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SNAP 2 DEVELOPMENTAL REACTOR
MOCKUP NO. 1
FINAL REPORT

AEC Research and Development Report

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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SNAP 2 DEVELOPMENTAL REACTOR
MOCKUP NO. 1
FINAL REPORT

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Frontispiece. SNAP 2 Developmental Reactor
Mockup No. 1 and Shield Assembly

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I. INTRODUCTION AND SUMMARY OF TEST RESULTS

The objective of the SNAP 2 Developmental Reactor Mockup No. 1 (S2DRM-1) test program was to demonstrate the ability of the reactor system to meet the system requirements at the qualification test levels, to improve the quality of marginal components by development, and to log sufficient operating time to establish system endurance confidence. The tests were designed to simulate the nonnuclear conditions to which the SNAP-2A reactor subsystem would be subjected from final assembly through 90 days of operation in orbit.

An associated objective of the program was to design, fabricate, and operate an ultrahigh-vacuum system capable of subjecting the reactor system to the severe expected space vacuum conditions.

The S2DRM-1 was started as part of the SNAP Reactor Improvement Program in July 1962. Building 062 at the AI Santa Susana Facility, which was set up for the thermal-vacuum tests, was completed in February 1963. The Developmental Reactor Mockup phase of the test program was deleted from the SNAP Reactor Improvement Program during August 1965, at which time all testing was terminated. The system, including test hardware, was disassembled and stored.

A brief summary of all S2DRM-1 tests to date follows in chronological order:

The reflector assembly was subjected to acceptance level and two simulated hot-critical thermal-vacuum tests as a separate unit in December 1964. The shield assembly was subjected to five thermal-vacuum cycles as a separate unit to simulate hot-critical testing that would be performed on a flight system. The shield tests were conducted between September 10, 1964 and October 12, 1964 in Vacuum System "B" at the Santa Susana Building 062 facility. A helium leak check, dimensional check, and x-ray inspections were made of the shield assembly prior to and after the simulated hot-critical thermal-vacuum tests to determine the effects of thermal cycling on the shield structure. The reactor system was assembled, and then subjected to launch simulation vibration tests at the Santa Susana Building 027 facility. NaK loading tests and the thermal-vacuum operational tests of the complete reactor system were performed in Vacuum

System "B" at the Santa Susana Building 062 facility between March 10, 1965 and April 28, 1965. A performance record test consisting of mechanical, electrical, and operation measurements was performed prior to and after each phase of testing to determine the integrity of the reactor system.

Thermal-vacuum testing was terminated on April 28, 1965, after 20 days of endurance, due to a NaK leak in one of the heater assemblies. (The program objective of 90 days was never reached due to cancellation of the project.) A new NaK heater was designed to be installed vertically in the chamber base of Vacuum System "B" at the Santa Susana Facility. The heating elements were designed to be inserted into thimbles so that they could be replaced from the bottom without interrupting the test. A major consideration in the heater design was to provide more ullage area above all the thimbles to decrease the possibility of hot spots on the thimbles resulting from accumulation of vapors in the event of film boiling. A new expansion reservoir was designed and fabricated to allow for expansion of the increased volume of NaK at elevated temperatures (up to 1500 °F).

A vacuum system was designed by expanding the existing state of the art in titanium-sublimation-supplemented ion pumping methods to meet the large gas loads anticipated from the S2DRM-1 reactor system. This method of achieving a "hard" vacuum uses a periodically replenished surface film of active titanium deposited on a liquid-nitrogen-cooled surface as the primary pump. An electron-beam gun is used to heat a module of titanium which vaporizes and deposits a thin film on the cooled surface. The pumping action is accomplished by chemical combination of the active gases which strike the titanium film and form low-vapor-pressure solids. Shields are mounted around each titanium module to prevent the vaporized titanium from striking the test item. Ion pumps supplement the getter pumping of the titanium film and are primarily used to pump the noble gases. Mechanical and oil diffusion pumps are used to rough the chamber down to the 10^{-6} torr range, and are valved off from the chamber after the ion pumps are started. A method of sealing the numerous flanges was devised using indium instead of elastomer O-rings, indium being a soft metal which flows under light force but has a very low vapor pressure. This decreased the chamber gas load caused by outgassing of elastomers.

The S2DRM-1 reactor system demonstrated its ability to withstand the shock, vibration, and thermal-vacuum environments that were imposed upon it without failure or sign of degradation. The SNAP 10A-type fine control drum motors demonstrated their versatility in controlling the fine control drums of a different reactor system at higher operating temperatures without failure or degradation.

Electron-beam gun problems encountered during the thermal-vacuum operational test of the S2DRM-1 reactor assembly were resolved; additional operational testing of the ultrahigh-vacuum system, however, would be required to demonstrate endurance capabilities.

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Figure 1. S2DRM-1 Reflector Assembly
Attached to Reactor Vessel

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II. GENERAL DESCRIPTION

The S2DRM-1 reactor system (Figure 1) was fabricated as a requirement for the SNAP 2 flight test program and took advantage of most of the improvements realized from the SNAP 10A program which were not incorporated in the SNAP 10A reactor system. Major improvements follow:

- 1) The LiH (lithium hydride) shield material was cast rather than cold-pressed, thus eliminating the machining of lithium hydride and the use of supporting springs at the bottom of the shield.
- 2) The reactor vessel was brazed to a reflector support plate which was bolted directly to the top of the shield casing, eliminating the need for reactor support legs.
- 3) The wiring harness insulation, containing silicone sizing, was baked out after harness fabrication to decrease the amount of troublesome contaminants during operation at elevated temperature.
- 4) The drum-position sensor case mounts were redesigned for increased rigidity.
- 5) Improvements were made on fine control drum bearings and drive assemblies.

The S2DRM-1 reactor system consists of a reactor vessel with top head, grid plates, dummy fuel elements, internal reflectors, the reflector assembly, the shield assembly, and the reactor vessel inlet and outlet NaK lines. Support structure varied from test to test depending on specific requirements. The support structures included the radiator-condenser heat simulator, or the reactor system heat simulator.

The reactor system heat simulator was designed to heat NaK and to pump it through the reactor vessel and coolant lines in a direction opposite to that of the NaK flow in the flight system. This reverse flow was necessary in order to maintain the reactor vessel outlet temperature at a higher level than the inlet temperature — the condition that would exist with the nuclear system.

The various tests to which the S2DRM-1 system was subjected are discussed in Section III. The most important of these was the Thermal-Vacuum Operational Test, on which emphasis was placed as it represents the major effort expended during the program, including development of an ultrahigh-vacuum system and a new NaK heater.

III. S2DRM-1 SYSTEM TESTS

A. REFLECTOR ACCEPTANCE LEVEL AND SIMULATED HOT-CRITICAL THERMAL-VACUUM TESTS

1. Test Setup

For these tests the S2DRM-1 reflector assembly was attached to a test reactor vessel in a small vacuum chamber at Building 004, AI Headquarters facility (Figure 2). The reactor vessel used contained electrical heating elements to provide the thermal inputs into the reflectors. A simulated reactor vessel outlet NaK line containing an internal heating element was used to support the Temperature-Actuated Band Release Device (TABRD). SNAP 10A drum-drive motors were used to rotate the fine control drums during testing. The vacuum system was capable of maintaining the chamber pressure in the 10^{-6} torr range during testing.

2. Test Operations

The scheduled sequence of operations for the acceptance level test and two simulated hot-critical thermal-vacuum tests performed was as follows:

- 1) Obtain a chamber pressure of 1×10^{-4} torr or less,
- 2) Obtain an isothermal reactor vessel temperature of $200^{\circ}\text{F} \pm 20^{\circ}$,
- 3) Simulate the reactor startup cycle and start fine control drums stepping inward.
- 4) Maintain isothermal conditions until the fine control drums reach 72 degrees from "full out."
- 5) Increase the reactor vessel top temperature from 200 to $1200^{\circ}\text{F} \pm 20^{\circ}$ at a rate of less than 10° per minute but greater than 4° per minute. Continue stepping the fine control drums inward.
- 6) When the vessel top temperature reaches $1200^{\circ}\text{F} \pm 20^{\circ}$, adjust the heating element controllers to obtain a vessel base temperature of $1000^{\circ}\text{F} \pm 20^{\circ}$ while maintaining the vessel top temperature at $1200^{\circ}\text{F} \pm 20^{\circ}$.
- 7) Stop the fine control drum stepping when the drums reach 135 degrees from "full out."

Figure 2.
S2DRM-1 Reactor
Assembly

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Figure 3.
S2DRM-1 Shield and Test Fixtures
Assembled for Simulated Hot
Critical Thermal-Vacuum
Test

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8) Maintain the vessel temperature (top at 1200°F, bottom at 1000°F) for a period of not less than 8 hours.

9) Step the fine control drums to their "full in" (154 degrees from "full out") position and start cooldown.

10) Decrease the vessel and reflector temperatures from their steady-state temperatures to less than 300°F at a rate not to exceed 10° per minute.

11) Conduct two temperature cycles from a vessel temperature of not greater than 200° to 1100°F $\pm 20^\circ$ at a rate of 8° per minute.

12) Maintain the vessel at 1100°F $\pm 20^\circ$ for 4 hours before cooling down.

13) The cooldown rate shall not exceed 10°F per minute.

3. Test Results

The acceptance level and simulated hot-critical thermal-vacuum tests followed the above-outlined program. The reflector temperature transients observed during these tests were comparable to the temperature transients obtained on the SNAP 10A reflectors.

4. Conclusion

There was no indication of degradation or malfunction of the reflector assembly during or following the reflector acceptance level and simulated hot-critical thermal-vacuum tests.

B. SHIELD THERMAL-VACUUM TESTS

1. Test Setup

The 2DRM-1 shield (SN 002), the reactor vessel heat simulator, and the radiator-condenser (RC) heat simulator were mounted to a base plate for thermal-vacuum testing in Vacuum System "B" at Building 062, Santa Susana facility (Figure 3). The reactor vessel core internals were replaced by three zones of heating elements and the vessel top head was fitted with a vacuum-tight conduit to carry the heater leads to the outside of the chamber. The RC simulator was used only to support the shield during testing. The reactor vessel heaters were programmed to simulate the average vessel base temperature that

Figure 4. S2DRM-1 Instrumentation

Figure 5. Original Vacuum System "B,"
Bldg. 062, Santa Susana Facility

would be encountered during hot-critical testing of a flight reactor system. No heat was applied to the shield support pads. Figure 4 shows the instrumentation consoles, in Santa Susana Building 062, which contain the vacuum controls, vacuum gage units, heater control units, temperature recorders, and data logger system used in conjunction with the tests.

The vacuum system used for thermal-vacuum testing (Figure 5) consisted of a water-cooled, double-walled chamber five-feet in diameter and nine-feet tall, with a 12-inch-diameter, right-angle shutoff valve, a 10-inch-diameter liquid-nitrogen-cooled cryobaffle, a 10-inch oil-diffusion pump with a water-cooled cold cup, a mechanical roughing pump, and a mechanical holding pump. The pumping system was capable of maintaining the chamber pressure in the 10^{-5} torr range during heatup of the reactor vessel, and in the 10^{-6} torr range during steady-state operation. The internal walls of the chamber were coated with a flat black epoxy paint to provide an emissivity of approximately 0.9 at a temperature of $70^{\circ}\text{F} \pm 10^{\circ}$.

2. Test Procedure

The sequence of test procedures scheduled for each thermal-vacuum test cycle is outlined below:

- 1) Obtain a chamber pressure of 1×10^{-4} torr or less.
- 2) Obtain a reactor vessel isothermal condition at $150^{\circ}\text{F} \pm 20^{\circ}$.
- 3) Increase the reactor vessel base temperature to $1000^{\circ}\text{F} \pm 20^{\circ}$ at a rate not to exceed $4^{\circ}/\text{minute}$.
- 4) Maintain the average reactor vessel base temperature at $1000^{\circ}\text{F} \pm 20^{\circ}$ for 4 hours.
- 5) Decrease the reactor vessel base temperature to below $150^{\circ}\text{F} \pm 20^{\circ}$ at a rate not to exceed $4^{\circ}/\text{minute}$.
- 6) The chamber may be vented to atmosphere after all shield and reactor vessel temperatures are below $300^{\circ}\text{F} \pm 20^{\circ}$.

Figure 6. Typical Temperature Distribution,
S2DRM-1 Shield Thermal-Vacuum Test

3. Test Results

The five thermal-vacuum test cycles followed the aforementioned sequence. The temperature distribution shown in Figure 6 is representative of the data obtained during the five thermal-vacuum test cycles. A post-test visual inspection revealed no damage due to thermal cycling. The reactor vessel was discolored in the heated areas due to the presence of contaminating gases within the chamber during the test.

A post-test examination, consisting of a physical dimension check, x-rays, and a helium leak check, was conducted on the shield and compared with the results of the pre-test examination. The data indicated that slight dimensional changes had occurred during thermal cycling; the overall dimensions, however, had not changed appreciably. X-rays revealed additional cracking and separation of the hydride; this was anticipated and does not affect the shielding or support capabilities of the shield. No indication of leakage was found during the helium leak checks made before and after thermal cycling.

4. Conclusions

From the information obtained, it can be concluded that the shield was not adversely affected by the simulated hot-critical thermal-vacuum tests. The actual internal condition of the shield can only be accurately determined by thorough dissection, which is not planned at this time.

C. LAUNCH SIMULATION VIBRATION AND SHOCK TESTS

1. Test Setup

The S2DRM-1 reactor system – consisting of a shield, reflector assembly, NaK inlet and outlet lines, and reactor vessel with top head, dummy fuel elements, grid plates, and internal reflectors (Figure 7) – was mounted to a vibration fixture and subjected to vibration and shock tests to simulate launch and placement in orbit. The reactor vessel and NaK lines were filled with distilled water to simulate the damping effects of NaK. The assembly consisted of S10A/2 flight-type hardware with the following exceptions:

- 1) Dummy fuel elements were used in the reactor vessel,
- 2) S10A fine control-drum motors were utilized,

Figure 7.
S2DRM-1 Reactor System
and Test Fixtures for
Vibration Tests

Figure 8.
S2DRM-1 Vibration Axis
Identification

3) An uncalibrated Temperature Actuated Band Release Device (TABRD), was employed, and

4) The reactor vessel top head was clamped to the reactor vessel to allow for post-test disassembly and cleaning.

The vibration fixture simulated the radiator-condenser structure so that the reactor system would be mounted to provide support for the ends of the NaK lines, and also allowed for orientation of the system for vibration on each of its axes.

2. Test Operations

The reactor system was subjected to vibration inputs along each of the three mutually perpendicular axes defined in Figure 8. The tests consisted of a single sinusoidal sweep along each axis from low to high frequency at a constant octave sweep rate in 45 (± 1) minutes. The vibration loads were applied to the shield mounting pads. The vibration input levels as measured by accelerometers attached to the shield bracket were applied as follows:

<u>Axis</u>	<u>Frequency</u>	<u>Load</u>
Longitudinal	5 to 12 cps	1/2 in. $\pm 10\%$ (double amplitude)
	24 to 400 cps	3.5 g $\pm 7\%$
	400 to 2000 cps	7.5 g $\pm 5\%$
Lateral and normal	5 to 10 cps	1/2 in. $\pm 10\%$ (double amplitude)
	10 to 250 cps	2.5 g $\pm 7\%$
	400 to 2000 cps	7.5 g $\pm 5\%$

The response of the reactor and shield was limited to the input values listed above by an accelerometer mounted on the reactor top head. A preliminary low-level (less than 1-g) survey was conducted to determine resonant frequencies prior to the specified vibration test. The reactor system was also subjected to two shocks in each direction along the three mutually perpendicular axes defined in Figure 8. The shock wave form was an approximate half sine wave with a duration of 8 ± 1 milliseconds. The shock input levels were measured by accelerometers attached to the shield mounting pads. The shock amplitudes were as follows:

<u>Axis</u>	<u>Amplitude</u>
Longitudinal	5.5 g $\pm 10\%$
Lateral and normal	1.5 g $\pm 20\%$

3. Test Results

The following principal modes for the reactor-reflector structure were determined:

	<u>Input Axis</u>	<u>Input Frequency (cycles/sec)</u>	<u>Maximum Trans- missibility</u>
Reactor vessel top head vs input at shield mounting brackets	X-X	240	8
	Y-Y	50	12
	Z-Z	70	21
Reactor vessel top head vs reflector support ring	X-X	240	2.7
	Y-Y	50	2.6
	Z-Z	70	2.3
Reflector support ring vs input at shield mounting brackets	X-X	250	3
	Y-Y	50	4.6
	Z-Z	70	9
Reflector top vs input at shield mounting bracket	X-X	70	10
	Y-Y	70	12.5
	Z-Z	70	20.0

The response of the control drums was similar to that of the reactor-reflector structure in the lateral direction and 1/2 the natural frequency and transmissibility of the reactor-reflector structure in the longitudinal direction. No failures were encountered during testing. A performance record test consisting of mechanical, electrical, and operational checks was conducted prior to and after the vibration and shock tests. Comparison of the results revealed only one minor change in the reactor system. The +Y fine control-drum position sensor had rotated 1° from its pre-test setting. This could be compensated for by shifting its operating curve, as the sensor output is predictable.

4. Conclusions

The S2DRM-1 reactor system demonstrated its ability to survive the vibration and shock environments that would be imposed upon it during launch and placement in orbit without detectable failure or degradation. Movement of the fine control drum position sensors could be prevented by incorporating a method of pinning the sensor case after final calibration.

D. NaK LOADING TESTS

1. Test Setup

The S2DRM-1 shield, reactor vessel, NaK lines, radiator-condenser heat simulator, and reactor system heat simulator were installed in Vacuum System "B" at Building 062, Santa Susana facility. The system was then connected to the NaK loading cart fill and return lines for the NaK loading operation (Figure 9). The reactor vessel was complete with top head, grid plates, internal reflectors and dummy fuel elements. The RC heat simulator was used only to support the shield and reactor vessel during loading operations. The reactor system heat simulator consisted of a heater assembly, expansion reservoir, flowmeter, d-c conduction (Faraday type) pump, and associated plumbing (Figure 10). The NaK lines from the reactor vessel to a point five inches below the bottom of the shield were of flight configuration. The reactor system heat simulator was designed to heat NaK and pump it through the reactor vessel and coolant lines in a direction opposite to that of the NaK flow in a flight system. This reverse flow is necessary to maintain the reactor vessel outlet temperature higher than the inlet temperature. Hence, in thermal-vacuum testing of S2DRM-1, the NaK entered the reactor vessel through the reactor NaK outlet pipe.

The vacuum system consisted of a double-walled stainless-steel chamber base with two pumping ports and eight instrumentation feedthrough ports, a 5-foot-diameter double-walled spool extension, a double-walled stainless-steel dome with five viewing ports and one instrumentation feedthrough port, and a pumping package (Figures 5 and 11). The pumping package included two 16-inch oil diffusion pumps, two mechanical roughing pumps, and two mechanical holding pumps. An 18-inch-ID angle shutoff valve was attached to each pumping port between the port and cold trap assemblies. A liquid-nitrogen-cooled circular chevron cryobaffle was installed between each shutoff valve and the diffusion

Figure 9. S2DRM-1 NaK Loading Test Setup

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Figure 10. Interim SNAP 10A/2 DRM-1 Heat Simulator System

Figure 11.
Upgraded Vacuum System "B,"
Building 062, Santa Susana
Facility

pump to improve the pumping speed of the diffusion pump and reduce the backstreaming of diffusion pump oils. Water-cooled baffles were installed in the roughing lines to reduce backstreaming of the mechanical pump oil vapors. Standard ion and thermocouple gages were used to monitor the chamber pressure during the test.

2. Test Operations

The NaK loading operation was conducted in a vacuum chamber operating in the range of 10^{-4} torr or less. The reflector assembly and harness were not installed for this test. The test consisted of two cycles which included the following specified conditions:

- 1) A sustained isothermal operation of the reactor vessel below 140°F.
- 2) An increase of the reactor inlet temperature to 850°F (+30°, -0°) at a rate of 5°/minute; maximum difference between reactor inlet and outlet temperatures of 50°F.

3) A steady-state temperature cycle during which the NaK flow was continued until an acceptable NaK purity level had been obtained or until 10 hours had elapsed, whichever was longer; the vessel temperature maintained approximately isothermal with the vessel inlet temperature held between 850 and 880°F; maximum difference between reactor inlet and outlet temperatures 50°F.

4) A decrease of the reactor vessel temperature to 200°F at a rate of 5°/minute or less.*

5) Repeat of Steps 1 and 2 using the heat simulator heater and pump.

6) Maintenance of a reactor vessel outlet temperature of 850°F (+30°, -0°) for a minimum of one hour.

7) Repeat of Step 4.

3. Test Results

NaK loading tests were conducted as outlined and the reactor system heat simulator performed as designed. No discoloration of the NaK lines, reactor vessel, or heat simulator was observed after the two temperature cycles. The reactor vessel top head and NaK lines were covered with gold-coated molybdenum foil after the NaK loading test to meet flight specifications.

4. Conclusion

The test equipment performed in the required manner and the test (or operation) was deemed satisfactory. This operation was not directly correlated with the S2DRM-1 flight system environmental tests.

E. THERMAL-VACUUM OPERATIONAL TEST

1. Test Setup

The S2DRM-1 reactor system, radiator-condenser heat simulator and the reactor system heat simulator were installed in the base of Vacuum System "B," Building 062 at the Santa Susana facility (Figures 11, 12, and 13). The system consisted of a reactor vessel (with top head, grid plates, dummy fuel elements,

*The reactor vessel temperature was controlled by raising or lowering the temperature of the NaK in the loading cart. The NaK was pumped and "cold-trapped" continuously during cycling.

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Figure 12. S2DRM-1 Reactor System
Installed in Vacuum System "B,"
Building 062, Santa Susana

and internal reflectors), the reflector assembly, the shield assembly (SN 002) and the reactor vessel inlet and outlet NaK lines. All items were S10A/2 flight hardware except for the fine control drum motors (SNAP 10A fine control drum motors were used), an uncalibrated temperature-actuated release device, and dummy fuel elements. The radiator-condenser heat simulator was designed to duplicate the geometry, materials, temperature (using electrical heating elements mounted at each of the shield support bracket attach points), and surface emissivity of the upper portion of the flight radiator condenser structure (minus the mercury tubes). The reactor system heat simulator assembly consisted of a heater, reservoir, flowmeter, pump, flow control valve, NaK loading valves, and associated NaK lines. The simulator assembly was mounted on a base plate located below the shield. The assembly was designed to withstand the qualification launch loads as well as to heat the NaK and pump it through the reactor

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Figure 13. S2DRM-1 Reactor System Heat Simulator Installation

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vessel and coolant tubes. The direction of flow was opposite to that of the NaK flow in the flight system in order to maintain the reactor vessel outlet temperature higher than the inlet temperature.

The base of the vacuum chamber (Figure 11) contained eight instrumentation feedthrough ports and two 18-inch-ID pumping ports. The feedthrough ports accommodated the control, temperature, and diagnostic instrumentation wiring for the reactor system. A right-angle shutoff valve, liquid-nitrogen-cooled circular chevron cryobaffle, and 16-inch oil diffusion pump were attached to each of the pumping ports. The right-angle valves were used to seal off the chamber from the diffusion pumps to eliminate contamination of the reactor system from oil backstreaming during the ultrahigh-vacuum portion of the test. Water-cooled baffles were installed in the roughing lines to prevent backstressing of the mechanical pump oil vapors.

The control wiring, instrumentation, and drum release actuators with live squibs were attached to the reactor system. After a checkout of all instrumentation was completed, the spool section of the vacuum system (Figure 11) was installed. This section consisted of a 6-foot-diameter, 5-1/2-foot-tall stainless-steel spool containing two ion pumps, a liquid-nitrogen-cooled substrate shroud and six electron-beam guns with titanium modules.

The ultrahigh-vacuum system used consists of a titanium-depositing getter pump for pumping reactive gases, two 1000-liters/second ion pumps used principally for pumping noble gases, two 16-inch oil diffusion pumps with related cryobaffles, angle valves, and mechanical pumping systems to pump the chamber down to the range in which the ion and getter pumps are efficient. The titanium getter film is deposited on a liquid-nitrogen-cooled shroud located next to the chamber wall. Titanium molecules are sublimated by the action of electron-beam guns which are aimed at titanium briquettes (Figures 14 and 15). The released titanium molecules are then directed to the shroud by properly located baffles.

By renewing the "active" surface periodically, a continuous pumping is achieved and the already trapped gases are permanently removed from the chamber atmosphere. The combination of the titanium film getter pump and the ion pumps is known as the "intro-chamber titanium sublimation pumping system" (Figure 16).

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Figure 14.
Sublimation Source and
Baffle - Ultrahigh-
Vacuum System

Figure 15.
Electron-Beam Gun -
Ultrahigh-Vacuum
System

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Figure 16. Titanium Sublimation and
Electron-Beam Gun Installation

The vacuum chamber dome (Figure 11) containing three viewing ports and a multidirectional ion gage feedthrough, was installed on the spool. The chamber was roughed down using two mechanical roughing pumps. Most of the seals exposed to the vacuum side of the chamber were of indium, to decrease the amount of outgassing from elastomers.

2. Test Procedure

The planned series of test procedures for the thermal-vacuum operation were as follows:

- 1) Obtain a chamber pressure of 1×10^{-5} torr or less,
- 2) Obtain a reactor vessel isothermal condition at $150^{\circ}\text{F} \pm 20^{\circ}$,
- 3) Maintain the reactor vessel isothermal temperature at $150^{\circ}\text{F} \pm 20^{\circ}$ for 30 minutes $\pm$ 5 minutes.
- 4) Simulate a Compact Power Unit (CPU) startup command signal which activates the startup controller, fires the drum release squibs, and starts the fine control drums stepping in at 0.5 degrees per 150 seconds.

5) When the fine control drums reach a position of 78 degrees from "full out," increase the reactor vessel outlet temperature from 150 to 1200°F $\pm 20^\circ$ at a rate of 5° per minute $\pm 1^\circ$ per minute. The difference between the reactor vessel inlet and outlet temperature shall not exceed 50°F during heatup. Maintain the NaK pressure in the NaK heat simulator between 2.5 and 3.5 psig, and adjust the flow rate as necessary to control the reactor vessel ΔT .

6) Continue stepping the fine control drums inward at a rate of 0.5 degrees per 150 seconds until they reach their "full in" position. The drum stepping shall then be stopped, and the stepper motor of one drum disabled for the remainder of the test. The other drum shall be stepped outward, then inward, 10 degrees in each direction twice each day for the remainder of the test.

7) Maintain the reactor vessel outlet temperature at 1200°F $\pm 20^\circ$ and decrease the reactor vessel inlet temperature to 1000°F $\pm 20^\circ$ by decreasing the NaK flow rate. The heat loss from the vessel to the reflectors will decrease the vessel inlet temperature when the flow rate is decreased.

8) When the reactor vessel temperatures have been established at 1200°F outlet and 1000°F inlet $\pm 20^\circ$, increase the temperature of the shield mounting pads to 600°F $\pm 20^\circ$ at the maximum capability of the test equipment. (The radiator-condenser heat simulator has two electrical heating elements in each shield mount pad.)

9) Decrease the vacuum chamber to 1×10^{-8} torr or less, using titanium sublimation and ion pumps.

10) Maintain steady-state conditions for 30 days (1200°F vessel outlet, 1000°F vessel inlet, 600°F shield mount pads, and a chamber pressure of 1×10^{-8} torr or less).

11) Increase the reactor vessel outlet temperature to 1300°F (1100°F inlet) at a rate not to exceed 4° per minute at the end of the 1200°F steady-state period. (Adjust the NaK flow rate as required to maintain the 200°F vessel ΔT .)

12) Maintain a steady-state temperature cycle in which the reactor outlet shall be held at 1300°F $\pm 20^\circ$ (1100°F inlet). The drum that was disabled (Item 6) during the 1200°F period shall remain disabled during this period.

The other drum shall be stepped outward, then inward, 10 degrees in each direction once each day for the remainder of the test.

13) A final stepping sequence shall be accomplished at the end of the test period just prior to cooldown. Both stepper motors shall be energized and the fine control drums shall be rotated 10 degrees outward from the "full in" position at a rate of 0.5 degrees per 150 seconds.

14) Start cooldown cycle in which the reactor vessel temperatures shall be reduced at a rate not to exceed 5°F per minute.

15) Perform a reflector retainer band separation test by energizing the electrically actuated band release device (EABRD). Operation of the temperature actuated band release device (TABRD) shall be monitored.

3. Operational Test Results

The thermal-vacuum operational test followed the program outlined above until an attempt was made to establish the 200°F temperature differential across the reactor vessel (Step 7). During this operation it was necessary to bleed off a portion of the argon cover gas from the NaK system to maintain the system pressure below 3.5 psig. A NaK system pressure of 2.5 to 3.5 psig was believed to be sufficient to prevent boiling of the NaK in the heater section of the reactor system heat simulator. As the NaK flow rate was decreased, a fluctuation in the NaK pressure occurred and the pressure was inadvertently decreased to less than 1 psig. A bumping sound from the chamber indicated NaK boiling, and the NaK flow rate was increased as a precautionary measure while NaK pressure was slowly increased to 3.5 psig. Shortly after the NaK system pressure and flow rate were increased, two of the NaK heater elements shorted out. The reactor vessel temperatures stabilized at 1170°F, outlet, and 1080°F, inlet. No further attempt was made to establish the 200°F ΔT across the vessel in view of the problems that had been encountered. These incidents were investigated, and the maximum pressure to which the reactor vessel could be subjected (at 1200 and 1300°F) was determined.

The shield mounting pad temperatures were increased to 600°F to simulate coolant flow in the radiator-condenser structure. The fine control drums were stepped inward at 0.5 degrees every 150 seconds throughout the heatup cycle.

Figure 17. Chamber Pressure and Reactor Outlet Temperature -
S2DRM-1 Thermal-Vacuum Test, Run 7, Phase 1

When the fine control drums reached "full in," preparations for the ultrahigh-vacuum pumpdown were initiated. The first attempt to start the titanium sublimation system resulted in arcing of the high-voltage leads outside the vacuum chamber. The arcing problem was corrected and the high-vacuum valves were closed. The chamber pressure was reduced to 6×10^{-7} torr 41 hours after starting the sublimation process. The reactor vessel outlet temperature was 1170°F. The vacuum chamber pressure continued to decrease to 4×10^{-8} torr; Figure 17 presents the chamber pressure during the test. Additional problems with the electron-beam guns were encountered; these included shorting of high-voltage circuits inside the vacuum chamber, improper focus, and incorrect alignment. During this time the reactor vessel temperature had decreased to 1150°F.

As a result of the aforementioned investigation, the NaK system pressure was increased from 3.5 to 6 psig and two of the NaK heaters were switched from 110 to 200 volts. The reactor vessel outlet temperature increased to 1203°F with a 90°F ΔT between inlet and outlet. In view of the problems encountered during the first attempt to establish a 200°F ΔT across the reactor vessel, it was decided to eliminate this requirement rather than risk jeopardizing the test program. The vacuum chamber remained in the low 10^{-7} torr range. Attempts to restart the titanium sublimation system failed. An investigation of the problems encountered was conducted to determine if a method of repair could be initiated. Before a solution for the problems could be finalized, however, three additional NaK heating elements shorted out and the reactor vessel outlet temperature decreased to 1060°F. Due to the shorting of the heaters, no voltage changes were made. A white deposit was discovered in the NaK heater element wiring duct, and an analysis of the deposit revealed the presence of NaK. The test was terminated as a precautionary measure.

Post-test inspection of the NaK heater section revealed the cause of the additional heater element shorting problems to be leakage of NaK back through the first heater element that failed (Figures 18, 19, and 20). Table 1 summarizes the major incidents that occurred during the thermal-vacuum tests.

Figure 18.
S2DRM-1 NaK Heater
Element Failure

Figure 19.
Results of Heater
Element Failure

Figure 20.
S2DRM-1 NaK Heater
Assembly

TABLE 1
HISTORY OF S2DRM-1 THERMAL-VACUUM TEST,
RUN 7, PHASE 1

Date	Time (Clock)	Incident
4-7-65	1705	Initiated startup of Thermal-Vacuum Test by firing drum release actuator squibs
4-7-65	2345	Initiated heatup of S2DRM-1 reactor assembly
4-8-65	0249	1200°F vessel outlet temperature obtained
	0300	Decreased NaK flow to increase ΔT across vessel from 100 to 200°F
		Boiling of NaK occurred; NaK flow increased to correct
	0313	NaK heater element C7 shorted
	0316	NaK heater element C1 shorted
	0525	Turned radiator-condenser heaters on
	0539	Shield mounting brackets reached 600°F
	0541	Fine control drum stepping stopped (drums "full-in"); vessel outlet temperature 1170°F
	0545	Initiated startup of ultrahigh-vacuum system. Turned on ion pump 1
	0603	Turned on ion pump 2
	0700	Filled chamber shroud with liquid nitrogen
	1105	Encountered arcing of electron-beam gun high-voltage leads outside chamber
4-9-65	0800	Chamber pressure 6×10^{-7} torr
4-11-65	0216	Completed repair of electron-beam gun leads. Aimed electron-beam guns 2, 4, and 6. Closed diffusion pump high-vacuum valves. Chamber pressure 4×10^{-7} torr, using both ion pumps
	0615	Fired electron-beam gun to sublime titanium for the first time
4-12-65	0830	Electron-beam gun problems encountered, chamber pressure 2×10^{-7} torr
4-13-65	1452	Chamber pressure 4.5×10^{-8} torr, vessel outlet temperature slowly decreasing (presently 1160°F)
4-17-65	2245	Apparent short circuit developed in electron-beam gun 1

TABLE 1 (Continued)

Date	Time (Clock)	Incident
4-21-65	0030	Apparent short circuit developed in electron-beam gun 2; no other electron-beam guns operating properly
	0800	No electron-beam guns operational, chamber pressure 4×10^{-8} torr, vessel outlet temperature 1150°F
	1450	Increased NaK system pressure from 3.5 to 6 psig; increased voltage on NaK heater elements C8 and C9 from 110 to 200 volts
	1650	Vessel outlet temperature 1203°F and stable
4-24-65	0800	Still unable to successfully operate electron-beam guns, chamber pressure 2×10^{-7} torr
4-25-65	1235	NaK heater elements C8, C9, and C2 shorted, vessel outlet temperature 1060°F
4-27-65	1700	Analysis of white deposits in NaK heater element wiring duct revealed presence of NaK
4-28-65	0800	Initiated preparations for shutdown; stepped both fine control drums outward, then inward 10 degrees in each direction; completed final performance record test.
	1400	Started 5°F/minute cooldown; vessel outlet temperature 1060°F
	1820	S2DRM-1 NaK outlet temperature 380°F; turned off NaK pump; chamber pressure increasing
4-29-65	0956	Turned off all S2DRM-1 instrumentation, terminating test
4-30-65	1047	Opened vacuum chamber
5-6-65		Completed performance record test and visual examination of S2DRM-1 and vacuum system.

4. Performance Results

a. Temperature Distribution

The steady-state reflector temperatures recorded were 50 to 80°F higher than calculated. The probable cause of this difference was the increased average temperature of the reactor vessel as a result of the lower ΔT . The average vessel temperature was approximately 60°F higher than it would have been with

the 200°F ΔT . Figures 21, 22, 23, 24, and 25 present the temperatures of the +Y reflector, +Y fine and coarse control drums, +Y fine control drum motor, and the shield external and internal temperatures recorded during the test.

b. Mechanical Measurements

Mechanical measurements were taken during each performance record test to evaluate the effects of testing on the drum bearings and to determine if relative movement had taken place between the reflectors and reactor vessel or shield.

(1) Clearance

The accuracy of the clearance measurements is limited to ± 0.005 inch, as a result of difficulty in reaching some of the areas. Comparison of the measurements taken does not show significant movement of the reflectors, vessel, shield, or NaK lines as a result of the testing program.

(2) Torque

The accuracy of the torque measurements made on the coarse control drums during the performance record test is $\pm 10\%$. The instrument accuracy was $\pm 5\%$, the added 5% being attributed to reading error. Comparison of the torque measurements indicates no degradation of the coarse control drum bearings or springs as a result of the testing program.

c. Electrical Measurements

Circuit and insulation resistance measurements were taken on the fine control drum motors and position sensors before and after each phase of testing and periodically during the thermal-vacuum test. There were no indications of shorting or insulation degradation during or after these tests. The major problem encountered was excessive connector pin contact resistance (discussed with the reactor harness assembly below). The measurements taken were accurate to $\pm 5\%$, most of which is attributed to instrument reading error.

5. Component Performance

a. Reactor Harness Assembly

The major problems encountered on the harness assembly were not a result of thermal-vacuum testing but of fabrication discrepancies. Some of the individual cable lengths were shortened during fabrication and could not be routed

Figure 21. Temperature of +Y Reflector, S2DRM-1 Thermal-Vacuum Test, Run 7, Phase 1

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Figure 22. Temperature of +Y Fine and Coarse Control Drums,
S2DRM-1 Thermal-Vacuum Test, Run 7, Phase 1

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Figure 23. Temperature of +Y Fine Control Drum Motor,
S2DRM-1 Thermal-Vacuum Test, Run 7, Phase 1

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Figure 24. Shield External Temperature, S2DRM-1 Thermal-Vacuum Test, Run 7, Phase 1

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Figure 25. Shield Internal Temperature, S2DRM-1 Thermal-Vacuum Test, Run 7, Phase 1

as indicated on the assembly drawing. This is not considered a failure, but resulted in lost time and improper clamping arrangements.

The reactor harness interface receptacle brackets had to be slotted to allow for proper mounting of the interface receptacles (Figure 26). When the receptacles were mounted on the opposite side of the brackets the mating connector nut would not tighten sufficiently to hold the connector stationary. It is recommended that the bracket design in future harnesses be thoroughly investigated for possible redesign to prevent this mating problem.

The major problem caused by the improper fit of the harness assembly was connector pin contact resistance. The mating receptacle has female sockets with a small stainless-steel spring to provide a side load against the connector pin for good mechanical and electrical contact. This stainless-steel spring is not tempered sufficiently to prevent its losing the original clearance for proper contact after repeated connector mating. This problem was encountered previously during S10DRM-1 testing, after which a change to lower temperature rated connectors was made on SNAP 10A. The changes made to the high-

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Figure 26. S2DRM-1 Interface
Receptacle Bracket

temperature connectors since the S10DRM-1 tests have not been sufficient to improve their reliability for repeated mating. It is recommended that this type of connector be eliminated or completely redesigned to prevent the recurring problem of high contact resistance after repeated mating.

The reactor harness, per se, demonstrated its ability to withstand the conditions imposed upon it without degradation or failure.

b. Fine Control Drum Motors

The S10A-type fine control drum motors were used to rotate the fine control drums inward during the start of the thermal-vacuum test to simulate actual reactor startup.

After the fine control drums reached "full in" the +Y fine control drum motor was disconnected from the controller and the drum was not moved until just prior to test shutdown. Twice daily during the test, the -Y fine control drum was stepped outward, then inward, 10 degrees in each direction. There was no sign of welding or hesitation when the +Y fine control drum motor was reactivated and stepped outward and then inward during this test. Insulation and winding resistance measurements taken on both of the fine control drum motors throughout the test showed no signs of degradation. The temperature distribution of the +Y fine control drum motor during the test appears in Figure 23. The +Y fine control drum motor was 30°F hotter than the -Y motor due to its proximity to the NaK line, which was at 1200°F.

It should be noted that the fine control drum motors had successfully completed qualification testing under S10A specifications prior to being attached to the S2DRM-1 reflector assembly.

c. Fine Control-Drum Position Sensor

Sensors were used to determine the position of the fine control drums during thermal-vacuum testing of the S2DRM-1 reactor assembly. Breadboard-type demodulators were used to supply the voltage to the sensors and convert the sensor outputs to dc for recording purposes. Comparison of the test data and pre-test calibrations showed lack of repeatability. This was attributed to insufficient control of the input to the demodulators from an external power supply.

No firm conclusion can be made regarding the position sensor and demodulator accuracy; the data obtained, however, indicates good linear characteristics and very little drift of the sensor units during steady-state conditions.

The high-emissivity coating that was applied to the position sensors flaked off during cleaning, handling, and testing of the reactor system (Figure 27). The coating used was PT404 (Product Technique, Incorporated) which does not resist abrasion or cleaning.

d. Startup Controller

An S10A flight-type startup controller was used to step the fine control drum motors during testing of the S2DRM-1 reactor system. This controller was also used during the thermal-vacuum testing of the S10DRM reactor system, where it logged over 2500 hours at operating temperature (150°F) without failure. During the S2DRM-1 testing, 480 additional hours were logged by the controller without failure to respond to a command signal. The time delay between stepping sequences was somewhat erratic due to noise being picked up by the temperature switch simulation leads and switch. This controller has demonstrated its ability to operate when commanded even after over 2500 hours of operation followed by storage without voltage applied for 1 year.

e. End-of-Life Devices

A temperature-actuated band release device (TABRD) and an electrically-actuated band release device (EABRD) were used during the testing of the S2DRM-1 reactor system. The TABRD was not calibrated prior to the test due to accidental damage to the rupture stud; it was therefore disarmed. Though the rupture stud was bent, indicating that it had been dropped, cause of the damage could not be established. The EABRD had been subjected to complete acceptance testing. Both devices survived the vibration, shock and thermal-vacuum testing without failure. Neither device was used to terminate the test.

f. Squibs and Drum Release Actuators

The drum release actuators survived the launch simulation vibration and shock tests with only minor abrasion to the pins (Figure 28). M130 squibs were installed in the actuators prior to start of the thermal-vacuum test. All of the squibs fired, and the actuators released the control drums when the startup command signal was given.

Figure 27. S2DRM-1 Fine Control
Drum Position Sensor

Figure 28. S2DRM-1 Control Drum Release
Actuators After Vibration Test

An inspection of the actuator assemblies was conducted after the thermal-vacuum test (Figure 29). The inspection revealed deposits from the expended squib charge inside the actuator. The snubber had also expanded and locked inside the striker. Removal of the snubber from the striker resulted in breaking of the lock ring that holds the snubber onto the piston assembly. The snubber could be returned to its original configuration with minor tooling and reannealing; however, it is recommended that the snubber be replaced prior to reassembly. Replacement of the lock ring would be mandatory for reassembly of each actuator.

g. Position Switches

V3-1301-type position switches were installed on the S2DRM-1 reactor system. The control drum reflector, and retainer band position switches were adjusted prior to the vibration test. No further adjustment of the switches was necessary prior to the thermal-vacuum test except for the reflector switches which were removed for the NaK loading operation.

There were no indications of switch failure or degradation during testing of the S2DRM-1 reactor system.

h. Control-Drum Bearings

Torque measurements were made on both of the coarse control drums during the performance record tests to ascertain effects of testing on bearing surfaces. No galling or binding of the bearings was indicated by the torque measurements taken throughout testing.

i. Reflectors, Retainer Band, Drums, Ejection Springs, and Drive Assemblies

The reflector temperatures during thermal-vacuum testing were 50 to 80° F higher than expected. This was probably due to the low emissivity of the substrate shroud as compared with that used for analytical calculation. Figure 22 shows the reflector and control-drum temperatures from startup to end of test.

Post-test examination of the reflectors revealed a large amount of discoloration of the beryllium due to the presence of contaminating gases resulting from test item and fixture outgassing and problems with the ultrahigh-vacuum equipment. No other abnormalities were found.

Figure 29. S2DRM-1 Actuator Assembly After Thermal-Vacuum Test

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Figure 30. Glow of NaK Line During Thermal-Vacuum Test

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Strain gages were not used on the retainer band due to the limited time available for starting the thermal-vacuum test.

j. NaK Lines

The reactor vessel NaK inlet and outlet lines were of flight configuration down to a point 5 inches below the bottom of the shield. The lines were covered with gold-coated molybdenum foil to reduce heat loss due to radiation during the thermal-vacuum test.

No failure or damage to the NaK lines was incurred during shock, vibration, NaK loading, or thermal-vacuum testing. During the thermal-vacuum test the NaK lines glowed red and a time exposure photograph was taken through a viewing port (Figure 30). The NaK outlet line was at 1200°F and the inlet line at 1100°F when the photograph was taken.

After the test, the portions of the NaK lines not covered by gold-coated molybdenum were darker in color than the portions covered by the foil. This is attributed to the contaminating gases in the residual atmosphere of the vacuum chamber.

k. Reactor Vessel

The S2DRM-1 reactor vessel — complete with internal reflectors, grid plates, and dummy fuel elements — was subjected to launch simulation vibration and shock tests, NaK loading tests, and the thermal-vacuum test as a part of the S2DRM-1 reactor system.

The inspection performed after the vibration test revealed slight chafing of the grid plates at the fuel element contact points. No additional wear or deformation was detected.

After the thermal-vacuum test the reactor vessel was drained of NaK, flushed with alcohol, steam-cleaned, and flushed with water prior to being cut open for inspection. When the vessel was opened, rust was visible beneath the grid plate springs, indicating that the plates or springs had become sensitized during the thermal-vacuum test. There was discoloration on the internal reflectors and dummy fuel elements, attributed to the cleaning process necessary to remove the NaK prior to opening the vessel. The external surfaces of the vessel were discolored due to the reaction of the contaminating gases present in the vacuum chamber during the thermal-vacuum test.

It is felt that the reactor vessel and internals endured the environments imposed upon them without visible damage or degradation which would result in a failure during orbital operation.

1. Shield SN 002

Figures 24 and 25 show the internal and external temperature distribution of the shield from start to end of thermal-vacuum testing. No apparent damage or deformation of the shield occurred as a result of testing; however, a final conclusion cannot be made without x-ray, helium leak check, and dimensional inspections which are not scheduled at this time.

IV. CONCLUSIONS

The acceptance level, shock, vibration, NaK loading, and thermal-vacuum operational tests demonstrated that the S2DRM-1 reactor assembly can survive the non-nuclear environments that would be imposed upon it from final assembly through start-up and 20 days of operation at temperature in a vacuum (simulating an earth orbit) without failure. The thermal-vacuum operational test was terminated (after 20 days) due to the failure of the NaK heater assembly, which was not part of the reactor system. Comparison of the performance record test data taken prior to and after each phase of testing showed no signs of degradation of the reactor assembly components. Following the failure of the NaK heater assembly during thermal-vacuum testing of the S2DRM-1 reactor system, a 30-element NaK heater and reservoir assembly was designed and fabricated for testing at elevated temperatures up to 1450°F. The heater and reservoir assemblies were not installed in the reactor system heat simulator due to program curtailment and thus the 90-day endurance objective was not fulfilled.

Due to the unavailability of SNAP 2 fine control drum motors, SNAP 10A flight-type motors (with mounting adapters) and controller were used to rotate the fine control drums during the tests conducted on the S2DRM-1 reactor assembly. The SNAP 10A fine control drum motors and controller demonstrated their compatibility with the SNAP 2 reflector assembly and operating requirements.

The vacuum chamber pressure obtained using the titanium sublimation and ion pumping system (UHV) system during thermal-vacuum testing of the S2DRM-1 reactor system substantiated the pre-test information. A preliminary pumpdown of the modified vacuum chamber was conducted prior to installing the reactor system. An ultimate pressure of 5×10^{-10} torr was obtained in the clean, dry, and empty chamber without bakeout. The lack of area and time to prepare and test the UHV equipment resulted in problems with high-voltage leads and proper aiming of the electron-beam guns. Methods of correcting the problems encountered were devised; due to program curtailment they have not been tested. Preliminary test results indicate that there was insufficient developmental testing of the UHV system prior to its use in testing the S2DRM-1 reactor system. The maximum capabilities of this type of vacuum pumping system should be determined by experimentation in order to benefit other space-oriented test programs.