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RFD-2 TELEMETRY SYSTEM

L. J. Keck, 9313

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IN NUCLEAR SCIENCE ABSTRACTS

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RFD-2 TELEMETRY SYSTEM

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July 1965

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ABSTRACT

This report describes the design and performance of the telemetry system flown on Re-entry Flight Demonstration No. 2, which was the second in Sandia's series of operational safety flight tests of systems for nuclear auxiliary power.

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FOREWORD

Nuclear power systems for space applications, now under extensive development by the United States, must be so designed that at no time will they offer any radiation hazard to the world's population. From the standpoint of safety, one of the most critical periods in their life cycle is that of re-entry into the earth's atmosphere, either through orbital decay after a successful mission, or in returning from a short-lived orbit such as that resulting from a launch-vehicle malfunction.

Several means of insuring that no radiation hazard will result from re-entry are now being explored. One of these means is to design the system so it will disassemble under the aerodynamic heating and mechanical forces experienced during re-entry, releasing the fuel capsules into the airstream. The capsules, once released, are in turn exposed to aerodynamic heating, and ablate into minute particles. Atmospheric winds then disperse these particles at very high altitudes, distributing the debris in such low concentrations that no radiation danger exists.

Sandia is conducting a series of full-scale re-entry experiments to evaluate the effectiveness of this method. In these flights, inert nuclear power sources are flown on a trajectory that simulates an orbital-decay trajectory as closely as possible within the limitations of the launch vehicle, range safety, instrumentation requirements, etc. Events occurring during the re-entry are recorded by land-based and airborne optical systems and by land-based, airborne, and shipboard telemetry (TM) stations.

The first such test, Re-entry Flight Demonstration No. 1 was conducted in May 1963. The power source flown was a simulated SNAP-10A reactor. The second flight, RFD-2, was made in October 1964. The inert power unit flown on this test was representative of the SNAP-9A, IMP-mission, and SNAP-19 isotopic generators.

It should be emphasized that the units flown on these experiments are inert. The nuclear fuel materials have been replaced by nonradioactive materials, and the flights cause no radiation hazard whatsoever.

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RFD-2 TELEMETRY SYSTEM

INTRODUCTION

RFD-2 was conducted to provide experimental data on the disassembly of a SNAP-19-type generator under re-entry heating, and to obtain information on the rate of fuel-capsule ablation. Flight-test data on heating rates were then correlated with the heating rates predicted by analytical methods and observed in laboratory experiments.

Primary objectives of RFD-2 were to:

1. Monitor (a) destruction of the outer housing of the generator, (b) destruction or separation of the thermoelectric modules and insulation surrounding the fuel cavity, and (c) separation of the simulated fuel capsules from the generator.
2. Obtain information on fuel ablation by optically recording the re-entry of tracer-loaded, simulated fuel capsules which were ejected from the test vehicle near the start of re-entry.

Additional objectives were to obtain information on the design of the re-entry vehicle (RV) used for the flight, and to acquire data from two subsidiary experiments. The subsidiary experiments involved measuring the intensity and approximate spectral content of light radiance in the re-entry wake, and testing the performance of heat-initiated thermal batteries.

The RFD-2 re-entry system (RS) was launched by a three-stage Scout vehicle* from the NASA facility at Wallops Island, Virginia, on a re-entry trajectory leading to impact about 150 nautical miles southeast of Bermuda. Optical and TM instrument systems on Bermuda and in ships and aircraft near Bermuda recorded the re-entry events. Figure 1 shows the re-entry flight path with respect to Bermuda and the downrange instrumentation elements.

*All previous Scouts had been flown with four stages, but safety problems developed with fourth-stage motors of the type planned for use, so the RFD-2 Scout was flown with only three stages. Since Scout launch loads are normally transferred into the payload through the structure of the fourth-stage motor, it was necessary to replace the fourth-stage-motor with a structural mockup, called the cylindrical load adaptor, or fourth-stage spacer.

Figure 1. RFD-2 re-entry flight path with respect to Bermuda and the downrange instrumentation elements

RFD-2 is considered to have been very successful. High-quality TM data were received throughout the flight, with 131 of the desired 132 channels of information being returned. Optical data were recorded throughout the re-entry, with 108 of the 111 cameras and other optical instruments operating as planned during the data period. The TM and optical data provided complementary information verifying that the objectives of the flight were met.

RE-ENTRY SYSTEM DESCRIPTION

Major elements in the re-entry system (Figure 2) included the simulated isotopic generator, the external fuel-capsule experiment, and the RV with its subsystems.

Generator

The inert nuclear power source tested in RFD-2 was representative of a series of radioisotopic-thermoelectric generators designed by the Martin Nuclear Division of the Martin Co., Baltimore, Md. Operational versions of these units are designed to produce 20 watts of electrical power for periods greater than three years.

In these generators, heat produced by the radioactive decay of plutonium 238 is converted directly into electrical power by thermoelectric elements. The cold junctions of the thermoelectric elements are kept at the proper operating temperature by means of controlled heat radiation into space.

The RFD-2 dummy generator and its associated instruments were supplied as an integral unit by the Martin Co. The generator was mounted by its back cover on the nose of the RV. The generator consisted of an HM31A magnesium outer vessel, a fuel cavity filled with simulated fuel rods, heat accumulators, dummy thermoelectric elements, aluminum module blocks, and insulation. The thermoelectric assemblies were arranged in a series of longitudinal rows between the fuel cavity and the vessel walls. The thermoelectric elements were separated by Min-K insulation. The generator was 10.14 inches long, the cover flange diameter was 7.00 inches, and the vessel body diameter was 5.313 inches. The generator is shown and its instrumentation is described on page 27 of this report.

Four simulated, tracer-loaded fuel capsules were carried in the fuel cavity of the generator. When the generator disassembled under re-entry heating, these capsules were released into the airstream, where aerodynamic heating caused the tracer materials to flare. The flares were recorded by ground-based and airborne optical instruments. The capsules were constructed with segmented, fallaway containers, so the tracers flared almost immediately after release, indicating the altitude of generator disassembly. Further information on the time of capsule release was provided by the TM system.

Figure 2. RFD-2 re-entry system

External Fuel-Capsule Experiment

Strapped to the outside of the generator were four simulated fuel capsules, each containing a different optical tracer element. These capsules were released from the RS early in re-entry. The tracers flared under re-entry heating, and the flares were optically recorded to provide information on fuel-ablation rates.

Re-entry Vehicle

The RV provided an aerodynamically stable support for the simulated isotopic generator and the external fuel-capsule experiment, a mounting and housing for the RV subsystems and the subsidiary experiments, and thermal protection for RS components which required it. The RV structure consisted mainly of an aluminum shell covered with a phenolic-fiberglass laminate. The ablation material was phenolic-Refrasil. Principal RV subsystems were a despin mechanism and a recovery package, which are described briefly below, and the TM system, which is described in detail in following sections of this report.

The cylindrical load adaptor fit partially into a cavity in the aft end of the RV. To achieve aerodynamic stability during re-entry, it was necessary to eject the adaptor from the RV shortly after apogee. A hot-gas generator pressurized a piston assembly to provide force to eject the adaptor and separate it from the RV.

Also for aerodynamic stability during re-entry, the RS was spun up to about 160 rpm a short time after apogee, with the spin force being supplied by four small rocket motors which were part of the Scout. Then, just before the beginning of re-entry, a yo-yo despin mechanism was actuated to reduce the RS spin rate to about 14 rpm. This was done to reduce centrifugal forces during re-entry, since high centrifugal force would have aided generator disassembly and thus made the test less realistic. The despin mechanism was separated from the RV after it had performed its function.

The recovery package included a parachute, two flotation bags, two RF beacons, and two flashing lights. The parachute was deployed at an altitude of 23,300 feet. The two flotation bags, one attached to the parachute and the other carried inside the RV, were inflated shortly after parachute deployment. One of the RF beacons was turned on before launch and operated throughout the flight, while the other was turned on at water impact. Both flashing lights were turned on at water impact. The re-entry vehicle was not recovered in this test.

TELEMETRY SYSTEM DESIGN REQUIREMENTS

Design of the TM system began almost immediately after preliminary discussions of the RFD-2 flight test were completed. The following guidelines were adopted:

1. Temperature measurements would be made at about 30 points on the isotopic generator.
2. An undetermined number (but probably six or fewer) of switch-type signals would be required to indicate release of the simulated fuel capsules from the generator fuel cavity.
3. Information on RS attitude during re-entry would be required.
4. Vibration and acceleration measurements would be helpful in determining the magnitude and spectrum of forces acting on both the generator and RS.
5. Temperature measurements would be made at about 30 points on the RV to verify its design integrity.
6. RS recovery should be attempted.
7. Radar tracking for trajectory analysis would be mandatory.
8. An on-board timer and programmer would be required to initiate in-flight functions.

In addition, it would be desirable to monitor (1) the voltage standing-wave ratio of the TM antennas, (2) TM battery voltages, (3) temperature of the TM system, and (4) performance of the timers in the programmer.

A major consideration in design of the TM was that RF blackout would occur during the time of generator disassembly, the most vital data period in the flight. Consequently, information on events occurring during blackout would have to be recorded for transmission after blackout ended. Other prime considerations were flexibility and reliability. Flexibility was necessary because the total number of measurements to be required had not been firmed up when TM design began, and the number would undoubtedly change (probably increase) several times as the program progressed. As for reliability, flight testing is extremely expensive, and its cost can be justified only if it provides data which cannot otherwise be obtained. The TM should therefore be the most reliable subsystem in the test vehicle.

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To meet the requirements set by the guidelines and considerations stated above, the following basic design approach was formulated:

1. As far as practical, only components with a record of performance and reliability, established in similar test programs or environments, should be used.
2. For additional reliability, redundancy should be used wherever possible.
3. To handle the data required, time-sharing and frequency-sharing techniques would be employed. Data with possible high-frequency components (acceleration, for example) would be carried on continuous subcarrier channels. Low-frequency data such as temperatures would be commutated and thus time-shared on other subcarriers.

Based on all the requirements thus far established, the following design decisions were made:

1. Two FM transmitters would be used, one for real-time data and the other for delayed transmission of data on events occurring during blackout.
2. An on-board tape recorder of the model used by Sandia on RFD-1 (slightly modified) and other missile programs would be used to store data on events occurring during blackout.
3. A maximum of 15 subcarrier frequencies would be transmitted. This limit was set by the maximum number of subcarrier oscillators (SCO's) that could be carried in two standard Sandia eight-channel SCO mounts (a millivolt-controlled SCO for thermocouple measurements required double space on the mount). Since one of the 15 frequencies would have to be a reference frequency for flutter and wow correction of the tape recorder, 14 subcarrier frequencies would be available for data transmission.
4. Two commutators would be employed. One, the low-level commutator, would carry only the millivolt-level signals generated by thermocouples. The other would carry high-level signals (0 to 5 volts). The data were to be carried on different commutators to (1) reduce possible crosstalk from the high-level signals onto the low-level signals, and (2) avoid having to amplify all low-level signals or attenuate high-level signals to make them compatible with a single SCO input.
5. A roll-stabilized gyro developed specifically for Sandia by Whittaker and used on many rocket and missile tests, including RFD-1, would be used to provide data on RV orientation.
6. A C-band beacon would be incorporated as a tracking aid for the Bermuda radar.
7. Two batteries composed of Sonotone F cells (SA-1207) would supply system power. These cells have been used in many missile tests and have been evaluated by Division 1323 (see SCDR 323-62 by G. H. Matvichuk).

8. It was decided to transmit a time code on both the real-time and delayed-time channels so that real-time and delayed-time data could be correlated if a range-recorded magnetic tape did not have a useable range-time code.

Requirements to measure light intensity in the re-entry wake and output of the two heat-initiated batteries were established after TM design work had started. The necessary provisions were incorporated into the system.

Late in the development program, the change to a three-stage Scout was made, greatly reducing the expected vibration input to the RV. Two vibration transducers which were to measure vibration transmitted to the RV through the fourth-stage adaptor section were consequently eliminated. At about the same time, it was decided to switch from a commercial timer-programmer to a special unit designed for RFD-2 by Division 1423. This unit was modified slightly to permit monitoring of the firing voltage buss. The monitor points replaced the vibration transducers on the two open subcarriers.

TELEMETRY SYSTEM DESCRIPTION

General

The TM system was designed to transmit information on both the temperature and breakup of the isotopic generator, on the orientation and temperature of the RV, on the vibration and acceleration experienced by the TM system, on the "state of health" of the TM system, and on results of the two subsidiary experiments. In addition, it included tracking aids, electronic and visual aids for post-impact location, and a timer-programmer for initiating in-flight functions. Figure 3 shows the TM package and a block diagram of the system. Table I lists the major TM components. Pickups are listed in the tabulations of channel assignments.

Two FM transmitters were used, one (Transmitter A, real time) operating at 231.4 mc and the other (Transmitter B, delayed time) at 240.2 mc. For increased reliability, each transmitter fed a separate antenna. Output of the real-time transmitter was 10 watts into a 50-ohm, $1\frac{1}{2}$ -wavelength, ring-dipole antenna within the RV. Output of the delayed-time transmitter was 5 watts into a 50-ohm, $\frac{1}{4}$ -wave stub antenna which protruded from the aft end of the RV. Radiant-heat tests of the RV indicated that the char layer formed on the ablation material would attenuate output of the ring-dipole antenna by at least 8 db. The stub antenna, which would not be covered by a char layer, was designed and incorporated specifically to transmit the delayed data. Both the stub and ring-dipole were polarized parallel to the longitudinal axis of the RV.

Mode of Operation

The RS experienced three distinct trajectory-dependent environments or data periods: (1) from launch to RF blackout, (2) during blackout, and (3) from the end of blackout to impact. During the first period, real-time data on performance of the Scout and on the performance and environment experienced by the RS were of first importance. Data collected and stored in the on-board tape recorder during the second period, RF blackout, covered the time of maximum heating to the generator and RV, and were therefore of primary importance to the flight test. After blackout, it was necessary to transmit both the recorded data collected during blackout and, for a short time, real-time data on RV performance and environment.

From launch to RF blackout, Transmitter B (240.2 mc) transmitted, in real time, the information listed in Table II.

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Figure 3. RFD-2 TM system

Figure 3 (cont)

TABLE I

TM System Components

Component	Quantity	Manufacturer	Model	Remarks
Transmitter, FM	1	Conic	CTM-205	231.4 mc, 5 watt
Transmitter, FM	1	Conic	CTM-210	240.2 mc, 10 watt
Directional coupler	2	Micro Lab	CH23T	For measurement of antenna VSWR
C-band beacon and circulator	1	Motorola	SST-131	For radar tracking
Tape recorder	1	CEC	178400	Continuous loop
Commutator, high level	1	Fifth Dimension	S/S2MT-565	60 channels, 2.5 rps
Commutator, low level	1	Fifth Dimension	S/S1MT-564	60 channels, 1 rps
Mount, oscillator	2	Teledynamics	M-138	8 subcarriers each
Oscillator, sub-carrier, voltage controlled	14	Teledynamics	1270A	0 to 5 volt input
Oscillator, sub-carrier, millivolt controlled	1	Teledynamics	1284CY	-4 to +16 millivolt input
Battery	2	Sonotone	SA-1207	3 amp-hr, hermetically sealed
Gyro	1	Whittaker	518025	Roll stabilized
Calibrator, subcarrier	1	Sandia	TRC	Three-step
CW beacon	1	Conic	CTB200-05	225.7 mc, 1/2 watt
Regulator, 5 volt	1	Vector	TV63	Short-circuit-protected
Regulator, 5 volt	1	Sonex	TEX3604	Isolated output
Line amplifier	2	Sonex	TEX3210	5-ohm output impedance
Diplexer	1	Bendix	TNC-15	231.4 and 225.7 mc
Time-code generator	2	Logitek	A690	Binary time code
Accelerometer, ± 35 g	1	Bourns	2006097001	Longitudinal acceleration
Accelerometer, ± 3 g	2	Bourns	2006096002	Lateral acceleration
Vibration transducer	1	Massa	AC-107	TM compartment, longitudinal
Amplifier, vibration	1	Massa	PA2	Voltage amplifier
Relay	14	Filtors	PL26H1M6A	Latching
Relay	6	Filtors	BRJ26J2P6A	Nonlatching
SARAH beacon	1	Simmonds	311020-01001	235-mc, 25 watts peak
Flashing light	1	ACR Electronics	ACR31	2,000,000 lumens peak
DC-DC converter	1	Simmonds	319004	SARAH power supply
Flashing light	1	ACR Electronics	ACR4C	500,000 lumens peak
Inflight programmer	2	Sandia	RFD-2	Special

TABLE II

Subcarrier Channel Assignments for Transmitter B

Subcarrier Frequency (kc)	Data Input	Type of Transducer	Transducer Range	Transducer Location
70.0	Pyro B monitor	--	--	--
40.0	Pyro A monitor	--	--	--
30.0	Vibration	Crystal accelerometer	± 10 g	TM structure, longitudinal
22.0	PAM	See Table IV		
14.5	PAM	See Table V		
10.5	Roll	Roll-stabilized gyro	0-360°	TM compartment
7.35	Yaw	Roll-stabilized gyro	$\pm 85^\circ$	TM compartment
5.4	Pitch	Roll-stabilized gyro	$\pm 180^\circ$	TM compartment
3.9	Acceleration	Swept-resistance accelerometer	± 35 g	TM compartment
3.0	Acceleration	Swept-resistance accelerometer	± 3 g	TM compartment
2.3	Acceleration	Swept-resistance accelerometer	± 3 g	TM compartment
1.7	Time Code B	Time-code generator	1 pps	TM compartment
1.3	Time Code A	Time-code generator	1 pps	TM compartment
50.0	Tape-speed compensation	--	--	--

Transmission of data on events occurring during blackout was handled by both transmitters, through the on-board tape recorder. The recorder was a continuous-loop unit with a simultaneous record-playback capability; that is, its operational sequence was a continuous one of record, store, playback, erase, record, store, etc. The recorder, which was started before liftoff, recorded the data listed in Table III. It stored this information for 80 seconds, then supplied the recorded signal to Transmitter A (231.4 mc) for transmission. After transmission, the previously recorded signal was erased and current data were recorded and stored for 80 seconds before transmission, in a continuous process. Thus, throughout the flight, data transmitted by Transmitter A were delayed by 80 seconds, which was more than enough to cover the period of blackout (42 seconds).

From the end of blackout until the time that no further real-time data were required (shortly after parachute deployment), Transmitter B continued to send real-time data, while Transmitter A continued to transmit in delayed time. After parachute deployment, the real-time circuit to Transmitter B was interrupted and the output of the recorder substituted. Therefore, after parachute deployment, both transmitters were sending the data recorded during blackout. The time between the end of blackout and water impact was 78 seconds, enough for almost a complete playback of the tapeloop. After the end of blackout, the record-erase-record mode was turned off to prevent the taped record of events during blackout from being erased and replaced by post-blackout data, which were of little significance to the primary

TABLE III

Subcarrier Channel Assignments for Transmitter A

Subcarrier Frequency (kc)	Data Input	Type of Transducer	Transducer Range	Transducer Location
40.0	Pyro A monitor	--	--	--
30.0	Vibration	Crystal accelerometer	± 10 g	TM structure, longitudinal
22.0	PAM	See Table IV		
14.5	PAM	See Table V		
10.5	Roll	Roll-stabilized gyro	0-360°	TM compartment
7.35	Yaw	Roll-stabilized gyro	$\pm 85^\circ$	TM compartment
5.4	Pitch	Roll-stabilized gyro	$\pm 180^\circ$	TM compartment
3.9	Acceleration	Swept-resistance accelerometer	± 35 g	TM compartment
3.0	Acceleration	Swept-resistance accelerometer	± 3 g	TM compartment
2.3	Acceleration	Swept-resistance accelerometer	± 3 g	TM compartment
1.7	Time Code B	Time-code generator	1 pps	TM compartment
1.3	Time Code A	Time-code generator	1 pps	TM compartment
50.0	Tape-speed compensation	--	--	--

objectives of RFD-2. Thus, if the RS could be recovered, the tape would provide a backup record of events during blackout.

The two TM batteries provided enough power to operate the complete TM system for at least one hour. These batteries also powered the RS pyrotechnic system and one of the RF beacons. To conserve battery life, only the 231.4-mc transmitter, the tape recorder, and the beacon remained on after water impact. Separate batteries powered the other RF beacon and the flashing lights.

Channel Assignments

After the data requirements were finalized, the signals were allocated to the subcarrier frequencies of commutator segments which best suited the voltage level and frequency content of each input. Tables II, III, IV, and V list the subcarrier and commutator channel allocations.

Two subcarriers (70.0 and 40.0 kc) were used to transmit data on performance of the airborne programming system.

One subcarrier (30.0 kc) transmitted data on the magnitude of vibration experienced by the TM structure.

TABLE IV

Segment Assignments for the High-Level Commutator

Channel	Data Input	Sensor or Other Signal Source	Range	Location or Description
1	Zero reference	--	0 volts DC	--
2	Full-scale reference	--	5 volts DC	--
3	Time A 2 ¹	Time-code generator	2-second pulse	TM compartment
4	Time B 2 ¹	Time-code generator	2-second pulse	TM compartment
5	Time A 2 ²	Time-code generator	4-second pulse	TM compartment
6	Time B 2 ²	Time-code generator	4-second pulse	TM compartment
7	Time A 2 ³	Time-code generator	8-second pulse	TM compartment
8	Time B 2 ³	Time-code generator	8-second pulse	TM compartment
9	Time A 2 ⁴	Time-code generator	16-second pulse	TM compartment
10	Time B 2 ⁴	Time-code generator	16-second pulse	TM compartment
11	Time A 2 ⁵	Time-code generator	32-second pulse	TM compartment
12	Time B 2 ⁵	Time-code generator	32-second pulse	TM compartment
13	Time A 2 ⁶	Time-code generator	64-second pulse	TM compartment
14	Time B 2 ⁶	Time-code generator	64-second pulse	TM compartment
15	Temperature 42	Minco S8B	0-170°F	Battery pack
16	Temperature 43	Minco S8B	0-170°F	Battery pack
17	Temperature 44	Minco S8B	0-170°F	TM structure
18	Temperature 45	Minco S8B	0-170°F	10-watt transmitter
19	Temperature 46	Minco S8B	0-500°F	RV shell, Al, body, Sta. 27.9
20	Temperature 47	Minco S8B	0-500°F	RV spacer, inner, Sta. 29.3
21	Full scale			
22	Temperature 48	Minco S8B	0-500°F	RV drogue gun, Sta. 33.1
23	Dipole VSWR	Bidirectional coupler	0-1.5 volts	Incident power
24	Dipole VSWR	Bidirectional coupler	0-1.5 volts	Reflected power
25 and 55	Switch 1	Contact switch	Open/closed	Isotopic generator
26 and 56	Switch 2	Contact switch	Open/closed	Isotopic generator
27 and 57	Switch 3	Contact switch	Open/closed	Isotopic generator
28 and 58	Switch 4	Contact switch	Open/closed	Isotopic generator
29	Temperature 49	Minco S8B	0-500 F	RV shell, Al, body, Sta. 38.8
30	Temperature 50	Minco S8B	0-500 F	RV spacer, inner, Sta. 39.8
31	Temperature 51	Minco S8B	0-500°F	RV shell, ablation, inner, Sta. 55.4
32	Temperature 52	Minco S8B	0-500 F	RV frame, outer, Sta. 55.4
33	Temperature 53	Minco S8B	0-500 F	RV shell, ablation, inner, Sta. 63.7
34	Temperature 54	Minco S8B	0-500 F	RV frame, outer, Sta. 67.5
35	Temperature 55	Minco S8B	0-500 F	RV shell, ablation, inner, Sta. 72.1
36	Battery voltage 56	Thermal battery	0-7 volts DC	RV flare, Sta. 75.3
37	Battery voltage 57	Thermal battery	0-7 volts DC	RV flare, Sta. 75.3
38	28-volt monitor	TM battery A	0-28 volts DC	TM compartment
39	28-volt monitor	TM battery B	0-28 volts DC	TM compartment
40	Radiance 1	Photosensor	0.01-1.0 foot-candles	Peak sensitivity - 5150 Å
41	Radiance 2	Photosensor	0.01-1.0 foot-candles	Peak sensitivity - 5150 Å
42	Radiance 3	Photosensor	1.0-300 foot-candles	Peak sensitivity - 5150 Å
43	Radiance 4	Photosensor	0.01-1.0 foot-candles	Peak sensitivity - 5500 Å
44	Radiance 5	Photosensor	0.1-10 foot-candles	Peak sensitivity - 5500 Å
45	Radiance 6	Photosensor	1.0-300 foot-candles	Peak sensitivity - 5500 Å
46	Radiance 7	Photosensor	0.01-1.0 foot-candles	Peak sensitivity - 6150 Å
47	Radiance 8	Photosensor	0.1-10 foot-candles	Peak sensitivity - 6150 Å
48	Radiance 9	Photosensor	1.0-300 foot-candles	Peak sensitivity - 6150 Å
49	Stub antenna VSWR	Bidirectional coupler	0-1.5 volts	Incident power
50	Stub antenna VSWR	Bidirectional coupler	0-1.5 volts	Reflected power
51	Full scale			
52	Temperature 58	Minco S8B	0-500°F	Adapter reference temperature, Sta. 2.3
53	Temperature 59	Minco S8B	0-500 F	Adapter reference temperature, Sta. 2.3
54	Temperature 60	Minco S6B	0-500 F	Vehicle reference temperature, Sta. 31.0
59 and 60	Master pulse	5 volts DC	--	--

TABLE V

Segment Assignments for the Low-Level Commutator

Channel	Data Input	Range	Sensor	Location
1	Zero reference	0-volts DC	--	--
2 & 32	Temperature 1	0-1300°F	Ch-Al	Isotopic generator, magnesium
3 & 33	Temperature 2	0-1300°F	Ch-Al	Isotopic generator, magnesium
4 & 34	Temperature 3	0-1300°F	Ch-Al	Isotopic generator, magnesium
5 & 35	Temperature 4	0-1300°F	Ch-Al	Isotopic generator, magnesium
6 & 36	Temperature 5	0-1300°F	Ch-Al	Isotopic generator, magnesium
7 & 37	Temperature 6	0-1300°F	Ch-Al	Isotopic generator, magnesium
8 & 38	Temperature 7	0-1300°F	Ch-Al	Isotopic generator, magnesium
9 & 39	Temperature 8	0-1300°F	Ch-Al	Isotopic generator, magnesium
10 & 40	Temperature 9	0-1300°F	Ch-Al	Isotopic generator, magnesium
11 & 41	Temperature 10	0-1300°F	Ch-Al	Isotopic generator, magnesium
12 & 42	Temperature 11	0-1300°F	Ch-Al	Isotopic generator, magnesium
13 & 43	Temperature 12	0-1300°F	Ch-Al	Isotopic generator, magnesium
14 & 44	Temperature 13	0-1300°F	Ch-Al	Isotopic generator, magnesium
15 & 45	Temperature 14	0-1300°F	Ch-Al	Isotopic generator, magnesium
16 & 46	Temperature 15	0-1300°F	Ch-Al	Isotopic generator, magnesium
17 & 47	Temperature 16	0-1300°F	Ch-Al	Isotopic generator, magnesium
18	Temperature 17	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, Al ₂ O ₃
19	Temperature 18	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, Al ₂ O ₃
20	Temperature 19	0-1300°F	Ch-Al	Isotopic generator, aluminum
21	Temperature 20	0-1300°F	Ch-Al	Isotopic generator, aluminum
22	Temperature 21	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, graphite
23	Temperature 22	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, graphite
24	Temperature 23	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, Al ₂ O ₃
25	Temperature 24	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, Al ₂ O ₃
26	Temperature 25	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, graphite
27	Temperature 26	0-3200°F	Pt-Pt+13% Rh	Isotopic generator, graphite
28	Temperature 27	0-2600°F	Pt-Pt+13% Rh	Isotopic generator, E-300
29	Temperature 28	0-2600°F	Pt-Pt+13% Rh	Isotopic generator, stainless steel
30	Temperature 29	0-2600°F	Pt-Pt+13% Rh	Isotopic generator, stainless steel
31	Temperature 30	0-2500°F	Ch-Al	Adapter section, Refrasil
48	Temperature 31	0-2500°F	Ch-Al	Adapter section, Refrasil
49	Temperature 32	0-700°F	Ch-Al	RV umbilical connectors
50	Temperature 33	0-700°F	Ch-Al	RV aft cover, inner
51	Temperature 34	0-2000°F	Ch-Al	RV stub antenna
52	Ablation 35	0-2000°F	Ch-Al	RV ablation shell, Sta. 34.5
53	Ablation 36	0-3200°F	Pt-Pt+10% Rh	RV ablation shell, Sta. 34.5
54	Ablation 37	0-3200°F	Pt-Pt+10% Rh	RV ablation shell, Sta. 34.5
55	Ablation 38	0-3200°F	Pt-Pt+10% Rh	RV ablation shell, Sta. 34.5
56	Heat meter 39	0-15 mv DC	Hy-Cal C-1143-A	RV ablation shell, Sta. 34.5
57	Heat meter 40	0-15 mv DC	Hy-Cal C-1143-A	RV frame, outer, Sta. 65.5
58	Heat meter 41	0-15 mv DC	Hy-Cal C-1143-A	RV ablation shell, Sta. 68.5
59 & 60	Master pulse	16 mv DC	--	--

Two subcarriers (22.0 and 14.5 kc) were used for the transmission of pulse-amplitude modulated (PAM) commutated data. The 22.0-kc channel (high-level commutator) carried data with signal voltages ranging from 0 to 5 volts, and the 14.5-kc channel (low-level commutator) carried data with signal voltages ranging from 0 to 16 millivolts. Segment assignments for the two commutators are listed on page 23.

Three subcarriers (10.5, 7.35, and 5.4 kc) carried, respectively, roll, yaw, and pitch data from a roll-stabilized gyro in the TM compartment.

Data on low-frequency accelerations along the longitudinal, pitch, and yaw axes of the RS were carried on three separate subcarriers (3.9, 3.0, and 2.3 kc).

Once-per-second clock pulses from the two time-code generators were carried on two separate subcarriers (1.7 and 1.3 kc). This allowed instant confirmation that the timers were operating and also provided a vernier for the time codes on the high-level commutator.

A constant 50-kc frequency was transmitted for tape-speed compensation of the airborne tape recorder.

High-Level Commutator (60 segments, 2.5 rps)

Twelve segments were used to transmit two binary time codes from the redundant programming system. These time codes were to be used to correlate real-time data with delayed-time data.

Seventeen segments were reserved for temperature data on the RV. Output from the temperature-sensitive resistance elements used for these measurements ranged from 1.35 to 4.0 volts for temperatures varying from 0 to 500°F.

Eight segments were allocated to four contact switches in the base of the isotopic generator, which indicated separation of the internal fuel capsules. With two segments per switch and a commutator revolution rate of 2.5 rps, each switch was sampled five times per second, permitting departure times of the capsules to be determined within 200 milliseconds.

Two segments were required for data on the activation time and voltage output of the two heat-initiated thermal batteries carried as a subsidiary experiment.

Two segments were reserved for data on voltage output of the TM batteries.

Nine segments were required for the data on light radiance in the re-entry wake.

Four segments were used for information on the incident and reflected power in the feed cables to the two TM antennas.

Two of the temperature-sensitive resistance elements carried on the high-level commutator were located in the adaptor section of the generator. Since the transition from thermocouple wire to copper wire took place in this location, it was necessary that the temperature of this cold junction be known to permit computation of the temperatures of the thermocouples on the generator. Transmission of this information required two segments.

Low-Level Commutator (60 segments, 1 rps)

Located in the inert isotopic generator were 29 thermocouples, 16 of which were sampled twice a second and 13 once a second. Transmission of these data required 45 segments.

Two segments were reserved for data from thermocouples in the adaptor section of the generator.

The remaining 10 segments on the low-level commutator were employed to transmit information concerning the RV; three were for temperatures, three for calorimeters, and four for an ablation sensor.

Airborne Programming System

A dual-channel system in the TM compartment handled firing and monitoring of the pyrotechnic devices in the RS and programmed certain TM functions. Each channel consisted of one Logitek Model A690 time-code generator, a special RFD-2 inflight programmer, control relays, and squib-monitoring circuits. The pyrotechnic events, programmed simultaneously through both channels, were as follows:

1. Inflight arming.
2. Ejection of the externally mounted fuel capsules, effected by the initiation of either of two Horex 2503 10-32 explosive bolts.
3. Separation of the cylindrical load adaptor, through the ignition of a hot-gas generator.
4. Despin, which required the initiation of a Horex 2801 guillotine to release the despin weights.
5. Separation of the despin band and associated hardware, effected by the firing of either of two Horex 2503 10-32 bolts.
6. Parachute deployment, initiated by firing a drogue gun.
7. Inflation of the internal flotation bag, effected by the firing of an explosively actuated valve on a CO₂ reservoir. (The flotation bag attached to the parachute was filled through a valve which was opened by the pull from a lanyard attached to a parachute shroud line.)

The programmed TM functions were as follows:

1. The record and erase electronics in the tape recorder were turned off shortly after the predicted end of blackout to prevent destruction of the taped data by post-blackout recording. This increased the probability of obtaining these data by continuous retransmission or possible recovery of the RS remains.
2. At 473 seconds after launch, output of the tape recorder, previously fed only to Transmitter A, was also fed to Transmitter B. This was done to increase the probability of recovering the recorded data on events during blackout. No real-time data of significance were expected after this time.

3. At the expected time of impact, all electrical systems powered by the TM batteries were turned off except for the tape recorder, Transmitter A, and one of the RF beacons. This was done to save battery power for the systems left on, which were to remain operating after impact.

Mechanical Design

The TM structure was required to house, mechanically support, and act as a heat sink for all TM components and for the beacons carried within the TM compartment. Also, it was sealed to form a flotation tank, providing additional buoyancy for the RS.

After the TM systems for the RS qualification units had been fabricated, a requirement for RS weight reduction necessitated redesign of the TM structure to be used in the flight units. Redesigned structures, included as integral parts of the RS units tested, successfully passed the acceptance tests.

TELEMETRY SYSTEM COMPONENTS

This section includes descriptions of the TM system transducers, signal-processing devices, transmission equipment, and checkout instruments, as well as components such as the RF beacons in the recovery system (see the Appendix for additional illustrations and circuit diagrams). Speaking strictly, such items as the RF beacons are not part of the TM system, but inclusion in this section is felt to be warranted because of their interaction with the TM system proper; i.e., shared components (such as antennas), common power source, etc.

It may at first appear that some of the transducers used had a greater range than necessary, but it should be recognized that the maximum values for some of the measurements to be made were selected through planning for failure. Since it may be presumed that a failure will occur as the result of mechanical forces, temperatures, etc., that are higher than expected, an impending failure will be signaled by the rise in level of these environmental inputs. While instruments capable of measuring these higher forces will not, of course, give the resolution of instruments designed only for the expected maxima, neither will they saturate when the expected levels are exceeded.

Generator Instrumentation

Thermocouples

Figure 4 shows the location of temperature pickups on the inert isotopic generator. Table V shows the channel and segment assignments for these transducers. In addition to showing the temperature rise of the generator parts, the thermal pickups also indicated, by the interruption of their output signals, the time of destruction or separation from the generator of the parts to which they were attached. Figure 5 shows a typical circuit diagram for the generator thermocouples.

T1-16 and T19-20 were chromel-alumel thermocouples used in the range of 0-1300°F, with output attenuated to the low-level VCO (16 millivolts). They were mounted on parts made of aluminum or magnesium alloys with melting points below 1300°F.

T17-18 and T21-29 were platinum/platinum-plus-13%-rhodium thermocouples with a range of 0-3200°F and a maximum output of 16 millivolts. They were mounted on parts made of materials with high melting temperatures, such as aluminum oxide, graphite, and stainless steel.

Figure 4. Location of temperature pickups on the simulated isotopic generator

Figure 5. Circuit for generator thermocouples

Switches

A switch was installed between the end of each of the simulated fuel capsules in the generator and the base of the fuel cavity. These four switches were spring-loaded toward the open position, but held closed by the capsules. When the capsules were released from the fuel cavity by generator disassembly, the switches opened and the signals passing through them were interrupted. Figure 6 shows the switch circuit.

Figure 6. Circuit for switches under internal fuel capsules

RV Thermal Instrumentation

Figure 7 shows the location of thermal pickups in the RV. Tables IV and V list their channel and segment assignments. The RV thermal transducers consisted of five chromel-alumel thermocouples, 17 Minco S8B thermal ribbons, three Hy-Cal C-1143A calorimeters, and one Hy-Cal ablation sensor.

Thermocouples

Two of the thermocouples (range 0-2500°F) measured temperatures of the Refrasil ablation material on the RV adaptor section, one (range 0-700°F) measured temperature of the RV umbilical connector, and one (range 0-700°F) measured temperature of the inner side of the RV aft cover; the fifth thermocouple was part of the ablation sensor.

Figure 7. Location of RV thermal pickups

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Thermal Ribbons

The Minco thermal ribbons (temperature-sensitive resistors) were used to monitor temperatures below 500°F. These devices have a nominal resistance of 676 ohms at 25°C, which increases at the rate of 3.06 ohms/°C above 25°C. They were excited by a constant current of 2.5 milliamps to produce a voltage output proportional to temperature. Four of the ribbons (range 0-170°F) measured temperatures on the TM batteries, TM structure, and the 10-watt transmitter. Ten (range 0-500°F) measured temperatures on the cylindrical load adaptor, parachute drogue gun, RV structure, and the inner surface of the ablation material. The remaining three (range 0-500°F) provided reference temperatures for the thermocouple cold junctions.

Calorimeters

The three calorimeters were of the thin-foil "asymptotic" type, which utilize a thermocouple in such a manner that the output is proportional to heating rather than temperature. They were mounted flush with the outer surface of the ablation shell and measured cold-wall heat inputs to the RV.

Ablation Sensor

The ablation sensor consisted of four thermocouples (one Ch-Al, three Pt/Pt +13% Rh) embedded in a phenolic-Refrasil plug which was screwed and bonded into the ablation shell. T38 was at the outer surface, T37 was 0.1 inch below the surface, T36 was 0.2 inch below the surface, and T35 was 0.4 inch below the surface. The precisely located thermocouples measured the temperature profile across the ablation shell.

Attitude, Acceleration, and Vibration Transducers

Roll-Stabilized Gyro

A Whittaker 518025 gyro designed especially for Sandia provided data on RS orientation during the flight. The gyro maintained its roll axis regardless of RS rotation, so roll, pitch, and yaw attitude of the RS could easily be determined by direct reading at any time during the flight. The gyro range was 0-360° in roll, ±85° in yaw, and ±180° in pitch.

Accelerometers

A Bourns 2006097001 potentiometric accelerometer (range ±35 g) measured acceleration along the longitudinal axis of the RS, and two Bourns 2006096002 potentiometric accelerometers (range ±3 g) provided data on lateral accelerations.

Vibration Pickup

A Massa AC-107 crystal accelerometer with a range of ± 10 g was mounted on the TM structure, sensing longitudinally, to detect any abnormal vibration during booster burning and re-entry. In addition, accelerometer response to the shock-waves produced by programmed pyrotechnic events confirmed the occurrence of these events.

Instrumentation for Subsidiary Experiments

Light Radiance

Cadmium sulfide photoconductive cells were used to measure light radiance in the re-entry wake. These cells are essentially light-sensitive resistors; their resistance decreases as intensity of the incident light increases. These cells were chosen because they have the necessary response in the visible portion of the frequency spectrum, can easily be incorporated into a measuring system, and are rugged, small, and light in weight.

Nine cells were used: three Type 1, which have their peak response at 5150 Å; three Type 2, with peak response at 5500 Å; and three Type 3, which have peak response at 6150 Å. The Type 2 cells were to be the prime source of information, since their response closely approximates that of the human eye. The cells were to detect three ranges of illumination (0.01-1.0, 1-10, and 10-300 foot candles), with one cell of each type assigned to each range.

Each sensor was incorporated in a circuit such as that shown in Figure 8. The values for R_1 and R_2 in the circuit were such that the signal voltage E_o was ≈ 2.5 when the energy incident on the face of the sensor was equal to the mid-range value of its assigned detection range.

Figure 8. Photosensor circuit

Heat-Initiated Thermal Batteries

A load resistor and a voltage-divider network (Figure 9) were placed on the output of the heat-initiated thermal batteries. (No battery output was detected during the flight.)

Figure 9. Circuit for monitoring output of the heat-initiated thermal batteries

Signal-Conditioning and Transmitting Equipment

FM Transmitters

Two solid-state Conic FM transmitters were used: one CTM 205, 231.4 mc, 5 watts output; and one CTM 210, 240.2 mc, 10 watts output. Particular advantages of transmitters of this type were:

1. They operated directly off the 28-volt TM batteries, eliminating the need for the high-voltage DC-DC converter which would have been required if tube-type transmitters had been used.
2. They could operate into any load impedance without damage, eliminating the antenna design problems associated with antenna impedance changes during re-entry.

Tape Recorder

The tape recorder was a CEC 178400 continuous-loop unit with simultaneous record and playback capability. A special feature incorporated for the RFD-2 TM application was record and erase ON-OFF controls, the function of which was described earlier.

Commutators

Two Fifth Dimension 60-segment mechanical commutators were used. They were identical except for their speed of rotation; the low-level commutator (S/S2MT-565) turned at 1 rps and the high-level (S/S1MT-564) at 2.5 rps. Each was driven by a constant-speed DC motor powered directly by the TM batteries.

Solid-state electronic commutators were tried in an RFD-2 prototype because of their high resistance to shock and vibration. However, their susceptibility to the high levels of RF radiation present on the RV and in its cabling prevented their use in the flight system.

Subcarrier Oscillators

The high-level SCO's used in the TM were 0 to 5-volt, $\pm 7\frac{1}{2}$ -percent-deviation, Teledynamics 1270A's, which are standard units carried as stock by Sandia.

The low-level SCO was a specially purchased Teledynamics 1284CY, selected to match the output characteristics of the Pt/Pt +13% Rh thermocouples. Maximum output from these thermocouples was expected to be 16 millivolts. A pedestal of about 20 percent is recommended by the IRIG specifications for PAM telemetry. Therefore, an oscillator accepting an input signal from -4 to +16 millivolts for $\pm 7\frac{1}{2}$ -percent deviation was specified. A special filter designed by C. E. Erickson, 9313, was placed between the low-level commutator and the low-level SCO to remove spurious voltages induced by RF fields.

Two Teledynamics M-138 eight-channel mounts, carried as stock by Sandia, were used to provide mechanical tiedown, calibration relays, and composite signal-amplitude adjustments for the SCO's. The SCO calibrator, a TRC item carried as stock by Sandia, inserted a three-step voltage calibration to appropriate SCO's on command from the control console in the Scout blockhouse at Wallops Island.

Voltage Regulators

Two 5-volt voltage regulators were employed. One, a Vector TV-63, provided the power for calibration and for transducer excitation. The other, a Sonex TEX-3604, provided the voltage reference and pedestal voltage for the low-level commutator. This regulator had a floating output which permitted splitting into both positive and negative voltages. Figure 10 shows the circuit for pedestal-voltage generation.

Figure 10. Circuit for pedestal-voltage generation

Line Amplifiers

Two Sonex TEX-3210 line amplifiers were included in the TM to permit operation and checkout of the system when the RV was in an area designated as hazardous or under other circumstances when emission of RF radiation was prohibited. The outputs of these amplifiers were brought to two coaxial connectors on the aft end of the RV. The inputs of the amplifiers were in parallel with the inputs to the TM transmitters.

RF Diplexer

A Bendix TNC-15 diplexer was incorporated to mix the output of the 231.4-mc TM transmitter and the 225.7-mc CW beacon, so that both could be fed to the stub antenna.

Bi-directional Couplers

Micro Lab CH23T bi-directional couplers, which detect the amplitude of signals traveling in each direction in a coaxial cable, were used to detect changes in antenna impedance and transmitter output power during the flight. (Because of problems with spurious RF pickup, only relative measurements were obtained.)

Time-Code Generators

Two Logitek A690 time-code generators were used. The time codes were fed in parallel to the high-level commutator to establish an on-board time code simultaneous with the data being transmitted. In addition, the 1-pps timer outputs provided a time base for the airborne programmers. These pulses were also fed to two separate subcarriers so that signal drive to the programmers could be confirmed before launch.

Antennas

Ring-Dipole

The ring-dipole TM antenna was of a type sometimes referred to as a "split-missile" antenna. The aluminum substructure of the RV from about Station 41.0 forward was one-half of the antenna. A 0.4-inch insulated gap separated this forward structure from a thin, aluminum shell inside the RV, extending to within about 2 inches of the aft end of the RV; this shell constituted the driven half of the antenna. Figure 11 shows the antenna coordinate system and the patterns for two cuts.

Figure 11. Coordinate system for ring-dipole antenna, and patterns for two cuts. (For both cuts, the model scale was 3.8, the model frequency was 910 mc, and the antenna was center-fed at 0° , 120° , and 240° ; the curves are plotted in power.)

Figure 11. (cont.)

Figure 11. (cont.)

Stub

The stub antenna (Figure 12) was a 10-inch tungsten rod which extended out the rear of the RV. The rod was held in place by an aluminum oxide ceramic cone at its base. The ceramic cone was protected by a glass-filled, silicon-resin ablation cover. This material was used because of its low carbon content and high efficiency as an ablator.

Figure 12. Stub antenna

Tungsten was used for the stub antenna because of its high strength at elevated temperatures. During re-entry, the tungsten reached a maximum temperature of about 3500°F, at which point about 85 percent of the input heating was reradiated and the remaining 15 percent absorbed by the tungsten and the ceramic base. For strength, the tungsten rod was tapered from a 1/2-inch diameter at the base to a 1/4-inch diameter at the tip. Figure 13 shows the antenna coordinate system and the patterns for two cuts.

C-Band

For the C-band beacon (described later), the antenna system consisted of six cavity antennas and a 6-way RF power divider. Three of these antennas (TE-142's) were tilted 15 degrees forward to aid in early radar acquisition. The other three (TE-176's) radiated at right angles to the longitudinal axis of the RS to permit tracking into the re-entry phase of the trajectory. The only difference between the two types of antennas was in the tilt of the cavity. Figure 14 shows the antenna coordinate system and patterns for two cuts.

Figure 13. Coordinate system for stub antenna, and patterns for two cuts. (For both cuts, the model scale was 3.8, and the model frequency was 880 mc; the curves are plotted in power.)

Figure 13. (cont.)

Figure 13. (cont.)

Figure 14. Coordinate system for C-band beacon antennas, and patterns for two cuts. (For both patterns, the model was full-scale and the model frequency was 5650 mc; the curves are plotted in db.)

Figure 14. (cont.)

Figure 14. (cont.)

Beacons

C-Band

A Motorola SST-131 C-band beacon was included in the TM system to extend the tracking range of the radars at Wallops and Bermuda. The C-band transponder received single-pulse interrogations and transmitted a single-pulse reply in the same frequency band.

The beacon was turned on and operationally tested before launch. It remained on throughout the flight, transmitting on 5750 mc and receiving on 5550 mc. The FPS-16 radars on Wallops Island and Bermuda were tuned to this beacon. An FPQ-6 radar on Wallops Island tracked a similar C-band beacon in the Scout.

Continuous Wave

To aid in post-impact acquisition, a 1/2-watt Conic CTB200-05 CW beacon operating at 225.7 mc was included in the RS electronics. This beacon provided an RF signal for search craft with CW direction-finding equipment. The low power requirements of this beacon permitted it to remain active for at least 12 hours. It was turned on and operationally confirmed before launch, and remained on throughout the flight. Output from this beacon was diplexed onto the stub antenna along with the output of the 231.4-mc TM transmitter.

SARAH

To further aid in post-impact location of the RS, a Simmonds 311020-01001 SARAH beacon was attached to the flotation bag on the main parachute. The beacon broadcast at 235 mc, with a peak output of 25 watts.

The antenna for the SARAH was attached to the flotation bag in such a manner that it would remain upright when the bag was inflated and floating. The SARAH was turned on at water impact by the closing of a saltwater-actuated switch.

Flashing Lights

Two ACR Electronics flashing lights were included among the beacons in the recovery system. One (ACR31) was attached to the flotation bag on the parachute and was powered by the SARAH batteries. It was turned on at water impact by the saltwater-actuated switch which turned on the SARAH beacon. This light had a peak intensity of 2,000,000 lumens and was designed to flash at intervals of once per second.

The other light (ACR4C), also turned on by a saltwater-actuated switch, was set into a flotation package of low-density foam and attached to the RV by a short line so it would float nearby. This light was also designed to flash once per second, and had a peak intensity of 500,000 lumens.

Ground Equipment

Control Panel

Sandia installed an RFD-2 control panel in the Scout blockhouse on Wallops Island to provide for complete operation and monitoring of the TM system. Included were provisions for synchronizing the panel operation with the NASA Scout launcher complex during checkouts and the final countdown.

TM Test Stations

Two TM test stations were used for checkout and monitoring of the TM system during qualification testing at Sandia and during assembly and countdown at Wallops Island. Each station included a receiver, discriminators, an oscilloscope, a counter, a test oscillator, and a voltmeter. An oscillographic recorder was used in conjunction with these stations when a permanent record of a system checkout was desirable.

TM Signal Simulator

TM data inputs came primarily from the generator and RV. Since these units were not available for preliminary TM checkouts, a signal simulator was designed and fabricated to provide appropriate inputs.

RFD-2 Payload Simulator

The umbilical cable from the Wallops Island blockhouse to the launcher was installed by NASA per Sandia's request. This cable provided all power and control for the RFD-2 TM, and an error in its installation could have caused damage to the system. Therefore, in addition to the normal ohmmeter tests, a special payload simulator was designed and fabricated to check for proper functioning of the control panel and umbilical cable before the umbilical cable was connected to the RFD-2 payload.

Pyrotechnic-Circuit Monitor

During checkout and qualification testing, it was desirable to operate and monitor the airborne programming system. A special tester utilizing indicator lamps was fabricated for this purpose.

Pyrotechnic Tester

An Alnico Model 101-5BF igniter-circuit tester and a pushbutton selection switch assembly were used to facilitate rapid and accurate measurement of all squib resistances. This system, which was suitcase-packaged for field use, was employed during all prelaunch system tests.

C-Band Beacon Checkout

A simulated radar was fabricated using another C-band beacon, reverse tuned to the one in RFD-2. This unit and its associated equipment (Figure 15) were installed in the Wallops Island blockhouse to permit interrogation of the RFD-2 C-band beacon during prelaunch system tests.

Figure 15. C-band beacon checkout

TELEMETRY SYSTEM PERFORMANCE

The RV performed well, showing good aerodynamic stability and providing its subsystems with more than adequate thermal protection. Events in the operation of the recovery system occurred as programmed. However, only the parachute, external flotation bag, and SARAH beacon were recovered. For reasons unknown, five of the ten parachute shroud lines parted after deployment, and the rest of the RS apparently sank on impact or shortly thereafter. The SARAH was operating at the time of recovery, and provided the signals by which recovery elements homed on the impact point.

Performance of the TM system was highly satisfactory, with all but one of the 132 channels returning data. The TM signal was never lost for significant periods of time, and the real-time and delayed-time links provided an overlap of coverage both before and after blackout (Figure 16). Most of the data were machine-reduced from either the Wallops Island or Sampan Hitch tapes. Data missing from these tapes because of signal loss (through atmospheric interference, etc.) were usually available from tapes recorded by the Range Recoverer or the Cooper's Island TM station. These data were read manually and inserted where required.

Figure 16. Sources and times for RFD-2 TM records

XXX

Performance of the transducers is discussed below, and samples of typical data return are presented. A complete record of the data obtained, along with a discussion of its significance in the RFD-2 flight test, is given in Final Report on Re-entry Flight Demonstration Number Two, SC-RR-65-43, Sandia Corporation, Unclassified, April 8, 1965.

Generator Instrumentation

Thermocouples

Data from the generator thermocouples were of excellent quality, permitting a detailed postflight analysis of heating rates, internal heat paths, and mode of disassembly. Apparently, all of these thermocouples functioned properly from launch until generator disassembly. Figure 17 shows a sample from the oscillograph record at the time of generator disassembly.

Figure 17. Sample from the oscillograph record at time of generator disassembly

The data from T7 and T8 are typical of those recorded by the generator thermocouples. Table VI lists the temperatures recorded by T7 and T8 from 300 seconds after launch (nominal time for the start of re-entry was 320 seconds) until about 368 seconds. Figure 18 compares plots of these temperatures with plots from the postflight theoretical thermal analysis; note the very close agreement.

TABLE VI
Temperatures Recorded by T7 and T8

T7				T8			
Time (sec from launch)	Temp. (°F)	Time (sec from launch)	Temp. (°F)	Time (sec from launch)	Temp. (°F)	Time (sec from launch)	Temp. (°F)
318.322	60	343.316	217	315.839	63	342.332	208
323.321	64	343.816	225	319.838	60	342.832	210
323.821	70	344.315	244	321.837	60	343.832	231
324.321	67	345.315	255	322.837	61	344.332	247
324.821	70	345.815	263	323.837	65	344.831	244
325.820	71	346.315	284	324.837	65	345.331	260
326.320	72	347.809	299	325.337	71	345.831	267
327.820	77	348.309	318	325.836	82	346.331	278
328.320	82	348.809	330	326.336	83	347.825	301
328.820	81	349.309	341	326.836	79	348.325	308
329.320	88	349.809	361	327.836	83	348.825	315
329.820	88	350.309	380	328.836	83	349.325	332
330.319	94	350.809	389	329.336	81	349.825	336
330.819	93	351.809	396	329.836	83	350.325	362
331.319	94	352.308	430	330.336	97	350.825	368
331.819	101	352.808	443	330.835	94	351.325	393
332.819	103	353.809	487	331.335	95	352.325	405
333.318	106	354.309	503	331.835	100	352.824	430
333.818	110	354.809	505	332.835	110	353.825	468
334.318	111	355.308	542	333.335	110	354.325	483
334.818	114	355.808	562	333.834	108	354.825	498
335.318	112	356.808	600	334.334	121	355.325	529
335.818	125	357.308	624	334.834	121	355.824	548
336.317	129	357.802	648	335.334	118	356.824	583
336.817	139	358.272	660	335.834	130	357.325	617
337.317	151	359.808	742	336.833	139	357.817	639
337.818	148	361.292	807	337.334	146	358.287	649
338.317	158	361.809	834	337.834	152	360.287	742
338.817	167	362.272	807	338.334	156	362.828	810
339.317	168	362.811	830	338.833	160	363.326	834
339.817	179	363.309	839	339.333	167	363.824	828
340.316	190	364.808	911	339.833	179	364.824	888
340.816	191	366.308	939	340.333	182	366.824	1004
341.316	195	366.808	998	340.832	186	367.325	1090
341.816	200	367.807	1079	341.332	195	367.823	1134
342.816	205	368.307	1129	341.832	204

Figure 18. Comparison of data from T7 and T8 with data from postflight thermal analysis (points show thermocouple data, solid lines show values computed in postflight analysis)

Switches

The four contact switches between the base of the fuel cavity and the simulated fuel capsules in the generator performed fairly well. All remained closed until 344.1 seconds, and remained open after 356.3 seconds, but two of the switches showed evidence of chatter and short periods of high resistance during the 12-second interval between these two times. The chatter probably resulted from thermal expansion of the generator and the initial stages of disassembly. The periods of high resistance are believed to have occurred when a semiconductive grease used to lubricate the switch pivots melted and momentarily bridged the gap between slightly open contacts.

RV Thermal Instrumentation

Clear, high-quality data on RV thermal response are available from launch until final loss of the TM signal. All RV temperatures were well below design limits. The records show that all but one of the RV thermal instruments functioned as planned. The inoperative gage was T46, a thermal ribbon on the aluminum structural shell. No significant data were lost through its failure to operate.

Thermocouples

All of the RV thermocouples functioned during the flight, but none showed any significant temperature rise. T33 (inside the RV aft cover) registered the greatest change; its readings for the 22-second period of maximum heating were as follows:

Time from Launch (sec)	Temperature (°F)
450.0	60 (launch temperature)
453.0	74
458.0	80
463.0	84
465.0	87
467.0	89
472.0	93 (no further rise)

Thermal Ribbons

The thermal ribbons indicated only moderate temperature rises during the flight. All of the ribbons operated except T46 (aluminum structural shell), which was damaged during RV assembly. Although this damage was detected in checkouts conducted after assembly, T46 was located so as to make replacement extremely difficult. Since identical pickups were installed in similar locations nearby, it was felt that no significant data would be lost if the gage were allowed to remain inoperative, so no attempt was made to replace it. Figure 19 shows a plot of the temperatures recorded by T51, T53, and T55 (inner side of the ablation shell), which registered the greatest increase of any of the thermal ribbons.

Figure 19. Records from T51, T53, and T55 (inner side of ablation shell)

Calorimeters

All three calorimeters functioned as intended. Figure 20 shows the data obtained from these meters.

Figure 20. Calorimeter data

Ablation Sensor

Data from the ablation gage (Figure 21) showed the temperature gradient across the Refrasil shell.

Figure 21. Ablation-gage data

Attitude, Acceleration, and Vibration Transducers

Roll-Stabilized Gyro

Data from the gyro presented a clear picture of RS attitude and roll rate throughout the flight. Figure 22 shows both raw data from the TM tapes and plots of the reduced data. Roll and yaw were essentially negligible until spinup, while the pitch record shows the programmed pitch into the desired trajectory, with slight disturbances at missile staging. The roll record shows spinup and despin, followed by damping oscillations in pitch and yaw.

Accelerometers

For about the first 250 seconds of the flight, the record of longitudinal acceleration (Figure 23) shows the repeating and ascending step-sawtooth curve typical of the ascent phase of multistage launch vehicles. The acceleration levels reached maxima of about 4, 11, and 16 g at the end of first-, second-, and third-stage burning, respectively. Re-entry deceleration began approximately 370 seconds after launch, following a 110-second interval of essentially zero-g flight. It increased smoothly to a maximum of about 22 g at 408 seconds, then returned toward zero, reaching it at about 445 seconds. Pitch and yaw accelerations of about ± 2 g were recorded from about 380 to 395 seconds, immediately following generator disassembly. Lateral accelerations were otherwise essentially nil throughout the flight.

Vibration Pickup

No significant level of vibration was detected throughout the flight.

Instrumentation for Subsidiary Experiments

Light Radiance

Data on light radiance were complete to 300 foot-candles (Figure 24), at which point the range of the sensors was exceeded. This condition prevailed for about 10 seconds, after which the level of light radiance returned within the range of the sensors.

Figure 22. Data on RS attitude and roll rate

Figure 22. (cont.)

Figure 22. (cont.)

Figure 22. (cont.)

Figure 23. Acceleration data

Figure 24. Data on light radiance in the re-entry wake

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APPENDIX A

CIRCUIT DIAGRAMS AND
ILLUSTRATIONS OF TM SYSTEM COMPONENTS

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Figure A-1. TM system components

Figure A-1. (cont)

TM TEST STATION

Figure A-2. Checkout equipment

PAYLOAD SIMULATOR

PYROTECHNIC-SYSTEM CONTINUITY TESTER

Figure A-2 (cont)

TM SIGNAL SIMULATOR

PYROTECHNIC CIRCUIT MONITOR

Figure A-2. (Cont)

Figure A-3. Circuit schematics and wiring diagrams

DESIGN ASSY	REV	DESCRIPTION	APPROVED BY	DATE	REV	DATE
PART OF CONTROL UNIT	1	MOORE, M. 4418-4				
CKN70546-000	2	REVISED WARSHECR 6413 4		1/1/57

REV	DATE	DESCRIPTION	BY	CHKD	APP'D
1	1/1/57	SCHEMATIC			
2	1/1/57	REVISED

Figure A-3 (cont)

Figure A-3
(cont)

- NOTES
1. ∇ INDICATES PYROTECHNIC SYSTEM GRD.
 2. $\perp$ INDICATES TM SYSTEM GRD.
 3. UNLESS OTHERWISE SPECIFIED RESISTANCE VALUES ARE EXPRESSED IN OHMS.
 4. UNLESS OTHERWISE SPECIFIED DIODES ARE SA173.
 5. ALL RELAYS IN SAFE, RESET & EXTERNAL CONDITION.

REVISIONS					
ISS	SHEET AND ZONE	DESCRIPTION	DATE	CHKD	ENGR
1		HARSHE, CR 4413-4	5/1/65		L. E. A.
2		REVISED HARSHE, CR 4413-4	1/6/65		

DWG CLASSIFICATION LEVEL UNCLASSIFIED		PART CLASSIFICATION		SHEET INDEX	
CLASSIFICATION CATEGORY		ISS	DATE	TITLE	FIRST APPLICATION
				SCHMATIC, PYROTECHNIC SYSTEM RFD-2A	
		MFG AGENCY APPROVALS		MFG AGENCY NO.	DWG NO. CKN 70544
				SCALE NONE	DOC. REF. SYM.
				SHEET 1	OF 1

Figure A-3 (cont)

PYROTECHNIC MONITOR

Figure A-3 (cont)

Figure A-3 (cont)

Figure A-3 (cont)

TERMINAL BOARD "E"

NOTES

1. CONNECT ALL SHIELDS TO GROUND.
2. ALL WIRE #22 EXCEPT WHERE NOTED.

REVISIONS					
ISS	ZONE	DESCRIPTION	PREPARED BY	DATE	CHKR
1		J. CRUIKSHANK 4411-2			
2		REVISED 2-28-64 JDH		1/11/64	
3		REVISED 'C' BAND BEACON & 'CW BEACON RJN		1/11/64 3-12-64	
4		ADDED DIODES & CAPACITORS TO SHLLTS 4, 5, 6, 8 CHANGED SOME WIRING DESIGNATIONS. CHANGED TE-E SHLET 1. 4/13/64 CS			
5		SHT 1: OMITTED P201, P202, P203, P204, P205, P206, P207, P208, P209, P210, P211, P212, P213, P214, P215, P216, P217, P218, P219, P220, P221, P222, P223, P224, P225, P226, P227, P228, P229, P230, P231, P232, P233, P234, P235, P236, P237, P238, P239, P240, P241, P242, P243, P244, P245, P246, P247, P248, P249, P250, P251, P252, P253, P254, P255, P256, P257, P258, P259, P260, P261, P262, P263, P264, P265, P266, P267, P268, P269, P270, P271, P272, P273, P274, P275, P276, P277, P278, P279, P280, P281, P282, P283, P284, P285, P286, P287, P288, P289, P290, P291, P292, P293, P294, P295, P296, P297, P298, P299, P300, P301, P302, P303, P304, P305, P306, P307, P308, P309, P310, P311, P312, P313, P314, P315, P316, P317, P318, P319, P320, P321, P322, P323, P324, P325, P326, P327, P328, P329, P330, P331, P332, P333, P334, P335, P336, P337, P338, P339, P340, P341, P342, P343, P344, P345, P346, P347, P348, P349, P350, P351, P352, P353, P354, P355, P356, P357, P358, P359, P360, P361, P362, P363, 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ALL LATCHING RELAYS. PL26HIM6A
ALL NON-LATCHING RELAYS BRJ26J2P6A

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Figure A-3 (cont)

Figure A-3
(cont)

Figure A-3
(cont)

ALL DIODES ON THIS BOARD TO BE 1N2613 OR 1N2610
ALL RESISTORS TO BE 2W WIREWOUND 1% EXCLPT
10 5Ω WHICH ARE 1/8 W MYLAR FILM

Figure A-3
(cont)