18 1.0	30 1.0	7 6.0
4	Shock (Peak G) Dwell (msec)	60 5.0	80 5.5	40 5.0	30 1.5	40 5.0	12 6.0	- -	60 1.0	80 4.5	80 4.5	23 5.0
5	Shock (Peak G) Dwell (msec)	70 5.0	80 5.0	40 5.0	20 2.0	30 6.0	18 6.0	- -	- -	100 2.0	150 3.0	24 3.5
6	Shock (Peak G) Dwell (msec)	90 5.0	80 6.0	30 5.0	40 3.0	34 4.0	12 6.0	- -	- -	- -	- -	24 5.0
7	Shock (Peak G) Dwell (msec)	60 8.0	70 7.5	40 7.0	15 4.5	20 5.0	9 6.0	- -	90 5.5	120 4.0	100 3.0	- -
8	Shock (Peak G) Dwell (msec)	80 9.0	80 10.0	50 9.0	22 5.0	22 7.0	17 9.0	- -	150 7.0	210 7.0	160 7.0	- -
9	Shock (Peak G) Dwell (msec)	78 5.0	80 5.0	60 5.0	18 4.0	18 5.0	18 8.0	- -	150 3.0	180 2.0	140 3.0	- -

NOTE: All accelerometers were oriented with the sensitive axis in the longitudinal direction of the reactor.

CONFIDENTIAL

NAA-SR-12300
62

CONFIDENTIAL

IV. SUMMARY AND CONCLUSIONS

The S8DRM-1 program objectives were met in the phases of the program that were completed. The capability of designing flight components, assembling these components into systems, and mating the systems into a complete development reactor mockup was demonstrated.

The test program assisted the design program in uncovering weaknesses to be redesigned or improved upon in future flight designs and as applicable to the S8DR design which was in the design phase during the S8DRM-1 testing. The wiring harness termination and insulation methods were completely reviewed and refined with closer control of the detail steps. A replacement harness incorporating these improvements was made available near the end of the program. The necessity for using anti-loosening devices on fasteners such as the grid plate and actuator bolts was demonstrated. The need for tighter control of vendor supplied parts such as the snap-in torsion springs and bellows couplings (where leaf welds were of poor quality) was shown.

The increases in the control drum bearing torque verified the same finding in the bearing development laboratory. A new set of bearings with well-controlled clearances and improved rubbing surfaces materials were available near the end of the program.

An alternate, less brittle material for the insulated positioning stops on the reflector assembly was seen to be needed as was the need for a sturdier weld stud for the NaK pipe.

A review of the V band design which holds the core vessel and shield together was indicated as necessary for future flight designs. Means of preventing loosening of the band and providing positive indexing of the core vessel to the shield will be required.

The squib circuitry was shown to need review for any future designs to isolate the reason for fusistor failure.

Also limit switch failures gave impetus to a shorting bar type switch development program under way at the time of S8DRM-1 testing. Also, the transistor failure, wrong-phasing, reset failure, and EMI malfunctioning of the controller showed up weak points that must be considered in future controller design.

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Data accumulated during the vibration tests proved valuable for dynamic analysis of future designs in predicting amplification factors in the structure and components. Also the shocks in various parts of the assembly resulting from firing of squibs can be estimated more accurately using data from the Startup Tests. Better prediction of temperatures at various locations on future designs can be made by using temperature data from these tests.

The S8DRM-1 program demonstrated the capability of completing numerous startup sequences and of operating with a simulated core heat source. Unfortunately, the tests to start up with a more completely simulated thermal environment and to operate for the intended lifetime in a hard vacuum were cancelled with the curtailment of SNAP 8 flight reactor program.

The information and experience gained during the S8DRM-1 program will apply directly to the design, fabrication, and testing of a flight reactor assembly at some future date.

NAA-SR-12300

64

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