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FINAL TECHNICAL REPORT

on

COSMIC RAY PARTICLE DETECTORS DESIGNED FOR INTERPLANETARY STUDIES UTILIZING THE PIONEERS 8, 9, AND 10 SPACECRAFTS

by

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Technical Report on Cosmic Ray Particle Detectors Designed for Interplanetary Studies Utilizing the Pioneers 8, 9, and 10 Spacecrafts

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1. INTRODUCTION

This report briefly summarizes the design, development, fabrication, and initial data reduction history of the SCAS cosmic ray detector packages for the Pioneers 8-10 deep-space probe missions. This report is intended to supplement rather than supercede the more detailed information supplied during the course of the programs in the form of contractually required monthly progress reports. We shall, therefore, make no attempt to re-discuss or re-describe in lengthy detail the day-to-day occurrences which have added to or subtracted from the complexities of preparing 4 instruments for flight certification. Rather we shall attempt to provide a concise report on the SCAS activities which led to the preparation of cosmic ray detector packages for the Pioneers 8, 9, and 10 missions. To achieve this aim, we shall divide this report into three somewhat general catagories:
1) The time-history of the SCAS program development; 2) A description of the particle detectors, along with preliminary data obtained from Pioneer 8; 3) Techniques employed in the reduction of the scientific data telemetered back to earth.

2. PROGRAM HISTORY

The Pioneer 6 and 7 deep-space probe missions have successfully provided vital information concerning the behaviour of the interplanetary processes occurring during the quiet years of the solar cycle. The purpose of the Pioneer 8, 9, and 10 missions was to extend these critical studies into the active years of the solar cycle. With this motivation, the SCAS cosmic ray team proposed an anisotropy detector in a document submitted to NASA headquarters on March 13, 1964 Funding was made available to SCAS on November 26, 1965 in form of NASA Contract NAS2-3332. Under the terms of this contract, and succeeding extension contracts, it was stipulated that SCAS, in addition to initial breadboarding designs, would be responsible for suppling to NASA/Ames Research Center four flight certified cosmic ray detector packages, as well as fabricating one non-flight certified design verification unit (along with the construction of two sets of ground support equipment). These detector units, along with their serial numbers are listed as follows:

1. Design Verification Unit (DVU) - no serial number.
2. Prototype - S/N 8C09-1.
3. First Flight Unit (Pioneer 8) - S/N 8C09-2.
4. Second Flight Unit (Pioneer 9), also backup for Pioneer 8 - S/N 8C09-3.
5. Third Flight Unit (Pioneer 10), also backup for Pioneer 9 - S/N 8C09-4.
6. Backup for Pioneer 10 - modified Prototype - S/N 8C09-1M.

Even though the funding was not released for the hardware contract until November 26, 1965 considerable progress had been made on the design, initial development, and breadboarding stages as a result of this group's past experiences on the Pioneers 6 and 7 hardware programs. Our proposed subcontractors were also, to a large extent, prepared for immediate start-up as contracts were released. Although the Pioneer instruments were designed and largely fabricated at the Southwest Center for Advanced Studies, subcontractors played prominent roles in the following critical areas.

a) Supplying and initially checking solid-state detectors and performing the packaging of the tri-telescopes - Oak Ridge Technical Enterprises Corporation, Tennessee.

b) Power Supply Packaging - Matrix Corporation, New Hampshire.

c) Packaging of electronic sub-assemblies - Marshall Industires, California and Sippican Corporation, Massachusetts.

To achieve mission lifetimes of six months to two years in a hostile space environment, the design, component selection and pre-stressing, assembly, and testing of the flight instruments were accomplished within the framework of strict quality assurance procedures. In our case it was necessary to institute a NASA - approved Quality Assurance and Reliability Program at SCAS consistent with NPC 200-3 with assembly and workmanship of instruments governed by procedures as outlined in NPC 200-4. Applicable documents from Ames Research Center established procedures for magnetic guidelines, preferred parts list, electrical parts screening requirements, non-magnetic materials, welding guidelines, printed circuit design, electrical equipment product listings, "clean-room" fabrication, as well as providing valuable input on the selection of suitable subcontractors.

The mean time between failure for the SCAS Pioneer 8 instrument, produced in a small university research laboratory with some basic modules subcontracted, has been calculated to be 13,000 hours (~1.5 years) using Mil-Hdbk-217 to establish failure rates for some 3100 electronic components.

The delivery dates of the various flight-certified detector packages to NASA/ARC were as follows:

S/N 8C09-1 - March, 1967
S/N 8C09-2 - June, 1967
S/N 8C09-3 - October, 1967
S/N SC09-4 - March, 1968
S/N 8C09-1M - August, 1968

3. DESCRIPTION OF THE SCAS PIONEER COSMIC RAY DETECTORS

The cosmic ray particle detector designed for the Pioneer missions is described in the following draft of a paper which is incorporated as a part of this final report. This paper is currently being finalized for submission to one of the scientific instrumentation journals. The paper describes the instruments from a scientific standpoint with brief discussions of some of the major engineering considerations. Very basically, the detector package consists of four particle detector telescopes, one crystal scintillator telescope and a triple solid-state detector telescope configuration.

THE PIONEER 8 AND 9 COSMIC RAY DETECTOR SYSTEM

by

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ABSTRACT

An instrument designed to measure the directional properties of cosmic ray propagation in the energy range 1-63 MeV per nucleon during solar active years is described. This instrument has been flown on the interplanetary space vehicles Pioneers 8 and 9. The detector package is discussed with regard to its mechanical, electrical, and data conditioning properties. In-flight calibration procedures are briefly discussed, and preliminary data from Pioneer 8 are presented to illustrate the performance of the instrument during a period of solar activity.

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I. INTRODUCTION

In recent years great emphasis has been placed upon the exploration of the interplanetary medium by means of cosmic ray detectors mounted on space vehicles which, subsequent to their injection into either geocentric or heliocentric orbits, escape the limiting confines of the earth's atmosphere and the geomagnetic field. The results of such studies have greatly contributed to an understanding of the basic nature of the interplanetary magnetic field structures and the manner in which both galactic and flare initiated cosmic radiation propagate therein.

Although it has been possible to study the degree of anisotropy of the high energy ($> 10^9$ eV) component of the

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cosmic ray flux from data obtained by cosmic ray detectors strategically located over the surface of the earth, these studies have suffered from such distinct disadvantages as the scarcity of strictly comparable detector systems, the necessary application of atmospheric and terrestrial magnetic field corrections to the collected data (these correction factors being a function of detector location) and the insensitivity of such ground based instrumentation to cosmic radiation of energies $< 10^9$ eV.

The Pioneer 8 and 9 spacecrafts, like their predecessors Pioneers 6 and 7 were launched into heliocentric orbits. Pioneer 8 was launched into an outbound orbit (similar to Pioneer 7) of predicted aphelion 1.1 AU at 0908 EST, December 13, 1967. Pioneer 9 was launched into an inbound orbit (similar to Pioneer 6) of predicted perihelion 0.8 AU at 0446 EST, November 8, 1968. A similar spacecraft had been planned for the ill-fated Pioneer 10 mission in August, 1969. The Pioneer spacecrafts are spin stabilized, self-contained observatories designed to make simultaneous measurements of the direction and magnitude of the interplanetary magnetic fields, the direction, temperature, and density of the interplanetary plasma ("solar wind"), the propagation of radio waves within the inner solar system, the velocities and density distributions of the interplanetary dust particles, and the degree of anisotropy and the temporal and spectral changes occuring in the cosmic ray flux.

The cosmic ray anisotropy detector system flown aboard Pioneers 6 and 7 have been previously described [1,2,3]. The instrument described in this paper is a logical extension of this detector system based upon both the acquired results of these previous "quiet sun" missions and the anticipated behaviour of the cosmic ray flux during the active years of the current solar cycle. The purpose of the Pioneer cosmic ray detectors is to provide co-ordinated measurements of the degree of anisotropy, the energy spectrum, and the temporal and spatial variations of solar flare induced cosmic radiation. The Pioneer network thus permits a comprehensive evaluation of the inner solar system to be continuously executed by providing four observation stations with comparable detector systems widely separated in solar azimuth. Such stations provide immediate information on the nature of long-lived, transient, co-rotating, localized, or spatially extensive interplanetary phenomena.

The Pioneer 8 and 9 detector systems consist of a scintillation counter telescope, along with a tri-telescope comprised of three solid state detectors arranged in a fan configuration surrounding a fourth. The physical orientation of the instrument package is such that as the spacecraft rotates about a spin axis perpendicular to the ecliptic plane, the scintillation counter records the fluxes of cosmic rays whose arrival directions at the spacecraft make small angles with the plane of the ecliptic, while the solid state tri-telescope also possesses the capability of recording the fluxes of cosmic ray particles whose arrival directions at the spacecraft make substantial angles to the plane of the ecliptic. This latter feature is highly significant in view of the reported filamentary microstructure[4,5] observed in the earlier Pioneer missions and the implications[6] of the possible existence of a cosmic ray density gradient perpendicular to the ecliptic plane.

2. THE DETECTOR SYSTEM (MECHANICAL)

The essential features of the scintillation counter telescope are illustrated in Fig. 1. The 12 g cm^{-2} thick Cs I(Tl) crystal scintillator C is encased on three sides by a cylindrical veto counter D constructed from scintillating polytoluene. Each scintillator is viewed by independent photomultiplier tubes, and logic circuits select those particles which produce light pulses within the Cs I(Tl) crystal unaccompanied by light pulses within the veto counter (i.e. $C\bar{D}$ logic). Thus, the scintillation telescope is unidirectional, selecting for study only those particles which enter the system through the open end of the veto counter and come to the end of their range in the crystal. Such criteria are satisfied only by particles less energetic than $\sim$ 90 MeV/nucleon and whose directions of arrival at the spacecraft define angles no greater than ± 38° with the plane of the ecliptic. This scintillation counter detector is very similar to the one utilized on the earlier Pioneer missions[1,2], the significant differences being:

1) For an incident particle of 7 MeV energy, the Pioneer 8 and 9 detector defines an opening angle which is ~ 53% of the opening angle of the Pioneer 6 and 7 detector. The surface area of the present detector is about one-third the surface area of the earlier detector. This large reduction in the geometric factor of the present Pioneer scintillation telescope readily accommodates the increased solar particle fluxes encountered in the current studies.

2) The photomultiplier tubes associated with the Pioneer 6 and 7 scintillators were directly coupled, optically, to their respective counters. However, as seen in Fig. 1, the photomultiplier associated with the CsI(Tl) crystal in the present detector is space-coupled to the crystal with a highly reflective light-integrating chamber acting as the coupling medium. Although the space-coupling of the phototube to the crystal results in a slight reduction of pulse height, such a technique removes the loss in efficiency of the veto counter due to "leakage" of particles to the CsI(Tl) scintillator though the orifice required for direct optical coupling.

The salient features of the solid state detector tri-telescope are illustrated in Fig. 2. Detectors A, E, and F are oriented in a fan arrangement around detector B, and when operated in coincidence with detector B define three telescopes AB, EB, and FB. All detectors are silicon surface barrier diodes of 100 mm^2 active surface area operated at their total depletion depths of 100 microns.

The physical orientation of the tri-telescope configuration within the instrument package is such that aboard the Pioneer spacecraft, the mean viewing direction of the AB telescope lies within the plane of the ecliptic, while the mean viewing directions of EB and FB are centered 48° above and below this plane, respectively. Each telescope configuration defines a cone of acceptance of half angle 23° which accommodates protons in the energy range 1-10 MeV.

3. THE DETECTOR SYSTEM (ELECTRICAL)

Pulse height analysis is performed upon the selected pulses from the CsI(Tl) crystal in exactly the same manner as described for the earlier Pioneer detectors[1]. The pulses are selected by a two-window analyzer, the differential energy windows corresponding to energy depositions of 7.4-21.5 MeV and 19.7-63.0 MeV.

The solid state detectors are electrically operated as back biased diodes, with the n-type aluminum backing at a positive potential (high enough to ensure total depletion of the silicon but not sufficiently high to produce dielectric breakdown) with respect to the p-type evaporated gold film. A negative potential of 50 VDC is applied to the sensitive gold surface of each detector, as shown in Fig. 3, while the aluminum contact surface is kept at circuit ground. The negative pulses arising from such an electrical configuration are then passed through a charge integrating amplifier/voltage amplifier network and into standard pulse height discriminators. The discriminator levels are determined from the energy response curves of the solid state detectors. An example of such a proton response curve for a pair of 100 micron detectors operating as a particle telescope is shown in Fig. 4. Herein is plotted the energy deposition ΔE_2 in the second detector (Detector B for each telescope arrangement) as a function of the energy deposition ΔE_1 in the front detector of the telescope. The corresponding energy of the incident protons are indicated at various positions along the curve. On the basis of such response curves, differential energy windows of 3.3-3.6 MeV and 3.6-6.7 MeV for incident protons were readily selected for anisotropic particle propagation studies. In addition to data obtained from the AB, EB, and FB logics, it is clear that additional information from different energy ranges may be obtained from pulse height analysis of the outputs of the detectors considered separately.

The directional sensitivity of either solid-state detector telescope EB or FB is shown in Fig. 5. Herein is plotted the relative directional response (relative detector cross-section times the cosine of the angle of incidence) as a function of the mean viewing direction measured with respect to the plane of the ecliptic.

The assembled instrument package acquires data under two data conditioning modes which operate concurrently.

1) The sun-synchronous mode: Under this mode of operation, data are accumulated over an integral number of

spacecraft spin periods. Measurements of particle anisotropies (i.e. directions of preferential particle flow) are readily achieved by means of "aspect clock" circuitry similar in nature to the circuitry[2] developed for the earlier Pioneer missions. Whereas the Pioneer 6 and 7 detectors collected anisotropy information by very accurately dividing each spacecraft spin period into four identically equal time segments, the Pioneer 8 and 9 instruments achieve directional response by very accurately dividing each spin period into eight identical time segments. This octant division is illustrated in Fig. 6(a) which illustrates the data accumulation intervals relative to the satellite-sun line. It is seen that the sun is centered roughly between octants 5 and 6. Figure 6(b) illustrates an alternate data collection mode to provide increased directional sensitivity. In this "slipped octant mode", the octants are shifted to the east of the satellite-sun line by 22.5° placing the sun at about the midpoint of octant 6. Data are collected alternately from each octant configuration during the flight life-time.

2) The telemetry-synchronous mode: Under this mode of operation data are accumulated over an integral number of telemetry main frames. Omnidirectional data are collected from numerous crystal and solid-state differential energy windows in a time-sequence which is synchronous with the spacecraft telemetry bit rate (the spacecraft telemetry operates at five different bit rates varying from 512

bits per second to 8 bits per second, the desired bit rate being initiated via ground command).

A simplified block diagram of the electronic networks which generate the above two data conditioning modes is illustrated in Fig. 7. Signals from the six detectors are directed by means of analog linear switches. One switch selects either the signal from the solid-state detector B or the CsI(Tl) crystal for analysis by the pulse height analyzer associated with the directional sun-synchronous mode (ANIS. PHA). A set of switches selects either the signal from A, E, or F to be used in conjunction with the coincidence discriminator and gating circuit. A final switch selects either the signal from A or C for analysis by the pulse height analyzer associated with the omnidirectional telemetry-synchronous mode (ISOT. PHA).

The functions necessary to prepare the digital data for transmission via spacecraft telemetry are described in great technical detail elsewhere[7], suffice to say that the directional data from both the crystal and solid-state detector systems are stored in two 9 bit logarithmic accumulators (labeled J and K in Fig. 7) while the omnidirectional data are stored in one 9 bit logarthimic accumulator (labeled M in Fig. 7). A 3-bit binary accumulator (L) acts as a spacecraft spin counter. The logarithmic 9-bit accumulators are so gated as to allow 2752 counts to be accumulated during each measurement. At a telemetry bit rate of 512 bits per second, these accumulators permit omnidirectional particle fluxes as large as about 400 particles cm^{-2}-sec^{-1}-$sterad^{-1}$ and directional fluxes as large as about 3 X 10^3 particles cm^{-2}-sec^{-1}-$sterad^{-1}$ to be recorded before accumulator overflow occurs.

4. INSTRUMENT DATA FORMAT

The spacecraft telemetry main frame consists of 32 seven bit words (6 data bits plus one parity bit) in which the present detector system is allotted five contiguous words for a total of 30 bits (excluding parity). These 30 bits are then used to define the outputs of the 9 bit omnidirectional accumulator M, the two 9 bit directional accumulators J and K and the 3 bit spin counter L.

For the sun-synchronous mode, data accumulation must start and stop with the recording of a pulse from the spacecraft sun sensor. All control signals are synchronous with the telemetry bit stream, and consequently completely asynchronous with the sun pulse. Figure 8 illustrates the manner in which compatability between these two asynchronous pulse streams is achieved, thereby allowing meaningful directional data to be recorded. The condition depicted therein refers to a bit rate of 512 bits per second, although Fig. 8 is also representative of the techniques employed for the lower bit rates. Data pertinent to a particular detector logic begin to accumulate coincident with the arrival of a sun pulse. These data are then accumulated over a time interval which includes the arrival of at least four word gate pulses. (The selection of four word gate pulses is somewhat arbitrary, the sole criterion being that this provides a convenient accumulation time at 512 bits per second.) Coincident with the arrival of the first sun pulse subsequent to the fourth word gate pulse, these directional data are transferred from the accumulators into the output buffer. The accumulators are immediately reset, the detector logic is changed, and a new accumulation is initiated. Upon the arrival of the first word gate during this new accumulation, the data stored in the output buffer from the former detector logic are read out. Hence directional data are contained in every fourth (or more, depending upon the relative phases of the word gate and sun pulse streams) readout, at 512 bits per second. Clearly, the relationship between the frequency of directional data readout and the word gate frequency is dependent upon the bit rate and the number of word gates utilized to define the accumulation time for the detector logics. Omnidirectional data are read out during each word gate pulse. Changes in detector logics for both the directional and omnidirectional modes, however, occur simultaneously.

5. PHYSICAL PROPERTIES OF THE ASSEMBLED INSTRUMENT

The completely assembled Pioneer 8 and 9 cosmic ray detector package contains 421 transistors, 786 diodes, 179 IC's, a high effeciency power supply, four solid-

state detectors, two scintillators, two photomultiplier tubes, and a thermistor network. The assembled detector system weights 2.56 kg, occupies a volume of 235 cubic inches, and consumes 1.72 watts of electrical power.
A front-end view of the completely assembled package is shown in Fig. 9. The crystal telescope is located on the lower right portion of the front face, while the solid-state tri-telescope occupies the upper left portion. Aluminized mylar sheets protect the sensitive surface areas of all the detectors.

Since a major aim of the Pioneer program is to provide precise information on the interrelationship of cosmic ray propagation, solar plasma outflow, and interplanetary magnetic field configurations (fluctuations in this latter parameter often being of the order of 10^{-6} Oe), extreme care was taken to ensure that the spacecraft and the entire scientific payload conformed to very stringent residual magnetic specifications. The cosmic ray detector package exhibited a magnetic field of $< 2 \times 10^{-5}$ Oe at a distance of 91 cm after an exposeure to a magnetic field of 25 Oe. This very low susceptibility to magnetism was achieved through a program of very strict screening of flight-certified parts and a design directed towards the use of a minimum amount of ferromagnetic material.

The nominal differential energy windows of the Pioneer 8 and 9 detector were finalized as follows:

a) Sun-synchronous Mode (Directional). The two differential crystal telescope windows were set to record incident particles of energies 7.4-21.5 and 19.7-63.0 MeV per nucleon. The two differential solid-state telescope windows were set to record incident protons of energies 3.3-3.6 and 3.6-6.7 MeV.

b) Telemetry-synchronous Mode (Omnidirectional). The six differential crystal telescope windows were set to record incident particles of energies 4.5-6.8, 7.0-9.6, 9.6-13, 13-20, 21-28, and 28-40 MeV per nucleon. Two integral windows record the fluxes of particles more energetic than 13.5 and 40 MeV. The six differential solid state telescope windows were set to record incident protons of energies 1-8, 1-5, 1-3, and 4-6 MeV, and incident alpha particles of energies 4-8 MeV.

6. IN-FLIGHT PERFORMANCE

An in-flight calibration sequence of the detector package is initiated periodically by ground command (at least once per day). This calibration sequence monitors the performance of the scintillation telescope, the "aspect clock" circuitry, and the accumulator-buffer system. This sequence is comprised of the following tests, the data being telemetered back to earth, in the normal manner, subsequent to each calibration:

a) A 10 nanocurie Am^{241} source is used to indicate any possible gain shifts in the CsI(Tl) crystal and its ancillary electronic circuitry. During the normal flight mission, the energy thresholds of the CsI(Tl) telescope are set high enough so as not to record the 5.3 MeV Am^{241} alpha particles. Upon the initiation of a calibration sequence these thresholds are lowered such that the alpha particle source is detected in the fourth and fifth energy windows in the omnidirectional mode of operation.

b) Pulses are fed into the data conditioning circuitry (beyond the PHA's) at the bit rate frequency. This allows an in-flight comparison of the counting rates from each octant in turn.

A continual check on the performance of the output buffer and one accumulator is executed routinely throughout the normal flight lifetimes of the pioneer spacecrafts, as one of the omnidirectional measurements monitors the bit rate. This constant monitor of the bit rate also acts as a valuable flag for data handling and processing.

Figure 10 illustrates the spin frequency of the Pioneer 8 spacecraft and the counting rate due to the Am^{241} source as a function of time. During this time there were no observable changes in the behaviour of the cosmic ray detector.

7. PRELIMINARY DATA FROM PIONEER 8

The primary purpose of the present generation of Pioneer cosmic ray detectors is to extend the studies of particle propagation within the interplanetary magnetic field structures throughout the active years of the current solar cycle. Consequently the detectors are expected to record information during frequent periods of solar flare activity. Figure 11 illustrates the output of the omnidirectional integral channel of the scintillation counter telescope during the solar active interval July 6-14, 1968. Illustrated are the hourly averages (counts per 224 sec) of the cosmic ray flux of energies > 13.5 MeV. On July 6, Pioneer 8 recorded the onset of a cosmic ray enhancement at ~ 1000 UT. Several small east-limb flares were observed to occur on July 6, the most probable event responsible for the enhancement being a 2B flare which commenced at 0900 UT at the solar coordinates N09^{o} E89^{o}. Thus, since Pioneer 8 was located in the plane of the ecliptic 15^{o} to the east of the earth-sun line, the counting rate increase recorded by Pioneer 8 appears to be due to particles which had diffused across the interplanetary field lines subsequent to their injection near the east solar limb. The cosmic ray injection from this event (and a second 3B event occurring at 1800 UT, July 8 from solar coordinates N12^{o} E57^{o}) resulted in an increased particle flux being measured at the orbit of earth until at least July 13.

At some time prior to 2100 UT on July 12 a second well-defined counting rate enhancement in the > 13.5 MeV flux was observed to commence at Pioneer 8. This second event was short-lived, rising to maximum flux value at

~0030 UT July 13 and decaying back to ambient flux value some 15 hours later. A similar enhancement was observed[8] after a delay of some 22 hours by the Explorer 34 spacecraft which was anchored in an earth-orbit. It has been shown[8] that the July 13 event was of the co-rotating variety and comprised largely of relativistic electrons which contributed significantly to the total flux > 13.5 MeV.

All of the July activity was characterized by anisotropic particle propagation. From July 6 to July 12, the cosmic ray flux appeared to be indicative of typical particle propagation through an Archimedes spiral configuration for the interplanetary magnetic fields, i.e. during this time small anisotropies (< 20%) were observed from the general "garden-hose" angle. However, the July 13 activity as recorded by Pioneer 8 exhibited a large anisotropy (~ 100%) which rapidly decayed to a persistent level of ~ 20% in about 6 hours. This is illustrated in Fig. 12 wherein is plotted the hourly averages of the magnitudes and directions (with respect to the satellite-sun line) of the anisotropies observed at the position of Pioneer 8.

Figure 13 illustrates the behaviour of the solid-state tri-telescope (differential energy window of 3.6-6.7 MeV protons) during this solar active period. Herein is shown an hourly time-plot (counts per 224 seconds) of the total counting rate (i.e. sum of all eight octants) recorded by the telescope (FB) scanning below the ecliptic plane subtracted from the total counting rate recorded by the telescope (EB) scanning above the ecliptic plane. Thus, in Fig. 13 an excess of particles arriving at the spacecraft from the hemisphere above the ecliptic plane is indicated by a positive number, while a negative number indicates an excess of particles from the hemisphere below the plane. It is seen that most of the activity from July 9 to July 14 was characterized by positive valued anisotropies (i.e. more particles arriving at the spacecraft from above the ecliptic plane). However, the onset of the July 13 event is characterized by a distinct anisotropy from below the ecliptic plane which very quickly reverses itself and becomes a more pronounced anisotropy from above the ecliptic plane. The implications of such a "whiplash" effect in the "above-below" anisotropies will be discussed in greater detail later.

ACKNOWLEDGEMENTS

Although the Pioneer instruments were designed and largely fabricated at the University of Texas at Dallas (Southwest Center for Advanced Studies) certain portions of the detector package were subcontracted. Oak Ridge Technical Enterprises Corporation, Tennessee provided the solid-state detectors and was responsible for the tri-telescope packaging. Matrix Corporation, New Hampshire provided the power supply. Marshall Industries, California and Sippican Corporation, Massachusetts performed integral roles in the packaging of electronic sub-assemblies.

Assistance of many kinds were provided by the Pioneer Project Manager, C. F. Hall and his staff. We are particularly indebted to Mr. J. Lepetich for providing a very smooth liaison between Project Office and the experimental groups.

The overall success of the Pioneers 8 and 9 cosmic ray detectors was brought about through the combined efforts of many people particularly crucial contributions being made by Dr. U. R. Rao and Messrs. F. Selva, H. W. Glasscock, E. E. Buchanan, Jr., G. A. Stokes, and T. B. Mercer. Computer assistance was very ably supplied by Mr. D. D. Mosier and Mrs. P. Luna.

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References

1) Bartley, W. C., K. G. McCracken and U. R. Rao, "The Pioneer 6 Detector to Measure the Degree of Anisotropy of The Cosmic Radiation In the Energy Range 7.5-90 MeV/Nucleon", Rev. Sci. Instr., <u>38</u>, 266-272, 1967.

2) Bartley, W. C., K. G. McCracken and U. R. Rao, "A Digital System For Accurate Time Sector Division of A Spin Stabilized Vehicle, I.E.E.E., Trans. Aerospace Electron. Systems, AES" 3, 230-235, 1967.

3) McCracken, K. G., U. R. Rao, and R. P. Bukata, "Cosmic Ray Propagation Processes, 1. A Study of the Cosmic Ray Flare Effect", J. Geophys. Res., <u>72</u>, 4293-4324, 1967.

4) Bartley, W. C., R. P. Bukata, K. G. McCracken and U. R. Rao, "Anisotropic Cosmic Radiation Fluxes of Solar Origin", J. Geophys. Res., <u>71</u>, 3297-3304, 1966.

5) Fan, C. Y., J. E. Lamport, J. A. Simpson and D. R. Smith, "Anisotropy and Fluctuations of Solar Proton Fluxes of Energies 0.6-100 MeV Measured on the Pioneer 6 Space Probe", J. Geophys. Res., <u>71</u>, 3289-3296, 1966.

6) Marsden, P. L., "Some Comments on the Existence of A Density Gradient of the Cosmic Radiation Perpendicular To the Plane of the Ecliptic", Annals of the IQSY, Vol. 4, 131-137, 1969.

7) Bartley, W. C., R. L. Bickel, H. W. Glasscock, D. R. Stang, and J. M. Younse, "Recent Advances In Cosmic Ray Payloads For Interplanetary and Planetary Spacecrafts", I.E.E.E. National Telemetering Conference, 238-244, 1968.

8) McCracken, K. G., R. A. R. Palmeira, R. P. Bukata, U. R. Rao, F. R. Allum, and E. P. Keath, "A Co-rotating Solar Cosmic Ray Enhancement Observed By Pioneer 8 and Explorer 34 on July 13, 1968", presented at the 11th International Conference on Cosmic Radiation, Budapest, Hungary, 1969.

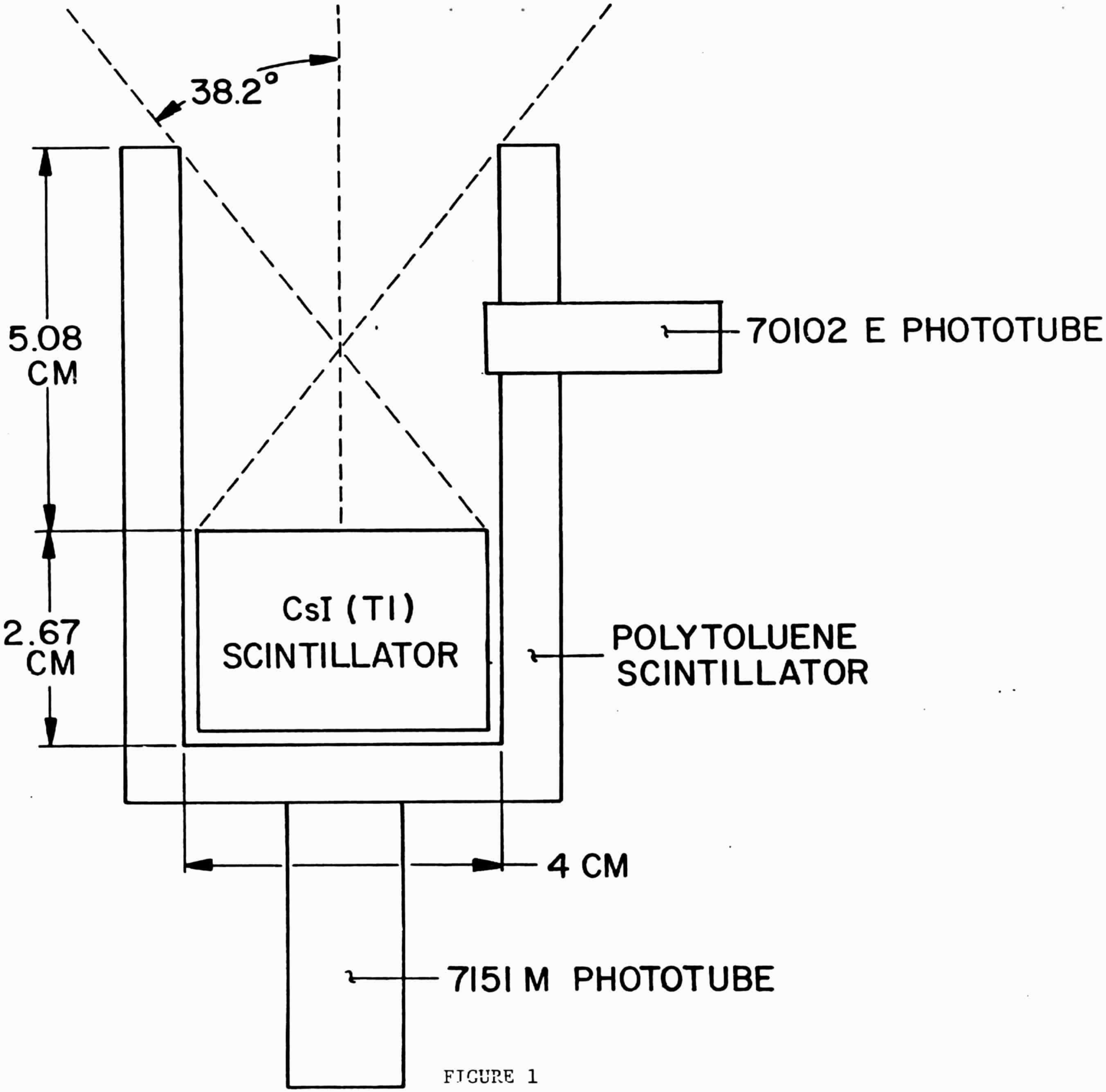

38.2°
5.08 CM
2.67 CM
CsI (TI) SCINTILLATOR
70102 E PHOTOTUBE
POLYTOLUENE SCINTILLATOR
4 CM
7151 M PHOTOTUBE

FIGURE 1

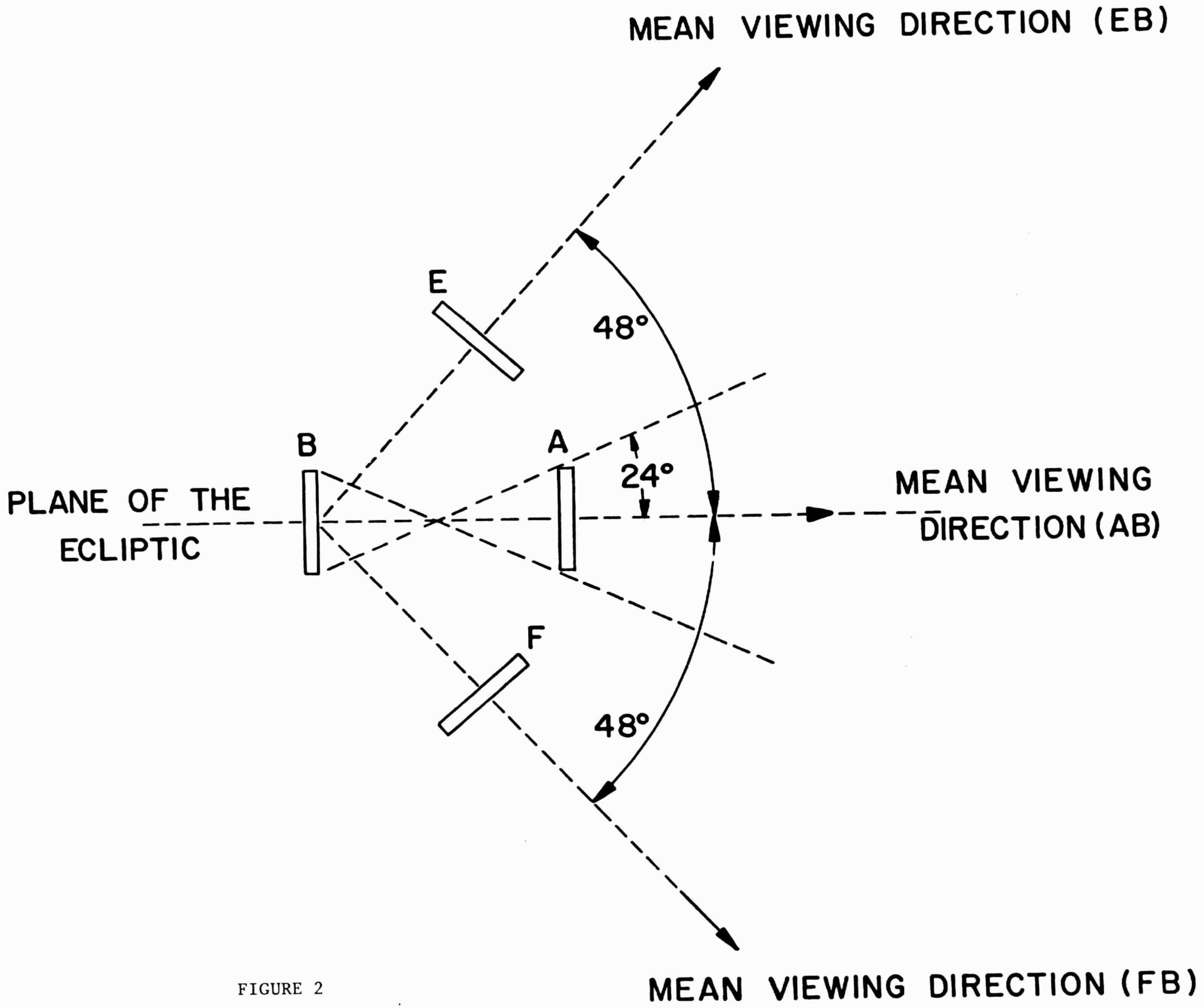

MEAN VIEWING DIRECTION (EB)
E
48°
B
A
24°
PLANE OF THE ECLIPTIC
MEAN VIEWING DIRECTION (AB)
F
48°
MEAN VIEWING DIRECTION (FB)

FIGURE 2

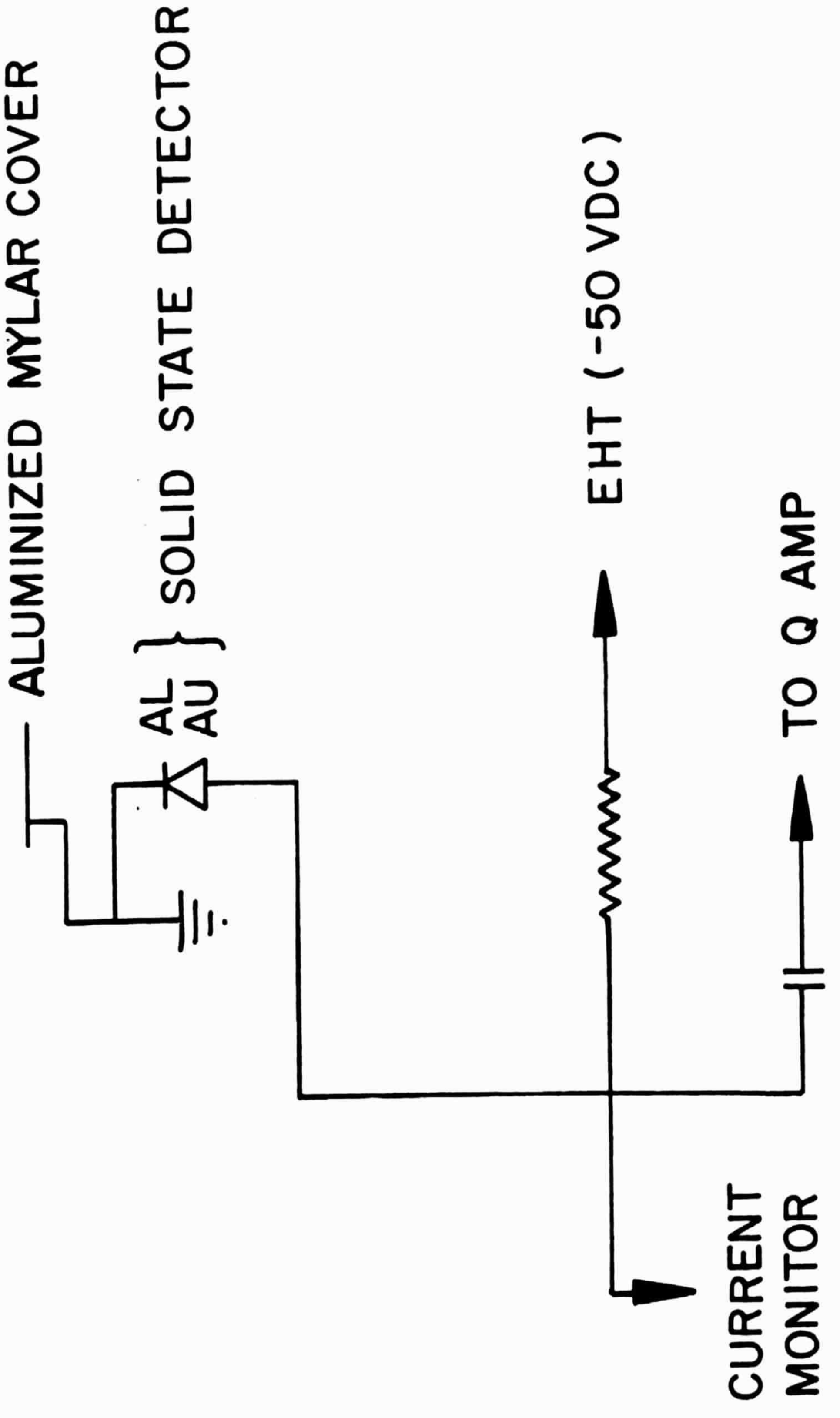

ALUMINIZED MYLAR COVER
AL
AU
SOLID STATE DETECTOR
EHT (-50 VDC)
TO Q AMP
CURRENT
MONITOR

FIGURE 3

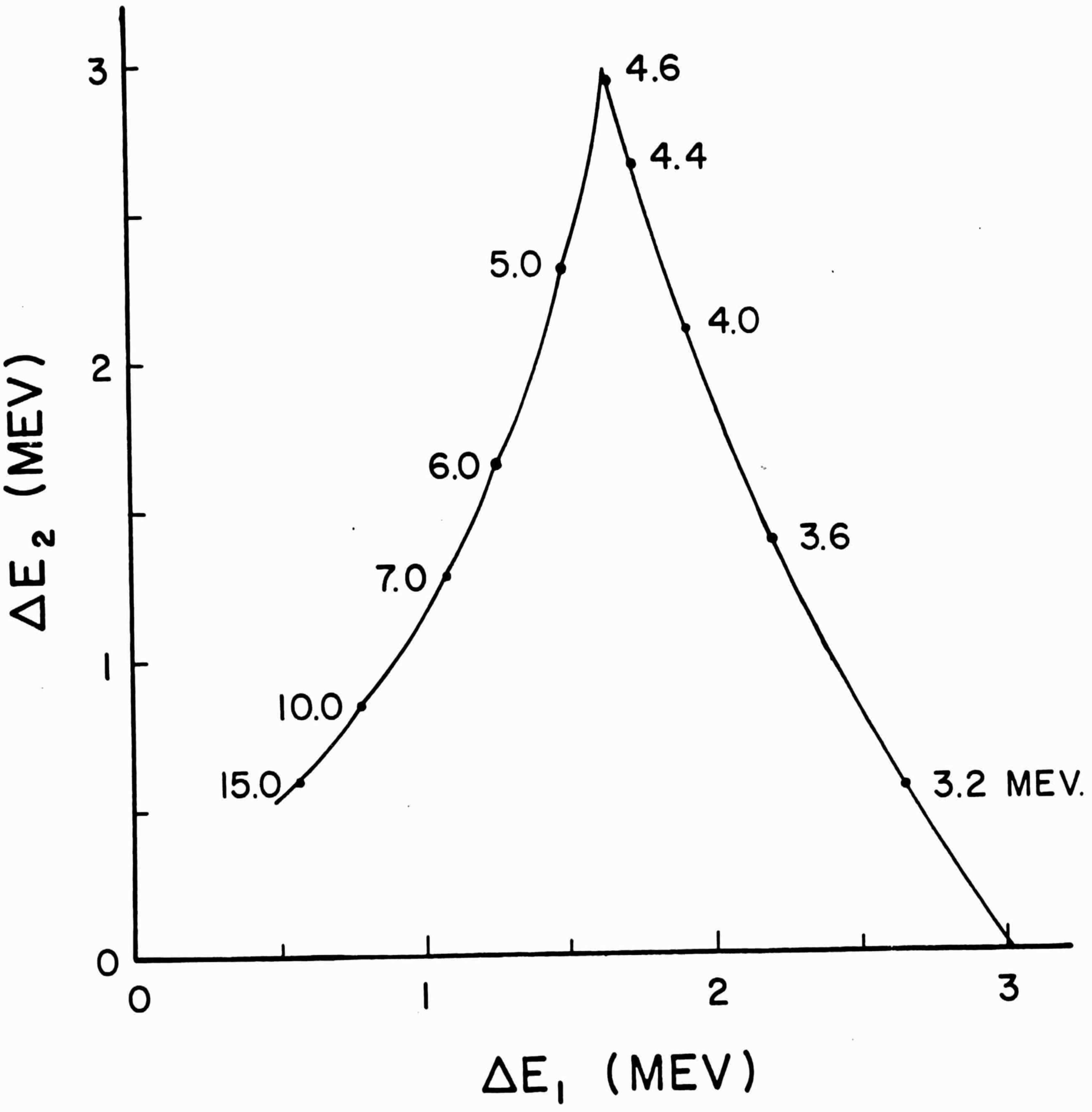


FIGURE 4

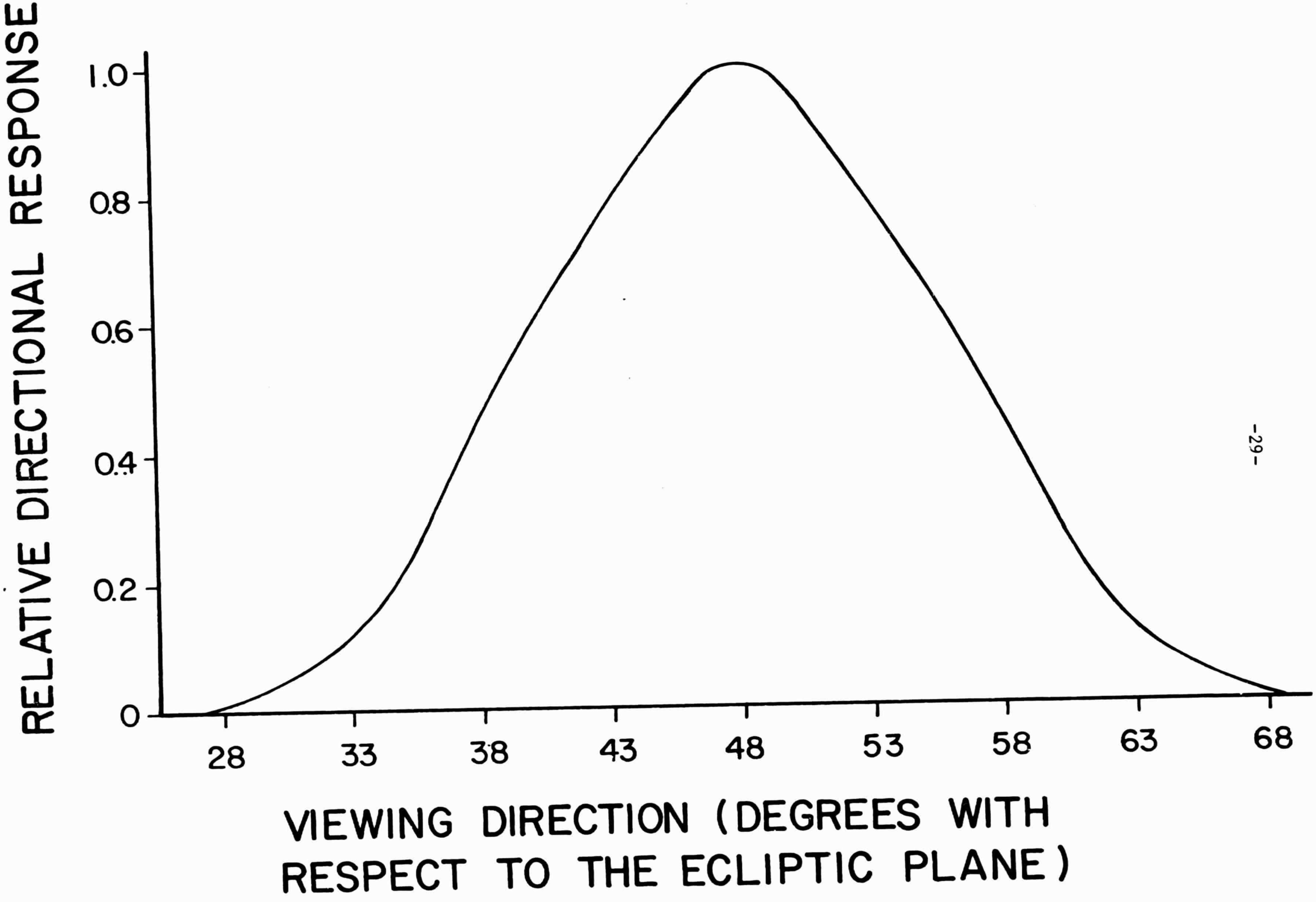

RELATIVE DIRECTIONAL RESPONSE
1.0
0.8
0.6
0.4
0.2
0
28
33
38
43
48
53
58
63
68
VIEWING DIRECTION (DEGREES WITH RESPECT TO THE ECLIPTIC PLANE)

FIGURE 5

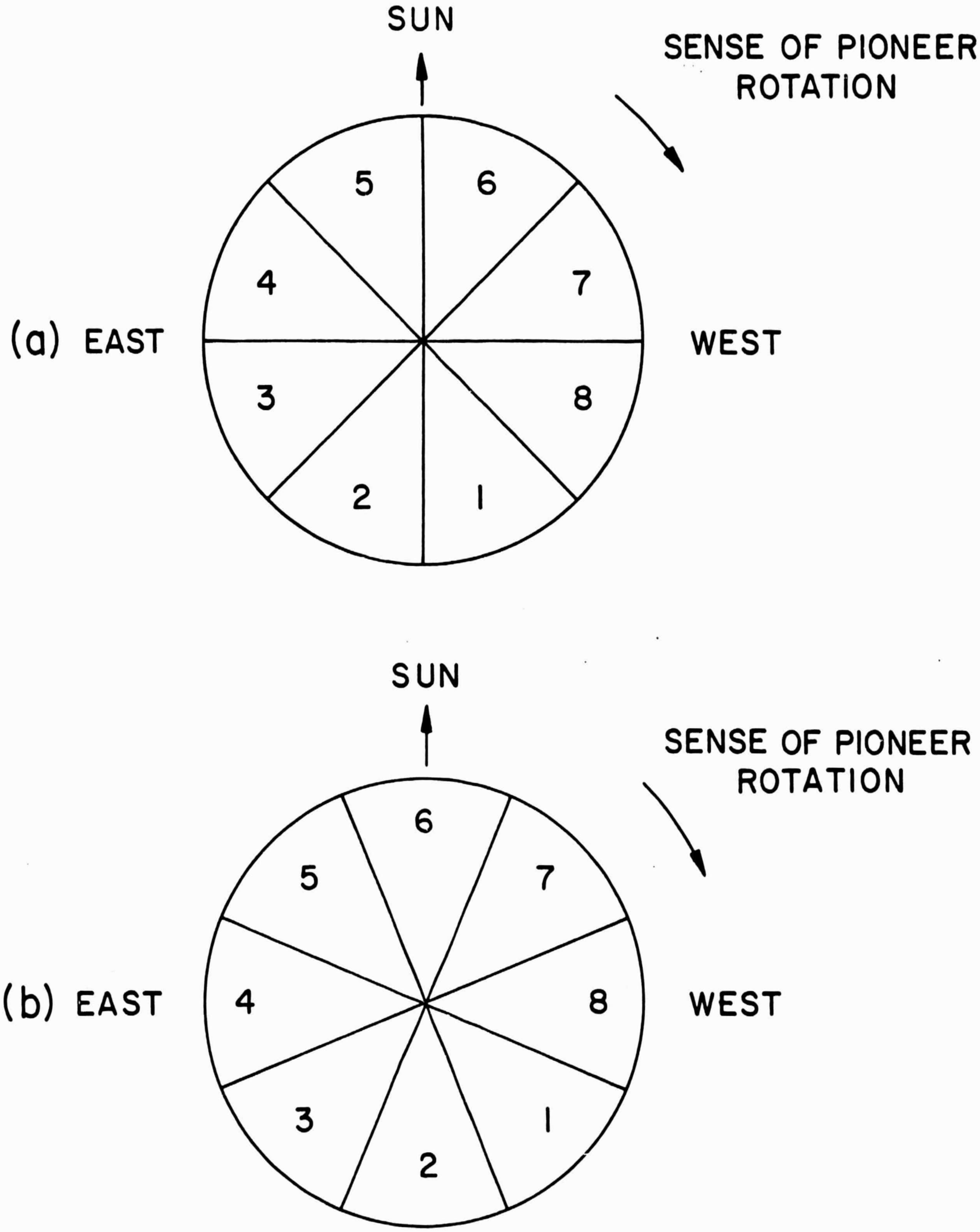

SUN
SENSE OF PIONEER ROTATION
(a) EAST
WEST
5
6
4
7
3
8
2
1
SUN
SENSE OF PIONEER ROTATION
(b) EAST
WEST
6
5
7
4
8
3
1
2

FIGURE 6

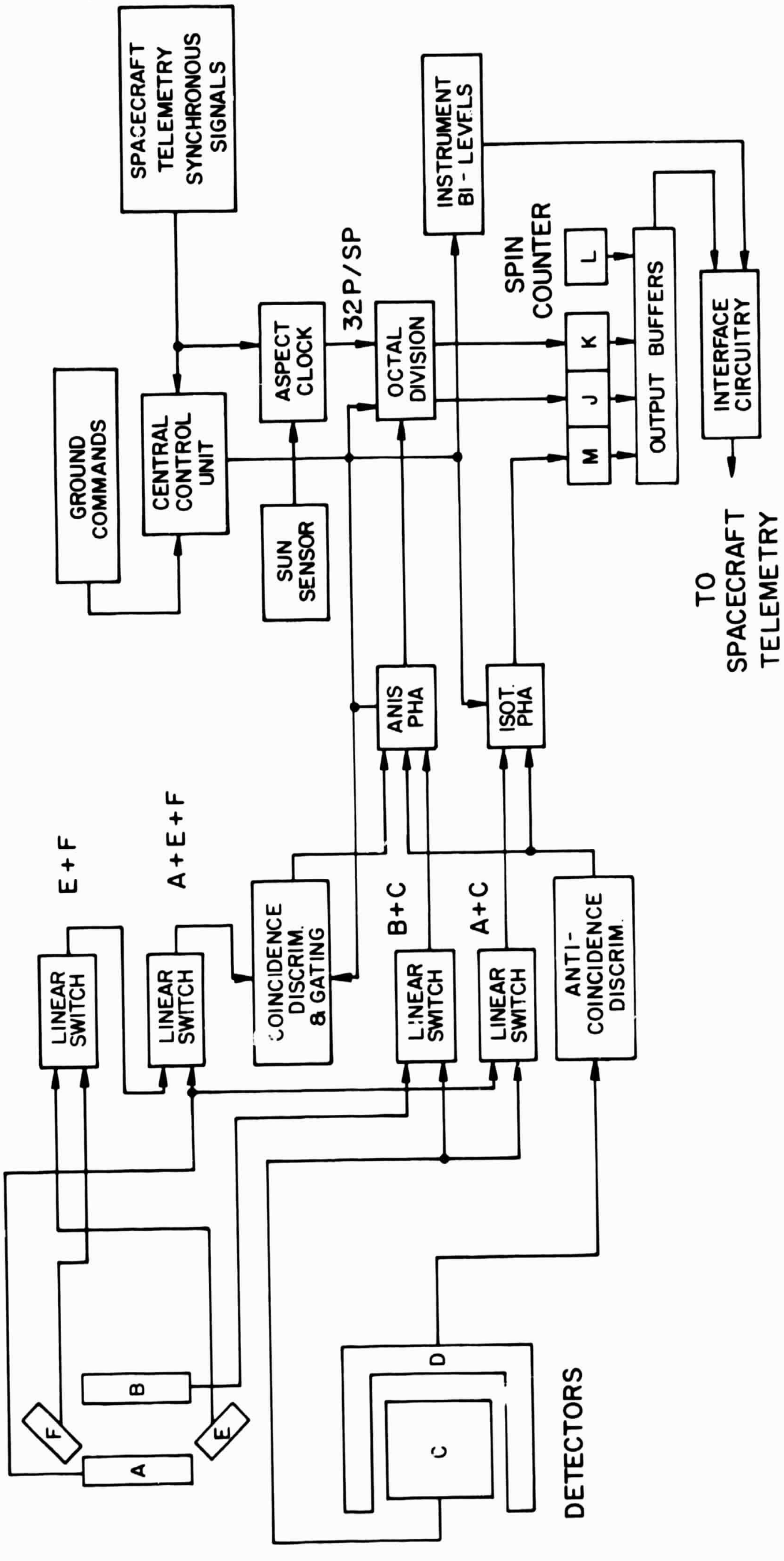

SPACECRAFT TELEMETRY SYNCHRONOUS SIGNALS
INSTRUMENT BI - LEVELS
GROUND COMMANDS
CENTRAL CONTROL UNIT
ASPECT CLOCK
32 P/SP
OCTAL DIVISION
SPIN COUNTER
L
K
J
M
OUTPUT BUFFERS
INTERFACE CIRCUITRY
SUN SENSOR
TO SPACECRAFT TELEMETRY
ANIS PHA
ISOT. PHA
E + F
A + E + F
B + C
A + C
LINEAR SWITCH
LINEAR SWITCH
COINCIDENCE DISCRIM. & GATING
LINEAR SWITCH
LINEAR SWITCH
ANTI-COINCIDENCE DISCRIM.
F
B
E
A
D
C
DETECTORS

FIGURE 7

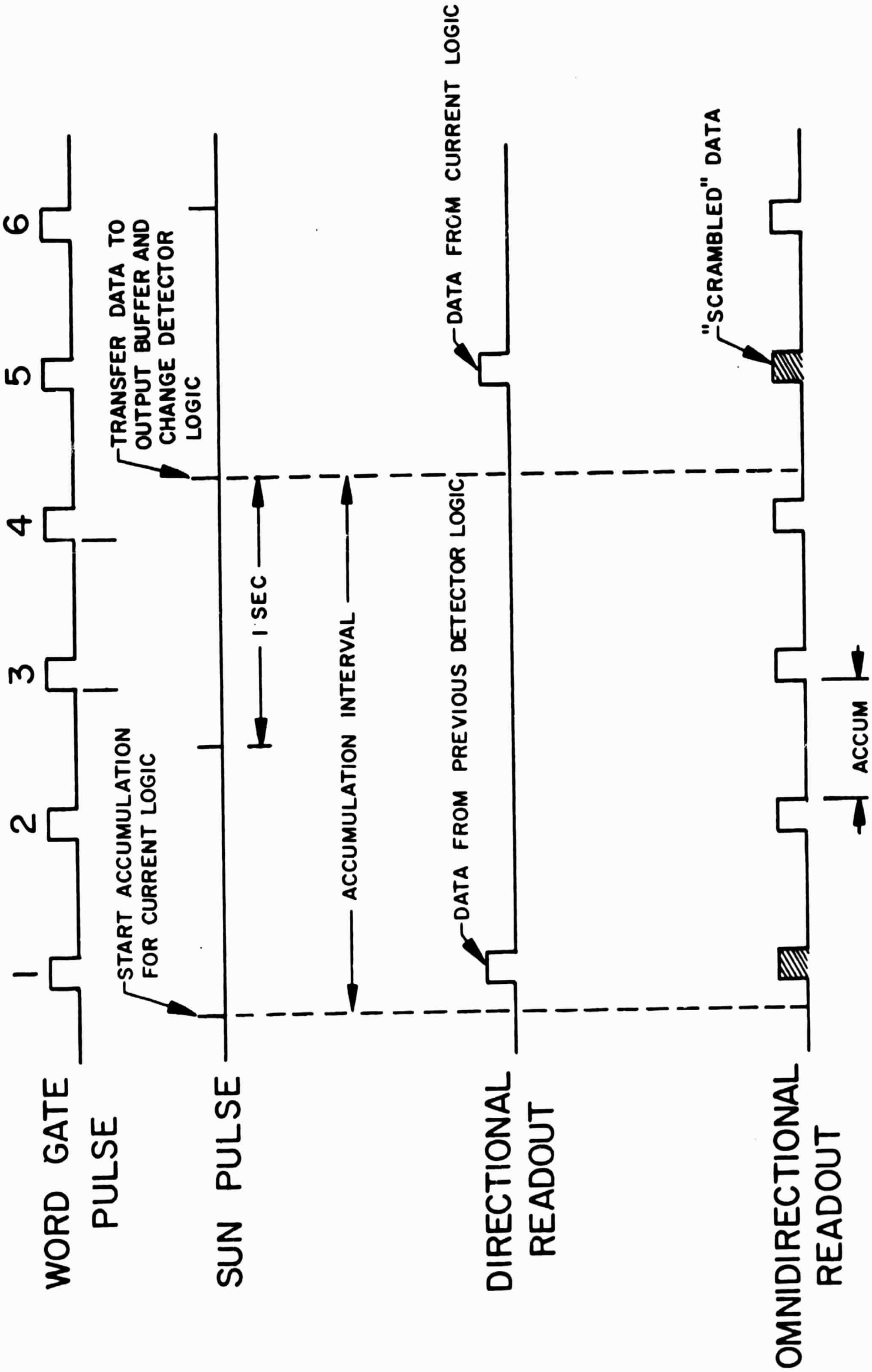

WORD GATE PULSE
SUN PULSE
DIRECTIONAL READOUT
OMNIDIRECTIONAL READOUT
1
2
3
4
5
6
START ACCUMULATION FOR CURRENT LOGIC
TRANSFER DATA TO OUTPUT BUFFER AND CHANGE DETECTOR LOGIC
1 SEC
ACCUMULATION INTERVAL
DATA FROM PREVIOUS DETECTOR LOGIC
DATA FROM CURRENT LOGIC
"SCRAMBLED" DATA
ACCUM INTERVALS

FIGURE 8

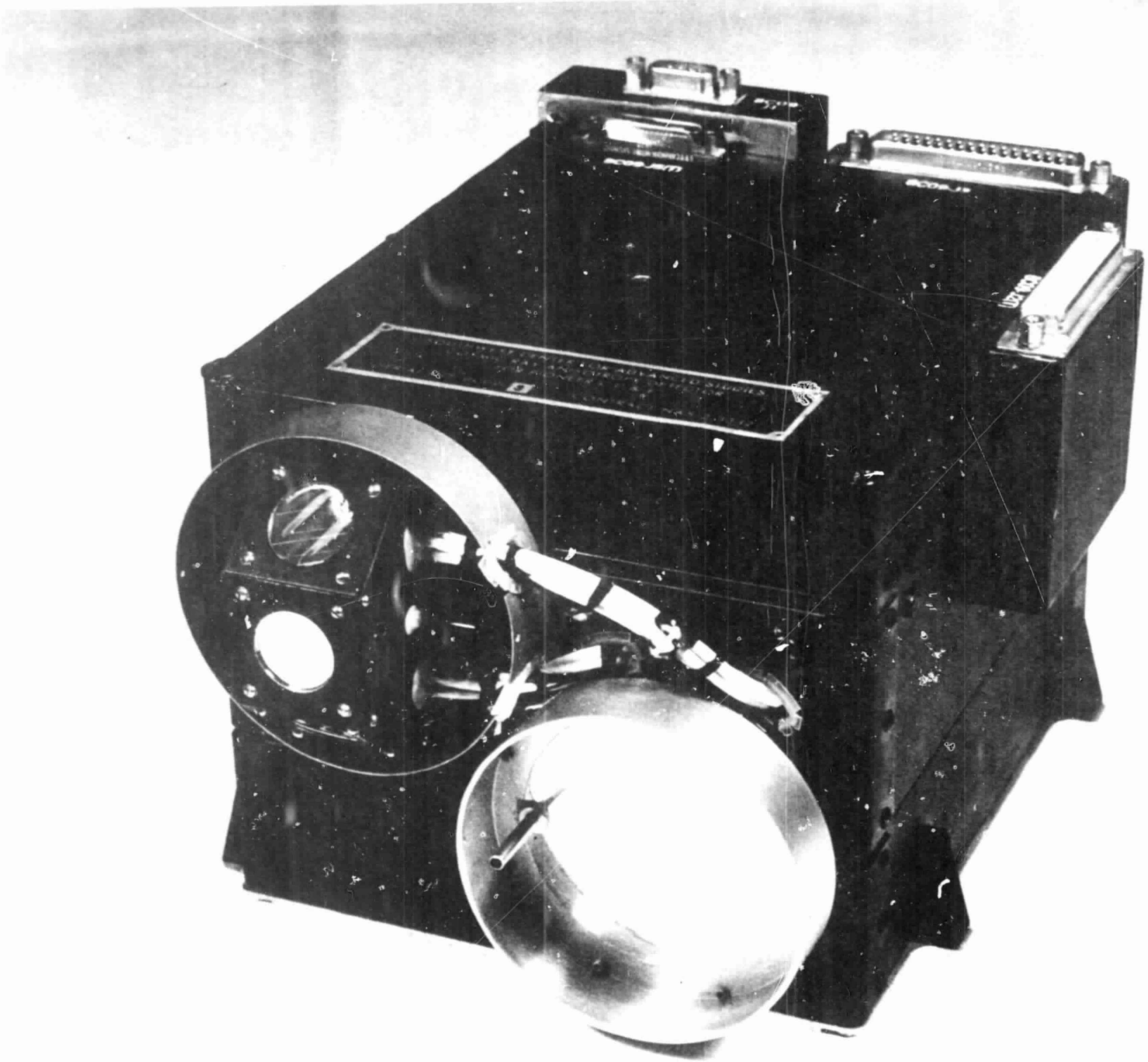


FIGURE 9

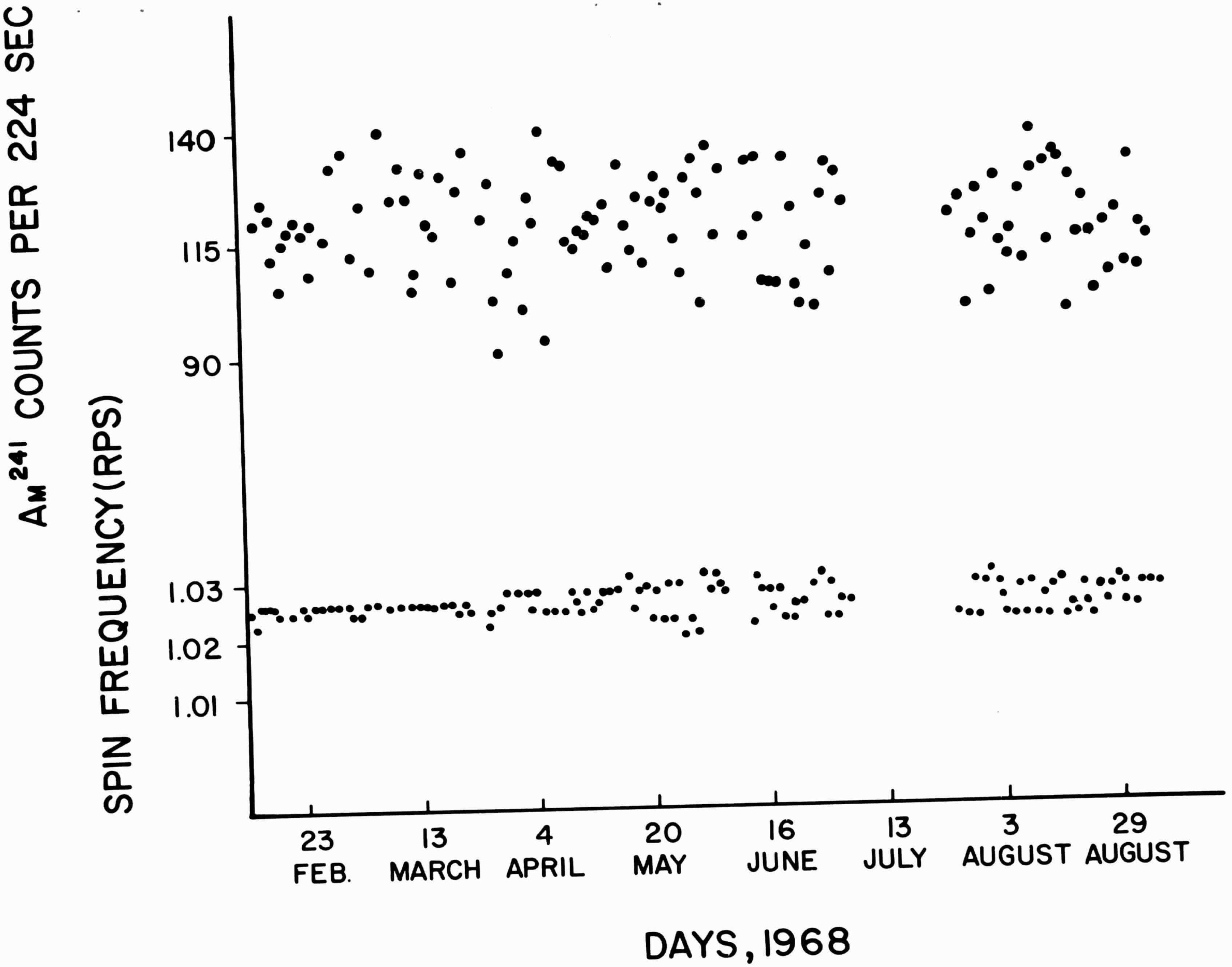
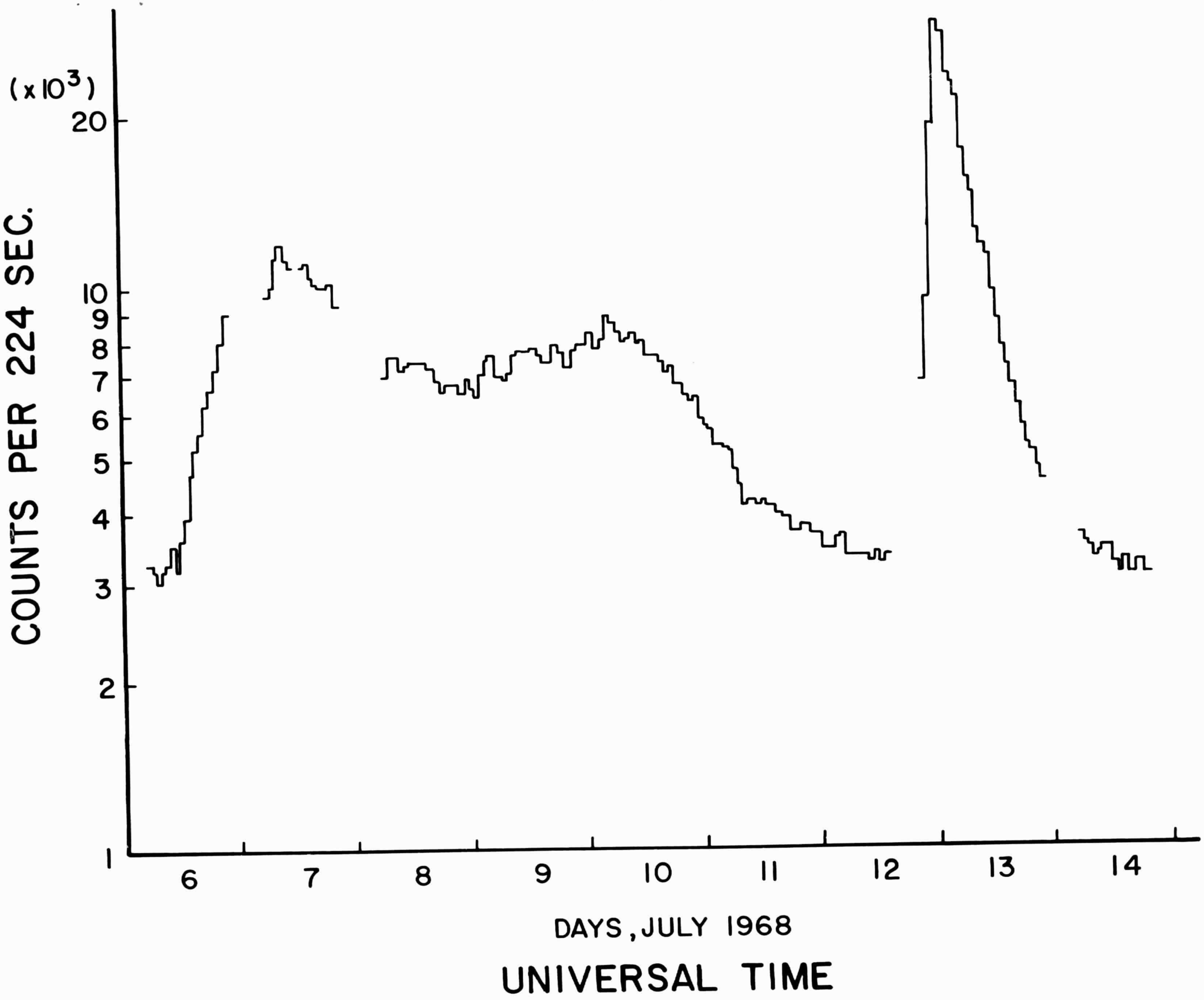

A_M^{241} COUNTS PER 224 SEC
SPIN FREQUENCY (RPS)
140
115
90
1.03
1.02
1.01
23 FEB.
13 MARCH
4 APRIL
20 MAY
16 JUNE
13 JULY
3 AUGUST
29 AUGUST
DAYS, 1968

FIGURE 10


(x10^3)
20
10
9
8
7
6
5
4
3
2
1
COUNTS PER 224 SEC.
6
7
8
9
10
11
12
13
14
DAYS, JULY 1968
UNIVERSAL TIME

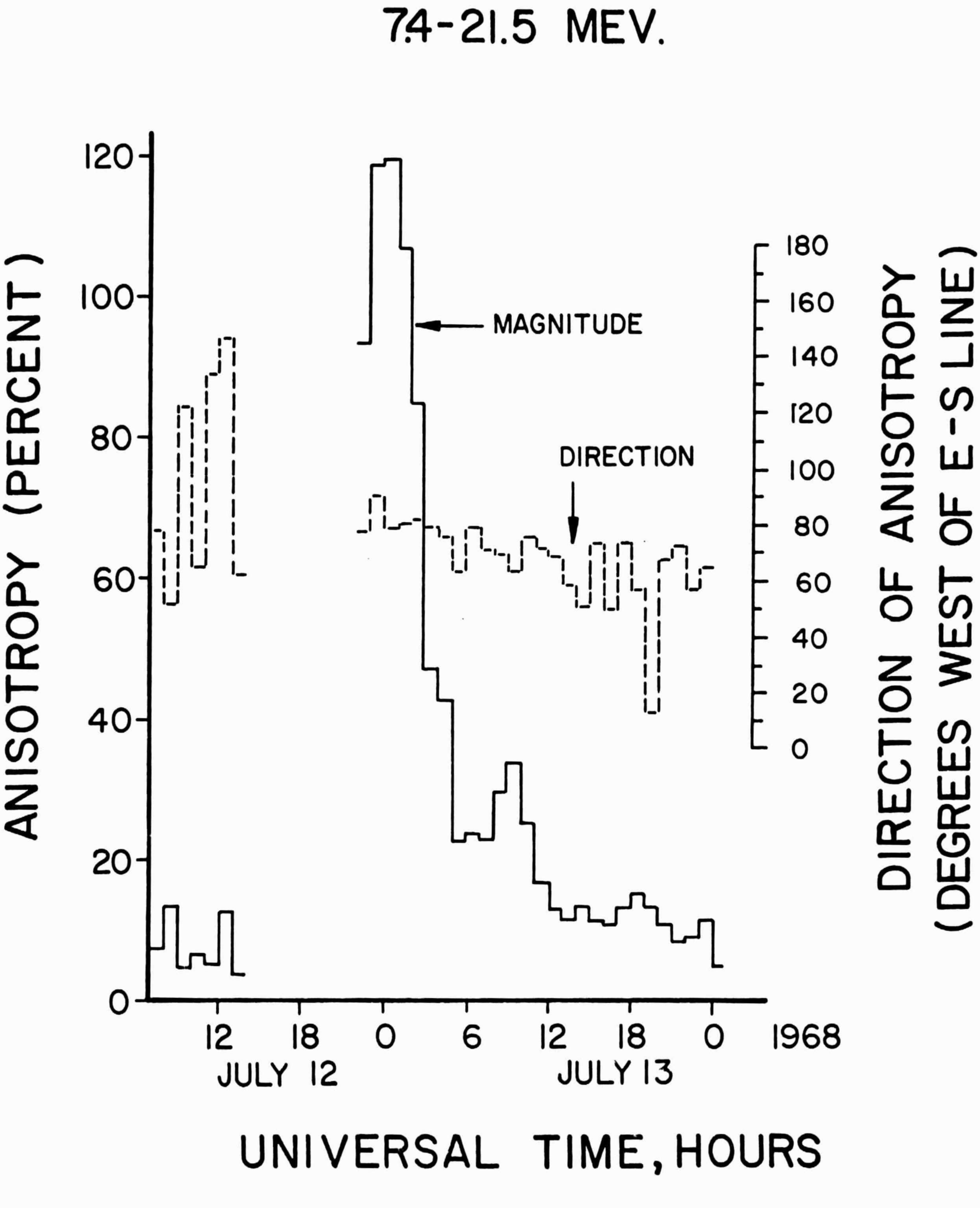
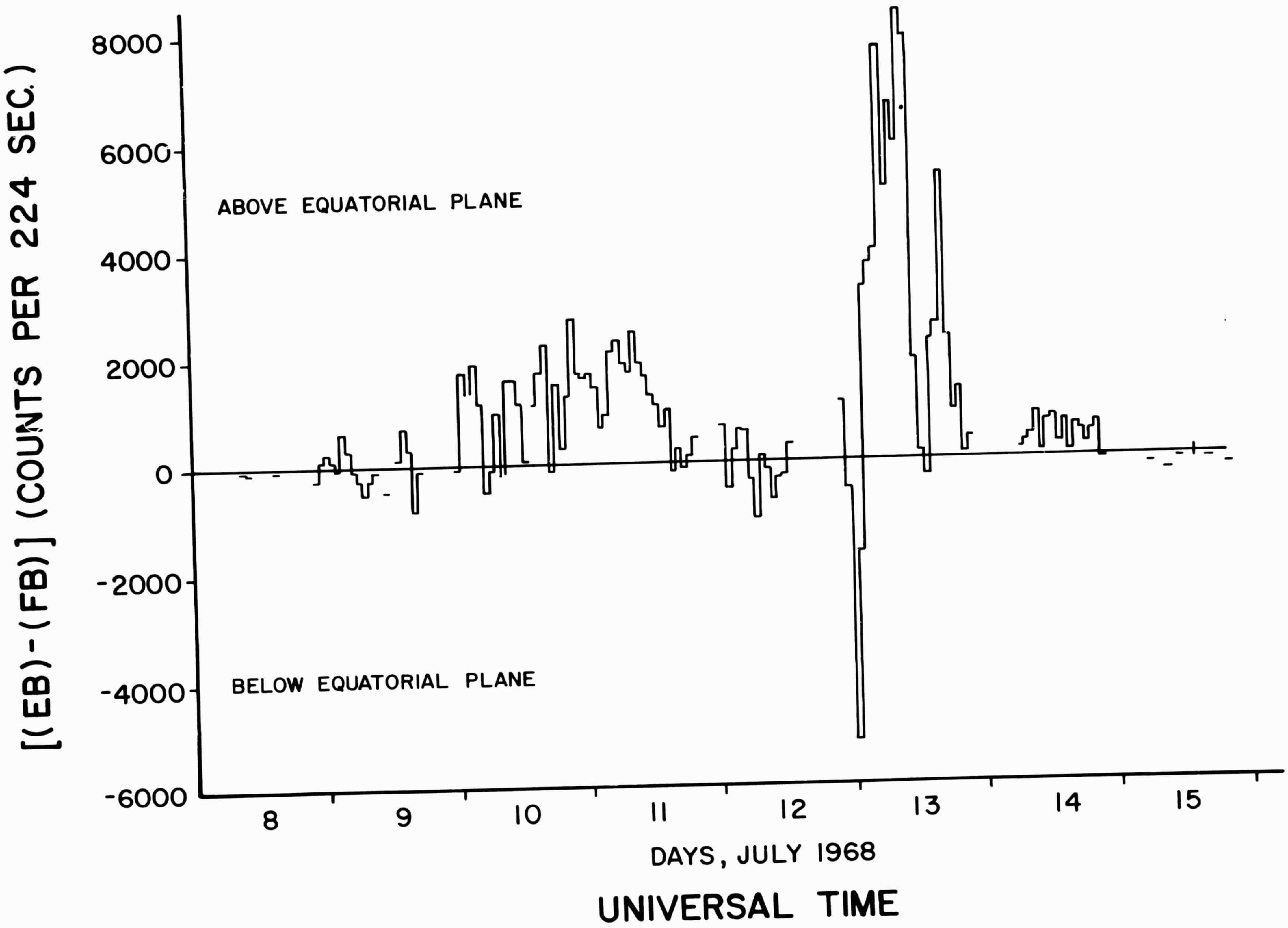

7.4-21.5 MEV.
ANISOTROPY (PERCENT)
0
20
40
60
80
100
120
MAGNITUDE
DIRECTION
DIRECTION OF ANISOTROPY (DEGREES WEST OF E-S LINE)
0
20
40
60
80
100
120
140
160
180
12
18
0
6
12
18
0
1968
JULY 12
JULY 13
UNIVERSAL TIME, HOURS

FIGURE 12


[(EB)-(FB)] (COUNTS PER 224 SEC.)
8000
6000
4000
2000
0
-2000
-4000
-6000
ABOVE EQUATORIAL PLANE
BELOW EQUATORIAL PLANE
8
9
10
11
12
13
14
15
DAYS, JULY 1968
UNIVERSAL TIME

4. PIONEER 8 AND 9 DATA REDUCTION

Figure 14 shows the overall data flow chart. The data from the SCAS UTD cosmic ray experiment is received from NASA in the form of magnetic computer tapes which contain the raw cosmic ray data plus other pertinent engineering and timing information. Before analysis can be performed, the data must be edited and reduced. These tasks are performed by two data conditioning programs. The first is the Edit Program which performs the following tasks:

1. Reads the NASA data tape.
2. Separates the data words.
3. Converts the data words from a logrithmic to a decimal base.
4. Removes data containing errors.
5. Assigns measurement and subcom numbers to each readout.
6. Calculates the Universal Time at which accumulation interval was terminated.
7. Writes an Edit output tape.

The output of the Edit Program represents a 'cleaned up' version of the raw data containing all the reliable information present in the original data which may be used for subsequent analysis. A printed output from this program is optional.

The data reduction is performed in the second conditioning program (SUMS Program) which uses the output from the Edit Program as input. This program calculates averages for the various logics and energy levels for time intervals of 7.5 min. and one hour. These averages are read out both on printed listings and on magnetic tape, and represent the basic "library" of data on which analysis is performed. The tapes and listing in the dashed box in Figure 14 represents material which is on permanent file in the SCAS Cosmic Ray data center.

An "in-house" library of analysis programs includes harmonic analysis, auto and cross-correlation, energy spectrum, power spectrum, and daily and monthly average programs.

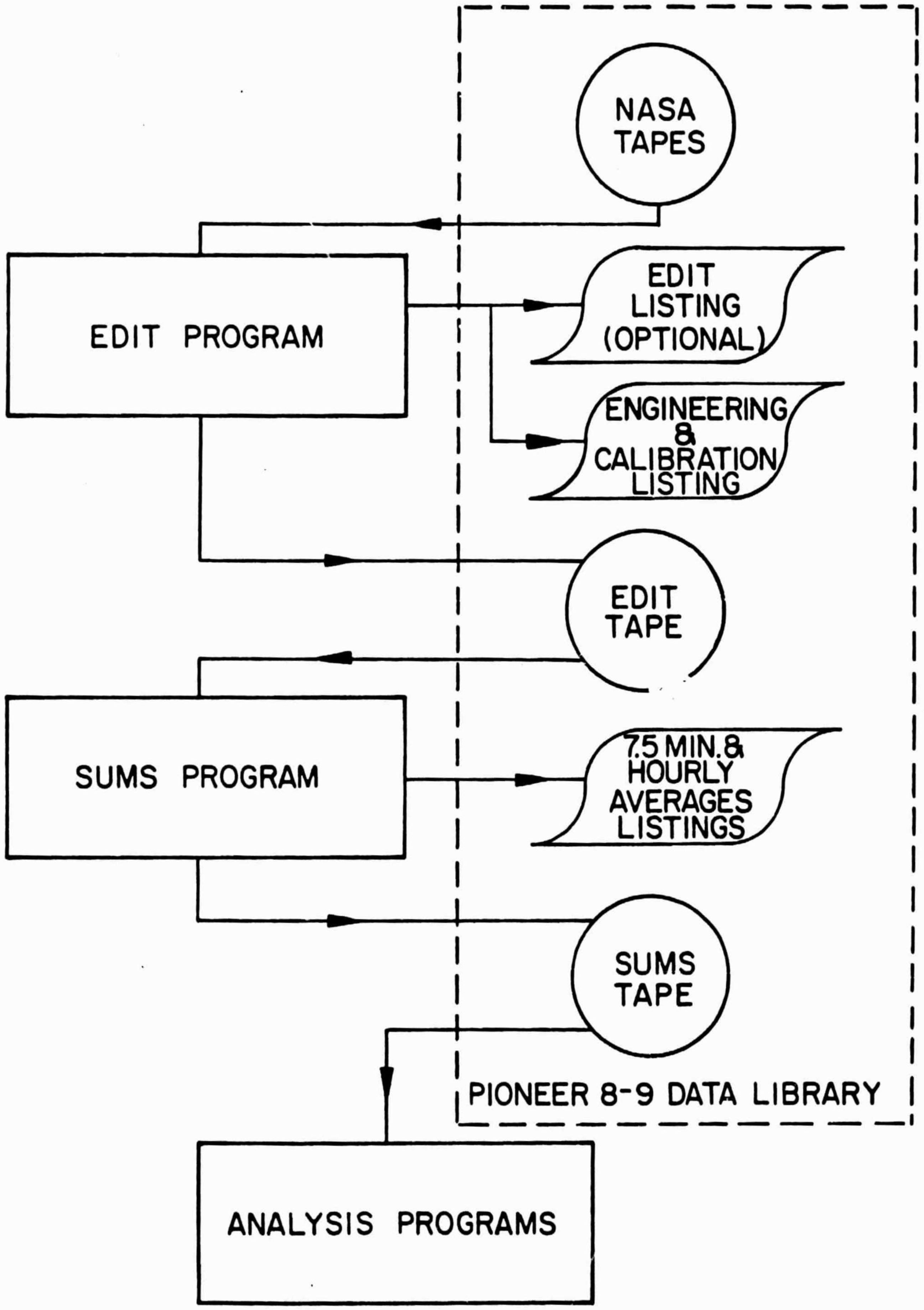

NASA TAPES
EDIT PROGRAM
EDIT LISTING (OPTIONAL)
ENGINEERING & CALIBRATION LISTING
EDIT TAPE
SUMS PROGRAM
7.5 MIN. & HOURLY AVERAGES LISTINGS
SUMS TAPE
PIONEER 8-9 DATA LIBRARY
ANALYSIS PROGRAMS

FIGURE 14