A RESEARCH PROGRAM TO INVESTIGATE
THE CHARGED PARTICLE FLUX
IN THE NEAR-EARTH MAGNETOSPHERE
FROM A P-11 SUB-SATELLITE

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FOREWORD

This document constitutes the final report for the research and development conducted under Contract No. AF 19 (628) - 2392, entitled, "Research directed toward the evaluation of the charged particle flux in the near-earth aerospace environment." This contract was between the Air Force Cambridge Research Laboratories, Office of Aerospace Research, Laurence G. Hanscom Field, Bedford, Massachusetts, and American Science and Engineering, Inc., Cambridge, Massachusetts.

The contract concerned the design, development, construction, testing, and calibration of instrumentation suitable for flight on Lockheed Missiles and Space Company Program Eleven (P-11) sub-satellites in order to obtain information on the energy spectra and angular distributions of protons and electrons in the magnetosphere. The contract also specified field assistance, data reduction, and a study leading to recommendations for instrumentation improvement for future sub-satellite use.

One of the instrument packages was flown on Air Force Satellite 1963-25B. This package was probably the most comprehensive ever flown to date on a single satellite with respect to the range of particle energies being investigated: from 30 ev to 120 Mev for protons and from 30 ev to 5 Mev for electrons, with few gaps over the ranges. A wealth of data has been acquired from this satellite -- data from over 150 orbits are on telemetry tapes, and digitized tapes from over 50 orbits have been received. Detailed analysis of these data can be

expected to yield much practical information applicable to questions concerning the effects of corpuscular radiation in the magnetosphere upon communication systems, weapon systems, and manned or other space vehicles, as well as information of purely geophysical interest.

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We are indebted to Dr. Martin Annis of American Science and Engineering, Inc., for his guidance and contributions to the design of the experiment during its gestation period, and to Professor Bruno Rossi of Massachusetts Institute of Technology for pointing out the significance of certain species of data, thereby influencing final instrument design. We also thank Dr. Jack Carpenter of ASE and Professor Herbert Bridge of MIT for many interesting discussions on some of the data obtained. We are also grateful to Professor Bridge for giving permission to include a brief discussion of the MIT plasma probe.

We wish to thank Dr. Bernard Gottschalk and Mr. Andy Kohler of the Harvard Synchrotron Laboratory for their aid in calibrating the proton scintillation spectrometer.

ABSTRACT

Three instrument packages were designed, developed, constructed, tested and calibrated for the purpose of investigating energy spectra and angular distributions of protons and electrons in the Earth's magnetosphere from a P-11 sub-satellite. Each instrument package, weighing a total of 42 pounds, included a retarding potential plasma probe for protons between 30 ev and 6 kev and electrons between 30 ev and 200 ev, (fabricated by the Massachusetts Institute of Technology Cosmic Ray Laboratory under separate contract); an electron spherical plate electrostatic analyzer, 10 to 100 kev; a proton electrostatic analyzer, 10 to 100 kev; an electron scintillation spectrometer, 0.4 to 4 Mev, which also measured total rate of energy deposited by electrons greater than 150 kev; a proton scintillation spectrometer for 1.0 to 5.3 Mev in one output channel, 7.5 to 120 Mev in a second; a Geiger counter for electrons greater than 4 Mev, and protons greater than 40 Mev. In addition were: two sets of three-axis magnetometers, one set of range -600 to +600 milligauss, the other, -200 to +200 milligauss, for pitch angle determinations; and a solar cell which aided in aspect determination. The sizes, weights, power requirements, and measurement capabilities of the various instruments are given. The principles of operation, complete circuit diagrams, testing and calibration procedures, and calibration curves pertaining to the ASE instruments are presented in detail. Pertinent payload integration information is given. Methods of data handling, reduction and analysis, including those aspects dependent upon computer utilization, are outlined. One of the instrument packages was flown

on Air Force Satellite 1963-25B, launched into orbit on 1 July 1963. Initial orbital parameters were: perigee, 176 NM, (326 km) at approximately 20° N latitude; apogee, 2240 NM (4150 km); inclination, 82.14° ; period, 132.6 minutes; rate of the advance of perigee, approximately 1.7° per day southbound. The satellite was spin-stabilized at 68. revolutions per minute. Some preliminary results on energy spectra obtained from early orbits are given. Above 0.5 Mev, the integral electron spectra decreased monotonically with energy, but the spectra obtained in the inner belt and "slot" were much flatter than those obtained in the outer belt. Between 10 and 100 kev, maxima in the differential spectra around 40 kev were observed in some regions of the inner belt. In this energy region the energy integrated intensity tended to decrease with increasing L beyond 1.6 — i.e., there was no distinct "slot". Between 18 and 60 Mev, in the inner belt around $L \approx 1.6$, proton integral spectra fit an $E^{-\gamma}$ law with $\gamma \approx 5.4$; between 1 and 4 Mev, the spectra monotonically decreased with energy but fit no simple law. There was some evidence of a slot in the belt structure at these energies. Geiger counter and electron spectrometer rate of energy deposition data illustrated belt profiles as expected. with distinct inner and outer zones with a well defined slot between them. Recommendations for future research from P-11 type satellites are presented.

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1.0 INTRODUCTION

1.1 Objectives and Scope of the Program

The overall objective of the research and development program reported in this document may be broadly said to be the evaluation of the charged particle flux in the near-earth aerospace environment. Specific objectives were to obtain and analyze data on energy spectra and pitch angle distributions of electrons and protons over a wide energy range. To implement these goals, instrument packages were designed, developed, constructed, tested and calibrated for flight on Lockheed Missiles and Space Company Program Eleven (P-11) sub-satellites. Each instrument package was capable of investigating electrons of energies between 30 ev and 4 Mev, and protons between 30 ev and 120 Mev.

1.2 Technical Discussion

The study of the Earth's radiation belt is a matter of practical importance as well as one of purely scientific interest. The successful operation of certain communication systems, missiles or other weapons systems, and manned or other space vehicles are all predicated upon adequate knowledge of the environment in which they are to function. Although many measurements have been made in the space environment, which have yielded increasingly more detailed information on the structure, composition, energy distributions and temporal variations of trapped radiation, there are serious gaps in the

knowledge. It is not our purpose here to review the extent of knowledge of the radiation belts; one such very excellent review article has been prepared by Van Allen (1962). However, to indicate some of the areas in which knowledge is scarce or lacking, we may mention energy spectra of protons of energies less than 30 Mev, and of electrons of energies less than 40 kev, and pitch angle distributions of both electrons and protons in general.

Detailed spectral information is important in assaying radiation damage to space systems since the penetrating power of a particle is a function of its energy. Both protons and electrons must be investigated since the first species of particle is maximum-ionizing and most responsible for solar cell damage (for instance), while the second species leads to bremsstrahlung which is extremely penetrating.

Detailed data on angular distributions are useful because they might influence the distribution of shielding on spacecrafts. The paramount importance of pitch angle distribution data has perhaps not been fully appreciated. A complete pitch angle distribution of charged particles obtained in a given L shell at some point where the magnetic field value is B determines completely and uniquely the angular distribution at any other point characterized by a $B' > B$ in the same shell (Van Allen 1962); thus, an equatorial pitch angle distribution would completely determine distributions throughout the shell. A pitch angle distribution obtained anywhere can be integrated over solid angle to obtain omnidirectional intensities. Thus, pitch angle data can lead to information about radiation intensities in regions of the magnetosphere not physically traversed by the satellite.

Energy spectra and pitch angle distributions considered together can lead to determinations of total particle populations in an L shell. This is a matter of particular importance in determining injection efficiencies of nuclear weapons.

The radiation belts are dynamic, rather than static entities. Thus, measurements must be undertaken over a period of time. Temporal studies correlated with solar events are particularly important. It is of practical value to learn the magnitude of loading of the radiation belts following a given class of solar flare, and to obtain information on the time scale required for the belt to approach normal conditions. Analysis of such data might add to the understanding of injection and dumping mechanisms in general.

1.3 Organization of the Report

Section 2 gives descriptions of the individual instruments comprising the payload. Complete specifications of each are included: size, weight, power requirement, range of spectral analysis, resolution, dynamic range, and accuracy of measurements. Principles of operation of the instruments are outlined and calibration procedures are described. Block diagrams, photographs, some outline drawings and complete circuit diagrams are included.

Section 3 describes the spacecraft and the integrated instrument packages. Pertinent interface information is presented, including commutator pin assignments, and a complete set of instrument calibration curves is also included. The orbital parameters of the satellite 1963-25B are given.

Section 4 concerns methods of data handling and analysis. The preparation of binary working tapes from digitized data and a program for generating reduced data tapes is outlined. This section also includes analytical notes concerning the calculation of energy spectra, pitch angle distributions, and physical parameters derivable from them.

Section 5 is a presentation of some experimental data obtained from satellite 1963-25B. The data, dealing mainly with energy spectra, are discussed.

Section 6 is a list of recommendations with respect to future instrumentation, data analysis techniques and extent, and satellites.

2.0 INSTRUMENTATION

The scientific payloads designed and fabricated under this contract were probably the most comprehensive instrument packages ever flown to date on a single satellite, with respect to the ranges of energies which could be analyzed - from 30 ev to 4 Mev for electrons, and from 30 ev to 120 Mev for protons. The payload consisted of the following six instruments for particle detection, the first five furnished by American Science and Engineering, Inc., and the sixth by the Massachusetts Institute of Technology:

1. An electron electrostatic analyzer for energies from 10 to 100 kev;
2. A proton electrostatic analyzer for energies from 10 to 100 kev;
3. An electron scintillation spectrometer for energies from 0.3 to 4 Mev; this instrument also measured the rate of energy deposition of electrons of energies greater than 150 kev;
4. A proton scintillation spectrometer, for 1.0 to 5.3 Mev in one channel, and 7.5 to 120 Mev in a second;
5. A Geiger counter, for electrons of energy greater than 4 Mev, and protons of energy greater than 40 Mev;
6. A retarding potential plasma probe, for protons of energies from 30 ev to 6 kev, and electrons from 30 ev to 200 ev.

In addition were: two sets of 3-axis flux gate magnetometers, one of range -200 to +200 milligauss, and the other of range -600 to +600 milligauss, for pitch angle determination; and a solar cell to aid in satellite attitude determination.

All instruments, with the exception of the Geiger counter, were capable of yielding detailed spectral information. The electrostatic analyzers were differential analyzers, measuring fluxes of particles of energies between a variable threshold E and $E + \Delta E$. The plasma probe was an integral analyzer, measuring particles between a variable threshold E and approximately $3E$. The two scintillation detectors were also integral analyzers, measuring particles between a variable threshold E and a fixed upper limit. The threshold energy for the plasma probe was discrete; the period for a complete scan was about twelve seconds. The threshold energies for the other four instruments were continuous with a period of about sixteen seconds. Complete energy spectra could thus be obtained in a time that was short enough so that the satellite could be considered to remain at constant (B, L) coordinates. Yet the threshold energies changed at a rate slow enough so that the change in energy that occurred over a couple of satellite spin periods was usually within the energy resolution of any given instrument. Since the signal from each instrument was sampled several times per satellite spin period, this meant that angular distributions of particles could be obtained at essentially a constant threshold energy for the instrument concerned.

Pitch angle distributions of highest angular resolution could be obtained from the proton detector, which had the narrowest angular aperture. Fairly high resolution could be obtained from the electron

detector, and somewhat poorer resolution from the electrostatic analyzers. The plasma probe and the Geiger counter were wide-aperture detectors.

Wide dynamic range (4 or more orders of magnitude) was achieved where needed by the use of count rate meter and current meter circuits of logarithmic response.

All instruments, except the plasma probe and Geiger counter, utilized scintillation detection. The relative response of the two scintillator materials used, CsI(Tl) and Pilot "B" plastic, to different particles of various energies, are given in Figures 2-1 and 2-2, respectively, for reference in following discussions.

Table 2.1 lists the chief characteristics of the various instruments. The principles of their operation and the methods used to calibrate the ASE instruments are given in detail in the remainder of this section.

All instruments were environmentally tested prior to delivery for integration. This included testing in vacua of 10^{-5} Torr or better and testing over a temperature range of -25°C to $+50^{\circ}\text{C}$ for several hours. All measurement circuits were temperature compensated so that negligible calibration drifts resulted over this range. In the case of logarithmic current meters and count rate meters, "negligible" meant that the equivalent current or counting rate error read out at any given signal output deviated by less than $\pm 5\%$ from the room temperature calibration. In the case of voltage monitors, "negligible" meant less than ± 0.05 volts deviation from the room temperature calibration in the monitor output. In the case of energy calibrations (as checked using laboratory sources), "negligible" meant that the equivalent energy error read out

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2-1

RELATIVE RESPONSE OF ANTHRACENE
APPROXIMATELY ANY ORGANIC SCINTILLATOR

RELATIVE RESPONSE OF CsI (TI)

Table 2-1

INSTRUMENT NAME	FIELD OF VIEW (cm ² ster)	PARTICLES DETECTED	SENSOR	TRANSDUCER	CHANNEL IDENTIFICATION	ENERGY RANGE	PHYSICAL INPUTS			LOGIC OUTPUTS					POWER CONSUMED (WATTS)	WEIGHT (lb)
							PHYSICAL QUANT. MEASURED	ABSOLUTE DYNAMIC RANGE	TYPE OF SPECTRA OBTAINED	MODE OF ENERGY DISCR.	MODE OF SPECTRAL SCAN	ELECTRICAL QUANTITY MEASURED	NATURE OF LOGIC	ELECTRONIC DYNAMIC RANGE		
PROTON SPECTROMETER	A ₀ = 4.42 m ² A ₁ = 0.0423 A ₂ = 0.061	p	B 0.04 gm/cm ² C 1.171 22.5 gm/cm ² PHOSWICH	PM ~10 ⁶ GAIN	LO-EN P	10 < E < 5.3 Mev	A ₀ $\frac{dN}{dt}$ A ₁ $\frac{dN}{dt}$ A ₂ $\frac{dN}{dt}$	10 ³ - 10 ⁵ sec/cm ² -ster	INT	PULSE HT DISC	LIN SWEEP ON LIN SWEEP OFF COMPAR	FREQ RATE NO. OF PULSES	LOG CRN	10 ⁻¹ - 10 ³ counts/sec 0 - 180 counts/sec (LAT SPEED TO 10 ³ cps)	0.64	7.5
ELECTRON SPECTROMETER	A ₀ = 0.122 A ₁ = 0.085 A ₂ = 0.148	e	B 2.5 gm/cm ² PHOSWICH	PM ~10 ⁴ GAIN	HI-EN P	0.4 < E < 4.1 Mev	A ₀ $\frac{dN}{dt}$ A ₁ $\frac{dN}{dt}$ A ₂ $\frac{dN}{dt}$	8 x 10 ⁻³ - 8 x 10 ³ sec/cm ² -ster	INT	PULSE HT DISC	LIN SWEEP ON LIN SWEEP OFF COMPAR	FREQ RATE	LOG CRN	10 ⁻¹ - 10 ³ counts/sec	0.27	2.9
MIT PLASMA PROBE	22 A ₁ = 2 A ₂ = 1.8	D, e	FARADAY CUP	PM	I CH	6-2 Mev 200-250 Mev 250-300 Mev 80-300 Mev	A ₀ $\frac{dN}{dt}$ A ₁ $\frac{dN}{dt}$ A ₂ $\frac{dN}{dt}$	5 x 10 ³ - 5 x 10 ⁵ sec/cm ² -ster	INT	RETARDING POTENTIALS	STEPPED SWEEP ON SWEEP OFF GRIDS	CURRENT	LOG I MTR	5 x 10 ⁻¹² - 2.5 x 10 ⁻⁶ amperes	3.11	5.9
ELECTROSTATIC ANALYZER e-SYSTEM	A ₀ = 0.198 A ₁ = 1.18 cm ² A ₂ = 0.193	e	B 0.10 gm/cm ² PHOSWICH	PM ~10 ⁶ GAIN	LO-EN P	10 < E < 10.5 Mev	A ₀ $\frac{dN}{dt}$ A ₁ $\frac{dN}{dt}$ A ₂ $\frac{dN}{dt}$	12 x 10 ³ - 12 x 10 ⁵ sec/cm ² -ster	INT	ELECTROSTATIC FOCUSING	LIN SWEEP ON LIN SWEEP OFF PLATES	CURRENT	LOG I MTR	~10 ⁻¹² - 3 x 10 ⁻⁶ amp	4.25 8.75 (4.05 el)	13.0 8.75 (19.1)
p-SYSTEM	A ₀ = 0.198 A ₁ = 1.18 cm ² A ₂ = 0.193	p	CsI (Tl) 0.10 gm/cm ²	PM ~10 ⁶ GAIN	LO-EN P	10 < E < 10.5 Mev	A ₀ $\frac{dN}{dt}$ A ₁ $\frac{dN}{dt}$ A ₂ $\frac{dN}{dt}$	2 x 10 ³ - 2 x 10 ⁵ sec/cm ² -ster	INT	ELECTROSTATIC FOCUSING	LIN SWEEP ON LIN SWEEP OFF PLATES	CURRENT	LOG I MTR	~10 ⁻¹² - 3 x 10 ⁻⁶ amp	12.44 (7.5, el)	17.5 (7.5, el)
GEIGER COUNTER	A ₀ = 0.122 A ₁ = 0.085 A ₂ = 0.148	e	GEIGER TUBE	PM	LO-EN P	10 < E < 10.5 Mev	A ₀ $\frac{dN}{dt}$ A ₁ $\frac{dN}{dt}$ A ₂ $\frac{dN}{dt}$	2 - 2 x 10 ⁴ sec/cm ² -ster	INT	ELECTROSTATIC FOCUSING	LIN SWEEP ON LIN SWEEP OFF PLATES	FREQ RATE	LOG CRN	10 ⁻¹ - 2 x 10 ³ counts/sec	0.99	2.1
MAGNETOMETER	47	e	SENSOR CIL	X, Y, Z AXES	LO-EN P	10 < E < 10.5 Mev	A ₀ $\frac{dN}{dt}$ A ₁ $\frac{dN}{dt}$ A ₂ $\frac{dN}{dt}$	0 - 0.6 to 10.6 gauss 0.2 to 0.2 gauss	INT	ELECTROSTATIC FOCUSING	LIN SWEEP ON LIN SWEEP OFF PLATES	FREQ RATE	LOG CRN	10 ⁻¹ - 2 x 10 ³ counts/sec	0.93	1.1

AUXILIARY EQUIPMENT

NAME	INSTRUMENT	POWER	WEIGHT
ORBITER	+22-29V 1NPEC +18V 1% REF +6V 1% REF -6V 1% REF 13V	0.29W	0.60 lb

BP-080

SUMMARY OF INSTRUMENT CHARACTERISTICS

at any given signal output deviated by less than approximately one-third the energy resolution at that point. All prototype instruments were tested for shock, vibration, and acceleration according to the schedule in Table 2-2. These specifications are one and one-half times those given by LMSC for the spacecraft; all flight instruments were subjected to one-half the LMSC specifications before delivery.

TABLE 2-2

SPECIFICATION SHEET FOR ENVIRONMENTAL TESTING OF
ASE P-11 SUB-SATELLITE INSTRUMENT

SHOCK TEST

16.5 g in 8 milliseconds 3 axes 3 drops/axis

RANDOM VIBRATION

0.075 g²/cps 15-2000 cps 5 min per axis

SINUSOIDAL VIBRATION - 3 min/octave

<u>Axis</u>	<u>Magnitude</u>	<u>Frequency</u>
Long. X Axis	3/4" double amplitude	5 - 12 cps
	3.0 g's	12 - 250 cps
	6.75 g's	250 - 400 cps
	11.25 g's	400 - 2000 cps
Lat. Y+Z Axis	3/4"double amplitude	5 - 8 cps
	1.5 g's	8 - 250 cps
	6.0 g's	250 - 400 cps
	11.25 g's	400 - 2000 cps

ACCELERATION

15 g constant acceleration in each axis for one minute duration.

*All flight packages tested to one-half LMSC specifications for acceptance tests.

2.1 Electrostatic Analyzers

2.1.1 Physical Description

Figure 2-3 illustrates an electrostatic analyzer similar to those used on the sub-satellite. The sub-satellite instrument was actually two such units mounted on a common chassis, and is shown assembled in Figures 3-3, 3-4, and 3-7 in the following section. Following is a tabulation of the principle characteristics of the dual instrument:

1. Particles detected: protons and electrons
2. Energy range: approx. 10 to 100 kev nominal
3. Energy resolution: $\pm 7 - 1/2\%$
4. Angular aperture: approx. $8 - 1/2^\circ \times 80^\circ$ or $0.19 \text{ steradian} \equiv \Omega$
5. Geometrical factor: $A\Omega = 0.20 \text{ cm}^2\text{-ster}$
6. Physical quantity measured: where Φ is the number of particles/kev-cm²-sec-ster, and E is the threshold energy in kev, the proton analyzer measures:

$$\int d(A\Omega) \int_E^{1.15E} \Phi dE$$

and the electron analyzer measures:

$$\int d(A\Omega) \int_E^{1.15E} (E + 10) \Phi dE$$

ELECTROSTATIC ANALYZER

CC-015

CC-016

7. Absolute dynamic range: $2 \times 10^5 - 5 \times 10^{10}$ kev/sec cm² ster
8. Physical size (Maximum dimensions);
three sub-assemblies:
 - a. Sensor-Logic 11-1/2 x 8 x 7-1/2 inches
 - b. Sweep circuits and power supply
7-1/2 x 4-1/4 x 2-1/4 inches
 - c. High voltage power supplies
7-1/2 x 5 x 8 inches
9. Weight: 13.0 lbs.
10. Power requirements: 4.25 watts at +28 volts unregulated input. Table 2-3 gives pin connection data.

2.1.2 Principles of Operation

Each of these instruments utilizes a concentric pair of spherical quadrants to affect spectral analysis; the spherical geometry is used to achieve three dimensional focussing, and reasonably large angular apertures. The relationship between the separation of the plates, d , the geometrical mean radius of the spheres R_g , the mean energy of the particle focussed E , and the magnitude of the voltage applied to each plate V (i.e., one plate is at $+V$ and the other at $-V$ volts) is given by $E = VR_g/d$. The energy resolution is given approximately by d/R_g (FWHM), and for the present instruments is about 15%.

Figure 2-4 is a block diagram of the two electrostatic analyzers. A linear sweep voltage (saw-tooth) of about 16 second period is applied to a control circuit of a programmable high voltage supply with balanced positive and negative outputs which are tied to appropriate plates of the

TABLE 2-3

ELECTROSTATIC ANALYZERS, PIN CONNECTIONS

A. Sensor Logic (2)

1	Chassis Ground
2	NC
3	GND
4	-6.5 V IN
5	GND
6	+6.5 V IN
7	GND
8	+18V IN
9	GND
10	+28V Unreg. IN
11	GND
12	NC
13	GND
14	NC
15	NC
16	Temp Mon OUT to TM
17	HV Mon OUT to TM
18	NC
19	Rate of Energy Deposition Signal, OUT to TM
20	NC
21	GND
22	NC
23	NC
24	NC
25	NC

Notes: 3, 5, 7, 9, 11, 13, 21
tied together.

Connector: Cannon, DBM-25

TABLE 2-3 (Cont'd)

B. Sweep Circuits and Power Supply (1)

1	GND
2	+28V Unreg. OUT
3	GND
4	+28V Unreg. OUT
5	GND
6	+27V Unreg. filtered, OUT
7	GND
8	-6.5V OUT
9	GND
10	+6.5V OUT
11	GND
12	+18V <u>+1%</u> Reg, OUT
13	NC
14	Ext. Sweep IN, Check
15	Sweep Cal. Check
16	+18V Mon OUT to TM
17	+6.5V Mon OUT to TM
18	Sweep Mon OUT to TM
19	GND
20	Sweep Gen OUT
21	GND
22	Fixed Control V., OUT
23	GND (+28V IN Return)
24	+28V Unreg IN
25	Chassis GND

Notes: 1, 3, 5, 7, 9, 11, 19
21, 23 tied together.
2, 4, 24 tied together.
14, 15 for in-lab testing only.
Connector: Cannon DBM-25

TABLE 2-3 (Cont'd)

C. High Voltage Power Supplies (2)

A1	Control Voltage IN
A2	HV Mon OUT to TM
1	+28V Unreg Pwr IN
2	GND
3	Chassis GND
4	NC
5	Reg. Pwr. Line Check

Noted: 5 for in-lab testing only
Connector: Cannon DAM-7W2

ELECTROSTATIC ANALYZERS

$10 < E < 100 \text{ kev}$

analyzers. Monitoring the sweep enables knowledge of the high voltage outputs, which in turn through the above equation (or by direct instrument calibration) gives the energy to which the analyzers are set at any time.

In the electron detection system, the electrons are detected following 10 kev post-acceleration applied to the very thin light shield covering a "B" plastic scintillator viewed by a photomultiplier; energy loss in the light shield is less than 2 kev. The post-acceleration increases sensitivity of the instrument at low energies. Both the scintillator and photomultiplier affect a multiplication of the current to be measured by the electronic logic, thereby increasing detection sensitivity. The current output of the photomultiplier is proportional to the rate of energy deposition in the scintillator. This photomultiplier current is measured by a circuit of logarithmic response to achieve wide dynamic range; the output signal of this circuit is calibrated in terms of rate of energy deposition. Since the energy of the incident particles is known by monitoring the sweep and by knowing the post-acceleration voltage, the particle flux is therefore immediately derivable. This instrument differs from others in the package in that it comes closest to yielding direct information on differential spectra, rather than on integral spectra.

The proton detection system is similar to the electron system, except that a CsI(Tl) scintillator is used, there is no post-acceleration, and the light shield over the scintillator is eliminated (since a low energy cut off of the order of 25 kev would result from use of an aluminum shield thick enough to keep out light). The analyzer plates are blackened to reduce sunlight scattered into the photomultiplier.

Complete circuit diagrams for either analyzer are shown in Figure 2-5.

NOTES

1. RESISTORS ARE $\pm 5\%$ UNLESS OTHERWISE SPECIFIED
2. COMPONENTS MARKED WITH AN ASTERISK ARE TO BE MOUNTED ON STANDOFFS
3. V_{H} MEASURED ≈ 45 VOLTS THE CONNECTOR
4. PINS 1, 3, 5, 9, 9, 2, 2, 2 ARE TIED TOGETHER AT CONNECTOR
5. PINS 1, 3, 5, 9, 9, 2, 2 ARE TIED TOGETHER AT "CONNECTOR" SIGNAL GROUND

NOTE: PINS 30 BOTH ELECTRON & PROTON
PINS 5 ARE IDENTICAL

CIRCUIT SCHEMATIC: ELECTROSTATIC ANALYZERS

2.1.3 Calibration Procedures

Calibration of the energy scale of the electrostatic analyzers - i.e., the determination of the correspondence between the sweep monitor (or the high voltage monitor) signals and the energy to which the analyzer plates were set was accomplished by two methods. The first method was carried out in vacuo on a set of isolated electrostatic analyzer plates - i.e., separated from the attendant sensor and logic. An electron gun, whose beam energy was variable from 3 kev to 20 kev, was set at various energies over this range and the beam was injected into the plate entrance aperture. High voltage applied to the analyzer plates was then varied until a maximum signal was detected in a Faraday cup placed at the exit aperture of the plate assembly. The correspondence between one-half the applied potential difference and the energy to which the plates were tuned was then recorded. This correspondence agreed, within the $\pm 2\%$ accuracy of the meters used, with the predicted relationship between the voltage V and electron energy E given by the formula in Section 2.1.2 preceding. This formula was then assumed to hold for energies above 20 kev as well. On all subsequent flight electrostatic analyzers, final energy calibration curves above 20 kev were derived using the formula and direct calibration of the high voltage power supply, high voltage monitor and sweep monitor signals.

The second method used to calibrate the electrostatic analyzer energy scale was carried out in vacuo using a complete flight instrument (actually the back-up for the one that flew on 1963-25B).

The electron gun was again used. All outputs of the analyzer being calibrated were recorded on an oscillograph. Electron energy was plotted as a function of the high voltage monitor and sweep monitor signals at which one-half of the peak amplitude of the rate of energy deposition signal was achieved. Results agreed with the previous method within the accuracy of reading meters and the oscillograph, about $\pm 3\%$. Figure 2-6 following is an energy calibration curve for the electrostatic analyzers which flew on 1963-25B.

Calibration of the rate-of-energy deposition scale of the analyzers was achieved as follows. A Po^{210} 5.3 Mev alpha particle source was previously assayed using a solid state detector and a multichannel pulse height analyzer. The absolute rate of energy emission from the alpha source could then be determined. The relative response of CsI(Tl) and anthracene to particles of different kinds (see Figures 2-1 and 2-2) were then used to derive an electron equivalent rate-of-energy deposition in Pilot "B" plastic (assumed identical to anthracene in its response), and a proton equivalent rate-of-energy deposition in CsI(Tl).

The logarithmic current meter alone of an analyzer was first calibrated using a laboratory current source; this resulted in a plot of signal out versus current in. The photomultiplier proper to this instrument was next set at fixed high voltage and connected to the log current meter input, the Po^{210} source was placed against the unshielded scintillator, and the output signal then recorded. Since the equivalent rate of energy deposition corresponding to this signal was known, and the corresponding PM current as well, and since PM output current is linearly proportional to the rate of energy

ELECTROSTATIC ANALYZERS: ENERGY CALIBRATION

deposited by electrons of the energy range of importance in plastic scintillator, a final calibration curve of log current meter signal out versus rate of energy deposition could be constructed by simply relabeling the current scale of the earlier curve. Rate of energy deposition calibration curves obtained in this way for electron and proton electrostatic analyzers are given in Figures 2-7 and 2-8.

The rate of energy deposition channel of the back-up instrument was calibrated directly in the same experiment (referred to earlier) that led to the energy scale calibration. The electron beam current entering the analyzer plates was measured using a Faraday cup. Results were consistent with the previous method within experimental accuracy.

Isolated analyzer plates were also experimentally investigated to determine their maximum transmission, the energy resolution, and the entrance aperture. The first parameter was measured to be 95% or better at normal incidence, at the center of the aperture. The energy resolution was measured by changing the electron beam energy off the set maximum and recording the energy deviations $\pm \Delta E$ at E which caused the output current to fall to one-half maximum; $\Delta E/E$ was measured to be consistent with the theoretical value $\pm 7.5\%$, although perhaps somewhat worse. The angle aperture was measured to be about $\pm 5^\circ \times \pm 40^\circ$ off normal incidence by rotating the plate assembly about one or the other of two perpendicular axes and observing the angles at which the output signal dropped to one-half maximum.

Various voltage monitors for the electrostatic analyzers were calibrated directly.

ELECTROSTATIC ANALYZERS, ELECTRON SYSTEM: RATE OF ENERGY DEPOSITION CALIBRATION

ELECTROSTATIC ANALYZERS, PROTON SYSTEM: RATE OF ENERGY DEPOSITION CALIBRATION

2.2 Proton Scintillation Spectrometer

2.2.1 Physical Description

Figure 2-9 is a photograph of the proton scintillation spectrometer. The instrument consists of two sub-assemblies, a sensor box and a logic box. In addition, this instrument shares the outputs of a third unit, a DC-DC converter and voltage regulator, with the electron scintillation spectrometer.

Figure 2-10 is a sectional drawing of the sensor showing the configuration of the internal components. The two scintillators (Pilot "B" and CsI(Tl)) and the light pipe are bonded together with Eastman adhesive. Optical contact between the glass light pipe and the photomultiplier is achieved by an interposing layer, one-eighth inch thick, of transparent RTV silicone rubber; pressure is exerted on this layer to insure good contact. The scintillators are cushioned on the sides by a sleeve, one-sixteenth inch thick, of white silicone rubber which also serves as a diffuse reflector to increase light collection efficiency. The front of the scintillator is covered with $2500 \text{ \AA}$ of evaporated aluminum for light shielding. All high voltage terminals are potted in RTV white silicone rubber. Electronics on the board near the connector are epoxy dipped. The structure of this sensor is typical of those used in other instruments also.

Following is a tabulation of the principle characteristics of this instrument.

[illegible]

2-9

TOP VIEW

SIDE VIEW

END VIEW

PROTON SPECTROMETER SENSOR

1. Particles detected: Protons
2. Energy range:
 - a. Low energy channel: 1.0 to 5.3 Mev
 - b. High energy channel: 7.5 to 120 Mev
3. Energy resolution:
 - a. Low energy channel: $\pm 20\%$ at 1.5 Mev, $\pm 4\%$ at 5.0 Mev
 - b. High energy channel: $\pm 23\%$ at 15 Mev, $\pm 5\%$ at 100 Mev
4. Angular aperture: Approximately an 8° cone, or $\Omega \approx 1.6 \times 10^{-2}$ ster
5. Geometrical Factor: A $\Omega \approx 8.4 \times 10^{-4} \text{ cm}^2 \text{ - ster}$
6. Physical quantity measured: Where Φ is the number of protons/Mev sec-cm²-ster, and E the threshold energy in Mev, the low energy channel measures:

$$\int d(\Lambda \Omega) \int_E^{5.5} \Phi dE$$

and the high energy channel measures

$$\int d(\Lambda \Omega) \int_E^{130} \Phi dE$$

7. Absolute dynamic range:
 - a. Low energy channel: $1.2 \times 10^4 - 2 \times 10^8$ particles/
 $\text{cm}^2 \text{ sec -ster}$
 - b. High energy channel: $0-4 \times 10^5$ particles/ $\text{cm}^2\text{-sec-ster}$
unambiguously
8. Physical size:
 - a. Sensor: $15-1/2 \times 2-3/4 \times 2-3/4$ inches
 - b. Logic: $7-1/2 \times 5 \times 3-1/4$ inches
 - c. Converter: $6 \times 3-1/2 \times 1-3/4$ inches
9. Weight, including converter: 8.1 lbs.
10. Power requirements: 0.64 watts including converter,
0.93 watts at nominal +28 volts unregulated input.

Table 2-4 gives pin connection data.

TABLE 2.4

PROTON SCINTILLATION SPECTROMETER, PIN CONNECTIONS

A. Sensor

A1	Anode Signal	OUT
A2	HV Mon	OUT to TM
A3	Dynode Sygnal	OUT
1	Chassis Gnd	
2	-13.5V Power	IN
3	GND	
4	-6.75V Power	IN
5	GND	
6	+6.75V Power	IN
7	GND	
8	NC	
9	GND	
10	+28V Unreg.	IN

Notes: 3, 5, 7, 9 tied together

Connector: Cannon, DBM-13W3

TABLE 2.4 (Cont'd)

B. Logic

A1	Anode Signal IN
A2	9 Ft. Clipping Line
A3	Dynode Signal IN
1	Chassis Gnd
2	Lo-Energy p-pulse, check
3	GND
4	-6.75V Power IN
5	GND
6	+6.75V Power IN
7	GND
8	+18V Power IN
9	GND
10	NC
11	GND
12	NC
13	GND
14	Ext. Sweep IN, Check
15	Sweep Cal. Check
16	Hi-Energy p-pulse
17	+18V Mon, OUT to TM
18	Sweep Mon OUT to TM
19	Lo-Energy Channel, OUT to TM
20	Hi-Energy Channel, OUT to TM
21	GND
22	NC

Notes: 3, 5, 7, 9, 11, 13, 21 tied together

"Check" points are for in-lab testing, are never connected to harness

Connector: Cannon, DCM-25W3

TABLE 2.4 (Cont'd)

C. Converter

1	GND
2	+28V Unreg. OUT
3	GND
4	+28V Unreg OUT
5	GND
6	+28V Unreg OUT
7	-13.5 @10 ma OUT
8	-6.75 @30 ma OUT
9	GND
10	+6.75V @30 ma OUT
11	GND
12	+18V, <u>±</u> 1%, Reg OUT
13	Int. Connection to 14, 21, 22
14	Int. Connection to 13, 21, 22
15	-13.5V @10ma OUT
16	-6.75V @30ma OUT
17	GND
18	+6.75V @30ma OUT
19	GND
20	+18V <u>±</u> 1% Reg OUT
21	Int. Connection to 13, 14, 22
22	Int. Connection to 13, 14, 21
23	GND (+28V IN Return)
24	+28V Unreg 1N
25	Chassis Gnd

Notes:

13, 14, 21, 22 tied together
 1, 3, 5, 9, 11, 17, 19, 23 tied together
 2, 4, 6, 24 tied together
 7, 15 tied together
 8, 16 tied together

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10, 18 tied together
 12, 20 tied together

Connector: Cannon, DBM-25

2.2.2 Principles of Operation

This instrument utilizes a "phoswich", a phosphor sandwich consisting of scintillators of different characteristic decay times. Following excitation by a charged particle, the (organic) plastic scintillator (commercial Pilot "B") emits 90% its light within a time of the order of 10 nanoseconds; the (inorganic) thalliated cesium iodide scintillator emits 90% of its light within a time of the order of 500 nanoseconds. The phoswich is viewed by a single photomultiplier, whose circuit parameters are so chosen that output pulse heights have the same shape (time behavior) as the rates of light emission by the scintillators (so-called "current pulse" mode).

Figure 2-11 is a block diagram of this instrument. A proton of energy less than 5.3 Mev will stop within the 15 mil thick plastic scintillator; the resulting PM pulse will then be characteristic of the plastic scintillation process only - i.e., will be a single 10 nanosecond pulse. A proton of energy greater than 5.3 Mev will penetrate the plastic and excite scintillation in the 5.0 cm thick (CsI(Tl) crystal as well. The PM pulse in this case will be characteristic of both crystal scintillation process - i.e., will be a superposition of a 10 nanosecond pulse (a so-called "fast component") upon a 500 nanosecond pulse (a so-called "slow component").

Analysis of "low energy" (< 5.3 Mev) proton spectra therefore involves analysis of fast component pulses unaccompanied by slow component pulses, that is analysis of fast component in anticoincidence with slow. The anticoincidence requirement is obviously

PROTON SPECTROMETER
 $1.0 < E_p < 5.3 \text{ Mev}$ $7.5 < E_p < 120 \text{ Mev}$

necessary to minimize "folding-back" contamination of the low energy proton spectra i. e., a double valued energy versus pulse height characteristic. This "folding-back" is illustrated in Figures 2-12A and 2-12B which show the energy deposited and light output, respectively, produced in 15 mils of Pilot "B" plastic, by protons of various incident energies. Because of the thinness of the plastic scintillator, electrons which stop in it lead to significant contamination of the low energy proton spectra only at pulse heights corresponding to 0.7 Mev (or less) protons. (This latter value of practical threshold was calculated under the assumption that proton and electron differential spectra have $1/E^3$ dependence and identical normalizing factors. Results of machine calibrations, and properties of organic scintillators were also utilized. "Significant" in this case means 25%).

Analysis of "high energy" (> 5.3 Mev) proton spectra involves analysis of slow component pulses accompanied by a suitably large fast component - i. e., analysis of slow component in coincidence with fast. The coincidence requirement limits analysis to particles which enter the aperture only. It rejects analysis of essentially all high energy protons, electrons or gamma rays which penetrate the shielding from the sides or back. The imposition of a minimum pulse height requirement on the accompanying fast component amounts to a measurement of dE/dx on particles penetrating to the CsI(Tl) crystal. In this way, high energy electrons are rejected from analysis; there is thus no electron contamination of the high energy proton spectra derived. By this means also, protons of energy greater than

39

2-12a

ENERGY DEPOSITED BY PROTONS IN 15. mil (0.0389-gm/cm²) PILOT B

SIGNAL PRODUCED BY PROTONS IN 15. mil (0.0389-gm/cm²) PILOT B

120 Mev, which leaves the CsI(Tl) crystal, are also rejected from analysis. There is therefore little "folding-back" contamination of the proton spectra. Figure 2-13 shows, for the size of CsI(Tl) used in this detector, the energy deposited and light output as a function of incident proton energy.

The low energy proton channel is associated with the anode circuit of the PM. The fast component of a pulse is extracted and the slow component is rejected by use of a clipping line of appropriate length. The fast pulse is amplified, stretched, delayed, then feeds two circuits in parallel. One circuit leads to the "electron rejection and high energy proton limit discriminator", which allows gate generator No. 2 to fire if the incident particle is a proton only, and of energy less than 120 Mev. The second circuit leads to linear antigate No. 3, through which it passes to the comparator for analysis only if there is no (or negligible) slow component accompanying it, therefore only if the pulse is due to a proton of energy less than 5.3 Mev.

The high energy proton channel is associated with the dynode circuit of the PM. The composite pulse is amplified, then feeds two circuits in parallel. One circuit leads to linear gate No. 2, where it is blocked if the pulse arose from anything except a proton of $E < 120$ Mev. If the pulse did so arise, the fast component is rejected, and the slow component retained, because of the sufficient delay in the opening of gate No. 2. Slow components passed through the gate proceed to the comparator for analysis. The second circuit following the amplifier leads to a second amplifier and then to linear gate No. 1 where conditions on gate opening are identical to those for gate No. 2. A slow component passed through gate No. 1 will subsequently lead to the "noise rejection discriminator" which (if

**ENERGY DEPOSITED AND SIGNAL OUT PRODUCED BY PROTONS
IN 22.5 gm/cm² CsI(Tl)
AFTER PENETRATING 0.0389 gm/cm² B PLASTIC**

the slow component is "legitimate") allows anti-gate generator No. 1 to fire. This generator therefore fires only for protons of energy greater than about 5.3 Mev (the minimum proton energy required to penetrate into the CsI(Tl) crystal). Firing of this generator blocks passage of the fast component in the anode circuit, and prevents its analysis. Hence, the anode circuit analyzes protons of energies less than 5.3 Mev, and the dynode circuit protons of energies somewhat greater than 5.3 Mev, but still less than 120 Mev.

In both dynode and anode circuits (i.e., high and low energy proton channels respectively) pulse height analysis is accomplished through the use of a comparator. This device is essentially a high-gain difference amplifier. One of its two inputs is fed by a linear sweep (saw-tooth) of 16 second period; the pulse to be analyzed is fed to the other output. The comparator yields an output signal only if the pulse to be analyzed has a height exceeding the "instantaneous" value of the sweep voltage at that time. There is a unique correspondence in each channel between proton energy, pulse height and maximum sweep voltage which allows the comparator to fire for a given pulse height. The sweep voltage therefore corresponds to a threshold energy. The firing rate of the comparator then corresponds to fluxes of protons of energies greater than this threshold value. Information on integral proton fluxes is thus obtained by monitoring the sweep voltage, and measuring the counting rate of comparator output pulses.

In the low energy channel, where fluxes can be high, comparator outputs are shaped, then fed to a logarithmic count rate meter. The signal output from this circuit is a voltage proportional

to the logarithm of the counting rate. Fluxes of less than 10 pps are easily measured and the dynamic range exceeds 10^5 pps before saturation occurs. The time of response of this circuit is fast, and statistical fluctuations correspond to approximately $\pm 30\%$ of the "instantaneous" counting rate at low counting rates.

In the high energy channel, where fluxes are relatively small, the comparator pulses are used to trigger 5 cascaded flip-flops interconnected to yield binary-to-base-32 conversion. The signal output is thus one of 32 voltage values indicating scaler states and therefore accumulated counts. Fluxes are thus derived from time interval information.

To facilitate testing and calibration of this instrument, a "universal pulser" was made whose outputs simulated variable mixtures of the Pilot "B" and CsI(Tl) scintillation current pulses. The circuit diagram for this auxiliary equipment is shown in Figure 2-14.

Figures 2-15, 2-16 and 2-17 are schematic diagrams of the proton spectrometer circuits.

2.2.3 Calibration Procedures

The two energy scales of this instrument were calibrated using proton accelerators. Prior to these machine runs, laboratory radioactive sources were used to set amplifier gains as close as possible to the ideal so that the desired ranges of particle energies being analyzed could be approached. The procedures used in this approximate calibration technique are first described.

The photomultiplier was first set at a fixed high voltage. In the low energy proton channel, the desired sensitivity (volts/Mev deposited) was 5 volts per 5.33 Mev proton at the input to the

UNIVERSAL PHOTOMULTIPLIER PULSE SIMULATOR

NOTES

- ALL RESISTORS ARE $\frac{1}{4}$ W, *5% UNLESS OTHERWISE SPECIFIED
- 2 NUMBERED PINS MOUNT TO THE CONNECTOR
- 3 - 4 5 6 7 9 ARE ALL TIED 4TH CONNECTOR SG GND)

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CIRCUIT SCHEMATIC: PROTON SPECTROMETER SENSOR

2-17

CIRCUIT SCHEMATIC: PROTON SPECTROMETER LOGIC (BOARDS C & D)

comparator (i. e., the output of antigate 3). Since the 5.30 Mev alpha particle from Po^{210} looks like a 1.65 Mev proton in Pilot "B" plastic (see Figure 2-1), this meant that for the same channel sensitivity this alpha should yield a 0.96 volts pulse at the comparator input. The Po^{210} source was placed against the plastic scintillator, and the amplifier gain in the anode circuit was therefore trimmed until this pulse height was obtained. The desired channel sensitivity immediately led to the required setting for the "electron reject and high energy proton limit discriminator" (refer to Figure 2-1) and this discriminator was accordingly trimmed using the universal pulser substituting for the PM anode.

In the high energy proton channel, the desired sensitivity was 5 volts per 120 Mev at the input to the comparator (i. e., the output of delayed gate 2). Since the 5.30 Mev alpha particle from Po^{210} looks like a 3.4 Mev in CsI(Tl) (see Figure 2-2), this meant that for the same sensitivity this alpha particle should yield a 0.14 volt pulse at the comparator. Since the delay in firing of gate 2 was measured to be 0.30 microseconds, the shape of the alpha particle (or a proton) pulse was such that the desired pulse height at the input of delayed gate 2 was 2.4 times the 0.14 volt output, or 0.34 volts. For convenience the amplifier feeding delayed gate 1 had been previously set at exactly 10. The output of this amplifier was then monitored and the gain of the amplifier feeding delay gate 2 was trimmed with the Po^{210} source against the CsI(Tl) scintillator until 3.4 volt pulses were observed at the monitor point. This channel was thus approximately calibrated.

The final calibration of the low energy proton channel was conducted at a 4 Mev proton van de Graaff generator. A gold foil,

0.05 mils thick, was used in the primary proton beam to produce a sufficiently low intensity secondary beam by Rutherford scattering. The foil and complete instrument were all placed in a vacuum chamber contiguous with the van de Graaff accelerator column. All electrical leads were fed through the vacuum chamber wall on a special vacuum tight connector, and the instrument outputs were all monitored on a recording oscillograph. The energy of the proton beam in any one run was ultimately determined by a previously calibrated 90° deflecting analyzing magnet.

The low energy calibration curve to about 4 Mev was generated by plotting the sweep monitor voltage at which the counting rate fell to one-half its maximum value as a function of incident proton energy (corrected for energy loss in the scattering foil). The universal pulser was later used to interpolate the calibration points and to extrapolate beyond 4 Mev; the scintillator response curve of Figure 2-1 was used for this latter work.

In these same experiments, the energy resolution (FWHM) was taken as twice the energy change corresponding to the sweep monitor voltage change in going from maximum counting rate to one-half maximum. Values obtained were consistent with the resolution determined using the Po^{210} alpha source (equivalent to a 3.4 Mev proton in "B" plastic) shown in Figure 2-18.

The final low energy calibration curve for the proton detector flown on 1963-25B is shown in Figure 2-19. This is not the curve immediately derived following the machine calibration. The gain of the amplifier feeding antigate 3 was slightly decreased by a measured fraction following the calibration runs to allow covering

RESOLUTION OF THE PROTON SPECTROMETER

P_0^{210} SPECTRUM IN PILOT "B" PLASTIC SCINTILLATOR

PROTON SPECTROMETER: LOW ENERGY CHANNEL ENERGY CALIBRATION

the desired energy range. Since the amplifier was linear, the revised calibration curve was derived by simply changing the energy scale of the old curve.

The final calibration of the high energy proton channel was conducted at the 180 Mev proton cyclotron at Harvard University. A low intensity external proton beam was used, and the instrument sensor was placed directly in the beam. Instrument outputs were all monitored on the recording oscillograph as before. The energy of the proton beam leaving the machine was determined by placing absorbers of accurately measured densities (gm/cm^2) into the beam until extinction was achieved, then using range-energy tables. The energy of the beam entering the entrance aperture of the proton sensor was varied by using various known combinations of these same absorbers.

The high energy calibration curve was then generated in the same manner as the low, and the resolution similarly measured. The resolution was not corrected for proton straggling, and is therefore perhaps somewhat worse than what would be expected.

The final high energy calibration curve for the 1963-25B instrument is shown in Figure 2-20. As was the case with the low energy channel, the curve of Figure 2-20 is not the one immediately derived following the cyclotron experiments. The gain of the amplifier feeding delayed gate was increased by a known amount to utilize the full range of monitoring voltage available. The energy scale of the old curve was then accordingly relabeled.

The energy calibration procedures described above were performed on the instrument which flew on 1963-25B. Subsequent in-

PROTON SPECTROMETER: HIGH ENERGY CHANNEL ENERGY CALIBRATION

struments were calibrated by using laboratory radioactive sources as reference standards.

The logarithmic count rate meter in the low energy proton channel was calibrated directly, by using a calibrated pulser of variable repetition rates, and simply plotting signal output as a function of repetition rate. The curve is shown in Figure 2-21.

The scaler in the high energy proton channel was calibrated as follows: the minimum and maximum voltage outputs were measured as 0.58 and 4.90 volts, respectively, and state N was determined from the voltage V by:

$$N = 32 \left(\frac{V - 0.58}{4.32} \right)$$

The remaining monitor circuits were calibrated directly with laboratory meters.

The geometrical factor (area times solid angle) of this instrument's sensor was calculated from the geometry of the shielding by using:

$$(A \Omega) = \int A(\theta) d$$

where $A(\theta)$ is a complicated function of the angle θ off the detector symmetry axis. Thus, $(A \Omega)$ does not quite equal $A_0 \Omega$ where A_0 is the normally projected area of the entrance aperture, and Ω is the solid angle field of view of the entrance aperture.

PROTON SPECTROMETER: LOW ENERGY CHANNEL, CRM CALIBRATION

2.3 Electron Scintillation Spectrometer

2.3.1 Physical Description

Figure 2-22 is a photograph of the electron scintillation spectrometer and Figure 2-23 is a sectional drawing of the sensor. The sensor construction is similar to that described for the proton spectrometer in Section 2.2, except for the addition of a copper grid, connected to the PM cathode potential, over the cathode face.

Following is a tabulation of the principle characteristics of this instrument.

1. Particles detected: electrons
2. Energy range: 0.4 to 4. Mev
3. Energy resolution: $\pm 15\%$ (FWHM) at 0.5 Mev to $\pm 5\%$ at 4.0 Mev
4. Angular aperture: approximately 25° cone; $\Omega = 0.15$ steradian
5. Geometrical factor: $A\Omega \approx 0.12 \text{ cm}^2\text{-ster}$
6. Physical quantity measured: where $\Phi(E)$ is the number of electrons / Mev-sec-cm²-ster, and E is the Ω threshold energy in Mev, the count rate channel measures:

$$\int d(A\Omega) \int_E^\infty \Phi dE$$

and the rate of energy deposition channel measures;

$$\int d(A\Omega) \left[\int_{0.15}^5 E\Phi dE + \int_5^\infty 5\Phi dE \right]$$

ELECTRON SPECTROMETER

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ELECTRON SPECTROMETER SENSOR

7. Absolute dynamic range:
 - a. Count rate channel: $8 \times 10 - 1 \times 10^6$ part/sec-cm²-ster
 - b. Rate of energy deposition channel: $8 \times 10^2 - 8 \times 10^8$ Mev/sec-cm²-ster
8. Physical size: two sub-assemblies:
 - a. Sensor: $13 \times 2\text{-}3/4 \times 2\text{-}3/4$ inches
 - b. Logic: $7\text{-}1/2 \times 4\text{-}1/2 \times 2\text{-}1/4$ inches
9. Weight: 2.9 lbs.
10. Power requirements: 0.27 watts; with converter-regulator, 0.56 watts at nominal +28 volts unregulated input
11. Table 2-5 gives pin connections.

2.3.2 Principles of Operation

This spectrometer is a scintillation type, using commercial Pilot "B" plastic. The scintillator is surrounded by side and back shielding adequate to keep out electrons of energy less than 5 Mev and protons of energies less than 50 Mev. The light shield within the entrance aperture is sufficient to stop protons of energy less than 5 Mev (electron energy losses on penetrating this shield will be of the order of 0.1 Mev). Electron spectra analyzed will be contaminated to some extent, chiefly by protons of energy greater than 5 Mev. (If one assumes E^{-2} integral spectra shapes for both protons and electrons, and identical scale factors, this contamination amounts to less than 1% when an electron threshold of 0.5 Mev is set by the sweep in the instrument logic to a little more than 10% at an electron threshold of 5 Mev. The situation is helped somewhat by the fact that the organic scintillator discriminates

TABLE 2-5

ELECTRON SCINTILLATION SPECTROMETER, PIN CONNECTIONS

A. Sensor

A1	Anode Signal OUT
A2	HV Mon OUT to TM
A3	Dynode Signal OUT
1	Chassis GND
2	NC
3	GND
4	-6.75V Power IN
5	GND
6	+6.75 Power IN
7	GND
8	+18V Power IN
9	GND
10	+28V Power IN

Notes: 3, 5, 7, 9 tied together

Connector: Cannon, DBM-13W3

TABLE 2-5 (Cont'd)

B. Logic

1	Chassis GND	A1	Anode Signal IN
2	e-Pulse Check	A2	NC
3	GND	A3	Dynode Signal IN
4	-6.75V Power IN		
5	GND		
6	+6.75 Power 1N		
7	GND		
8	+18V Power IN		
9	GND		
10	NC		
11	GND		
12	NC		
13	GND		
14	Ext. Sweep IN Check		
15	Sweep Cal Check		
16	Temp Mon OUT to TM		
17	+6.75V Mon OUT to TM		
18	Sweep Mon OUT to TM		
19	Rate of Energy Deposition Signal	OUT to TM	
20	Counting Rate Signal	OUT to TM	
21	GND		
22	NC		

Notes: 3, 5, 7, 9, 11, 13, 21 tied together

Check points for in-lab testing, never connected to harness

Connector: Cannon, DCM-25W3

against protons, always yielding less light output for a proton than for an electron of the same energy; see Figure 2-1). Corrections can be made for such contamination by utilizing data obtained from the proton spectrometer if this seems warranted, but the degree of contamination is almost certain to be within statistical uncertainties in the data.

Figure 2-24 is a block diagram of the electron spectrometer. This instrument has two channels of information. One channel, in connection with the sweep monitor, gives spectral information much in the same way as the low energy proton channel of the proton detector. The second channel gives us little spectral information, but instead measures total power deposited in the scintillator by electrons of energy greater than about 0.15 Mev and protons of energy greater than about 5 Mev by means of a logarithmic current meter. This channel is expected to read long after the counting rate channel is saturated, even within the hearts of the Van Allen belts.

Figures 2-25 and 2-26 are circuit schematics for the electron spectrometer sensor and logic respectively. This instrument also utilizes the DC to DC converter and regulator described in the preceding section.

2.3.3 Calibration Procedures

The calibration of the energy scale was achieved by two methods, one utilizing radioactive laboratory sources, the other utilizing a particle accelerator, in a manner similar to that described for the proton detector.

The first method was used primarily to set the input amplifier gain to a value which would allow spectrum analysis over the energy range of interest. The PM high voltage was first fixed, and the

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2-24

ELECTRON SPECTROMETER

$$0.4 < E_e < 4.0 \text{ Mev}$$

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NOTES

- 1 ALL RESISTORS ARE $\frac{1}{4}$ W, $\pm 5\%$, UNLESS OTHERWISE SPECIFIED
- 2 NUMBERED PINS MOUNT TO CONNECTOR
- 3 PINS 3, 5 & 9 ARE ALL TIED AT CONNECTOR (SIG GND)

CIRCUIT SCHEMATIC ELECTRON SPECTROMETER SENSOR

amplifier gain was trimmed until the 0.34 Mev Compton edge from the 0.51 Mev annihilation gamma produced by a Na^{22} source yielded 0.34 volts output from the amplifier. The amplifier gain was further checked using the 5.3 Mev Po^{210} alpha particle. The amplifier output pulse height in this case was consistent with an equivalent 0.56 Mev electron in the plastic scintillator (see Figure 2-1). In principle, since the sweep monitor could be directly calibrated utilizing an auxiliary laboratory pulser - so as to obtain the correspondence between the pulse height out of the amplifier and the sweep monitor voltage at which the comparator first fired - the instrument could have been calibrated in this way. Such a calibration would not have been satisfactory in practice since: 1) the calibration points 0.34 and 0.56 Mev were at the extreme lower end of the electron spectral range, where resolution is poor; 2) corrections for electron energy loss in the light shield would have had to be calculated.

For these reasons, final calibration was carried out at a 3.0 Mev van de Graaff electron accelerator at High Voltage Engineering Corporation. Various thin foils (1/4 mil mylar, 1 mil aluminum and 1 mil copper) were used at various energies in the primary electron beam from the accelerator to produce a sufficiently low intensity secondary beam by Rutherford scattering. The electron detector, located in a lead house to reduce bremsstrahlung background, viewed the foils at 90° . The primary beam current was monitored during calibration procedures. All instrument outputs were recorded on an oscillograph. Calibration up to 3 Mev then involved plotting electron energy, corrected for ionization losses in the van de Graaff

exit window and scattering foil, as a function of the sweep monitor voltage at which the logarithmic count rate meter output signal achieved one-half peak value. Peak value was taken as the value of the plateaus obtained over each sweep period; at very low discrimination levels, the bremsstrahlung background contributed significantly to the signal. Calibration above 3 Mev was accomplished by using the auxiliary pulser, and normalizing to the highest energy machine calibration point. The final energy calibration curve for the 1963-25B instrument is shown in Figure 2-27.

The energy resolution of the instrument was also determined during the machine calibration run. The full width at half maximum was taken as twice the energy change corresponding to the sweep monitor voltage change in going from maximum counting rate to one-half maximum. Resolutions at energies above 3 Mev were calculated by using the approximation $\Delta E(E) \approx \Delta E(3) \times [3/E]^{1/2}$. Resolution is also indicated in Figure 2-27.

The logarithmic count rate meter was calibrated directly, using the auxiliary pulser as for the proton scintillation spectrometer. The curve for the 1963-25B instrument is given in Figure 2-28.

The rate of energy deposition calibration was conducted in a manner similar to that described for calibrating the electrostatic analyzers; the Po^{210} source was used. Figure 2-29 is the result of this calibration on the 1963-25B instrument.

Various voltage monitors were calibrated directly using laboratory multimeters.

The geometrical factor (area times solid angle) of this detector was calculated from the geometry of the shielding.

ELECTRON SPECTROMETER: ENERGY CALIBRATION

ELECTRON SPECTROMETER: CRM CALIBRATION

ELECTRON SPECTROMETER: RATE OF ENERGY DEPOSITION CALIBRATION

2.4 Geiger Counter

2.4.1 Physical Description

Figure 2-30 is a photograph of the Geiger counter.

The principle characteristics of this instrument are:

1. Particles detected: electrons of energies above (approximately) 4 Mev and protons of energies above 40 Mev.
2. Angular aperture: approximately a quarter of a sphere when mounted alone; the sub-satellite geometry further restricted the field of view to about 1 steradian.
3. Geometrical factor: $A \Omega \approx 1 \text{ cm}^2 \text{ ster}$
4. Physical quantity measured: where $\Phi_e(E)$ is the number of electrons/MeV-sec-cm² ster and $\Phi_p(E)$ is similarly defined for protons, this instrument measures

$$\int d(A\Omega) \left[\int_4^\infty \Phi_e dE + \int_{40}^\infty \Phi_p dE \right]$$

5. Absolute dynamic range: $10 - 2 \times 10^4$ particles/sec-cm² ster
6. Physical size: 7-1/4 x 5-1/4 x 2-1/4 inches
7. Weight: 2.1 lbs.
8. Power requirements: 0.59 watts at nominal 28 volt unregulated input.
9. Table 2-6 lists pin connections for this instrument.

GEIGER COUNTER

BP-061

BP-062

TABLE 2-6

GEIGER COUNTER, PIN CONNECTIONS

Pin	
1	Chassis GND
2	GT Sig Check
3	GND
4	-6.5V Check
5	GND
6	+6.5V Check
7	GND
8	NC
9	GND
10	+28V Unreg IN
11	GND
12	+6.5V Mon OUT to TM
13	GND
14	HV Mon OUT to TM
15	CRM Output OUT to TM

Notes: 3, 5, 7, 9, 11, 13 tied together
2, 4, 6 for in-lab testing only
Connector: Cannon, DAM-15

2.4.2 Principle of Operation

Figure 2-31 is a block diagram of the Geiger counter. The sensor is an Anton type 302 Geiger tube, shielded over one quarter of a sphere by approximately 2 g/cm^2 of aluminum or equivalent (including the satellite skin), over an adjacent quarter of a sphere by approximately 6 g/cm^2 of aluminum, over the remaining hemisphere by 10 or more g/cm^2 of matter. The minimum detection thresholds are thus about 4 Mev for electrons and 40 Mev for protons. The Geiger tube pulses are amplified, shaped, and fed to a logarithmic counting rate meter; the various circuit elements making up the logic are similar in operation to those previously described. Figure 2-32 is a complete circuit diagram for this instrument.

2.4.3 Calibration Procedures

The energy thresholds for particle detection were not directly measured, but were calculated from shielding considerations. However, the efficiency of this detector to electrons (the particles responsible for most of the counts recorded) was not expected to be much different from that experimentally measured by O'Brien for an identical Geiger tube (Anton 302) in very similar shielding. This latter efficiency curve is shown in Figure 2-33. The geometrical factor (area times solid angle) for the Geiger counter which flew on 1963-25B was estimated to be about 1 cm^2 steradian on the basis of the configuration of the sub-satellite as a whole with respect to the mounting position of the counter. The primary functions of the Geiger counter were to serve as a monitoring device for quickly determining regions of relatively intense radiation levels in the magnetosphere, to enable quick comparison with earlier Geiger

GEIGER COUNTER
 $E_e > 4 \text{ Mev}$ $E_p > 40 \text{ Mev}$

NOTES
 1. ALL RESISTORS ARE 1/2 WATT, 5% TOL, UNLESS OTHERWISE SPECIFIED.
 2. ALL DIODES ARE 1N4001 UNLESS OTHERWISE SPECIFIED.
 3. VOLTAGE IS 100V TO 100V CONNECTOR.
 4. PINS 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100 ARE ALL TIED TOGETHER AND CONNECTED TO GND.

CIRCUIT SCHEMATIC: GIEGER COUNTER

EFFICIENCY OF ANTON 302 GEIGER TUBE (O'BRIEN ET AL 1962)

tube data (such as obtained by Van Allen) and to provide a reference for comparison of the data obtained from the other several instruments of the payload, thereby enabling checks for consistency, and further aiding in data interpretation.

The proper operating potential for each Geiger tube used in one of these instruments was determined by running the usual counting rate versus applied voltage curve, and finding the voltage corresponding to the center of the plateau; a typical curve is shown in Figure 2-34. A Na^{22} source was used. All Geiger tubes were remarkably similar, with plateau lengths over 100 volts; they furthermore retained their characteristics over several months without noticeable aging effects. On an assembled Geiger counter, the high voltage applied was measured by means of the previously calibrated high voltage monitor; the unit was then further checked with the source.

The Geiger tube dead time (following the detection of a particle) was measured on an oscilloscope to be typically 30 microseconds. This meant that the counters saturated at approximately 3×10^4 counts per second.

The logarithmic count rate meter was calibrated in the usual way; the result for the flight instrument is shown in Figure 2-35. Other voltage monitors were calibrated directly.

TYPICAL ANTON 302 GEIGER TUBE CURVE

GEIGER COUNTER: CRM CALIBRATION

2.5 Plasma Probe

This instrument was developed, fabricated, tested and calibrated by the Cosmic Ray Group of the Massachusetts Institute of Technology under separate contract between M.I.T. and Air Force Cambridge Research Laboratories. ASE served to integrate this instrument with the remainder of the scientific payload. This brief discussion of the instrument is included here for the sake of completeness.

Figure 2-36 is a photograph of the instrument, which weighs 5.9 lbs., requires 3.11 watts at a (nominal) +28 volts input, and occupies a volume approximately 10 x 7 x 9 inches.

Figure 2-37 is a block diagram of the plasma probe. This instrument utilizes a Faraday cup with retardation grids to effect an absolute measurement of particle currents. Three of the cup's four grids serve to screen, or to suppress secondary emission. The fourth is modulated in a programmed way to yield integral spectra information. The voltage applied to the modulating grid consists of a square wave of peak-to-peak voltage 2V riding on a DC bias level of V ; the signal from the cup's collector is then the current due to particles whose energy lies between V and $3V$ electron volts in energy. Chopping enables cancellation of residual signals due to photoelectric emission, and simplifies amplification of the signals. A logarithmic amplifier is used to achieve wide dynamic range, as in other instruments. Spectra are analyzed in 6 energy bands or modes, 5 for protons, 1 for electrons. The mode is made to change every two cycles of a 1.0×60 commutator ring through

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PLASMA PROBE

PLASMA PROBE
 $ev < E_p < 6 \text{ kev}$ $30 \text{ ev} < E_e < 200 \text{ ev}$

the use of a voltage pulse on one commutator segment with about a 12 second period. Other elements of the logic supply a calibration signal during a portion of the electron mode time. Still others are used to subcommutate between the mode indication signal and a temperature signal.

The instrument was calibrated and tested with the aid of a low energy proton gun as well as by means of laboratory current sources.

2.6 Magnetometers

The magnetometers used in this payload were Schonstedt Instrument Company "Heli-Flux".flux gate magnetometers. The component of magnetic field along the axis of a flux gate is measured by the second harmonic content of the signal picked up in the secondary coil of a saturable core transformer under excitation by a pure sine wave in the primary coil.

Two three-axis systems were utilized; the axes in each being mutually perpendicular, and aligned with the principle axes of the spacecraft. One system was composed of RAM-5C flux gates, of range -600 to +600 milligauss; the other consisted of MND-5C200 flux gates (made to special order) of range -200 to +200 milligauss. The systems were on separate halves of the payload, associated with independent commutators.

The systems were not merely redundant, but complementary. Because of the wide variation of the Earth's magnetic field strength over the spacecraft orbit, the two different sensitivities were required in order to achieve satisfactory accuracy in determining the pitch angles of particles detected by the various instruments, i. e., aspect of the instruments relative to the Earth's magnetic field. (Figures 4-5 and 4-6 of Section 4 illustrate the variation in aspect accuracy with the magnitude of the magnetic field).

Each three-axis system weighed approximately 0.60 lbs., and required approximately 0.30 watts at a nominal +27 volts of unregulated input power. Figures 3-3 and 3-5 of Section 3 illustrate the magnetometers mounted on the two payload halves. Table 2-7 gives pin connections.

TABLE 2-7

MAGNETOMETER PIN CONNECTIONS

A. Sensor

<u>Pin</u>	
A	NC
B	Sensor Coil
C	Sensor Coil
D	NC
E	Exciter Coil
F	Exciter Coil
H	NC

Connector: Amphenol

B. Logic

<u>Pin</u>	
A	+28V Unreg IN
B	GND (Sig and Power Ret)
D	Signal OUT to TM
E	Bias Mon OUT to TM
H	NC

Connector: Amphenol

Each flux gate was factory calibrated. Figures 2-38 and 2-39 are typical calibration curves for the ± 600 milligauss and ± 200 milligauss units, respectively. The following tables, 2-8 and 2-9, give complete calibrations of the instruments; calibrations were made with the signal output feeding a 100K impedance.

2.7 Solar Aspect Sensor

As an aid in determining absolute satellite aspect, or simply to determine when certain instruments were viewing the Sun, one of the spacecraft's solar cell panels, which was being monitored to study degradation due to the radiation environment, was also utilized as a crude solar aspect sensor. The circuit which allows this is shown in Figure 2-40. Aspect information is obtained whether the voltage of the cell is monitored (switch K20 open) or whether the (almost) short circuit current is monitored (switch K20 closed).

TYPICAL CALIBRATION CURVE, RAM-5C MAGNETOMETER

SERIAL No. 55

TYPICAL CALIBRATION CURVE, MND-5C200 MAGNETOMETER

SERIAL No. 30

TABLE 2-8

CALIBRATION OF RAM-5C MAGNETOMETERS

Magnetic Field in Milligauss	Output Signals in Volts DC		
	Ser#29 Axis X	Ser #32 Axis Y	Ser #55 Axis Z
600	4.80	4.79	4.81
561	4.65	4.64	4.67
497	4.41	4.40	4.43
432	4.15	4.14	4.16
367	3.88	3.86	3.88
324	3.69	3.67	3.69
259	3.42	3.40	3.42
216	3.23	3.23	3.23
130	2.88	2.87	2.88
64.8	2.63	2.63	2.64
0	2.40	2.40	2.40
-64.8	2.16	2.17	2.16
-130	1.91	1.92	1.91
-216	1.56	1.58	1.57
-259	1.37	1.39	1.38
-324	1.10	1.12	1.12
-367	.92	.94	.93
-432	.65	.67	.65
-497	.39	.41	.38
-561	.15	.16	.13
-600	.00	.02	-.02

TABLE 2-9CALIBRATION OF MND-5C200 MAGNETOMETERS

Magnetic Field in Milligauss	Output Signals In Volts DC		
	Ser #32 Axis X	Ser #31 Axis Y	Ser #30 Axis Z
200	4.721	4.855	4.736
175	4.431	4.554	4.444
150	4.107	4.242	4.146
125	3.825	3.938	3.855
100	3.533	3.612	3.559
75	3.236	3.299	3.268
50	2.946	2.990	2.980
25	2.646	2.679	2.680
0	2.365	2.381	2.393
-25	2.070	2.090	2.103
-50	1.777	1.779	1.798
-75	1.489	1.470	1.511
-100	1.194	1.161	1.219
-125	0.902	0.849	0.923
-150	0.605	0.547	0.632
-175	0.320	0.212	0.322
-200	0.031	-0.083	0.040

TO VOLTAGE LIMITER

SOLAR CELL ASPECT SENSOR

3.0 INTEGRATED PAYLOADS

The characteristics of the individual instruments have been described in the preceding Section 2. This section deals with the assembled instrument packages as integrated to be compatible with the mechanical and electrical interfaces of a Lockheed Missiles and Space Company Program 11 sub-satellite.

3.1 Description of the Spacecraft and Integrated Payloads

It is not the purpose of this report to deal in great detail with the P-11 spacecraft itself. However, a brief description may aid in understanding and appreciating the integrated instrument packages.

Figure 3-1 is a photograph of a sub-satellite, complete with instruments. The scientific payload was contained within the two truncated pyramidal side sections, each with bases approximately 12 x 36 inches, and a height of 11 inches, containing a volume of approximately 3000 cubic inches. The central "orange crate" section measured approximately 13 x 15 x 36 inches. Most of the exterior surface area of the satellite was covered with Silicon solar cells; ports were provided in the satellite skin to allow the instruments to look out. The complete sub-satellite weighed about 200 pounds.

The "orange crate" section contained all the auxiliary equipment necessary to enable the scientific instruments to accomplish this mission. The equipment included:

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COMPLETE SUBSATELLITE

1. A solid fuel rocket motor (Titan vernier type).
2. Launch sequence timer.
3. Nickel-cadmium storage batteries.
4. Voltage and current regulators, and battery recharging circuits used with the solar cells.
5. A command receiver.
6. A command decoder and programmer.
7. Two time reference generators (TRG) one for each payload half.
8. Two mechanical commutators, one 1.0×60 , the other 0.5×60 , one for each payload half. Data from the instruments were thus time-shared. A third commutator, 0.01×60 fed a data point of the 1.0×60 for "house-keeping" function monitoring.
9. A two track tape recorder, one for each payload half; the playback ratio was 12 to 1.
10. Four voltage controlled oscillators (VCO), a set of two for each payload half. Of each set, one was used in transmitting real time data, the other in transmitting tape recorded data.
11. A telemetry transmitter; the overall telemetry system was thus a PAM/FM/FM system.

The data handling portion of the telemetry system is shown in block diagram form in Figure 3-2.

Figures 3-3 and 3-4 are an outline drawing and a photograph of the payload section feeding the 0.5 x 60 commutator. The instruments in this section included the two electrostatic analyzers, the Geiger counter, and the ± 600 milligauss magnetometer. Figures 3-5 and 3-6 are a drawing and a photograph of the payload section feeding the 1.0 x 60 commutator. This section included the M.I.T. plasma probe, the proton scintillation spectrometer, the electron scintillation spectrometer, and the ± 200 milligauss magnetometer. The various instruments are identified in the outline drawings.

Figures 3-7 and 3-8 show the payload sections mounted upon the "orange crate". The configuration of the instruments was such to permit dynamic balancing of the satellite as a whole, and yet to allow each instrument an unoccluded field of view with the removal of a minimum number of solar cells. It will be noted that the "detection vector" of each instrument - that is the vector defining the direction of maximum detector sensitivity - is perpendicular to the symmetry axis of the satellite, about which the satellite was spin-stabilized. This enabled covering the maximum range of pitch angles over a satellite spin. Table 3-1 gives the relative orientations of each instrument's detection vector.

3.2 Logistical and Operational Summary

Under this contract, three instrument packages suitable for spacecraft flight were fabricated, tested and calibrated.

The first of these, carried on an Agena, was launched on 17 March 1963, from Vandenberg Air Force Base, California. Seventy-two hours before the scheduled launch of this vehicle, ASE was informed that the Agena was overweight, and the 42 pound scientific payload would therefore

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SUBSATELLITE PAYLOAD

0.5x60 SIDE

BP-067

BP-068

SUBSATELLITE PAYLOAD

1.0x60 SIDE

BP-063

BP-065

SUBSATELLITE PAYLOAD SECTION

0.5 x 60 SIDE OF PROTOTYPE NO. 1

- 1 ANALYZER PLATES
- 2 ANALYZER PLATE WINDOW
- 3 ELECTROSTATIC ANALYZER (ELECTRON SIDE) LOGIC AND SENSOR
- 4 ELECTROSTATIC ANALYZER (PROTON SIDE) LOGIC AND SENSOR
- 5 POWER DISTRIBUTION
- 6 MAGNETOMETER TERMINAL BOARD
- 7 GEIGER TUBE
- 8 15 Kv POST ACCELERATOR
- 9 15 Kv HIGH VOLTAGE SWEEP
- 10 MAGNETOMETER LOGICS
- 11 SOLAR ASPECT SENSOR
- 12 SOLAR CELLS
- 13 COMMUTATOR CONNECTORS
- 14 MAGNETOMETER SENSORS
- 15 ELECTROSTATIC ANALYZER WINDOWS

SUBSATELLITE PAYLOAD SECTION

1.0 x 60 SIDE OF PROTOTYPE NO.1

- 1 COMMUTATOR CONNECTORS
- 2 PROTON SENSOR
- 3 ELECTRON SENSOR
- 4 ELECTRON LOGIC
- 5 MAGNETOMETER TERMINAL BOARD
- 6 DC/DC POWER SUPPLY
- 7 MAGNETOMETER SENSORS
- 8 PROTON LOGIC
- 9 MAGNETOMETER LOGICS
- 10 M.I.T. PLASMA PROBE
- 11 SENSOR WINDOWS
- 12 SOLAR CELLS
- 13 M.I.T. PLASMA PROBE WINDOW

TABLE 3-1

ORIENTATION OF INSTRUMENT DETECTION VECTORS

Instrument	Colinear Directional Magnetometer Axes		Satellite Axis
	<u>+200 mg</u> (1 x 60 side)	<u>+600 mg</u> (0.5 x 60 side)	
Electrostatic Analyzers	+Y	-Y	-Z
Proton Spectrometer	-X	+X	X
Electron Spectrometer	-X	+X	X
Plasma Probe	-Y	+Y	Z

have to be reduced to 10 pounds to avoid compromising the primary mission of the Agena. Accordingly, it was decided to fly only the electron scintillation detector (with modified shielding so as to give better angular resolution), the Geiger counter, and the ± 600 milligauss magnetometer. The truncated payload was newly laid out, and new harnessing was fabricated from the old.

The vehicle bearing the modified sub-satellite was launched on schedule and appeared to program normally. However, the Agena was never subsequently located, and must be presumed to have failed to achieve orbit.

The second instrument package, carried on an Agena, was launched on 26 June 1963. Figure 3-9 is a photograph of the sub-satellite nested on an Agena "door". The Agena achieved orbit, and the sub-satellite was deployed and launched at 0850 PDT on 1 July 1963. The official international designation of the sub-satellite is 1963-25B; its popular name is Hitch-hiker I.

The initial orbit of 1963-25B is illustrated in Figure 3-10. Perigee was at 176 NM (326 km); at approximately 20° N latitude and apogee was at 2240 NM (4150 km); perigee advanced at a rate of approximately 1.7° per day, southbound. The inclination of the orbit was 82.14° and its period was 132.6 minutes. The satellite was spinstabilized about its axis of symmetry (its Y axis, but magnetometer Z axes) at 68 revolutions per minute.

The scientific instruments aboard the satellite all functioned to specifications throughout the useful satellite life. Tape recorded data was obtained until 7 September 1963, at which time the command

BP-077

SUBSATELLITE ON AGENA

PERIOD - 133 minutes
SPIN RATE ~68 rpm
LAUNCH DATA - 1 JULY 1963

P-11 ORBIT
(1963-25B)

logic broke down making it impossible to read in data to the recorder, or to obtain real time data unless the real time readout command was continuously transmitted. Up to this time data from more than 100 orbits were obtained for analysis. Some useful real time data were subsequently obtained until 17 September 1963. Occasional short bursts of real time data were obtained beyond this, the last being on orbit 2065 (January) at which time all scientific instruments were still functioning.

The power available was sufficient for a maximum operational usage of 4 complete orbits a day. It was necessary to operate the vehicle two orbits a day to prevent the batteries from overcharging.

The third instrument package was to serve as a back-up for either of the other two flights. This package will possibly fly in the near future on a P-11 type or Blue Scout satellite.

3.3 Electrical Interface and Calibration Catalog

In this section, complete information on the wiring of the instruments into spacecraft 1963-25B, and the calibration data referring to all ASE instrument outputs are given.

Figures 3-11 and 3-12 are wiring harness diagrams for the two payload sections, and Table 3-2 is a table of commutator point assignments. The remaining Figures and Tables give calibration data as follows:

1. Figures 3-13 through 3-20 refer to the proton and electron electrostatic analyzers
2. Figures 3-21 through 3-24 concern the proton scintillation spectrometer. A further item

3-11

Table 3-2

COMMUTATOR	I.O. x 60, RING A																							O.OI x 60																																																																				
PLUG IDENTIFICATION	J25 J1																							J25 J3																							J27 J1																																													
PIN DESIGNATION	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	R	S	T	U	V	W	X	Y																																																																					
COMMUTATOR POINT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23																																																																					
ELECTRON DETECTOR																																																																																												
a. SENSOR																																																																																												
b. LOGIC																																																																																												
PROTON DETECTOR																																																																																												
a. SENSOR																																																																																												
b. LOGIC																																																																																												
PLASMA PROBE																																																																																												
MAGNETOMETER (±200mg)																																																																																												
(PRE-EMPTY)																																																																																												
COMMUTATOR	O.5 x 60, RING A																							O.OI x 60																																																																				
PLUG IDENTIFICATION	J24 J1																							J24 J2																							J24 J3																							J28 J1																						
PIN DESIGNATION	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	R	S	T	U	V	W	X	Y																																																																					
COMMUTATOR POINT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23																																																																					
ELECTROSTATIC ANALYZER																																																																																												
a. POWER & SWEEP GENERATOR																																																																																												
b. HIGH VOLTAGE SWEEP																																																																																												
c. POST-ACCELERATOR																																																																																												
d. e-SENSOR-LOGIC																																																																																												
e. p-SENSOR-LOGIC																																																																																												
GEIGER TUBE																																																																																												
MAGNETOMETER (±600mg)																																																																																												
(PRE-EMPTY)																																																																																												

KEY:

- R — RATEMETER SIGNAL
 I — CURRENT METER SIGNAL
 S — SCALER SIGNAL
 E — ENERGY LEVEL SIGNAL (SWEEP MONITOR)
 EH — ENERGY LEVEL SIGNAL
 (HIGH VOLTAGE SWEEP MONITOR)
 X, Y, Z — MAGNETOMETER SIGNALS, X ETC AXIS
 XM, ETC — MAGNETOMETER BIAS MONITORS
 6M — +6.5 TO +6.75V B⁺ MON
 18M — +18V B⁺ MON
 HM — HIGH VOLTAGE MONITORS ON PM'S, MS'S
 AM — POST-ACCELERATOR HV MON
 O — POINTS PRE-EMPTY BY LOCKWHEEL.
 UNAVAILABLE FOR ASE USE
 G — GROUND REFERENCE
 A1 — RADIAL ACCELEROMETER
 A2 — AXIAL ACCELEROMETER
 SC — SOLAR CELL ASPECT SENSOR
 TM — TEMPERATURE MONITOR

COMMUTATOR POINT ASSIGNMENTS, 1963-25B

ELECTROSTATIC ANALYZERS: ENERGY CALIBRATION

ELECTROSTATIC ANALYZERS: ENERGY CALIBRATION

ELECTROSTATIC ANALYZERS, ELECTRON SYSTEM: RATE OF ENERGY DEPOSITION CALIBRATION

ELECTROSTATIC ANALYZERS, PROTON SYSTEM: RATE OF ENERGY DEPOSITION CALIBRATION

ELECTROSTATIC ANALYZERS, ELECTRON SYSTEM: VOLTAGE MONITORS

ELECTROSTATIC ANALYZERS, PROTON SYSTEM: VOLTAGE MONITORS

ELECTROSTATIC ANALYZERS: VOLTAGE MONITORS

ELECTROSTATIC ANALYZERS: THERMOMETER CALIBRATION

PROTON SPECTROMETER: LOW ENERGY CHANNEL ENERGY CALIBRATION

PROTON SPECTROMETER: LOW ENERGY CHANNEL, CRM CALIBRATION

PROTON SPECTROMETER: HIGH ENERGY CHANNEL ENERGY CALIBRATION

PROTON SPECTROMETER: VOLTAGE MONITORS

of calibration information not covered in the figures refers to the determination of the state N of the scaler output of the high energy proton channel from the signal voltage V read on pins 8, 17, 26, 35, 44 and 53 of the 1.0×60 commutator; the relationship is:

$$N = 7.40 (V - 0.58)$$

3. Figures 3-25 through 3-29 pertain to the electron scintillation spectrometer.
4. Figures 3-30 and 3-31 refer to the Geiger counter.
5. Figures 3-32 and 3-33, and Tables 3-3 and 3-4 give magnetometer calibrations.

Some of the curves were presented earlier in Section 2; they are duplicated here for convenience.

ELECTRON SPECTROMETER : ENERGY CALIBRATION

ELECTRON SPECTROMETER: CRM CALIBRATION

ELECTRON SPECTROMETER: RATE OF ENERGY DEPOSITION CALIBRATION

ELECTRON SPECTROMETER: VOLTAGE MONITORS

3-28

ELECTRON SPECTROMETER: THERMOMETER CALIBRATION

GEIGER COUNTER: CRM CALIBRATION

GEIGER COUNTER: VOLTAGE MONITORS

TYPICAL CALIBRATION CURVE, RAM-5C MAGNETOMETER

SERIAL No. 55

TYPICAL CALIBRATION CURVE, MND-5C200 MAGNETOMETER

SERIAL No. 30

TABLE 3-3CALIBRATION OF RAM-5C MAGNETOMETERS

Magnetic Field in Milligauss	Output Signals in Volts DC		
	Ser #29 Axis X	Ser #32 Axis Y	Ser #55 Axis Z
600	4.80	4.79	4.81
561	4.65	4.64	4.67
497	4.41	4.40	4.43
432	4.15	4.14	4.16
367	3.88	3.86	3.88
324	3.69	3.67	3.69
259	3.42	3.40	3.42
216	3.23	3.23	3.23
130	2.88	2.87	2.88
64.8	2.63	2.63	2.64
0	2.40	2.40	2.40
-64.8	2.16	2.17	2.16
-130	1.91	1.92	1.91
-216	1.56	1.58	1.57
-259	1.37	1.39	1.38
-324	1.10	1.12	1.12
-367	.92	.94	.93
-432	.65	.67	.65
-497	.39	.41	.38
-561	.15	.16	.13
-600	.00	.02	-.02

TABLE 3-4

CALIBRATION OF MND-5C200 MAGNETOMETERS

Magnetic Field in Milligauss	Output Signals in Volts DC		
	Ser #32 Axis X	Ser #31 Axis Y	Ser #30 Axis Z
200	4.721	4.855	4.736
175	4.431	4.554	4.444
150	4.107	4.242	4.146
125	3.825	3.938	3.855
100	3.533	3.612	3.559
75	3.236	3.299	3.268
50	2.946	2.990	2.980
25	2.646	2.679	2.680
0	2.365	2.381	2.393
-25	2.070	2.090	2.103
-50	1.777	1.779	1.798
-75	1.489	1.470	1.511
-100	1.194	1.161	1.219
-125	0.902	0.849	0.923
-150	0.605	0.547	0.632
-175	0.320	0.212	0.322
-200	0.031	-0.083	0.040

4.0 GENERAL METHODS OF DATA HANDLING AND ANALYSIS

4.1 Generation of Binary Working Tapes

The raw satellite data (either dumped from the satellite-borne tape recorder or given in real time) were telemetered to ground stations upon command, and recorded on magnetic tape in the usual way. These telemetry tapes were subsequently sent to Aerospace Corporation, California, for further processing. This processing involved the translation of the data from frequency modulated signals into digital form compatible with the IBM 7090. The format of these digitized tapes is described in Document 63.1957.8-021, dated 25 January 1963, from the Data Reduction and Analysis Section of Aerospace Corporation. Digitized tapes were then transmitted to ASE for analysis.

Satellite ephemeris information was given to ASE on separate tapes, also IBM compatible, by the 6594th Aerospace Test Wing. The format of these ephemeris tapes is described in LMSC Program Documentation 75172AA, LMSC 656536.

To facilitate data reduction and analysis, ASE developed a computer program for generating a single binary "working tape" from a pair of digitized data and ephemeris tapes. The program normalizes and formats the raw data; assigns universal and systems times to each data word; merges the ephemeris data by correlating universal time; indicates the quality of data based on noise and consistency criteria; and computes (B, L) coordinates using a sub-routine developed by McIlwain. It is possible to use any magnetic field model in the

(B, L) program, but the Jensen and Cain (1960 epoch) model was used in this case. This working tape also permits computer-print out of data suitable for quick look purposes; instrument outputs are given, decommutated, in volts of analog signal - thus calibration curves must be subsequently used. This program is flexible enough to be easily adapted to meet data reduction requirements for any satellite with a telemetry system similar to 1963-25B. Details on the program are given in ASE publication number ASE-470, dated 29 November 1963, entitled, "IBM 7090 Program to Process Digitized Data Tapes from Satellite 1963-25B."

So far, data analysis has utilized print-outs of the working tapes. A further program is under development for generating "reduced data tapes" from working tape inputs; this is described in Section 4.3.

4.2 Energy Spectra and Pitch Angle Distributions

As pointed out earlier, the reduced data of primary interest are energy spectra and pitch angle distributions; from these all other physical parameters that characterize particles in the magnetosphere may be derived.

The term "energy spectra" is used in this report in two senses. One sense refers to the unidirectional intensity $j(E)$ (units: particles/sec cm² ster) of particles of energies greater than some threshold energy E (in Mev) as a function of E ; in cases where ambiguity may arise, such spectra may be further qualified by the word "integral". Spectra obtained from the proton scintillation spectrometer and the electron scintillation spectrometer are of this type. A constant pitch angle θ is implied in such spectra. The second sense refers to the energy derivative of the unidirectional intensity dj/dE (units: particles/sec cm² ster kev) of particles of mean energy E (in kev) as a function

of E ; in cases of ambiguity, such spectra may be called "differential energy spectra". The two electrostatic analyzers yield spectra of this type. Again, a constant pitch angle is implied.

Uncertainties in determining E may arise from two sources: the resolution capabilities of the instrument and telemetry signal noise. The resolution of the various instruments is indicated in the energy calibration curves presented earlier, and in all cases is the dominant factor in determining such uncertainty, since data which is too noisy is rejected. A possible source of systematic error in determining E is a change in photomultiplier (PM) gain. If such a change is due to PM high voltage supply drift it can be corrected by the application of Figure 4-1, which gives the multiplier to go from apparent to corrected energy as a function of change in PM high voltage. This curve was experimentally derived by averaging the effects measured in three photomultipliers.

Uncertainties in the measured value of j may also arise from two sources: fluctuations in the logarithmic count rate meters used to derive j due to fluctuations in j itself (governed by Poisson statistics) and uncertainties in reading the signal due to telemetry noise. The former is the predominant factor, although the latter (especially at high counting rates) is not negligible. Figure 4-2 is a universal curve for all instruments whose outputs are logarithmic count rate meters, giving the relative (RMS) error

$\sigma(j)/j$ in unidirectional intensity as a function of counting rate; the curve is universal because all count rate meters were essentially identical. Figure 4-2 was derived from the theory of counting rate meters, the experimentally observed telemetry noise, and instrument calibration curves.

UNIVERSAL CURVE FOR CORRECTING ENERGY OR RATE OF ENERGY DEPOSITION CALIBRATION CURVES FOR PM HIGH VOLTAGE DRIFT

RELATIVE ERRORS IN UNI-DIRECTIONAL FLUX: $\frac{\sigma(j)}{j}$

The electrostatic analyzer outputs were calibrated directly in terms of rate of energy deposition in the scintillator. To convert this to a function linearly proportional to the unidirectional intensity dj/dE , multiplication by an energy function $K(E, E_0)$, shown plotted in Figure 4-3, is necessary. This follows from the relation:

$$I = \int_{E - \frac{\Delta E}{2}}^{E + \frac{\Delta E}{2}} \frac{dR}{dE} dE (E + E_0) \approx \frac{dR}{dE} \Delta E (E + E_0) \\ \approx \frac{dR}{dE} (0.15E) (E + E_0)$$

whence

$$\frac{dR}{dE} \approx \frac{6.67}{E(E + E_0)} I = K(E, E_0) I$$

I is the rate of energy deposition in (kev/sec); dR/dE is the counting rate, particles/sec-kev; E_0 is the post-acceleration voltage; and $\Delta E/E = 0.15$ is the resolution of the instrument.

Uncertainties in the measured values of dj/dE arise for the same reasons as those in j . Figure 4-4 is a curve which gives the relative (RMS) error $[\sigma(dj/dE)]/[dj/dE]$ in the energy derivative of the unidirectional intensity dj/dE as a function of dj/dE and E . The curves were derived from the theory of integrating circuits, experimentally observed telemetry noise, and the ESA rate of energy deposition calibration curves.

$K(E, E_0)$ FOR CONVERTING TO DIFFERENTIAL ENERGY SPECTRA

**RELATIVE ERRORS IN ENERGY-DERIVATIVE OF
UNI-DIRECTIONAL FLUX $\sigma/dj/dE$**

A "pitch angle distribution" as the term is used in this report refers to the unidirectional intensity $j(E)$ (units: particles/sec-cm²-ster) of particles of some implied constant energy interval ΔE about an energy threshold E as a function of the particle pitch angle θ i.e., the angle between the detected particle velocity (therefore the detector vector) and the magnetic field. The minimum energy interval ΔE would be the energy resolution of the instrument; ΔE is somewhat larger than this in practice since E changes in the time required to sweep over the pitch angle range. The range of pitch angles that can be covered in one or two satellite spins (over which time interval ΔE is usually still within the instrumental resolution) is almost always limited because the satellite is spin stabilized. Only when the spin axis is perpendicular to the magnetic field is the full range 0 to 180 covered; when the spin axis is parallel or anti-parallel to the field, only $\theta = 90^\circ$ is viewed; at intermediate angles α between the spin axis and the field, only a range $(90 - \alpha)$ to $(90 + \alpha)$ is covered. Consequently, pitch angle distributions obtained will seldom be complete.

Pitch angles are derived from magnetometer data. The problem resolves to the determination of the angle between the appropriate magnetometer at any time and the magnetic field, and its cosine is therefore directly measured by the ratio of the measured magnetic field component to the magnitude of the field. Uncertainties in the determination of the pitch angle for a 3-axis system can be shown to be a function only of: the magnetometer sensitivity (i.e., signal change per unit field change); the magnitude of the field; telemetry noise, i.e., uncertainties in reading out the magnetometer signal. It is not a function of the orientation of the field with respect to

the three magnetometer axes. Figure 4-5 is a graph of pitch angle uncertainties as a function of magnetic field strength for the two different magnetometer systems used under various conditions of telemetry signal reading accuracy. Here it would be well to point out that $\sigma(V)$, the RMS fluctuations (due to noise) in a constant signal is typically experimentally determined from the fluctuations in the so-called "1/2 cal" point of the commutator outputs, which should read a nominal 2.50 volts. $\sigma(V)$ was generally of the order of 0.015 volts in 1963-25B; hence this number has been frequently used in discussing errors. Figure 4-6 is a graph which gives the uncertainty in the determination of the cosine of the pitch angle as a function of the cosine, per 10° uncertainty in pitch angle. This curve is of interest since it is generally more useful to plot pitch angle distributions as a function of $\cos \theta$ rather than θ .

4.3 Omnidirectional Flux and Other Derivable Parameters

This section is essentially a formulary for deriving other physical parameters from the energy spectra and pitch angle distributions obtained as primary data from the instruments.

Section 1 pointed out that a complete pitch angle distribution of charged particles obtained at some point B in a given L shell leads to complete determination of the pitch angle distribution at some other point $B' > B$ in the same L shell. This statement assumes that the magnetic moment of a charged particle in the Earth's magnetic field is an adiabatic invariant and that there are no dissipative influences such as atmospheric scattering (Van Allen 1962). The transformation law is explicitly given by:

$$j(E, \theta', B', L) = j(E, \theta, B, L)$$

PITCH ANGLE ERRORS DUE TO MAGNETOMETER SIGNAL FLUCTUATIONS

ERRORS IN PITCH ANGLE COSINE

where the j 's are unidirectional intensities (particles/sec-cm²-ster) of charged particles of a given species of energy greater than some threshold E , and where the correspondence between θ' and θ is given by:

$$\frac{\sin^2 \theta'}{B'} = \frac{\sin^2 \theta}{B}$$

A similar expression holds for the differential energy spectra dj/dE .

The omnidirectional flux $J(E, B, L)$ may be calculated (under the same assumptions) by integrating over solid angle:

$$J(E, B, L) = 2\pi \int_0^\pi j(E, B, L, \theta) \sin \theta \, d\theta$$

The above equation may be rewritten as:

$$J(E, B, L) = 2\pi \int_{-1}^1 j(E, B, L, \cos \theta) \, d\cos \theta$$

Thus, if j is plotted as a function of $\cos \theta$ (instead of θ) J is linearly proportional to the area under the curve. Similar expressions hold for the energy derivatives, dJ/dE and dj/dE .

The density of particles of a given energy, $d\rho/dE$ (number/cm³-Mev) is derivable from dJ/dE by:

$$\frac{d\rho}{dE} = \frac{1}{v(E)} \frac{dJ}{dE} = \frac{1}{\beta(E)} \frac{1}{c} \frac{dJ}{dE}$$

where v is the particle velocity, and $\beta = v/c$. Thus, the density of all particles of a given species above an energy threshold E is

$$\rho(E) = \frac{1}{c} \int \frac{dI}{dE} \frac{dE}{\beta(E)}$$

For protons of energies less than 100 Mev or so, $\beta^2(E) \approx (2E/Mc^2)$ and

$$\rho(E) \approx \frac{1}{c} \int \frac{dI}{dE} \left[\frac{Mc^2}{2E} \right]^{1/2} dE$$

For high energy electrons, $\beta(e) \approx 1$ and

$$\rho(E) \approx \frac{1}{c} J(E)$$

The total population of particles of energies greater than E $N(E, L, \Delta L)$ in a belt of width ΔL about L may be found by integrating $\rho(E)$ throughout the belt:

$$N(E, L, \Delta L) = \int \rho(E, B, L, \bar{R}) d^3R$$

where $\bar{R}$ denotes position bounded by L , and $L + \Delta L$, and where d^3R is a volume element.

4.4 Final Reduced Data Tapes

American Science and Engineering, Inc. has been developing a computer program for the final reduction of data, suitable for almost any conceivable scheme of further analysis. This program, which utilizes the working tapes discussed above, at present is

about 80% coded and 40% checked out. The primary function of this final program is to catalog conveniently and efficiently the physically significant parameters derivable from instrumental data. Under this program, data obtained from a complete orbit (on working tapes) is sampled in pre-determined regions traversed by the satellite - such as the magnetic poles, apogee, perigee, the magnetic Equator and various L shells. The regions sampled are labeled with orbit number, geocentric, geodetic, geomagnetic, (R, λ) and (B, L) coordinates, and with the date-time interval of data acquisition. In each (B, L) interval, for all data points of each channel giving spectral information: the channel signal, count rate, unidirectional intensity, energy threshold, detected particle pitch angle and its cosine, and the corresponding pitch angle and cosine in the equatorial plane, are listed as functions of universal time. "Extrapolated" omnidirectional intensity, calculated from the unidirectional intensity averaged over each complete satellite spin, and again over the total time spent in the given (B, L) interval, are also listed. For all data points of each channel not giving detailed spectral information (such as the Geiger counter and electron scintillation spectrometer rate-of-energy deposition channels) similar listings are given with the exception of an energy threshold, and omnidirectional intensities or energy fluxes are given averaged over the whole (B, L) interval. Table 4-1, following, summarizes the relationship between some of the parameters which will appear on the reduced data tapes.

The above program uses sub-programs for folding in instrument calibration curves and geometrical factors for the conversion of detector signals into the various physically meaningful parameters; determining the satellite attitude relative to the magnetic field

CONVERSION TABLE FOR VARIOUS PHYSICAL PARAMETERS
MEASURED BY 1963-25B INSTRUMENTS

INSTRUMENT OR CHANNEL	COUNT RATE	UNI-DIRECT'L INTENSITY	OMNI-DIRECT'L INTENSITY	RATE OF EN'GY DEPOSITION	SPECTRAL DISTR. F	EN'GY DIFF'L UNI-DIR'L INT	EN'GY DIFF'L OMNI-DIR'L INT	RATE OF EN'GY DEPOSITION	UNI-DIRECT'L EN'GY FLUX	OMNI-DIRECT'L EN'GY FLUX	GEOM FACTORS
	R	j	J	I	dR/dE	dj/dE	dJ/dE	I	ε	Ε	(AΩ)
	$\frac{\text{counts}}{\text{sec}}$	$\frac{\text{particles}}{\text{cm}^2\text{-sec-sr}}$	$\frac{\text{particles}}{\text{cm}^2\text{-sec}}$	$\frac{\text{kev}}{\text{sec}}$	$\frac{\text{counts}}{\text{kev-sec}}$	$\frac{\text{particles}}{\text{cm}^2\text{-sec-sr-kev}}$	$\frac{\text{particles}}{\text{cm}^2\text{-sec-kev}}$	$\frac{\text{Mev}}{\text{sec}}$	$\frac{\text{Mev}}{\text{cm}^2\text{-sec-sr}}$	$\frac{\text{Mev}}{\text{cm}^2\text{-sec}}$	$\text{cm}^2\text{-sr}$
ESA-e	—	—	—	$I(E,\theta)$	$\frac{6.67}{E(E+10)} I^{(1)}$	$\frac{dR/dE}{0.198}$	$4\pi \left(\frac{dj}{dE}\right)_{av}^{(2)}$	—	—	—	0.198
ESA-p	—	—	—	$I(E,\theta)$	$\frac{6.67}{E^2} I^{(1)}$	$\frac{dR/dE}{0.198}$	$4\pi \left(\frac{dj}{dE}\right)_{av}^{(2)}$	—	—	—	
e SCINT	$R(E_{thr}, \theta)$	$\frac{R}{0.122}$	$4\pi \bar{j}^{(3)}$	—	—	—	—	$I(\theta)$	$\frac{I}{0.122}$	$4\pi \epsilon_{av}^{(4)}$	0.122
p _{Lo} SCINT	$R(E_{thr}, \theta)$	$\frac{R}{8.42 \times 10^{-4}}$	$4\pi \bar{j}^{(3)}$	—	—	—	—	—	—	—	8.42×10^{-4}
p _{Hi} SCINT	$R(E_{thr}, \theta)$	$\frac{R}{8.42 \times 10^{-4}}$	$4\pi j_{av}^{(2)}$	—	—	—	—	—	—	—	
GT	$R(\theta)$	$\frac{R}{1.0}$	$4\pi j_{av}^{(4)}$	—	—	—	—	—	—	—	1.0

- NOTES: 1. $K(E, E_0) \equiv \frac{6.67}{E(E+E_0)}$ is plotted
2. Average over a complete satellite spin within each commutator frame
3. $\bar{j} \equiv \frac{\int_{\pi/2-a}^{\pi/2+a} j d\Omega}{\int_{\pi/2-a}^{\pi/2+a} d\Omega}$ within each commutator frame
4. Average over a complete (B,L) bin
5. Define as the total no. of counts accumulated between successive data points divided by the time interval

(i.e., the pitch angle); the conversion of pitch angle at the (B, L) coordinates at which data was acquired to the corresponding pitch angle in the equatorial plane at (B_o, L) ; and integrating intensities or fluxes over pitch angle. At the present time, the overall data handling and buffering scheme, the pitch angle determination problem, and energy threshold determination (an interpolation problem) have been checked out and found to be satisfactory. This final reduced data program will thus allow the extraction of data - either as a digital printout or as an X-Y plot - for further analysis. For example, unidirectional intensity at "constant" pitch angle versus energy (i.e., an energy spectrum) in a given (B, L) interval can be conveniently extracted; similarly for unidirectional intensity at "constant" threshold energy versus pitch angle (i.e., an angular distribution). Iso-intensity contours are likewise easily derivable.

5.0 EXPERIMENTAL DATA

5.1 Catalog of Data Obtained

Data from 173 orbits were obtained during the useful life of the satellite 1963-25B. Of these, approximately 140 yielded data over complete orbits (stored for later playback on the satellite tape recorder). 38 orbits of tape recorded data and fragments of an additional 14 orbits of real time data have been received to date by ASE. Table 5-1 is a catalog of these orbits with times of data acquisition also given.

5.2 Presentation and Discussion of Some Preliminary Data *

Data collected on orbit 25 and telemetered on orbit 26 of the satellite were selected for a preliminary look since the data are of high quality with only a small amount rejected due to noise and other criteria. This orbit occurred on 4 July 1963 (UT).

Figure 5-1 describes orbit 25 by means of a dipole plot in McIlwain's B and L coordinates. The data begin at 400 seconds UT, at this time the satellite crossed the geographic Equator south-bound at an altitude of 4000 km, in the heart of the inner radiation belt. Apogee of 4133 km occurred at latitude 17°S , longitude 119°W at time 690 sec. The satellite then went through the outer belt and reached its most southerly point of 82°S , 41°W , altitude 2400 km, at 2850 sec. The satellite then traversed the outer belt and the horn of the inner belt, and intersected the Equator at 43°E at 4400 sec. Perigee of 340 km occurred at 17°N , 45°E , at 4680 sec. The

*This section is a revision of the previously released document ASE-503 and supercedes it.

TABLE 5-1
IN-HOUSE ORBITS

Ø #		RT Start		RT End		PB Start		PB End	
4	7/1	01.28.25	7/1	01.38.15					
5		03.36.42		03.46.45					
9	7/2	11.44.56	7/2	11.52.04					
10		13.55.30		13.59.38					
14		23.31.44		23.40.03					
20	7/3	12.02.38		12.11.58	7/3	10.03.51	7/3	12.02.59	
25		23.50.09	7/4	00.06.15		17.04.17		20.04.17	
26	7/4	01.48.25		02.01.52	7/4	00.06.15	7/4	01.48.20	
27		04.01.45		04.08.25		03.35.52		04.51.40	
31		12.20.27		12.30.03		01.51.40		03.35.52	
32		14.29.59		14.38.03					
37	7/5	02.05.05	7/5	02.35.11					
42		12.38.45		12.48.07	7/5	09.25.47	7/5	11.13.35	
43		14.47.55		14.56.29		08.13.35		09.25.47	
53	7/6	12.57.16	7/6	13.08.20	7/6	03.25.00	7/6	06.25.00	
54		15.07.49		15.14.35					
65	7/7	15.25.26	7/7	15.34.27	7/7	03.29.21	7/7	05.01.45	
69	7/8	00.43.30	7/8	01.13.51		18.29.55		21.29.55	
75		13.30.49		13.39.30	7/8	01.13.51	7/8	02.38.03	
85	7/9	11.38.11	7/9	11.48.07	7/9	02.09.43	7/9	05.09.43	
90		23.06.44		23.36.50		16.49.50		19.49.50	
96	7/10	11.56.08	7/10	12.07.09	7/10	05.19.19	7/10	08.19.19	
107	7/11	12.14.07	7/11	12.25.25		23.56.49	7/11	02.56.49	
112	7/12	00.01.45	7/12	00.20.33	7/11	14.32.46		17.32.46	
118		12.32.50		12.43.23	7/12	04.11.52	7/12	06.16.40	
119		14.42.31		14.50.35		03.16.40		04.11.52	
123	7/13	00.06.45	7/13	00.36.50		17.45.00		20.45.00	

TABLE 5-1 (Cont'd)

Ø #	RT Start		RT End		PB Start		PB End	
129	7/13	12.51.49	7/13	13.02.33	7/13	07.15.22	7/13	09.15.34
130		15.01.46		15.08.49		06.15.34		07.15.22
139	7/14	10.56.45	7/14	11.07.33	7/14	05.26.28	7/14	07.32.40
140		13.08.25		13.14.59		04.32.40		05.26.28
144		22.25.04		22.55.10		16.11.40		19.11.40
150	7/15	11.13.40	7/15	11.26.23	7/15	02.07.12	7/15	04.38.13
151		13.23.17		13.31.45		01.38.13		02.07.12
155		22.48.24		23.18.32				
162	7/16	13.43.25	7/16	13.52.20	7/16	04.58.42	7/16	05.42.06
172	7/17	11.51.45	7/17	12.03.55	7/17	05.22.44	7/17	08.22.44
204	7/20	10.33.22	7/20	10.43.23				
205		12.43.25		12.51.45				
220	7/21	22.28.25	7/21	22.54.19	7/21	19.06.40	7/21	22.06.40
226	7/22	11.10.05	7/22	11.20.03	7/22	01.50.07	7/22	04.50.07
238	7/23	13.36.45	7/23	13.45.05	7/23	02.55.00	7/23	03.39.00
350	8/2	21.40.04	8/2	22.10.57				
360	8/3	19.46.44	8/3	20.17.49				
371	8/4	20.00.04	8/4	20.30.48				
377	8/5	08.42.28	8/5	08.58.36	8/5	02.31.09	8/5	05.31.09
383		22.36.54		23.07.35		08.58.00		11.58.00
393	8/6	20.44.18	8/6	21.14.24	8/6	12.13.20	8/6	15.13.20
403	8/7	19.10.20	8/7	19.16.38	8/7	11.13.25	8/7	14.46.45
410	8/8	09.40.04	8/8	09.58.55	8/8	05.30.40	8/8	08.30.40
415		21.35.39		21.49.17		09.58.55		12.58.55
421	8/9	10.10.58	8/9	10.19.14		21.49.17	8/9	00.49.17

**ORBIT 25 IN B, L COORDINATES
SHOWING THE LOGARITHM OF THE COUNTING RATE
OF THE GEIGER TUBE
BY THE WIDTH OF THE SHADED LINE**

satellite maintained a low altitude in this portion of the orbit missing the inner belt, and passed through the horn of the outer belt at high latitude. The most northerly point was at 82°N , 126°E at 5775 sec. At this point the satellite was near the horizon and data transmission was terminated.

To give a qualitative picture of the gross aspects of the radiation in the magnetosphere, the orbit shown in Figure 5-1 has been shaded to a width that corresponds to the logarithm of the Geiger tube counting rate. The inner and outer belt regions and the slot between them are clearly distinguishable. Figure 5-1 also indicates the various regions for which energy spectra obtained from the instruments are presented. These selected regions are: I1 and I2 in the inner radiation belt; S1, S2 and S3 in the slot; O1, O2, O3 and O4 in the outer radiation belt; P in the polar region; and L at low altitude (perigee). Table 5-2 describes these regions and lists their B and L coordinates and other relevant data. To accumulate the spectra presented in the following sections a small region of the orbit, corresponding to less than a minute in flight time, was taken about the Universal Time indicated.

5.2.1 Geiger Counter

The data from the Geiger counter for orbit 25 are plotted as a function of time in Figure 5-2. Values of B and L, and the locations of the selected regions are indicated. The data points were obtained by plotting the counting rates from the Geiger tube for every fifth commutator frame (about 10 seconds), there being two data points per frame. The counting rates have not been corrected for the 40 microsecond dead-time of the tube, so that at the high rates there is appreciable loss of observed counts.

TABLE 5-2
 REGIONS SELECTED FOR DATA ANALYSIS
 Ø25, 4 July 1963

Location	Code	Universal Time (Seconds of Day)	B (Gauss)	L (Earth radii)	Altitude km	Latitude Geographic	Longitude
Inner Belt (heart)	I1	430	.071	1.64	4100	9°S	118°W
Inner Belt (horn)	I2	4020	.256	1.77	739	28°S	41°E
Slot	S1	1800	.121	2.90	3670	50°S	116°W
Slot	S2	3735	.240	3.03	1103	45°S	38°E
Slot	S3	5265	.405	2.95	663	58°N	52°E
Outer Belt	O1	2205	.151	4.33	3276	64°S	111°W
Outer Belt	O2	3525	.238	4.69	1410	57°S	35°E
Outer Belt	O3	5430	.389	5.18	849	68°N	59°E
Outer Belt	O4	6360	.228	4.81	2200	60°N	159°W
Polar	P	5820	.328	16.6	1385	82°N	144°E
Low Altitude	L	4695	.327	1.05	340	18°N	45°E

Note: Parameters shown correspond to those at the times shown. The data presented in this paper were obtained over a time spread of the order of ± 30 seconds about the times given above.

COUNTING RATE FROM THE GEIGER TUBE THROUGH ORBIT 25

For example, in the inner zone a rate of 1.7×10^4 counts per second is recorded but this represents a true corrected rate of 5.3×10^4 cps.

The Geiger tube is nominally sensitive to electrons of energy greater than 4 Mev. However, the efficiency will vary appreciably with energy even above this value. Lower energy electrons can also be counted from their bremsstrahlung, though at much lower efficiency. Figure 2-33 shown earlier, is a curve for the efficiency of this type of tube that was taken from a paper by O'Brien et al (1962) with slightly less shielding so that electrons of 1.6 Mev could penetrate. This curve still provides a good estimate of the efficiency of our detector as a function of electron energy, however.

The counting rate in Region I1, the inner belt, was 5.3×10^4 cps. We can compare this number with the value of about 6×10^3 cps seen by O'Brien et al (1962) from their detector on Explorer XII. Their data was at a radial distance of 14,000 km whereas ours was at 10,400 km; it would appear they were not quite in the region of highest counting rate. The curve in Figure 5-2 for the counting rate throughout the orbit behaves as expected. It is interesting to note how rapidly the counting rate drops at the edge of the horn of the inner belt, region I2, where it changes from 200 counts/sec to essentially zero in 40 seconds, corresponding to a distance of approximately 200 km along the orbit and 40 km in altitude.

5.2.2 Proton Electrostatic Analyzer

The proton electrostatic analyzer (ESA-p) uses a spherical capacitor to select proton energy and to direct the protons into an unshielded CsI(Tl) crystal on a photomultiplier for detection.

Although the deflection plates were blackened to reduce stray light into the photomultiplier, the detector was still light sensitive, and large spurious signals were generated each time the Sun was viewed. The detector output, plotted for the part of orbit 25 in darkness, is shown in Figure 5-3. There are still some sharp peaks that look like a light input. These may have been from the Moon, which was two days before the full at the time of the orbit 25. It is possible to discount the spurious signals since they are so sharp and relatively infrequent; when this is done, there do not seem to be any protons present in this part of the orbit. Some preliminary results for orbit 198, which occurred on 20 July 1963 the day of the new Moon, are shown in Figure 5-4. There are no spikes and the counting rate is almost constant throughout the energy sweep. This part of the orbit was in the inner belt at $B = 0.08$ and $L = 1.60$. The flatness of the plot suggests that the differential energy spectrum is of the form $dj/dE \sim E^{-2}$ particles/cm² ster sec kev in this region.

5.2.3 Electron Electrostatic Analyzer

The electron electrostatic analyzer (ESA-e) was sensitive to electrons of energy between about 10 kev and 100 kev. The voltage on the plates varied with about a 13 second period, during which time the complete energy range could be observed. The satellite spun at 68 rpm so that there is roll modulation of the signal as well as the energy modulation due to the sweeping voltage. This makes the analysis more complicated.

The data to be discussed were analyzed by taking the maximum value of the detector signal during the course of a roll and interpolating

ESA-P OUTPUT SIGNAL IN THE DARK, ORBIT 25

ESA-P OUTPUT SIGNAL IN THE DARK, ORBIT 198

the energy sweep to determine correct electron energy. Figure 5-5 shows the signal from the ESA-e plotted as a function of time for several commutator frames. The value of the energy sweep is also shown. The maximum of the detector signal measures the maximum unidirectional electron flux, but care must be used in attempting to derive an omnidirectional flux.

It appears that the ESA-e was also light sensitive, though to a much lesser degree than the ESA-p. This could be due to a pinhole in the very thin aluminum light shield over the scintillator which developed some time after launch. Figure 5-6 pertains to Region O1, in sunlight. The sharp spikes are attributed to a light leak since they are correlated with the satellite spin but not with the energy sweep. The spikes are superimposed on the roll modulation that was apparent in Figure 5-5. Where the particle flux into the ESA-e is large enough, the Sun signals may be masked; Figure 5-7, taken in Region I1, the heart of the inner belt, illustrates this.

Since the spikes from the Sun were so sharp, it was possible to discount them in many cases. This could not be done in every one of the regions described in Table 5-2 but worked out quite well for about half of them. The remaining maxima of the roll modulated data points were then converted to a rate of energy deposition spectrum (Figure 5-8 through 5-14) and then to a true differential energy spectrum using the equation:

$$dR/dE = \frac{6.67I}{E(E + 10)}$$

where I is the rate of energy deposition of energy in kev/sec, E is the energy in kev and dR/dE is in units of number of electrons/sec kev.

ESA-6 OUTPUT SIGNAL IN REGION I2
(IN THE DARK)

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5-6

**ESA -e OUTPUT SIGNAL IN REGION 01
(IN SUNLIGHT)**

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5-7

**ESA-e OUTPUT SIGNAL IN REGION I1
(IN SUNLIGHT)**

The energy spectra are also shown in Figures 5-8 through 5-14, where the conversion has been done for the smoothed curves through the data points. The curves for dR/dE have been collected in Figure 5-15 for convenient comparison. If the values of dR/dE are divided by $0.198 \text{ cm}^2 \text{ ster}$, the geometrical factor of the detector, the resulting values of dj/dE are in units of electrons/sec kev $\text{cm}^2 \text{ ster}$.

This method of treating data is open to some objection due to the subjective nature of the criteria for rejection of part of the data. These objections are recognized, but it seems preferable to get some idea of spectra in this preliminary examination rather than to reject too much.

The collected spectra in Figure 5-15 present several interesting features, the most striking of which are the maxima in the curves exhibited by the spectra I2 and S1 (and perhaps L). I2 is taken in the dark so there is no question of spurious light effects causing distortion. S1 was taken in the slot, and L at low altitude. The three curves of the outer belt, O1, O2 and O4, are of generally similar shape, with no turnover. There does not seem to be a simple correlation between turnover and altitude.

Spectra of low energy electrons are usually quite variable in shape. They are sometimes representable as a power law spectrum of the form $E^{-\gamma}$ and values of γ may range from 0 to 2 in the low magnetic latitude region below 60° and from 0 to 7 above 60° (see for example, O'Brien, Laughlin, et al (1962)). They are generally softer, (i.e., γ is larger) at higher latitudes. Our region I2 was at geographic latitude 28°S which is roughly 23°S magnetic latitude, so that a fairly flat spectrum would be expected on the basis of the cited reference. It is possible that such a

RATE OF ENERGY DEPOSITION I AND DIFFERENTIAL ENERGY SPECTRUM dR/dE FROM THE ESA-6 IN REGION L (LOW ALTITUDE)

RATE OF ENERGY DEPOSITION I AND DIFFERENTIAL ENERGY SPECTRUM dR/dE FROM THE ESA-6 IN REGION I1 (INNER BELT)

RATE OF ENERGY DEPOSITION I AND DIFFERENTIAL ENERGY SPECTRUM dR/dE FROM THE ESA-6 IN REGION I2 (INNER BELT)

RATE OF ENERGY DEPOSITION I AND DIFFERENTIAL ENERGY SPECTRUM dR/dE FROM THE ESA-6 IN REGION S1 (SLOT)

RATE OF ENERGY DEPOSITION I AND DIFFERENTIAL ENERGY SPECTRUM dR/dE FROM THE ESA- ϕ IN REGION O1 (OUTER BELT)

RATE OF ENERGY DEPOSITION I AND DIFFERENTIAL ENERGY SPECTRUM dR/dE FROM THE ESA-6 IN REGION O2 (OUTER BELT)

RATE OF ENERGY DEPOSITION I AND DIFFERENTIAL ENERGY SPECTRUM dR/dE , FROM THE ESA- $\bullet$ IN REGION 04 (OUTER BELT)

5-14

DIFFERENTIAL ENERGY SPECTRA OF ELECTRONS 15-100 kev

maximum as we have observed would not be detected by O'Brien et al since their spectrometer utilized two broad channels (40 - 60 kev and 80 - 110 kev) so that neither the resolution nor the energy span can compare with our detector. Hence, it would appear very desirable to pursue this feature through other orbits and locations to verify the existence of this turnover and to measure the low energy electron spectrum in the whole region sampled by this satellite.

5.2.4 Electron Scintillation Spectrometer

The electron scintillation spectrometer has two output channels as described in Section 2.3. One gives the integral of the number of electrons above a swept threshold, the other records the rate of deposition of energy.

The spectrometer output is shown in Figures 5-16 and 5-17 for thresholds of 1 and 2 Mev for the whole of orbit 25. This is the same type of plot that is shown in Figure 5-2 for the Geiger counter, which was sensitive to higher energy electrons. As expected, there is great similarity between these plots though the relative peak counting rates vary due to the difference in energy thresholds.

Integral energy spectra for the electrons in various parts of the orbit were derived from the output of this spectrometer. The data during each commutator frame (about 1 second) correspond roughly to the energy threshold indicated by the sweep monitor since the sweep period is about 17 seconds and the energy monitor point is in the middle of the frame. The maximum value of the spectrometer output during a frame was selected and plotted to correspond to the sweep threshold voltage. Trial graphs using

COUNTING RATE FROM THE ELECTRON SCINTILLATION SPECTROMETER
DUE TO ELECTRONS OF ENERGY GREATER THAN
1 MeV DURING ORBIT 25

**COUNTING RATE FROM THE ELECTRON SCINTILLATION SPECTROMETER
DUE TO ELECTRONS OF ENERGY GREATER THAN
2 MeV DURING ORBIT 25**

interpolation for the threshold voltage were tried, but differences in the spectra derived were not significant. Figures 5-18 through 5-21 are plots of the counting rate in this detector as a function of threshold energy for various locations in the orbit. There are three in the outer belt, three in the slot, two in the inner belt, one polar and one at low altitude. For ease of comparison, a curve was drawn through each of these plots, and the smoothed curves are shown in Figure 5-22. The ordinate has been converted to maximum unidirectional intensity on the assumption that all the detector signal is due to electrons entering the aperture of the detector. This plot shows a great qualitative difference between spectra obtained in the outer belt and those obtained elsewhere. The three curves for the outer belt are almost indistinguishable, and these spectra are much steeper than the others. The two spectra for the inner belt were taken one at the heart of the belt and the other at the horn; these spectra are remarkably similar in shape though differing in intensity by a factor of a hundred. Slot spectra as a class are also almost indistinguishable, and relatively flat.

The second channel of this instrument gave the rate of energy deposition in the scintillator for electrons above 0.15 Mev and protons above 5 Mev. Data for the first part of the orbit are shown in Figure 5-23 (compare this with the plot for the Geiger tube, Figure 5-2). The points were plotted every ten seconds, there being two points taken per frame, spaced about 0.5 seconds apart. The roll of the satellite affects the signals appreciably as can be seen from the fluctuations in the figure.

COUNTING RATE IN THE ELECTRON SCINTILLATION SPECTROMETER AS A FUNCTION OF THRESHOLD ENERGY FOR REGIONS I1, I2 AND S2

COUNTING RATE IN THE ELECTRON SCINTILLATION SPECTROMETER AS A FUNCTION OF THRESHOLD ENERGY FOR REGIONS O1, S1 AND L

COUNTING RATE IN THE ELECTRON SCINTILLATION SPECTROMETER AS A FUNCTION OF THRESHOLD ENERGY FOR REGIONS O2 AND S3

COUNTING RATE IN THE ELECTRON SCINTILLATION SPECTROMETER AS A FUNCTION OF THRESHOLD ENERGY FOR REGIONS P AND O4

ENERGY SPECTRA OF ELECTRONS 0.5 - 4 Mev

**RATE OF ENERGY DEPOSITION CHANNEL OF THE ELECTRON
SCINTILLATION SPECTROMETER DURING THE FIRST PART OF THE ORBIT**

5.2.5 Proton Scintillation Spectrometer

The proton spectrometer also had two output channels, one that measured the number of protons between a threshold and 5.5 Mev (the low energy channel), the other the number between another threshold and 130 Mev (the high energy channel).

Energy spectra from the low energy channel were derived by taking the maximum counting rate per commutator frame and plotting against the threshold energy. Due to the relative insensitivity of the detector, good spectra were obtained at only a few points in the orbit. Figures 5-24 and 5-25 show spectra for the heart of the inner belt, region 11; the horn of the inner belt, 12; the outer belt, 01; and the slot, S1. Smoothed curves through the data points are shown in Figures 5-26; the ordinate is the maximum unidirectional flux (on the assumption that all observed counts are due to protons entering the aperture of the detector). The threshold of sensitivity of this channel was about 5×10^4 protons/cm² sec ster; the maximum observed rates were two or three hundred times this figure at 1 Mev proton threshold.

The counting rate in the high energy proton channel was always very low except in the heart of the inner zone. In this region, 11, the number of counts occurring during 3/4 of a frame was read out, converted to counts per second from the frame rate and then to unidirectional intensity. These data are plotted in Figure 5-27 versus the threshold energy. The full range of the detector was not useful; points were obtained from 19 to 60 Mev. The lower limit of energy was set by the counting rate becoming so large that the scale-of-32 ran over an indeterminate number of times while the upper limit was due to lack of counts. The integral

INTEGRAL PROTON SPECTRA FROM THE PROTON SCINTILLATION SPECTROMETER FOR REGIONS I1 AND I2

INTEGRAL PROTON SPECTRA FROM THE PROTON SCINTILLATION SPECTROMETER FOR REGIONS S1 AND O1

PROTON ENERGY SPECTRA 1-4 Mev

INTEGRAL ENERGY SPECTRUM FROM THE HIGH ENERGY CHANNEL OF THE PROTON SCINTILLATION SPECTROMETER IN THE HEART OF THE INNER BELT (REGION 11)

spectrum for the number of protons that exceeded the threshold energy E , could be described by the expression $2.2 \times 10^{12} \times E^{-5.4}$ protons/sec cm^2 ster where E is in Mev.

We may compare this spectrum with that obtained by Freden and White (1959) for protons of energy between 75 and 100 Mev. Their differential energy spectrum was proportional to $E^{-1.8}$ which gives an integral spectrum proportional to $E^{-0.8}$. This is much flatter than we see. Naugle and Kniffen (1961), however, showed that the spectrum varies greatly with position and can be considerably steeper. Their differential spectra varied between $E^{-4.5}$ and $E^{-1.7}$ and the maximum number of protons of energy greater than 31 Mev was 190 protons/sec cm^2 ster which is to be compared with our number of 1.5×10^4 . Naugle and Kniffen observed at an altitude of about 1600 km at 20°N latitude so that they were on the edge of the inner zone. Their differential spectra can be converted to an integral spectrum for the number of protons above energy E described by $2 \times 10^6 E^{-3.5}$ in the range of 10 to 50 Mev. Our spectrum was $2.2 \times 10^{12} E^{-5.4}$ in the same units. Thus we would seem to have a very much higher counting rate.

The recent results of Imhof and Smith (1964) give (by interpolation of their data) an omnidirectional flux of about 7×10^3 protons/ cm^2 sec above an energy of 59 Mev at $B = 0.071$, $L = 1.64$. From our figure 5-27 we get an average unidirectional flux of 1×10^3 protons/ cm^2 sec ster at 59 Mev at the same B , L . This gives an omnidirectional flux of the order of 1.25×10^4 protons/ cm^2 sec if one assumes that the flux is fairly uniformly distributed in pitch angle. Thus the two observations are consistent in this respect. The spectra do not agree so well in detail. They found that the differential energy spectrum went as $E^{-3.2}$. However, perhaps not too much weight should be given to this point since their spectral information was obtained from three

threshold detectors, whereas ours was obtained by pulse height analysis, with much better resolution.

5.2.6 Internal Consistency of Results

The particle fluxes indicated by the several detectors in the satellite ought to be self-consistent so that it is interesting to try comparing them even at this early stage of the analysis. We will consider the data from the heart of the inner zone, region 11.

The true counting rate from the Geiger tube was 5.3×10^4 cps. The area x solid angle factor for this detector was $1 \text{ cm}^2 \text{ ster}$ and it had an efficiency for electrons above 4 Mev that varied from zero to perhaps 80% taking account of dead volume in the tube. Hence, the rate gives a flux of about 1.1×10^5 particles/sec $\text{cm}^2 \text{ ster}$, taking an average efficiency of 50%.

From the electron detector (Figure 5-22) the electron flux exceeding 4 Mev was 2×10^5 electrons/sec $\text{cm}^2 \text{ ster}$ and from the proton detector (Figure 5-27) the flux above 40 Mev was 4×10^3 protons/sec $\text{cm}^2 \text{ ster}$. Thus the proton flux was negligible compared with the electron flux and the two values of the electron flux above 4 Mev agree.

Now consider the rate of energy deposition channel of the electron detector. This yields (from Figure 5-23) a value of 5.5×10^5 Mev/sec which converts with the known geometrical factor of this instrument to a rate of 4.5×10^6 Mev/sec $\text{cm}^2 \text{ ster}$ for electrons of energy above 0.15 Mev and protons of energy greater than 5 Mev.

From the electron spectra measured we get 5×10^5 electrons/sec cm^2 ster at 0.5 Mev and 2×10^5 at 4 Mev so in this region we have about 5.3×10^5 Mev/sec cm^2 ster. Above 4 Mev we have to assume some kind of spectrum and an E^{-2} integral spectrum is quite reasonable. Integrating the energy deposited by this type of spectrum we get 1.6×10^6 Mev/sec cm^2 ster. Below 0.5 Mev we can extrapolate our spectrum and arrive at a contribution of roughly 1.5×10^5 Mev/sec cm^2 ster. So the energy deposited by the electrons can be estimated to be $(0.53 + 1.60 + 0.15) \times 10^6 = 2.3 \times 10^6$ Mev/sec cm^2 ster as compared with the measured value of 4.5×10^6 Mev/sec cm^2 ster.

While this can be considered good agreement under our approximations we should see if there is appreciable contribution from the protons. The spectrum obtained from the low energy proton detector is falling rapidly at its upper limit of 3 Mev but if we extrapolate (see Figure 5-28) we get a spectrum that gives the number of protons that exceed energy E as $2.0 \times 10^9 \times E^{-9.05}$. If we calculate the energy deposited by this spectrum of protons of energy above 5 Mev we get a total of 5.2×10^3 Mev/sec cm^2 ster. This is negligible. If we take the high energy proton spectrum which gives the number of protons above energy E as $2.2 \times 10^{12} \times E^{-5.4}$ (Figure 5-27) and calculate the energy deposited we get the inconsistent figure of 2.1×10^9 Mev/sec cm^2 ster. This gives us another reason for suspecting that the high energy proton data may be in error.

5.2.7 Recent Developments

Since the preceding sections have been written, some further analysis has been accomplished. This analysis reveals that the spectra obtained from 0.5 to 4 Mev electrons in regions L, II,

LOW ENERGY PROTON SPECTRUM FROM REGION I1 REPLOTTED ON LOGARITHMIC ENERGY SCALE

I2, S1, S2, S3, and P — that is, the relatively flat spectra — may be contaminated by electrons of energies exceeding 10 Mev which penetrate the shielding around the scintillator, and by bremsstrahlung produced by electrons of energy less than 10 Mev. This contamination was computed to account for (of the order of) one-half the counts observed. The nature of the first type of contamination is such as to leave the slope of the spectra practically unchanged, while the second would tend to increase the slope. The qualitative statements made concerning the 0.5 to 4 Mev spectra are therefore still valid.

The high energy (15 to 50 Mev) proton spectrum of regions I2, in Figure 5-27, may be significantly contaminated because of accidental coincidences arising from bremsstrahlung and high energy electrons. The effect of bremsstrahlung would be, as in the case of the 0.5 to 4 Mev electron spectra, to increase the slope of the observed spectrum, as well as its intercept, and this may be why the spectrum of Figure 5-27 is so steep.

Some 0.5 to 4 Mev electron and 1 to 4 Mev proton, pitch angle distributions have also been obtained; these were symmetric about maxima at 90° .

The most recent results on data analysis will be published in Space Research V., which will give the proceedings of the Fifth International Space Science Symposium, being held in Florence, Italy, 12 to 16 May 1964. This latter paper is included as Appendix I of this report.

6.0 RECOMMENDATIONS

6.1 Instrumentation

On the whole, the instrumentation proved satisfactory. There is no evidence of outright failure of any instrument, providing some measure of the ruggedness of the devices.

Yet there is certainly room for improvement - there are some shortcomings in all the instruments. Some of these were evident from the start of the program; compromises were made because of the extremely tight time schedules which had to be met. Other shortcomings did not become evident until data analysis was begun. The various ASE instruments are considered individually in the following.

6.1.1 Spectrometers in General

All spectrometers in the payload used continuously varying sweep voltages to affect spectral analysis. This complicates the analysis of pitch angle distributions. Future instruments will use staircase (discrete level) sweeps sync'd with appropriate commutators to perform spectral analysis in 8 or 16 discrete energy bins.

6.1.2 Electrostatic Analyzers in General

The upper limit of the dynamic range of these detectors could be diminished by a factor of 10 without saturating the measurement logic. It would be well at the same time perhaps to lower the limit of detection by the same factor of 10.

Both could be accomplished with no change in logic by increasing the geometrical factor, (area times solid angle) of the instrument.

In view of the extremely interesting data from the electron ESA, it now appears regrettable that a smaller solid angle of acceptance was not designed in, so that pitch angle distributions could be accurately measured. The present instrument views a fan-shaped segment of space approximately $9^{\circ} \times 80^{\circ}$; $9^{\circ} \times 9^{\circ}$ would be better for this purpose. Diminishing the solid angle by the above large factor would require that the detection area be increased to preserve sensitivity. This is difficult with the present design, but a new design (utilizing spherical octants instead of quadrants) combines large area with small solid angle and is presently being developed under a separate Air Force contract.

Detection sensitivity need not depend upon achieving large geometrical factors. Utilizing some new extremely low-noise photomultipliers, or perhaps open end electron multipliers, may provide the means of higher sensitivity.

6.1.3 Proton Electrostatic Analyzer

This proved the most disappointing of the instruments in that useful data could be acquired only in the dark. Its extreme sensitivity to light resulted from the use of an uncoated scintillator; any light opaque material covering the scintillator would have raised the proton energy detection threshold to something like 25 to 50 kev. In the early phases of this program attempts were made to utilize open-end electron multipliers, but gain stability presented a problem which could not be solved in the limited time available. Thus there is still no satisfactory proton spectrometer

for the energy range 5 to 100 kev in existence. It is strongly recommended that a research and development program for the construction of such an instrument be initiated.

6.1.4 Proton Scintillation Spectrometer

The upper limit of the dynamic range of the low energy (1 to 5 Mev) channel of this instrument appears to have been well chosen; in the heart of the inner belt, the counting rate came within a factor of 5 of this upper limit. A lower limit of sensitivity appears worthwhile however. The optimum way to achieve this would be to increase the detection area.

A logarithmic count rate meter in parallel with the scaler output of the high energy (7 to 120 Mev) channel seems desirable; in the present instrument, data was lost over the range 7 to 18 Mev in the heart of the inner belt because of scaler recycling.

A further shortcoming of the present instrument is its bulk. While not serious in the present case - payload capabilities of the P-11 were adequate - such bulk might exclude its use on other satellites. Solid state detectors would facilitate making smaller units. A solid state proton spectrometer for the range 0.3 to 5 Mev has already been developed under a separate Air Force contract. Some further development to extend the range to 100 Mev or so is required, although some thought has already been given to this problem.

The use of a solid state detector enables extending the energy detection threshold to 0.3 Mev. The present limit of 1.0 Mev was imposed by the characteristics of plastic scintillators (see Section 2.2).

6.1.5 Electron Scintillation Spectrometer

The upper limit of the dynamic range of the counting rate channel of this instrument appears to have been chosen a bit low in the heart of the inner belt, this limit was approached within 20% or so. There may be some resultant distortion of the spectra at high counting rates. A factor of 3 or so decrease in the geometrical factor of the instrument seems desirable.

The main shortcoming of this instrument, in retrospect, is its large angular opening, a full 25° cone, 0.15 steradian, resulting in poor resolution in pitch angle distribution measurements. Future instruments will use a smaller angle and a larger area.

A further disadvantage is perhaps its sensitivity to protons. Future instruments might profitably use a thin transmission (dE/dx) solid state detector in front of the scintillator to anticoincide out incident protons, identifiable by their large energy deposition in the dE/dx detector.

6.1.6 Geiger Counter

The chief shortcoming in this instrument was its directional sensitivity. One of the reasons for including it in the spacecraft was to obtain some direct measurement of omnidirectional fluxes; this was poorly achieved with the present instrument. Future instruments may benefit from arrays of similar Geiger counters connected in parallel to a common counting logic, or more safely, used independently. The shielding around the Geiger tube, equivalent to about a 4 Mev electron detection

threshold, appears to be about right if each Geiger tube is not to saturate in the heart of the inner belt.

6.1.7 Plasma Probe

The data obtained from the plasma probe proved virtually impossible to interpret because of the extremely wide angular field of view of the instrument. Future investigation of particles in the energy range 10's of ev's to few kev's might do well to utilize electrostatic analyzers of narrow angular apertures.

6.1.8 Magnetometers

The use of two conventional three-axis flux gate magnetometers of different sensitivities was, on the whole, satisfactory. The use of a single instrument of logarithmic response or a switching circuit between the two systems might be more satisfactory in requiring fewer data points.

6.2 Spacecraft

The mechanical aspects of the spacecraft proved satisfactory in general. Certain changes in the electrical system appear desirable however.

A basic error was made in the assignment of commutator data points to the various instruments; the magnetometers were sampled only once each per commutator frame. While preliminary analysis had shown that this would prove adequate for good pitch angle determinations, actual reduction of the magnetometer data showed it to be barely so. On future satellites, at least one of the flux gate magnetometers perpendicular to the satellite spin axis should be sampled four or more times per satellite spin.

This above compromise was made to allow a higher frequency of sampling of the outputs of the particle measuring instruments, since the data sampling rate of the existing telemetry system was barely adequate to meet the requirements of the particle instruments alone. The obvious solution of this problem is to increase data sampling rate capabilities of future P-11 satellites. This could be accomplished most simply, at some sacrifice of TM signal to noise ratio (which has not been a problem so far) by replacing the Channel A VCO and the 0.5 x 60 commutator feeding it by a Channel E VCO fed by a 2.0 x 60 commutator. The data sampling rate would thereby be doubled.

Magnetometers and satellite time reference generators should furthermore always be cross-strapped to all commutators used. Not only would this ensure partial success of the experiment if some one TM VCO or commutator were to fail, but this would also simplify data reduction by aiding time correlations between the data on the independent commutators.

Time correlation of data would be further facilitated by adding a saw-tooth output to the time reference generator (TRG) to interpolate between the levels of the least significant time channel of the TRG. This could be generated from the scalers inside the TRG itself, or by external auxiliary circuitry.

The command relay logic on board satellite 1963-25B failed some time after orbit 670, making it impossible subsequently to read in data to the tape recorder; only real time data acquisition was possible. The design of the logic should be re-examined and modified if necessary.

6.3 Data Analysis

Briefly, data reduction and analysis should continue.

Specific recommendations are to:

1. Maintain the program for deriving binary working tapes. These tapes will contain the merged satellite ephemeris and all normalized instrument data as functions of universal and systems times. All data on the tapes will be quality tested.

2. Complete the program for deriving the final reduced data tapes. These tapes will contain ephemeris and time information and for all instruments, listings of physically significant parameters such as unidirectional intensities, omnidirectional intensities, particle energies, local and equatorial pitch angles, etc., as functions of universal time selected from "interesting" regions of space. "Interesting" in this context means for example, in magnetic polar, equatorial, or anomalous regions; at satellite apogee or perigee; at various sample L shells (hearts of the inner and outer belts, the slot, those which once contained artificial radiation belts). These tapes will be in a format suitable for efficiently extracting the data in any combination of parameters, such as proton unidirectional intensity at constant pitch angle, at given (B, L) versus threshold energy.

3. Analyze proton and electron energy spectra for various regions of the magnetosphere.

4. Analyze proton and electron pitch angle distributions for various regions of the magnetosphere.

5. Investigate the temporal variations associated with the energy-angle distributions, in particular, those which may be correlated with solar activity.

6. Prepare iso-intensity contours of the magnetosphere for various times of interest.

6.4 Future Experiments

The electron electrostatic analyzer data examined so far shows many surprising aspects of the corpuscular radiation in the 10 to 100 kev energy region, not the least surprising of which is its prevalence. There are some indications that a similar statement may be made concerning the M.I.T. plasma probe data, which investigated the 30 ev to 5 kev energy range of protons and 30 ev to 200 ev range of electrons. This suggests that future satellites should concentrate on the investigation of kev particles. Very few measurements have been made in this region to date - all from rockets usually in the auroral regions - none from satellites. Analysis of the electron electrostatic analyzer data obtained from 1963-25B will rectify this situation to some extent, but there will remain the necessity for obtaining sufficient good data on the protons in the 10 to 100 kev region, and both electrons and protons below 10 kev.

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APPENDIX I

"MEASUREMENTS IN THE RADIATION BELTS FROM HITCH-HIKER I"

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MEASUREMENTS IN THE
RADIATION BELTS FROM
HITCH-HIKER I

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ABSTRACT

The Air Force sub-satellite Hitch-hiker I was launched into an elliptical polar orbit on 1 July 1963. The satellite carried a payload which included six radiation detection instruments for simultaneously investigating the energy spectra and angular distributions of protons and electrons in the Earth's magnetosphere over a broad range of energies. Data from an orbit of 4 July show qualitative differences in the structures of the radiation belts defined by the different energy bands investigated. Electrons of energies greater than 4 Mev (as detected by a Geiger counter) define two distinct zones with hearts at $L \sim 1.6$ and $L \sim 4.5$, with a pronounced slot between them at $L \sim 3.0$. Electrons of energies between 1 and 4 Mev behave similarly. Protons of energies between 1 and 4 Mev are also found to lie in two zones, congruent with the electron zones, but with the outer one not so well pronounced. Electrons of energies between 15 and 100 kev define a single zone, extending beyond $L \sim 6.9$, and with a heart around $L \sim 1.6$. Differential spectra of electrons from 15 to 100 kev, measured with a 15% resolution, exhibit maxima around 40 kev over an extensive region of the magnetosphere, $L < 4$, but monotonically decrease from 15 kev in regions beyond $L \sim 4$. Integral spectra of electrons from 0.5 to 4 Mev differ in the two zones: those of the outer zone are very steep, those of the inner, relatively flat. Integral spectra of protons from 1 to 4 Mev are all steep, and very similar in shape. Pitch angle distributions of the outer belt ($L \sim 4.3$) electrons (0.5 to 4 Mev) and protons (1 to 4 Mev) are symmetric about maxima at 90° .

INTRODUCTION

The Air Force sub-satellite Hitch-hiker I (1963-25B) was launched from a circular-orbiting Agena at 0850 PDT, 1 July 1963, into an elliptical polar orbit of 82.14° inclination. The initial orbital period was 132.6 minutes. Perigee was at 176 NM (326 km) at approximately 20° N latitude, and apogee was at 2240 NM (4150 km). Perigee advanced at a rate of approximately 1.7° /day southbound. The sub-satellite was spin stabilized at 68 rpm.

Hitch-hiker I carried a 42 lb. payload of instruments, developed partly by American Science and Engineering, Inc., and partly by Massachusetts Institute of Technology, Cosmic Ray Group, under the direction of the Air Force Cambridge Research Laboratories. The radiation detection instruments were capable of obtaining spectral information on electrons of energies from 30 ev to 4 Mev, and protons of energies from 30 ev to 120 Mev, with some gaps over these ranges. Pitch angle distributions could also be investigated. The sub-satellite had a PM/FM/FM telemetry system. Power was derived from batteries recharged by solar cells. Data could be acquired by real-time read-out, or by read-out of an on-board tape recorder capable of storing data from a time longer than the orbital period.

Data from over 170 orbits were obtained during the useful life (over three months) of this satellite. The data of this paper were

obtained from an early orbit (25). and deal primarily with energy spectra of 15 to 100 kev electrons, 0.5 to 4 Mev electrons, and 1 to 4 Mev protons. Pitch angle distributions of 0.5 to 4 Mev electrons and 1 to 4 Mev protons in the outer belt ($L \approx 4.3$) are also shown.

INSTRUMENTATION

The scientific payload consisted of the following six instruments for particle detection, the first five furnished by ASE, and the sixth by MIT.

1. An electron electrostatic analyzer for energies from 10 to 100 kev;
2. A proton scintillation spectrometer for 1.0 to 5.3 Mev in one mode, and 7.5 to 120 Mev in a second;
3. An electron scintillation spectrometer for energies from 0.3 to 4 Mev; this instrument also measured the rate of energy deposition of electrons of energies greater than 150 kev;
4. A Geiger counter, for electrons of energy greater than 4 Mev, and protons of energy greater than 40 Mev;
5. A proton electrostatic analyzer for energies from 10 to 100 kev;
6. A retarding potential plasma probe, for protons of energies from 30 ev to 6 kev, and electrons from 30 ev to 200 ev.

Two sets of 3-axis flux-gate magnetometers, one of range -200 to +200 milligauss, and the other of range -600 to +600 milligauss were used for pitch angle determination.

The data of this paper were derived from the first four instruments listed above. These are described in detail below.

Electrostatic Analyzer (Electrons)

The electrostatic analyzer used a quadrant of a spherical capacitor, to whose plates a linear high voltage sweep was applied, to accomplish spectral analysis. The transmitted electrons were post-accelerated and detected in a plastic scintillator with a photomultiplier (PM). Electronics fed by the PM measured its current, which was linearly proportional (after subtracting dark current) to the rate of energy deposition in the plastic. Particle fluxes were derived from this quantity and the electron energy.

The energy to which the flight analyzer was set at any time was found to depend linearly upon the voltages (of equal magnitude, positive and negative) applied to the plates. An electron gun, variable from 5 to 20 kev was used in this calibration. The plate voltage was measured by calibrated circuitry (the sweep monitor) whose output range was compatible with the spacecraft telemetry system. Energy-voltage linearity above 20 kev was assumed to derive the final calibration curve expressing particle energy as a function of sweep monitor signal. The flight instrument spanned the range 10 to 105 kev. The resolution was measured to be 15 percent full-width at half-maximum (FWHM) at 20 kev and was assumed constant over the full range; the resolution function dropped off very sharply beyond the half-width.

The PM current meter, which had a logarithmic response, was independently calibrated using a laboratory current source. The correspondence between the rate of energy deposition and current meter output was determined originally by a one-point normalization which used an accurately assayed Po^{210} source on the unshielded scintillator. An electron energy of 0.50 Mev was taken to be equivalent in light output to the 5.30 Mev Po^{210} alpha particle; this relation holds for anthracene⁽¹⁾ and was consistent with laboratory measurements on the plastic used.

Another electrostatic analyzer, identical to the flight instrument, was later calibrated using the 20 kev electron gun; results agreed with the Po^{210} calibration within the ± 6 percent RMS fluctuations expected for the flight instrument at the same flux levels. The dynamic range of the flight instrument's current meter corresponded to 4×10^4 (equivalent to the PM dark current) to 10^{10} kev/sec. The accuracy of the electron intensity (particles/cm² sec ster) derived from the current meter signal varied from a ± 30 percent RMS fluctuation at very low intensities (because of particle counting statistics) to a minimum of about ± 6 percent RMS fluctuations at higher intensities (because of telemetry signal variations). The magnitudes of fluctuations were calculated.

The angular aperture of the flight analyzer was measured to be $8\frac{1}{2}^\circ$ by 80° (FWHM); these values are consistent with the theoretical values expected from the spherical plate geometry. The area of the entrance aperture, determined by a rectangular hole in a grounded plane, was 1.18 cm^2 . The transmission of the spherical capacitor was measured to be 95 percent at normal incidence for a monoenergetic beam at the proper energy. The net geometrical factor of the instrument was calculated to be $0.198 \text{ cm}^2 \text{ ster}$ from these figures.

The electrons are post-accelerated by 10 kev. Thus, the rate of energy deposition I (kev/sec) measured by the instrument at an energy E (kev) is related to the electron energy differential flux dR/dE (electrons/sec-kev) by the expression

$$I = \int_{0.925E}^{1.075E} dE' (E' + 10) \frac{dR}{dE'} \approx 0.15E (E + 10) \frac{dR}{dE}$$

dR/dE may be related to an average energy-differential unidirectional intensity $\langle dj/dE \rangle$ (electrons/cm² sec ster kev) through the geometrical factor 0.198 cm² ster. The averaging is with respect to integration over the pitch angle range spanned by the fan-shaped angular field of view of the instrument. The resulting relation

$$\langle dj/dE \rangle = 33.7 I [E(E + 10)]^{-1}$$

was used in the reduction of the data of this paper.

The logarithmic current meter signal was sampled at 0.13 second intervals over 1.33 seconds of a nominally 2.00 second commutator period. The sweep monitor was sampled once per commutator period. The photomultiplier high voltage, post acceleration voltage, and B+ voltages, were also monitored to check proper instrument functioning.

Proton Scintillation Spectrometer

The proton scintillation spectrometer used a "phoswich" of 40 mg/cm² of Pilot "B" plastic scintillator (corresponding to the range of a 5.3 Mev proton or a 0.20 Mev electron) on 22.5 g/cm² of CsI(Tl) scintillator (corresponding to the range of a 130 Mev proton or a 50 Mev electron). The scintillators were shielded on the sides by steel, and on the back by a glass light pipe, to prevent penetration by electrons of energies less than 50 Mev, and protons of energies less than about 150 Mev. The scintillator light shield was 5000 Å aluminum, corresponding to a proton range of about 150 kev.

Pulse-shape discriminating logic separated the pulses arising from energy deposited in each of the scintillators. Pulses of sufficient amplitude from the plastic alone unattended by pulses from the CsI(Tl) (i.e., in anticoincidence) were predominantly due to protons of energies 1 to 5.3 Mev (with some contamination at lower energies due to straggling electrons or to bremsstrahlung) and were accepted for analysis in the "low energy proton channel". Pulses from the CsI(Tl) in coincidence with pulses of sufficient amplitude from the plastic (i.e., corresponding to a minimum dE/dx equivalent to a 0.80 Mev proton or a 0.21 Mev electron energy loss) could be due to protons of energies between 7.5 and 130 Mev or to accidental coincidences arising from electrons and bremsstrahlung and were accepted for analysis in the "high energy proton channel". This spectrometer was subjected to a flux of $10^5 - 3$ Mev electrons/cm² sec (from an electron Van de Graaff) with no measurable response in either channel; electrons of this energy at this flux level or resulting bremsstrahlung were therefore practically rejected from analysis.

Spectral information was derived by pulse height analysis. The pulse to be analyzed was fed to one input of a comparator, the other input of which was fed by a linear sweep (sawtooth) of about 16 seconds period. The comparator output signal repetition rate thus corresponded to fluxes of protons of energies greater than some threshold energy E , related to the sweep voltage.

Calibration of an energy scale of this spectrometer thus required determining the correspondence between the sweep voltage (monitored in flight) and the minimum particle energy sufficient to switch the comparator. Approximate calibrations were accomplished using

laboratory beta and alpha particle sources. Final calibration of the low energy channel was accomplished with the aid of a 1/2 to 4 Mev (variable) proton Van de Graaff accelerator. Final calibration of the high energy channel used the 180 Mev Harvard cyclotron; absorbers were placed in the beam to vary the incident proton energy. The resolution of the low energy channel was experimentally measured to vary from about $\pm 20\%$ at 1.5 Mev to about $\pm 4\%$ at 4.0 Mev. That of the high energy channel was measured to vary from about $\pm 23\%$ at 15 Mev to about $\pm 5\%$ at 120 Mev.

In the low energy channel, comparator output pulses were shaped and fed to a logarithmic count rate meter with a range of sensitivity from about 10 counts/sec to 1.5×10^5 counts/sec. The accuracy of the counting rate derived from the meter signal varied from about $\pm 28\%$ RMS fluctuations at 10 counts/sec to about $\pm 4\%$ at 10^5 counts/sec. The count rate meter was calibrated using a laboratory pulser of variable repetition rate; RMS fluctuations were calculated. In the high energy channel, comparator output pulses were fed to a scale-of-32 circuit, which in turn fed a binary-to-base-32 converter. Scaler state was therefore ultimately determined by one of 32 discrete voltage levels.

The entrance aperture was calculated from geometry to be a cone of 8° (FWHM); the corresponding solid angle was 1.6×10^{-2} steradians. The total geometrical factor (area times solid angle) was $A \Omega \approx 8.4 \times 10^{-4} \text{ cm}^2 \text{ ster}$. The absolute dynamic range of the low energy channel was from 1.4×10^4 to 2×10^8 particles/cm² sec ster. As a result of the telemetry sampling rate, the useful absolute dynamic range of the high energy channel was from 0 to about 4×10^5 particles/cm² sec ster. If $\Phi_p(E, \theta)$ is the

number of protons/cm² sec ster Mev, at pitch angle θ , and E the threshold energy in Mev, the low energy channel therefore measured (neglecting electron or bremsstrahlung contamination) a counting rate $R_L(E, \theta)$:

$$R_L(E, \theta) \approx A\Omega \int_E^{5.5} \Phi_P(E', \theta) dE'$$

$$= A\Omega [j_P(E, \theta) - j_P(5.5, \theta)]$$

where $j_P(E, \theta)$ is the unidirectional intensity of protons at pitch angle θ (in units of protons/cm² sec ster). The high energy channel measured (neglecting sources of accidental coincidences) a counting rate $R_H(E, \theta)$:

$$R_H(E, \theta) \approx A\Omega \int_E^{130} \Phi_P(E', \theta) dE'$$

$$= A\Omega [j_P(E, \theta) - j_P(130, \theta)]$$

The high and low energy proton channels were each sampled at 0.15 second intervals over 0.75 seconds of a 1.00 second commutator period. The sweep monitor, photomultiplier high voltage monitor, and B^+ power monitors were each sampled once per second.

Electron Scintillation Spectrometer

The instrument used a 2.5 gm/cm² Pilot "B" plastic scintillator for detection (equivalent to the range of a 5.0 Mev electron and a 55 Mev proton). The plastic scintillator was shielded on the sides

by steel, and on the back by a glass light pipe, against electrons of energies less than 10 Mev and protons of energy less than about 65 Mev. The scintillator light shield was 50 mg/cm^2 of aluminum (corresponding to the practical range of a 200 kev electron and a 5.0 Mev proton). Observed spectra might therefore be contaminated principally by protons of energy exceeding 5 Mev which enter the aperture proper, and by high energy electrons or bremsstrahlung which penetrate the shielding.

Spectral information was derived, as with the proton spectrometer, by pulse height analysis using a comparator and linear sweep. The output stage was a logarithmic count rate meter similar to that in the previous instrument, and similarly calibrated.

The energy calibration of this spectrometer employed laboratory radioactive sources for an approximate calibration, and a 0.5 to 3.0 Mev (variable) electron Van de Graaff accelerator for final calibration. The measured resolution varied from $\pm 15\%$ at 0.5 Mev to about $\pm 6\%$ at 3 Mev.

A second output channel of this spectrometer measured the rate of energy deposited by electrons of energies greater than 200 kev and protons of energies greater than 5 Mev. This channel was calibrated like the electrostatic analyzer, using the Po^{210} alpha particle source against the unshielded scintillator. The RMS fluctuations expected in the rate of energy deposition derived from the output signal of this channel was calculated to be of the order of $\pm 6\%$ at sufficiently high fluxes.

The entrance aperture was calculated to be a cone of about 25° (FWHM), corresponding to a solid angle of 0.15 steradians.

The total geometrical factor was $A \Omega \approx 0.12 \text{ cm}^2 \text{ ster}$. The absolute dynamic range of the counting rate channel was 6×10^4 to 10^6 particles/cm² sec ster.

The counting rate channel of this instrument therefore measured (neglecting radiation which penetrated the shielding) $R_e(E, \theta_o)$ defined by:

$$\begin{aligned} R_e(E, \theta_o) &= \int d(A \Omega) \int_E^\infty \Phi_e(E', \theta) dE' \\ &= \int j_e(E, \theta) d(A \Omega) \\ &\equiv A \Omega \langle j_e(E, \theta_o) \rangle \end{aligned}$$

where $d(A \Omega)$ is a function of θ , θ_o is the pitch angle corresponding to the axis of the detector's conical field of view, $\langle j_e(E, \theta_o) \rangle$ is unidirectional flux averaged over the entrance aperture of the instrument, other parameters are as defined before, and Φ_e is analogous to Φ_p . The rate of energy deposition channel measured (neglecting radiation which penetrated the shielding, and protons of energies greater than 55 Mev)

$$\begin{aligned} &\int d(A \Omega) \left[\int_{0.15}^5 E' \Phi_e(E', \theta) dE' \right. \\ &\quad + \int_5^\infty 5 \Phi_e(E', \theta) dE' \\ &\quad \left. + \int_5^{55} E' \Phi_p(E', \theta) dE' \right] \end{aligned}$$

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The counting rate channel was sampled at 0.15 second intervals over 0.75 seconds of a 1.00 second commutator period. The sweep monitor, photomultiplier high voltage monitor, and B^+ power monitors were each sampled once per second. The rate of energy deposition was sampled twice per second.

Geiger Counter

The Geiger counter used an Anton type 302 tube, shielded over one quarter of a sphere by approximately 2 g/cm^2 of aluminum (or equivalent), over an adjacent quarter of a sphere by approximately 6 g/cm^2 of aluminum, and over the remaining hemisphere by 10 or more g/cm^2 of material. Minimum detection thresholds are thus about 4 Mev for electrons and 40 Mev for protons. The net geometrical factor for this instrument was estimated to be about $1 \text{ cm}^2 \text{ ster}$ for these thresholds when mounted on the satellite.

The output stage of this counter was the usual logarithmic count rate meter, calibrated in the usual way. The Geiger tube dead time was measured to be 40 microseconds. The absolute dynamic range of the counter thus was from 10 to about 2×10^4 particles/ $\text{cm}^2 \text{ sec ster}$.

This instrument's counting rate R_G (at fluxes where saturation was negligible) thus measured:

$$R_G = \int d(A\Omega) \left[\int_4^\infty \Phi_e(E') dE' + \int_{40}^\infty \Phi_p(E') dE' \right]$$

The Geiger counter channel was read out at approximately 1 second intervals. The high voltage and B^+ voltages were also monitored.

DATA AND DISCUSSION

The data presented here were obtained from orbit 25 of 4 July 1963. Apogee of 4133 km occurred at 17°S latitude, 119°W longitude, at 0011:30 UT; perigee of 340 km occurred at 17°N latitude, 45°E longitude, at 0118:00 UT. Computers were extensively utilized in the data reduction.

Energy Spectra of Electrons, 15 to 100 kev

Figure 1 is a typical plot of the rate of energy deposition from the electrostatic analyzer as a function of Universal Time (UT, given in seconds of day). Also shown is the energy of accepted particles (open circles) as a function of UT. The variation in the signal produced by the satellite spin is clearly evident. The most surprising feature about this spin modulation is that only one maximum occurs per satellite spin period. (The spin period measured from telemetry radiation patterns is indicated in Figure 1). This implies (since the satellite spin precession was negligible) that the pitch angle distribution was asymmetric about 90° and that consequently electron precipitation into the atmosphere must have been occurring. The computer program for determining pitch angle from magnetometers on the satellite has not yet been completed, so detailed angular distribution analysis of the electrostatic analyzer cannot yet be presented.

Figures 2 and 3 present energy spectra acquired over the time interval 3340 to 4550 seconds. Ephemeris information pertaining to each spectrum is given in Table I. Two successive energy sweeps were analyzed for each spectrum shown, covering a time interval of about 25 seconds. The data points shown as solid and open circles are the

maximum values in $\langle dj/dE \rangle$ that were observed in each satellite revolution (analogous to the points marked M in Figure 1); no interpolation in $\langle dj/dE \rangle$ was attempted. The heavy dashed curve in Figure 2, Spectrum 1, indicates the $\langle dj/dE \rangle$ equivalent of the PM dark current as measured prior to launch. The light dashed curve indicates the $\langle dj/dE \rangle$ corresponding to the minimum current meter signal observed in the data analyzed; it therefore represents an upper limit to the PM dark current, if one allows the possibility of its changing. The data points corrected for PM dark current are indicated in the figures as vertical bars whose limits are the differences between the data points and the two dashed curves. Data points were plotted versus linearly interpolated values of the energy E. Because of this method of data treatment, the scatter of the data points is often greater than the RMS fluctuations (indicated in the figures for sample points) expected a priori.

The angle between the satellite spin axis and the Earth's magnetic field remained essentially constant throughout the time each spectrum was acquired and the maxima occurred at time intervals equal to the satellite spin period; the various $\langle dj/dE \rangle$ plotted therefore correspond to the same range of pitch angle. The energy dependence of dj/dE is thus investigated over an approximately constant range of pitch angles. It is not necessarily legitimate to compare spectra obtained from widely separated regions of space, however, since these will not all pertain to the same range of pitch angles. The following comments should be taken with reservation in view of these limitations.

The spectra of Figures 2 and 3 were obtained consecutively in time as the satellite cut through L shells at almost constant B (See

Table I for precise information). Spectra 1, 2, and 3 indicate a decrease in $\langle dj/dE \rangle$ with increasing energy E . Spectrum 4 shows $\langle dj/dE \rangle$ relatively flat with energy below about 40 kev. Spectrum 5 indicates a decrease in intensity below about 40 kev. The remaining spectra all exhibit this same characteristic below 40 kev. In addition Spectra 5 through 9 indicate a decrease above about 40 kev. As L decreases from 6.86 (Spectrum 1) to 1.73 (Spectrum 9) the differential spectrum above 40 kev flattens, while the integral spectrum (from 40 to 100 kev) increases. Thus, there is no slot at these energies. As L decreases from 1.73 (Spectrum 9) to 1.14 (Spectrum 12) the 40 to 100 kev integral spectrum decreases. Spectrum 14 shows a very sudden change in the spectrum over the time of one energy sweep. The qualitative aspects of these spectra are perhaps more evident in Figure 4, which is an isometric representation of $\langle dj/dE \rangle$ as a function of E and L .

The State University of Iowa (SUI) group - Frank, Laughlin, O'Brien, Rosser and Van Allen, have previously made measurements^{(2), (3), (4), (5), (6), (7)} from Injun I, Explorer XII, and Injun III satellites on electrons of the energy range above 40 kev. Using a two-channel magnetic spectrometer, covering about 40 to 60 kev in one channel, 80 to 110 in the other, they found^{(2), (3)} that outer belt omnidirectional intensities, within 20° of the geomagnetic Equator, were at most 10^8 particles/cm² sec and generally of the order of 10^7 particles/cm² sec in these ranges. These numbers can be compared with calculations based on the data of Spectrum 4 which represents the closest approach to the Equator while still in the outer belt. Assuming an isotropic angular distribution, an upper limit of about 6×10^6 particles/cm² sec over the range 40 to 60 kev, and about the same value over the range 80 to 110 kev are obtained. The numbers are not inconsistent when the complicated viewing geometry of the electrostatic analyzer is recalled. It is interesting to note that

the maximum intensities observed (Spectrum 9) lead to values of about 4×10^7 particles/cm² sec.

The SUI group also stated⁽²⁾ that a wide spread in spectral slopes from 40 to 100 kev could be deduced from their data (assuming a power law spectrum) and pointed out that there was a tendency to a steeper slope as L increased. The data of this paper, although taken in different regions of the magnetosphere, support this statement. The SUI^{(2), (4)} group furthermore obtained angular distributions of electrons of energy above 40 kev which conclusively showed dumping; as mentioned, the spin modulation of our electrostatic analyzer signals suggests that dumping must have been occurring during the acquisition of all spectra presented.

At 1000 km altitude, between magnetic latitudes 45° to 75°, the SUI magnetic spectrometer gave typical intensities of 10^6 particles/cm² sec ster in the 40 to 60 kev⁽⁵⁾ channel and about half this in the 80 to 110 kev channel, with maxima of 2×10^6 and 3×10^5 , respectively. Taking the data of our spectrum 6 (1090 km, magnetic latitude approximately 45°S), there results about 1.5×10^6 electrons/cm² sec ster for each range. The values are consistent. We may make some comparison with the data of the 213 Geiger tube flown on Injun I⁽⁵⁾ which gave typical intensities of 10^5 to 10^6 electrons/cm² sec ster with a peak of 4×10^6 , for electrons of energies exceeding 40 kev. Again using spectrum 6 and fitting an exponential shape $\langle dj/dE \rangle \approx 1.3 \times 10^5 \exp(-0.010E)$ above 40 kev, we obtain about 9×10^6 electrons/cm² sec ster for $E \geq 40$ kev, not inconsistent with the Geiger tube results in view of the assumption regarding the spectrum shape.

The maxima observed may simply be representative of the higher scattering cross sections in the atmosphere for lower energy particles.

Future analysis will therefore first concentrate on deriving pitch angle distributions to look for evidence of dumping in those regions where the maxima are exhibited.

Geiger Counter Data

The gross aspects of the more energetic radiation in the magnetosphere may be best illustrated by the Geiger counter results. The data are plotted as a function of time in Figure 5. Values of B and L and certain regions of interest are also indicated. The data points were obtained by plotting the counting rates from the Geiger tube for every fifth commutator frame (about a 10 second interval), there being two data points per frame. The counting rates have not been corrected for the 40 microsecond dead-time of the tube, so that the rate of 1.7×10^4 counts/sec recorded in the inner zone represents a true rate of about 5.6×10^4 counts/sec. This number can be compared with the value of about 6×10^3 counts/sec observed by O'Brien, et al (1962) ⁽⁵⁾ from their detector on Explorer XII. Their data was acquired at a radial distance of 14,000 km, whereas ours was at 10,400 km; it would appear that Explorer XII was not quite in the region of highest counting rate.

The inner belt (with heart around $L \approx 1.6$) the outer belt (with heart at $L \approx 4.5$) and the slot between them (at $L \approx 3.0$) are clearly distinguishable in Figure 5. The locations of the slot and the outer belt heart are at L values somewhat greater than those observed earlier ⁽⁸⁾. It is interesting to note how rapidly the counting rate drops at the edge of the inner belt, region 12, where it changes from 200 counts/sec to essentially zero in 40 seconds, corresponding to a distance of approximately 200 km along the orbit and 40 km in altitude.

Energy Spectra of Electrons, 0.5 to 4 Mev

Figure 6 is a plot of the unidirectional intensity $\langle j(E) \rangle$ derived from the electron scintillation spectrometer as a function of threshold energy, for various regions of the orbit: two in the outer belt, one in the slot and two in the inner belt (as defined by the Geiger tube counting rates). Pertinent ephemeris data are given in Table II. The maximum value of the spectrometer output which occurred during each frame is plotted versus the sweep threshold voltage, much in the same manner as for the electrostatic analyzer. Subsequent pitch angle analysis (see below) suggests that these maxima occur around 90° . Curves have been drawn through some of the points in the figure for ease of readability. Horizontal bars indicate the energy resolution (FWHM), and vertical bars give $\pm$ RMS fluctuations of the intensity readings.

Figure 6 exhibits great qualitative differences between spectra obtained in the outer belt and those obtained elsewhere. The two curves for the outer belt are almost indistinguishable, and these spectra are much steeper than the others. The two spectra for the inner belt were taken one at the heart, and the other at the fringe. They are remarkably similar in shape, although they differ in the intensity scale by a factor of a hundred. The slot spectrum is relatively flat, similar in shape to the inner belt spectra. All spectra may be reasonably well fit by an exponential law of the form $j(E) = j_0 \exp(-kE)$.

As pointed out earlier, spectra may be contaminated by: 1) protons of energy greater than 5 Mev which enter the aperture proper, 2) electrons of energies above 10 Mev which penetrate the shielding, and 3) bremsstrahlung which penetrates the shielding. If the proton spectra of Figure 7 (in the section following) are extrapolated to 5 Mev, the unidirectional intensity $j(E)$ may be estimated at about 10 protons/cm^2

sec ster. This is almost an order of magnitude below the limit of sensitivity of the electron spectrometer. In the second case, the fractional contamination may be defined as $f \equiv (A\Omega)_1 \langle j(E+10) \rangle / (A\Omega)_0 \langle j(E) \rangle$ where the ratio of geometrical factors $(A\Omega)_1 / (A\Omega)_0$ for the shielded sides and entrance aperture, respectively, is about 80. In the approximation that $\langle j(E) \rangle$ is an exponential function of E of the form $j_0 \exp(-kE)$, the contamination is independent of E , and a function of k only. The ratio f is equal to, or greater than, unity for k equal to, or less than, approximately 0.45 Mev^{-1} . Thus, such a contamination may be significant for the spectra obtained in regions I1, I2, and S1 but not for those of regions O1 or O2. Such a contamination, it will be noted, does not affect the slope of an exponential spectrum, but only its intercept. Contamination by bremsstrahlung is difficult to calculate, but approximations indicate that the counting rate from the bremsstrahlung background would be comparable to the counting rate from electrons entering the aperture proper in the cases of the relatively flat spectra from regions I1, I2 and S1, and negligible for the steep spectra from O1 or O2. Bremsstrahlung contamination affects the shape of the true spectrum, tending to make it steeper.

Thus, despite possible contamination of the I1, I2, and S1 spectra, the qualitative statements made above regarding spectral shape are valid. Caution must be exercised in accepting absolute intensities, however.

We may compare the intensities of electrons of energies above 4 Mev as measured by the Geiger counter and the spectrometer. The corrected counting rate from the Geiger tube was 5.6×10^4 cps in the heart of the inner belt. The geometrical factor for this detector was 1 cm^2 ster, and it had an efficiency for electrons above 4 Mev that varied from zero to perhaps 80%, taking account of dead volume in the tube. Hence, the rate gives an intensity of about 1.2×10^5 particles/sec cm^2 ster, using an average efficiency of 50%. From the electron spectrometer

(Figure 6) the electron flux in the heart of the inner belt exceeding 4 Mev was of the order of 10^5 electrons/sec cm^2 ster; the proton spectrometer data (see following section) imply that the proton flux was negligible compared with the electron flux, and the two values of the electron flux are therefore in good agreement.

Energy Spectra of Protons, 1 to 4 Mev

Energy spectra from the low energy channel were derived by taking the maximum unidirectional intensities occurring in each commutator frame and plotting against the threshold energy similar to the procedure used for electrons. These maxima have also been found to be around 90° (see following section). It must be recalled that the ordinates are $[j(E) - j(5.5)]$ and not simply $j(E)$. At very low energies, this quantity is very nearly $j(E)$, but as 5.5 Mev is approached, may differ considerably. Due to the relative insensitivity of the detector, good spectra were obtained at only a few regions of the orbit. Figure 7 shows spectra for regions I1, I2, S1, O1, and O2, described in Table II. The horizontal bars in Figure 7 indicate energy resolution (FWHM) and the vertical bars indicate $\pm$ RMS fluctuations in the intensity values. The lines in Figure 7 are drawn merely to aid in reading the graphs.

Figure 7 shows the spectrum from region O1 lying wholly above the spectrum from S1 for energies below 2 Mev. Thus, at these energies, protons apparently exhibit a two-belt structure, like electrons. High energy protons ($E > 60$ Mev) on the other hand, are essentially a single (inner) belt phenomenon⁽⁸⁾. The different spectra are similar in shape, and within statistical fluctuations appear to satisfy an exponential law, as did the 0.5 to 1 Mev electrons. The proton spectra are much

steeper than any of the electron spectra, however. It will further be noted that these protons predominate over electrons of comparable energy in the inner belt and slot, but that intensities of the two species of particles are comparable in the outer belt.

The spectra of Figure 7 are essentially free of contamination by electrons or bremsstrahlung. Calculations show that about 3% of electrons of energy 250 kev straggle sufficiently to deposit energy equivalent to a 1 Mev proton, about 2% of energy 400 kev, and about 1-1/2% of energy 1 Mev. If we use an intensity of 3×10^5 electrons/cm² sec ster as typical of these energies for the worst case (the electron spectrum for the region O1 as given in Figure 6) there results a contribution of about 10^4 electrons/cm² sec ster; this is at the threshold of sensitivity of the proton spectrometer. The contribution from bremsstrahlung was calculated to be equivalent to 3×10^4 protons/cm² sec for an incident flux of 10^5 electrons/cm² sec ster of energy greater than the proton equivalent threshold. If one pessimistically assumes that all the electron energy goes into bremsstrahlung, and that the shielding around the spectrometer provides no attenuation of the bremsstrahlung. There might thus be some effect at the tail (above 2.5 Mev) of the proton spectrum I1. Contamination of low energy proton spectra by protons of energies exceeding 130 Mev which penetrate the shielding would be significant (10% or more) only if the intensity at 130 Mev exceeded the intensity at the threshold by more than a factor of about 1.2×10^{-3} (taking account of geometrical factors). In view of the slopes of the low energy proton spectra in Figure 7 this seems extremely unlikely. The electron spectra of Figure 6 suggest that the 50 Mev intensity, even in the worst case of I1, is well below 1 particle/cm² sec ster. The 50 Mev electron intensity could be as high as 10 electrons/cm² sec ster and still be below the sensitivity threshold of the proton detector.

Some data on protons of energies between 15 and 50 Mev have been obtained, but analysis of these is not complete. Contamination of the spectrum by accidental coincidences, mentioned in an earlier section, seems to be a problem.

Pitch Angle Distributions

While the computer program for deriving pitch angle distributions has not yet been completed, and this phase of work is only in a preliminary stage, some results on 0.5 to 4 Mev electrons and 1 to 4 Mev protons are available. Pitch angle information was derived by analysis of the data from the high sensitivity magnetometer, which shared the same commutator as the two scintillation spectrometers.

Figure 8 gives distributions of electrons of various energies in the outer belt, $(B, L) \approx (0.150, 4.3)$, altitude about 3280 km, and Figure 9 gives distributions of protons in the same region. The energy interval characteristic of each distribution is indicated in the figures, and generally was of the order of the energy resolution of the instruments.

Within statistical limits, all curves exhibit symmetry about 90° with the maximum unidirectional intensity at 90° . Unfortunately, in this region the range of pitch angles which could be covered was limited from 30° to 150° (the angle between the satellite spin axis and magnetic field was 120°), so fluxes beyond the expected cutoffs of 30° and 150° could not be investigated. However, the trends of the curves suggest that the data are consistent with the theoretical cutoff imposed by the Earth's surface.

SUMMARY

The data and observations of the preceding sections may be synthesized to draw a qualitative picture of the structure of the Earth's radiation belts as they appeared on 4 July 1963. Details of the picture depend to a large extent upon the species and energies of the particles considered. Electrons of energies 15 to 100 kev defined a single belt, extending outward to at least $L \sim 6.9$. The heart of this belt lay around $L \sim 1.6$; beyond this, the energy integrated intensity decreased with increasing L . Electrons of energies 0.5 to 4 Mev (measured with the spectrometer) and of energies greater than 4 Mev (measured with the Geiger counter) on the other hand defined two distinct belts, with hearts at $L \sim 1.6$ and $L \sim 4.5$, with a pronounced slot at $L \sim 3.0$. Protons of energies between 1 and 4 Mev also defined two belts congruent with the higher energy electron belts, but the outer proton belt was not so well pronounced. Below 3 Mev, protons predominated in the inner belt and in the slot. In the region of the outer belt investigated, $L \sim 4.5$, proton and electron intensities were comparable.

The data of this paper gives for the first time well-resolved differential spectra of electrons over the energy range 15 to 100 kev. Maxima around 40 kev were exhibited by these spectra over the region of the magnetosphere, $L < 4$. For $L > 4$, the electron spectra decreased monotonically from 15 to 100 kev.

Integral spectra of electrons from 0.5 to 4 Mev remained similar within each belt. Spectra from the inner belt and the slot were relatively flat, very similar in shape, but differed in intensity by three orders of magnitude. Spectra from the outer belt were very steep compared to the former, and differed little from each other. The integral spectra of the 0.5 to 4 Mev electrons seemed to be fairly well described by an exponential law of the form $j_0 \exp(-kE)$ where k is a measure of the logarithmic slope.

Integral spectra of protons of energies from 1 to 4 Mev were all very similar in shape but differed in intensity by about 2 orders of magnitude. These spectra also seemed to be fairly well described by an exponential law. The logarithmic slopes observed for these spectra were greater than any of those observed in spectra of electrons of comparable energy.

Preliminary pitch angle distributions of electrons of energies 0.5 to 4 Mev, and of protons of energies 1 to 4 Mev, obtained in the outer belt, $L \sim 4.3$, were symmetric about intensity maxima at 90° . There was some indirect evidence that the 15 to 100 kev electron pitch angle distributions were asymmetric about 90° , implying dumping of such particles into the Earth's atmosphere.

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TABLE I

EPHEMERIS DATA: 15-100 KEV ELECTRON SPECTRA

Initial Values							Final Values					
Spectrum	Time (sec)	Lat. (deg)	Long. (deg)	Alt. (km)	B (gauss)	L	Time (sec)	Lat. (deg)	Long. (deg)	Alt. (km)	B (gauss)	L
1	3346.35	-66.2	29.6	1681.6	0.235	6.9	3371.37	-65.0	30.5	1643.0	0.235	6.5
2	3426.49	-62.3	32.2	1558.4	0.236	5.8	3449.71	-61.1	32.9	1522.9	0.237	5.5
3	3519.58	-57.5	34.5	1417.0	0.237	4.74	3543.06	-56.3	35.0	1381.7	0.238	4.51
4	3597.50	-53.4	36.0	1300.8	0.238	4.01	3623.00	-52.0	36.4	1263.3	0.239	3.81
5	3678.10	-48.9	37.2	1183.4	0.239	3.40	3703.10	-47.5	37.6	1147.8	0.240	3.23
6	3743.55	-45.2	38.1	1090.9	0.241	2.98	3769.11	-43.7	38.4	1055.5	0.241	2.84
7	3824.45	-40.4	39.0	980.7	0.243	2.54	3847.91	-39.0	39.2	949.7	0.244	2.43
28 8	3916.41	-34.9	39.8	862.2	0.248	2.14	3942.01	-33.3	40.0	830.6	0.250	2.04
9	4010.17	-29.0	40.5	750.2	0.255	1.80	4033.58	-27.5	40.7	723.9	0.257	1.73
10	4090.00	-23.8	41.1	663.2	0.262	1.58	4113.39	-22.2	41.2	639.3	0.264	1.52
11	4234.18	-14.1	42.0	528.4	0.272	1.28	4258.29	-12.5	42.1	509.0	0.274	1.24
12	4313.09	- 8.7	42.4	468.5	0.276	1.17	4337.11	- 7.0	42.6	452.3	0.278	1.14
13	4391.94	- 3.1	42.9	419.5	0.280	1.093	4416.12	- 1.4	43.0	406.6	0.282	1.078
14	4444.74	0.6	43.2	392.8	0.284	1.063	4469.02	2.4	43.3	382.3	0.286	1.052
15	4511.13	5.4	43.5	366.9	0.290	1.037	4535.57	7.1	43.7	359.5	0.293	1.030

Note: Longitude East is +

TABLE II EPHEMERIS DATA: 0.5 to 4 Mev Electron and 1 to 4 Mev Proton Spectra

		INITIAL VALUES						FINAL VALUES					
Region	Code	Time (sec)	Lat (deg)	Long (deg)	Alt (km)	B (gauss)	L	Time (sec)	Lat (deg)	Long (deg)	Alt (km)	B (gauss)	L
Inner Belt (Heart)	I1	404.93	-8.9	-118.8	4095.60	0.071	1.64	448.07	-10.2	-118.8	4105.3	0.071	1.64
Inner Belt (Fringe)	I2	4003.06	-29.4	40.5	758.4	0.255	1.83	4047.06	-26.6	40.8	709.0	0.258	1.69
Slot	S1	1789.21	-50.3	-116.3	3681.7	0.120	2.87	1833.29	-51.9	-116.0	3644.5	0.123	2.98
Outer Belt	O1	2176.54	-63.1	-111.8	3307.6	0.148	4.2	2221.15	-64.5	-110.5	3258.0	0.152	4.4
Outer Belt	O2	3494.36	-58.8	34.0	1455.1	0.237	5.0	3539.05	-56.5	34.9	1387.7	0.238	4.6

Note: Longitude East is +

RATE OF ENERGY DEPOSITION VARIATIONS

ELECTRON SPECTRA

$6.86 \leq L \leq 2.04$

Figure 2

ELECTRON SPECTRA

$$1.80 \leq L \leq 1.03$$

Figure 3

Figure 4

ELECTRON SPECTRA FOR VARIOUS L VALUES

COUNTING RATE FROM THE GEIGER TUBE THROUGH ORBIT 25

ELECTRON ENERGY SPECTRA 0.5 TO 4 Mev

Figure 6

PROTON ENERGY SPECTRA

1-4 Mev

Figure 7

ELECTRON PITCH ANGLE DISTRIBUTIONS IN OUTER BELT

Figure 8

PROTON PITCH ANGLE DISTRIBUTIONS IN OUTER BELT

<p>fit an $E^{-\gamma}$ law with $\gamma \approx 5.4$; between 1 and 4 Mev, the spectra monotonically decreased with energy but fit no simple law. There was some evidence of a slot in the belt structure at these energies. Geiger counter and electron spectrometer rate of energy deposition data illustrated belt profiles as expected, with distinct inner and outer zones with a well defined slot between them. Recommendations for future research from P-11 type satellites are presented.</p>		<p>fit an $E^{-\gamma}$ law with $\gamma \approx 5.4$; between 1 and 4 Mev, the spectra monotonically decreased with energy but fit no simple law. There was some evidence of a slot in the belt structure at these energies. Geiger counter and electron spectrometer rate of energy deposition data illustrated belt profiles as expected, with distinct inner and outer zones with a well defined slot between them. Recommendations for future research from P-11 type satellites are presented.</p>	
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SATELLITE by Dr. F. R. Paolini, et al. Air Force Cambridge
Research Laboratories, Bedford, Mass. Scientific Report —
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Unclassified Report

Three instrument packages were designed, developed, constructed, tested and calibrated for the purpose of investigating energy spectra and angular distributions of protons and electrons in the Earth's magnetosphere from a P-11 sub-satellite. The instrumentation is described in detail. One of the instrument packages was flown on Air Force Satellite 1963-25B, launched into orbit on 1 July 1963.

Some preliminary results on energy spectra obtained from early orbits are given. Above 0.5 Mev, the integral electron spectra decreased monotonically with energy, but the spectra obtained in the inner belt and "slot" were much flatter than those obtained in the outer belt. Between 10 and 100 kev, maxima in the differential spectra around 40 kev were observed in some regions of the inner belt. In this energy region the energy integrated intensity tended to decrease with increasing L beyond 1.6 — i.e., there was no distinct "slot". Between 18 and 60 Mev, in the inner belt around L ≈ 1.6, proton integral spectra

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4. Proton Integral Energy Spectra, 1 to 5 Mev, in the Earth's radiation belt.

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- II. Contract AF 19 (628) - 2392
- III. Dr. F. R. Paolini, et al.
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