NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1197

Trapped Radiation Detector—Mariner V

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Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

Acknowledgment

The author wishes to acknowledge the valuable assistance provided by the following University of Iowa personnel in the preparation of this report: Dr. J. A. Van Allen, principal investigator; Dr. S. M. Krimigis, co-investigator; Mr. D. K. Leimer, project manager; and Mr. D. Camp, assistant project manager.

The author also wishes to express his gratitude and appreciation to Mr. W. K. Proniewicz of Jet Propulsion Laboratory for his contribution to the experiment.

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Abstract

The trapped radiation detector (TRD) was one of the scientific instruments selected for the *Mariner V* flyby mission to Venus in 1967.

The instrument was designed and fabricated at the University of Iowa, under the direction of Dr. J. A. Van Allen.

The experimental objectives were to perform further studies of geomagnetically trapped particles, interplanetary radiation levels including solar X-rays, and search for the existence of magnetically trapped particles in the vicinity of Venus.

Detailed descriptions are shown in the text, which include the design, test history, methods of calibration and data handling techniques. Also discussed are the look angles, geometric factors, and energy levels of the various detectors used in the instrument.

Included in this report is a complete history of the developmental problems encountered during the fabricating and testing effort, and the corrective action taken to make the instruments flightworthy. The *Mariner IV* TRD was modified to meet the *Mariner Venus* 67 mission requirements.

Trapped Radiation Detector—*Mariner V*

I. Introduction and Objectives

The primary objective of the *Mariner Venus* 67 project is to conduct a flyby mission of Venus in 1967 in order to obtain scientific information which will complement and extend the results obtained by *Mariner II* relevant to determining the origin and nature of Venus and its environment.

Secondary objectives are to acquire engineering experience which will convert and operate a spacecraft designed for flight to Mars into one flown to Venus, and to obtain information on the interplanetary environment during a period of increasing solar activity.

II. Trapped Radiation Detectors and Radiation Belts

The trapped radiation detector (TRD) is one of the seven scientific instruments selected for the *Mariner V* spacecraft payload. It was designed and fabricated at the University of Iowa for the support of further studies on geomagnetically trapped particles by Dr. James Van Allen. He discovered what are now called the Van Allen radiation belts during the early *Explorer* satellite flights.

These belts are believed to contain charged particles emanating from solar eruptions which ultimately are trapped in the magnetic field of the earth. There are essentially two belts: the inner and the outer belts. The inner belt consists primarily of protons and is at a distance of approximately 5,000 km from the earth at the equator. The outer belt is composed primarily of electrons and is approximately 10,000 to 15,000 km from earth at the equator.

A. TRD Objectives

The objectives of the trapped radiation detectors are:

(1) An improved search for a radiation belt around Venus. If the actual Aphrodiocentric radial miss distance is as small as the intended value of 9,000 km (versus 41,000 km for *Mariner II*) it will be possible to detect a radiation belt due to a planetary magnetic moment as small as 10^{-3} to 10^{-4} of that of the earth. A negative result will establish such a value as an upper limit.

(2) A search for low energy particle effects in the magnetohydrodynamic wake of Venus. The intended passage of the approach trajectory across the anti-solar wake of the planet will provide

another sensitive test of the interaction of the planet (even if intrinsically unmagnetized) with the solar wind.

(3) The study of the occurrence, intensity, and energy spectra of solar protons, electrons, and alpha particles, are separately identified in the following energy ranges:

electrons:	$E_e > 45$ keV
	$E_e > 95$ keV
	$E_e > 150$ keV
protons:	$0.30 < E_p < 12$ MeV
	$0.50 < E_p < 5.3$ MeV
	$0.98 < E_p < 2.2$ MeV
alpha particles:	$2.1 < E_a < 18$ MeV

Such measurements are of special interest during the period of anticipated high solar activity during the flight of *Mariner V*. The measurements will be made throughout the interplanetary flight of some 120 days. It is hoped that the observations can also be continued after encounter for as long a period of time as physically possible. Comparison of such observations with those of other spacecraft widely distributed in solar longitude will contribute further to the understanding of interplanetary propagation of solar-emitted particles.

(4) The observation of soft X-ray ($\lambda < 10$ Å) intensity from the sun throughout interplanetary flight. Such X-ray emissions are related in an essential way to the occurrance of solar flares and to the emission of particles. The spacecraft will be able to view portions of the sun which are not visible from the earth.

(5) Finally, in the unlikely but not impossible case of a large error in the encounter trajectory, the X-ray detector may see a partial eclipse of the sun by the Venusian atmosphere and may therefore contribute significant information on atmospheric density.

B. Constraints and Characteristics

Because of necessity, spacecraft instruments must meet weight, power and size constraints.

The volume of the TRD chassis is approximately 82.5 in.^{3}, with a total weight of 2.67 lb. The power consumption is 450 mW or less. The input voltage is 50 V, rms $\pm$ 2% 2400 Hz (square wave). Turnon and short circuit current are limited to 200% of the normal operating current. Further protection to the spacecraft power subsystem is provided by two 50-mA fuses in parallel (1/10 A) in the 2400-Hz input power line. The input rise time requirements are 5 μs $\pm$ 4 μs.

The thermal requirements for the operating temperature limits of the entire unit are $-20°$C to $+50°$C and the nonoperating temperature limits are $-30°$C to $+60°$C.

The following section describes the look angles and geometric factors of the detectors:

Detector A look angle axis is directed to 0 deg to the spacecraft sun probe line. Soft X-rays, electrons and protons will be detected within a solid aperture angle of 10 deg. The unidirectional and omnidirectional geometric factor of detector A is 1.7×10^{-3} cm^2 sr and approximately 0.15 cm^2, respectively.

Detectors B, C, and D share the same look angle axis, which is 70 deg to the sun-probe line, and have full aperture angles of 60 deg, 60 deg, and 80 deg, respectively. Detectors B and C have unidirectional and omnidirectional geometric factors of 0.13 cm^2 sr.

Figure 1 is a drawing indicating the look angles and the aperture angles as described.

C. Description

Modifications. The *Mariner IV* trapped radiation detector design was modified to fulfill the *Mariner Venus* 67 (MV-67) mission requirements as follows:

(1) A four-channel solid state detector was substituted for the existing two-channel detector. The electronic components for the additional two channels were packaged in modules. The modules and mother board were mounted on the available space in the existing instrument.

(2) Detector A was relocated. The look angle axis was changed from 135 deg to zero deg to the sun-probe line of the spacecraft, and a beryllium foil was added. The full aperture angle of the detector was decreased from 60 deg to 10 deg, which prevents saturation of the detector during periods of

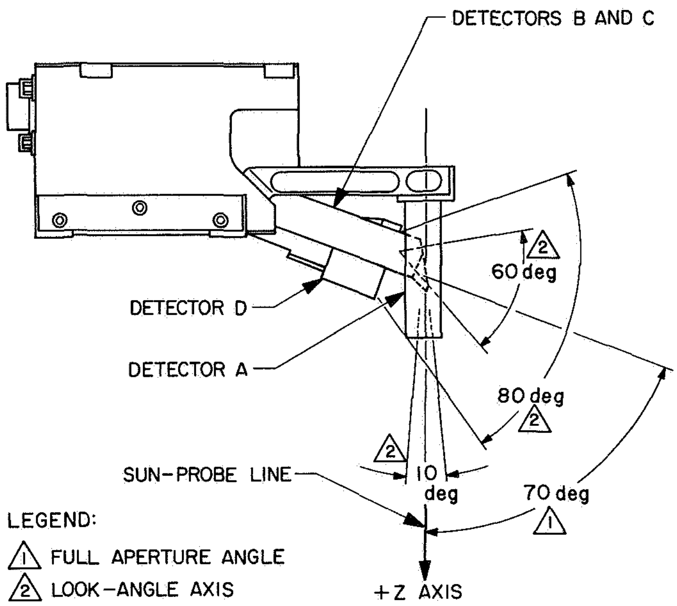

Fig. 1. Side view of TRD showing look and aperture angles

high solar activity. Detector A was mounted on the instrument so that no part of the spacecraft would obscure its conical field of view.

(3) The full aperture angle of detector D was increased from 60 deg to 80 deg. The aperture angle was opened up in order to increase the total collecting area and thus raise the count for a given flux density. This need was made apparent by earlier *Mariner IV* measurements.

Three Geiger-Mueller (G-M) tubes are used for proton and electron detection. Detectors A, B and C are EON type 6213 Geiger-Mueller end-window counters, which measure the total number of charged particles passing through their sensitive volumes. The sensitive volume of each tube is shielded so that low energy particles can enter only by passing through the window at the end of the tube. By allowing for omnidirectional flux of higher energy particles, a directional measurement can be made of the low energy particles.

The window of detector A is covered by approximately 1.4 mg/cm^2 of mica. Detector A will measure electrons > 95 keV and protons > 2.7 MeV. A beryllium (9.4 mg/cm^2) shield defines the energy threshold of the flux that enters the window. The window of detector B is covered by approximately 1.6 mg/cm^2 of mica. Detector B will measure electrons > 45 keV and protons > 0.65 MeV. A sun shade is incorporated on the end of each tube housing to protect the detectors from exposure to direct sunlight during the cruise mode.

The window of detector C is covered with 1.6 mg/cm^2 of mica, and an aluminum foil of approximately 20 mg/cm^2 is placed behind the aperture of the detector. This increases the threshold energy to 150 keV for electrons and 3.1 MeV for protons. The G-M counter outputs are shaped by means of saturating current amplifiers before being sent to the data automation system.

The solid state detector (SSD), detector D, is a totally depleted silicon surface-barrier diode with a thin (0.2 mg/cm^2 air equivalent for alpha particles) nickel foil for light shielding. The sensor is 31.7 μm thick and has a normal sensitive area of 12 mm^2. The detector, used as a 4-channel (D1-D2-D3-D4) proton and alpha particle spectrometer, is capable of detecting protons and alpha particles in a high flux of electrons. Sensitivity to electrons is minimized by (1) making the detector too thin to stop energetic electrons, and (2) setting the discrimination level much higher than the expected electron energy loss.

The detector D output is fed into a linear charge-sensitive preamplifier, which is followed by a series of highly stable voltage amplifiers (post-amplifiers). The output of the second post-amplifier is fed in parallel to two post-amplifiers having different voltage gains. The outputs of these amplifiers are in turn transferred to four identical amplitude discriminators with a common reference supply. Gain of the post-amplifiers is set to produce pulses at the discriminators that correspond to the particles detected. The discriminator reference supply is temperature compensated to keep the discrimination levels constant.

Figure 2 is a block diagram of the TRD electronics. The G-M detectors A, B, and C have a double-pulse resolution time of 20 μs. True counting rates may be expected to range from a background of 0.64 count to 10^7 counts/s while the maximum apparent rate possible is about 30,000 counts/s. Laboratory calibrations extend the dynamic range to a maximum of 10^7 counts/s.

The SSD has a double-pulse resolution time of 10 μs. The maximum output or apparent counting rate will be limited to approximately 100,000 counts/s. In this case, also, laboratory calibrations extend the dynamic range to about 10^7 counts/s. A weak inflight source will provide about 0.05 count/s on D1 and a smaller counting rate on D2, D3, and D4.

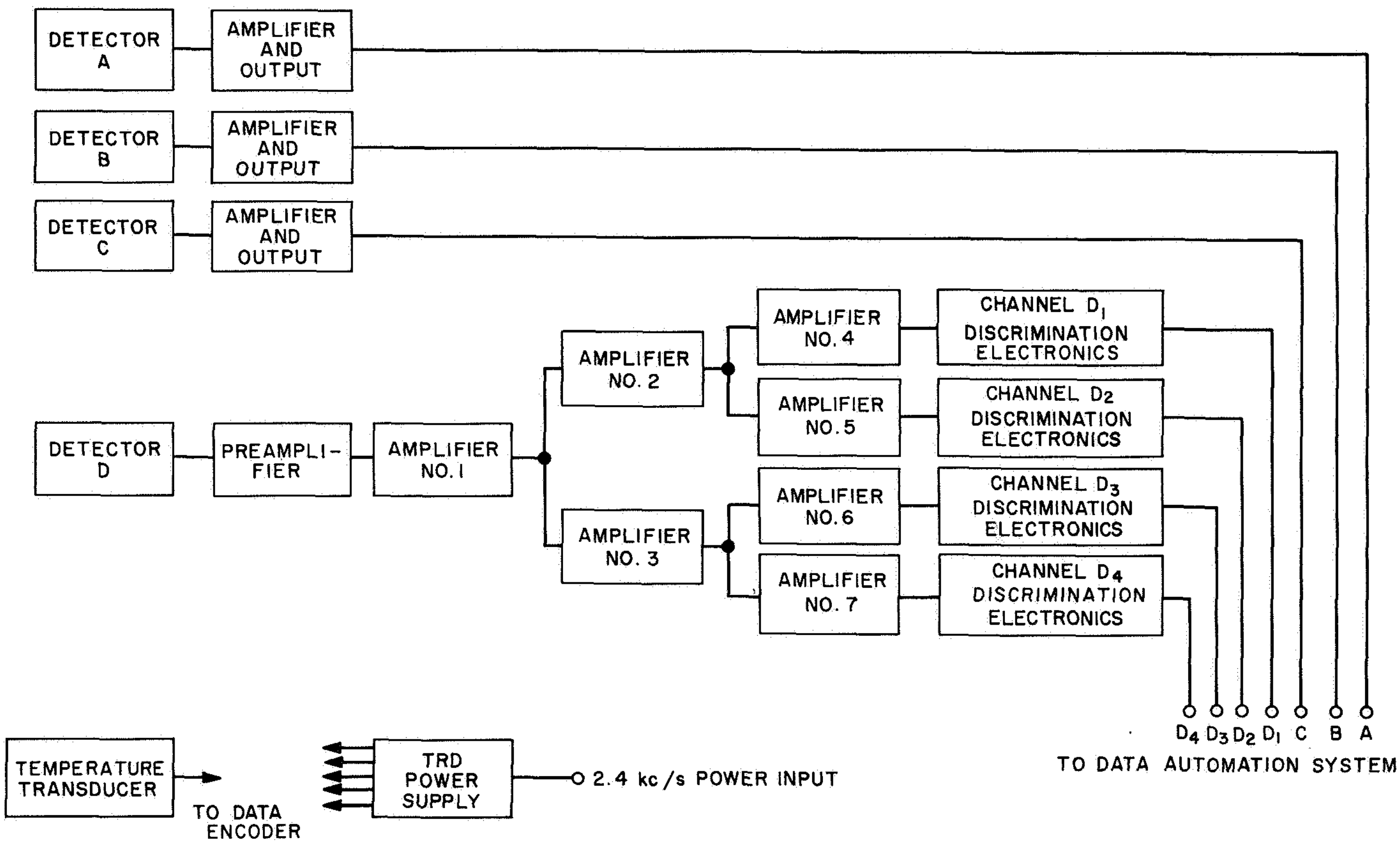

Fig. 2. Trapped radiation detector functional diagram

A summary of detector characteristics is contained in Table 1 below.

Table 1. Detector characteristics

Detector	Shielding	Energy for penetration	Dynamic range in true counts/s
A	Magnesium Teflon Beryllium foil	Electrons $E_e > 95$ keV Protons $E_p > 2.7$ MeV X-rays $\lambda < 10$ Å	$0.6–10^7$ $0.6–10^7$
B	Magnesium Teflon	Electrons $E_e > 45$ keV Protons $E_p > 0.65$ MeV	$0.6–10^7$ $0.6–10^7$
C	Magnesium Teflon Aluminum foil	Electrons $E_e > 150$ keV Protons $E_p > 3.1$ MeV	$0.6–10^7$ $0.6–10^7$
		Electrons insensitive to any energy. protons:	
D1		$0.30 < E_p < 12$ MeV	$0.05–10^7$
D2		$0.50 < E_p < 5.3$ MeV	$0.05–10^7$
D3		$0.98 < E_p < 2.2$ MeV	$0.05–10^7$
		alpha particles:	
D4		$2.1 < E_a < 18$ MeV	$0.05–10^7$

Figure 3 is a drawing of the instrument showing the physical configuration of the four detectors. The sensors were mounted on a magnesium chassis. The volume of the chassis is approximately 82.5 in.^{3} (5.5 × 4.0 × 3.1 in.).

The detectors are, from left to right, the solid state proton detector, and the G-M tubes C, B and A. The chassis contains the G-M tube electronics, power supply, and the electronics for the solid state detector. The D detector electronics are contained in a separate RF-shielded chassis within the main chassis.

A total of 419 electronic components were used in the instrument. The weight and power measurements of all the units are listed in Table 2 below.

Table 2. Weight and power measurements

Instrument	Spacecraft	Weight, lb	Power, W
MC-1	Spare	2.67	0.450
MC-5	Flight	2.66	0.450

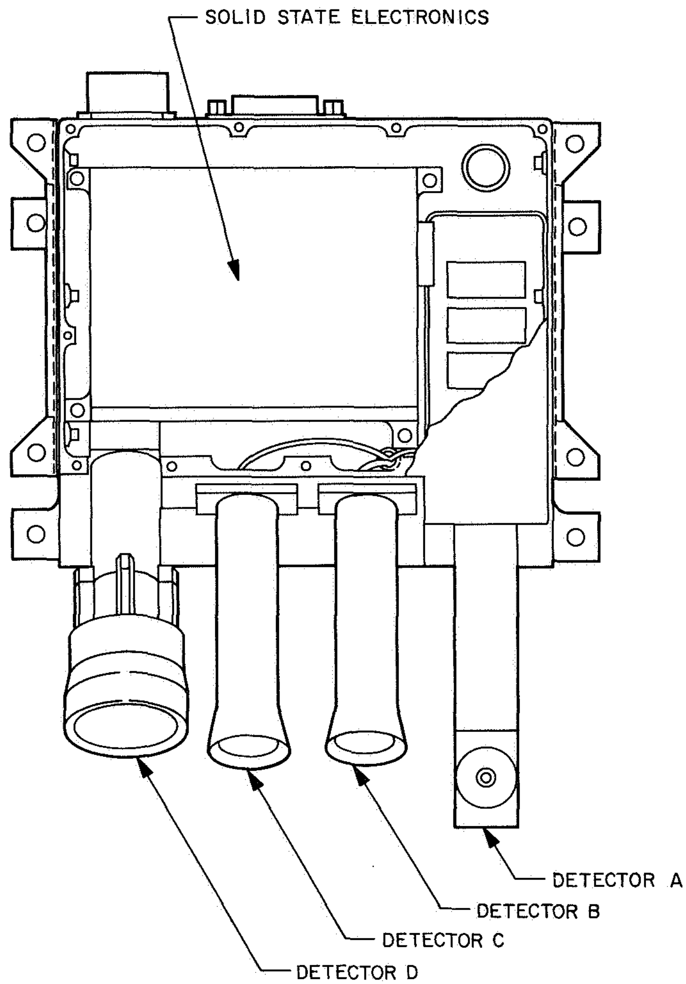

Fig. 3. Drawing of TRD showing physical configuration of the four detectors

The instrument is located atop the bus directly above Bay IV, midway between the −X and −Y axes of the spacecraft as shown in Fig. 4.

Temperature control of the instrument is passive, being monitored by means of a thermal transducer contained within the instrument. The data encoder channel assignment number is 438.

D. Data Flow

The following describes how the TRD data is handled by the data automation system. At the low spacecraft bit rate 8-1/3 bits/s, the output data channels are commutated so that each output is sampled for 37.2 s out of every 403.2 s. The total counts during this sample period is telemetered to earth. If the total count during this 37.2-s period exceeds 2^{19}, the number transmitted to earth is

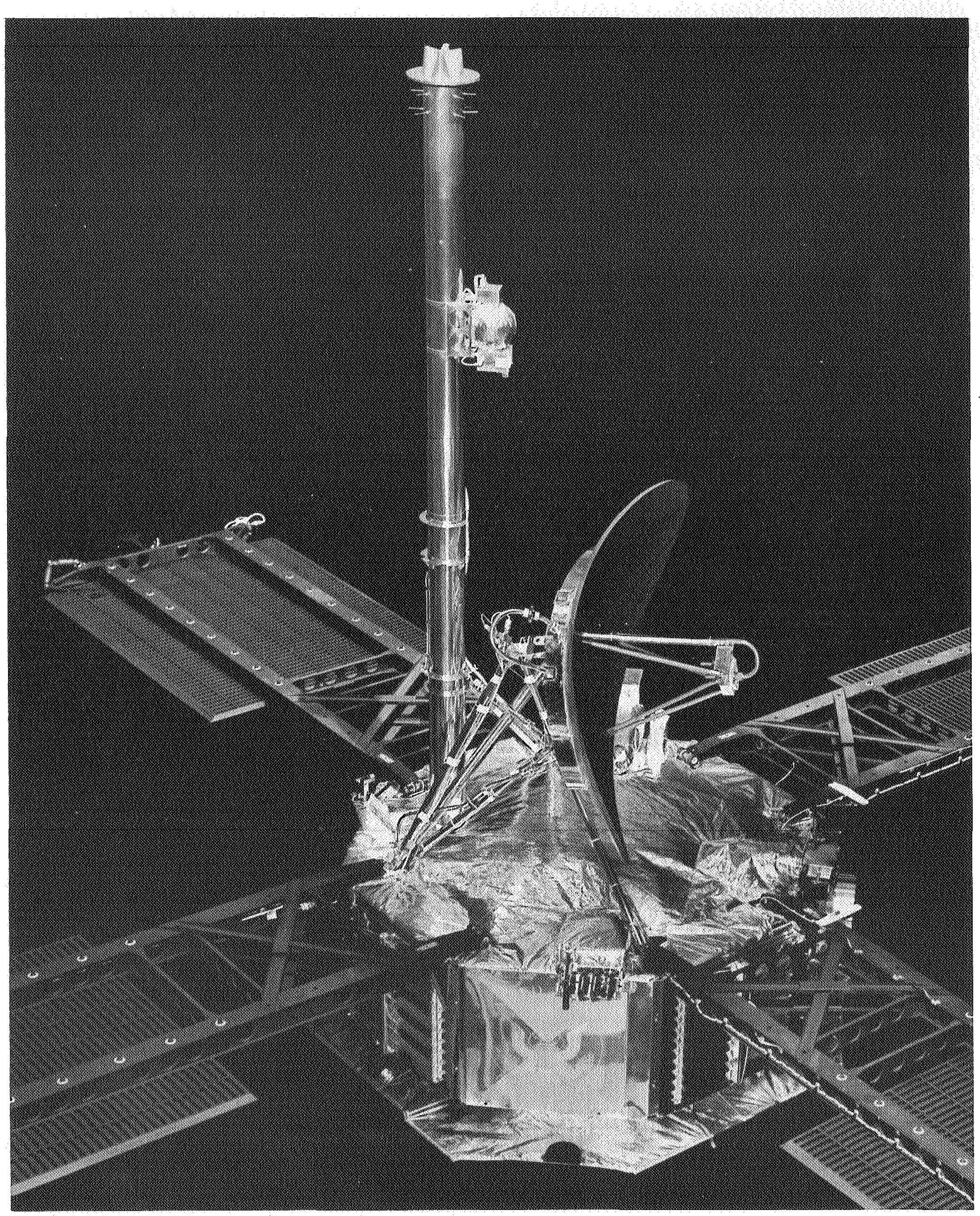

Fig. 4. The *Mariner V* spacecraft showing TRD

2^{19} plus one-fourth of the number of counts in excess of 2^{19}. At the high spacecraft data rate 33-1/3 bits/s, the above times are reduced by a factor of four.

The commutation order of the data channels is A, C, B, D1, D2, D3, D4, D1. One data channel is commutated from each frame. All data telemetered in real time is also recorded by the spacecraft tape recorder during the encounter sequence.

In addition to the commutation sequence of the seven data channels, detector B output is sampled for 31.2 s out of every 50.4 s at the low spacecraft bit rate and for 5.4 s out of every 12.6 s at the high bit rates. The data telemetered in real time is the total count which occurs during the first 21.6 s of this 31.2-s period. In addition, during the encounter recording sequence the count accumulation is recorded on tape every 1.2 s during the 31.2-s period. In either case this additional detector B data has a maximum value of 512 counts due to the data automation system (DAS) limitations.

E. Instrument Test History

(1) Type approval (TA). A modified *Mariner IV* TRD was used as the *Mariner Venus* (MV)-67 TA. The unit passed TA vibration and magnetic environmental testing on August 24, 1966.

(2) Flight instrument MC-1. This MC-1 instrument was received at JPL from the University of Iowa on October 3, 1966. Flight acceptance (FA) test commenced October 12, 1966 and was completed October 19, 1966. The unit was returned to the university for modifications to eliminate the cross talk problem noted during data automation system compatibility tests. During the rework, detector B G-M window was fractured. The instrument was repaired and returned to JPL on November 1, 1966. FA requalification commenced on November 1 and was successfully completed November 5, 1966. On December 12, 1966 the unit was again carried to the university for problem failure report (PFR) modification and returned to JPL three days later. MC-1 was again sent to the university for the last time on February 20, 1967 for the scheduled calibration. The experiment was returned to JPL on March 15, 1967 and installed on the MV-67-1 spacecraft on the following day. Upon certification into the spacecraft assembly facility, MC-1 had 1310 *Mariner IV* operating hr and 296 MV-67 hr for a total of 1606 hr of operating time.

(3) Flight instrument MC-5. The MC-5 instrument was received December 14, 1966 and successfully passed flight acceptance testing on December 18, 1966. Final calibration was completed at the University of Iowa on January 5, 1967. MC-5 was certified into the spacecraft assembly facility with 158.35 hr operating time on January 9, 1967. The TRD was installed on the MV-67-2 spacecraft and launched on June 14, 1967.

(4) Critical problem failure reports. The major concern during the testing phase was in the area of solid state detector data channels. Crosstalk problems were encountered. Under certain conditions, the solid state detector data channel would count the G-M pulses and the 2.4-kHz power supply. These problems were solved by the addition of decoupling networks in the +8-V line of the internal power supply. By the addition of power supply decoupling, the experiment became very stable and the crosstalk anomaly was completely eliminated. Environmental testing was performed according to JPL specifications.

F. Test Experience

(1) The engineering change requirements (ECR) summary list is shown below.

ECR	Units	Remarks
8027	MC-1	Add 3 capacitors in power supply.
8041	MC-1 & MC-5	Substitute a four-channel solid state detector for the existing two-channel detector.
8089	MC-1 & MC-5	Relocate detector look angle directed to 0 deg to the spacecraft sunprobe line. Decreased the full look angle of detector A to 10 deg.
8312	Documentation	Change JPL functional specification.
8475	MC-1 & MC-5	Change the solid state detector full field of view from 60 to 80 deg.

ECR	Units	Remarks
8530	Documentation	Correction of a documentation error.
8587	MC-1 & MC-5	Add one 100-Ω resistor and 0.82-μF capacitor.
8588	Documentation	Correction of documentation errors.
8671	MC-1 & MC-5	Add 180-mH inductor in series with +8-V line.
8674	MC-5	Remove 3 ACI resistors and replace with 3 IRC resistors.
8712	Documentation	Amend functional specification.
8846	Documentation	Correct functional specification error regarding energy levels.

(2) Shown below is a summary list of all problem failure reports covering flight instruments prior to launch:

PFR	Units	Problem	Corrective action
011031	MC-1 & MC-5	Mounting washers cracked.	Mounting hardware modified.
011034	MC-1	Wiring error, output of G-M detectors.	Wiring errors corrected.
011038	MC-1 & MC-5	Cross talk on output data channels.	Decoupling network added on +8-V supply.
011039	MC-1	Loss of electrical contact between mating connectors.	Foreign material removed by cleaning connector.
011091	MC-1 & MC-5	Safety PFR thermocouples attached to unit (space simulator test).	Locations moved.
10562V	MC-1 & MC-5	Channel D1 counted 2.4-kHz power supply.	180-mH inductor added as decoupling in +8-V supply.
105638V	MC-1	Fractured G-M window.	G-M and voltage regulator tube replaced.
105741V	MC-1	High background count of SSD after shake.	Solid state detector replaced.
010857	MC-5	Foreign material found in SSD source.	Foreign material removed.
010892	MC-5	SSD D1 read 11% higher than nominal during Eastern Test Range tests.	Epoxy on SSD source prevented source bottoming. Epoxy removed.
011033	TA	Failure of G-M tube A due to extensive testing.	No action taken—*Mariner 1964* life test model.

G. Calibrations

The calibrations off the spacecraft were performed at the University of Iowa.

The window thicknesses of the G-M tubes were determined through the use of an electron gun at the University of Iowa. The relationship between apparent counting rates, and true counting rates (i.e., that which would be observed by a G-M counter with zero dead time), was measured on the completed instruments. An X-ray machine was used to provide the high radiation flux necessary for this calibration.

The determination of the energy ranges to which the solid state detector is sensitive, and the detector depletion depth necessary to achieve this were made by the experimenter. Through selection of (1) thin detector, and (2) high discrimination levels, to minimize electron sensitivity, the sensor is capable of detecting protons in a high proton flux. A linear pulser and alpha source of known value were used to set these discrimination levels. The alpha source used was polonium 210. Calibrations were verified by placing the unit in a proton beam from a Van de Graaff accelerator.

Calibrations on the spacecraft are used primarily to verify the correlation between the instrument counting rates and the science data output. The sources used are of sufficient flux to produce an overflow condition in words 10 and 11 of the science data automation system (bit one of word 10, binary one).

A strontium 90, 1 Ci source was used to stimulate the G-M tubes to saturation. Readouts were recorded at both 8-1/3-bits/s and 33-1/3-bits/s rates. The source was placed successively on all three G-M tubes.

In the same manner, a polonium 210 source of approximately 80 mCi was placed on the solid state detector. Data was recorded at 8-1/3, and 33-1/3-bits/s rates. The saturation levels with the polonium 210 and the strontium 90 were as follows:

Solid state detector	100 kHz
Detector A	37 kHz
Detector B	30 kHz
Detector C	33 kHz

A light source (300 W flood lamp) was held at the detector D aperture to check for damage to the nickel foil, and data was recorded from the DAS. No increase in counting rate was observed, indicating that the foil had not been damaged. The nickel foil is used to prevent detector contamination through direct exposure to the sun. This foil is 0.2 mg/cm^2 of air equivalent for alpha particles (approximately 12.5 $\times$ 10^{-6} in. thick).

Counting rates of the detectors were taken over 1-hr periods, using the sources associated with the instrument throughout the FA, and systems testing phase of the program. These sources are approximately 200 microcuries (μCi) of cobalt 60 for the G-M tubes and approximately 1 μCi of americium 241 for the solid state detector D. The counting averages were compared with data from previous tests for degradation indications and none were noted.

Quiet tests were made for seven hr with no sources on the instruments to verify the background count rates of the detectors (on both MV-67-1 and MV-67-2 spacecraft). Figure 5 shows the TRD with the cobalt 60 and americium 241 test sources mounted on the instrument.

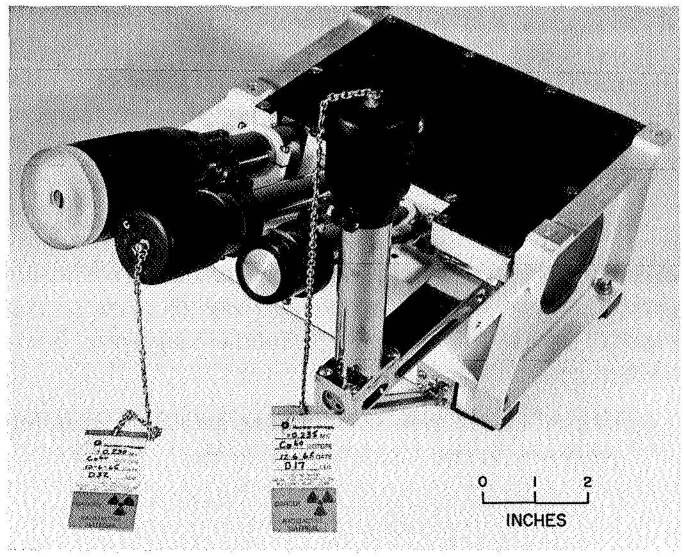

Fig. 5. Flight TRD with radioactive test sources installed

In-flight calibration consists of an americium 241 source (0.01 μCi) mounted in detector D housing assembly to establish background counting rates. This source produces 3–4 counts/min in the D1 channel and 2–3 counts/min in the D2 channel. There is no provision for in-flight checks on the G-M tubes, although a rough check may be obtained from their background counting rates. Figure 6 is a photograph of a TRD flight unit.

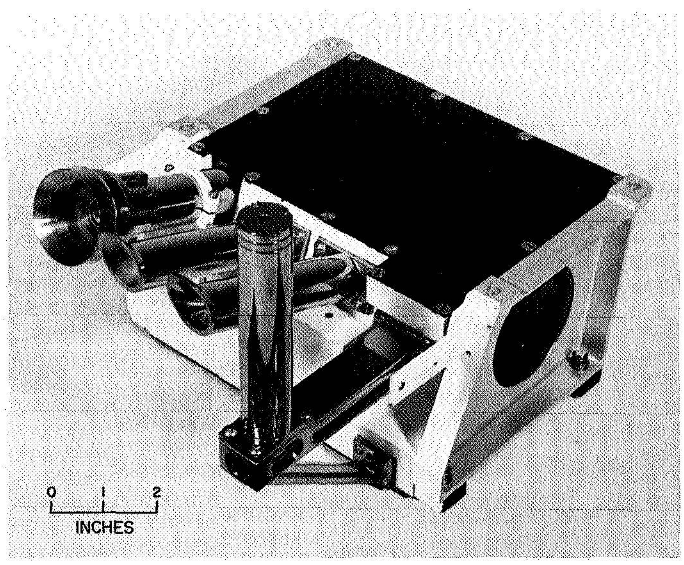

Fig. 6. Trapped radiation detector flight unit

H. Procurement

The contract for the design and fabrication of the instrument as with that of *Mariner IV* is with the University of Iowa, and supported under NASA contract. Electronic components used in the fabrication of the units and the circuitry, with the exception of the power supply, G-M tubes, and solid state detector, were purchased and screened under JPL cognizance. Three major problems were evinced in the delivery of parts to the vendor, which caused some schedule slippages. They were:

(1) The delay at JPL in obtaining screened parts for delivery to the University of Iowa.

(2) The unavailability of flight quality solid state detectors from the experimenter's vendor.

(3) Unscheduled requirement for screened components needed for PFR modifications.

The power supply was fabricated by the Matrix Corporation under subcontract to the University of Iowa for the *Mariner IV* contract. The G-M tubes were purchased from EON Corporation of Brooklyn, New York, and the solid state detectors were purchased from Nuclear Diode Corporation of Highland Park, Illinois.