NORTH-HOLLAND
PHYSICS
PUBLISHING

N/IMS

THE LOW ENERGY PARTICLE DETECTOR SLED (~ 30 keV–3.2 MeV) AND ITS PERFORMANCE ON THE PHOBOS MISSION TO MARS AND ITS MOONS

S. McKENNA-LAWLOR [1], V.V. AFONIN [2], K.I. GRINGAUZ [2], E. KEPPLER [3], E. KIRSCH [3], A. RICHTER [3], M. WITTE [3], D. O'SULLIVAN [4], A. THOMPSON [4], A.J. SOMOGYI [5], L. SZABO [5] and A. VARGA [5]

[1] *St. Patrick's College and Space Technology Ireland, Ltd., Industrial Park, St. Patrick's College, Maynooth, Co. Kildare, Ireland*
[2] *Space Research Institute, Moscow, USSR*
[3] *Max Planck Institut für Aeronomie, Lindau, FRG*
[4] *Dublin Institute for Advanced Studies, Dublin 4, Ireland*
[5] *Central Research Institute for Physics, Budapest, Hungary*

Received 25 May 1989

A low energy particle detector system (SLED) is described which was designed to measure the flux densities of electrons and ions in the energy range from ~ 30 keV to a few MeV in (a) the varying solar aspect angles and temperatures pertaining during the Cruise Phase of the Phobos Mission and (b) in the low temperature environment (reaching −25°C) pertaining during Mars Encounter. Representative data illustrating the excellent functioning of SLED during both phases of the mission are presented.

Reprinted from NUCLEAR INSTRUMENTS AND METHODS
IN PHYSICS RESEARCH A

Nuclear Instruments and Methods in Physics Research A290 (1990) 217-222
North-Holland

THE LOW ENERGY PARTICLE DETECTOR SLED (~ 30 keV-3.2 MeV) AND ITS PERFORMANCE ON THE PHOBOS MISSION TO MARS AND ITS MOONS

S. McKENNA-LAWLOR [1], V.V. AFONIN [2], K.I. GRINGAUZ [2], E. KEPPLER [3], E. KIRSCH [3], A. RICHTER [3], M. WITTE [3], D. O'SULLIVAN [4], A. THOMPSON [4], A.J. SOMOGYI [5], L. SZABO [5] and A. VARGA [5]

[1] *St. Patrick's College and Space Technology Ireland, Ltd., Industrial Park, St. Patrick's College, Maynooth, Co. Kildare, Ireland*
[2] *Space Research Institute, Moscow, USSR*
[3] *Max Planck Institut für Aeronomie, Lindau, FRG*
[4] *Dublin Institute for Advanced Studies, Dublin 4, Ireland*
[5] *Central Research Institute for Physics, Budapest, Hungary*

Received 25 May 1989

A low energy particle detector system (SLED) is described which was designed to measure the flux densities of electrons and ions in the energy range from ~ 30 keV to a few MeV in (a) the varying solar aspect angles and temperatures pertaining during the Cruise Phase of the Phobos Mission and (b) in the low temperature environment (reaching −25 ° C) pertaining during Mars Encounter. Representative data illustrating the excellent functioning of SLED during both phases of the mission are presented.

1. Introduction

The Phobos Mission to Mars and its Moons was launched during July 1988. It comprised two identical three-axis stabilized space probes, one backup to the other, launched into a transfer orbit to Mars and separated in time by five days.

The present paper provides a short technical description of the low energy particle detector system SLED, identical versions of which were flown aboard both spacecraft. Representative data recorded by both instruments are presented to illustrate the excellent performance of these devices in space.

2. Scientific objectives / preliminary results

The scientific objectives of SLED may be divided between Cruise Phase Science and Martian Science. The instrument also acted as an on-board monitor for payload instrumentation incorporating components which could be adversely affected by energetic particle radiation.

During the Cruise Phase, July 1988 to February 1989, SLED monitored the state of the interplanetary medium during a period when the characteristic signatures of co-rotating interaction regions which dominate periods of low solar activity were under gradual replacement by signatures characteristic of dynamic transient solar events. These data potentially provide an input to the Solar Interplanetary Variability Programme established by COSTEP to coordinate interdisciplinary studies of how one representative interplanetary state evolves into another during the transition from minimum to maximum solar activity. Preliminary results obtained using data recorded by SLED1 and SLED2 are contained in ref. [2].

SLED is the only particle detector operating in the range from ~ 30 keV to a few MeV ever dispatched to explore the Martian environment. Consequently, an important objective was to study interactions at the boundary layers inside and outside the Martian magnetosphere as well as to mount a pioneering search for trapped particle populations close to the planet. In a series of elliptical orbits about Mars in February 1989, pericentre 867 km, SLED recorded the presence of energetic particles (30 keV− < 350 keV:) deep in the Martian magnetosphere at an altitude above the planet of < 1000 km. A preliminary account of these data and their significance is contained in refs. [3] and [4].

3. The sensor system

The weight assigned to SLED was 1.55 kg; the power allocation was 0.7 W and the telemetry allocation 960 8-bit words per 20 m (corresponding to a bit rate of 0.8 bps).

Due to the weight constraint, the sensor was based on the well known principle of measuring the incoming

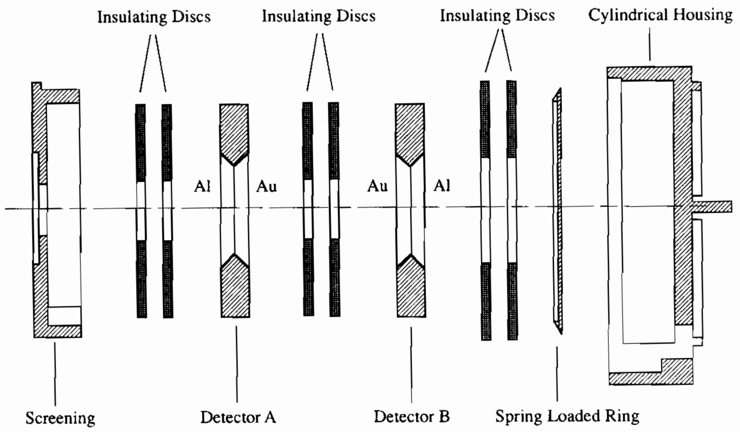

Fig. 1. Schematic drawing providing an exploded view of the detector mount.

fluxes (ions and electrons) in two telescopes, one of which was protected by a foil – the purpose of which was to prevent low energy ions from reaching the detectors while permitting the passage of electrons. The open telescope meanwhile recorded both ions and electrons above an energy threshold determined by detector noise. Count rate differences between the telescopes which were mounted to observe in the same direction, allow protons and electrons to be distinguished according to a method developed by Anderson et al. [1].

Fig. 1 shows the design of the telescope mount. For convenience the front and back detectors are, hereafter, referred to by the letters A and B respectively. The geometric factor of each telescope was 0.21 cm^2 sr. The absorber in front of detector A of Te2 was composed of 36 $\mu g/cm^2$ of Al and 479 $\mu g/cm^2$ of Mylar. Using a 30 keV threshold, this corresponded to $E > 350$ keV for protons (1.6 MeV for He; 8 MeV for oxygen). The unprotected detector simultaneously recorded electrons and low energy ions above an energy threshold of 30 keV.

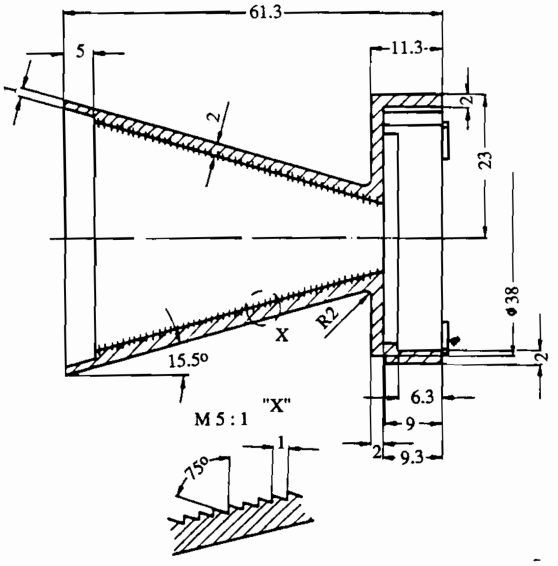

Fig. 2. Schematic drawing of the telescope showing a detail of the internal structure.

The overall configuration of the telescope is shown in fig. 2. The cylindrical compartment illustrated housed the detectors, which were shielded from low energy galactic cosmic ray radiation by a tantalum collar. The aperture had, as shown, an internal structure to reduce scattering of light and electrons. Furhter light protection was provided by a thin sheet metal helmet. The geometry was such that each telescope, with a 40° apex angle, was tilted in the ecliptic plane with respect to the spacecraft–Sun line by 55° to the west of the Sun (the garden hose angle).

The detector elements operated at about 50% overbias for radiation damage protection. The bias voltage, as well as necessary voltages for the analogue and digital electronics, were derived from a custom-built dc–dc converter which suitably transformed and rectified the 27 V supply provided by the spacecraft bus.

4. Analog/digital electronics

The front detector used four discriminators, thus providing four separate thresholds A1–A4, while the back detector used only one such threshold, B1. By appropriate coincidence/anticoincidence arrangements, six channels for each telescope were realized. Table 1 presents the channel specifications and discriminator logic and fig. 3 illustrates the detection principle. In the lower energy channels, anticoincidence signals from the back detectors were used in both telescopes to reject particles which penetrated the front detectors. It is noted that, in the case of Te2, Channel 4, the setting of

Table 1
Energy ranges and coincidence requirements

Telescope 1	(1)	A1 $\overline{A2}$ $\overline{B1}$	30–50 keV	ions + electrons
(without foil)	(2)	A2 $\overline{A3}$ $\overline{B1}$	50–200 kev	ions + electrons
	(3)	A3 $\overline{A4}$ $\overline{B1}$	200 keV–0.6 MeV	ions + electrons
	(4)	A4 $\overline{B1}$	0.6–3.2 MeV	ions
	(5)	A4 $\overline{A3}$ B1	$\geqslant$ 3.2 MeV	ions
	(6)	B1	background rate ($\geqslant$ 30 MeV)	
Telescope 2	(1)	A1 $\overline{A1}$ $\overline{B1}$	30–50 keV	"electrons" (350–400 keV ions)
(with foil)	(2)	A2 $\overline{A3}$ $\overline{B1}$	50–200 keV	"electrons" (400–500 keV ions)
	(3)	A3 $\overline{A4}$ $\overline{B1}$	200 keV–0.6 MeV	particles (500 keV–1 MeV ions)
	(4)	A4 $\overline{B1}$	0.8–3.2 MeV	ions
	(5)	A1 B1	> 3.2 MeV	ions
	(6)	B1	background rate ($\geq$ 30 MeV)	

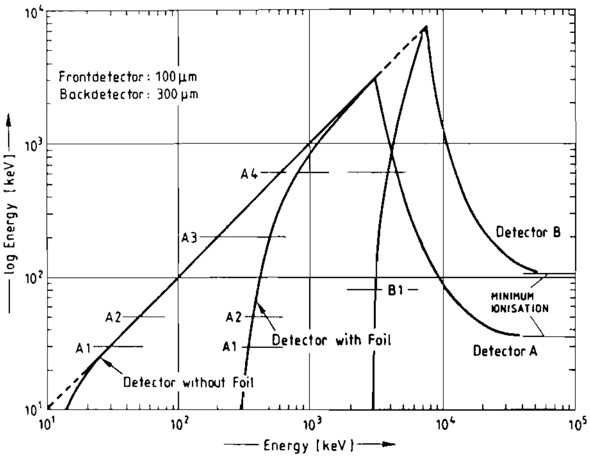

Fig. 3. Energy loss diagram for detectors A and B of SLED, showing the positions of individual discriminator thresholds.

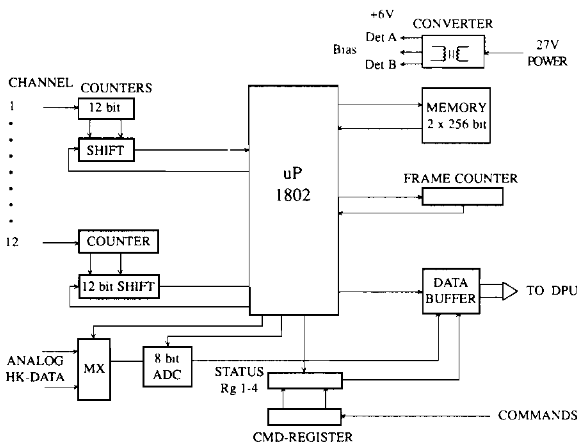

Fig. 5. Functional block diagram showing the digital electronic system.

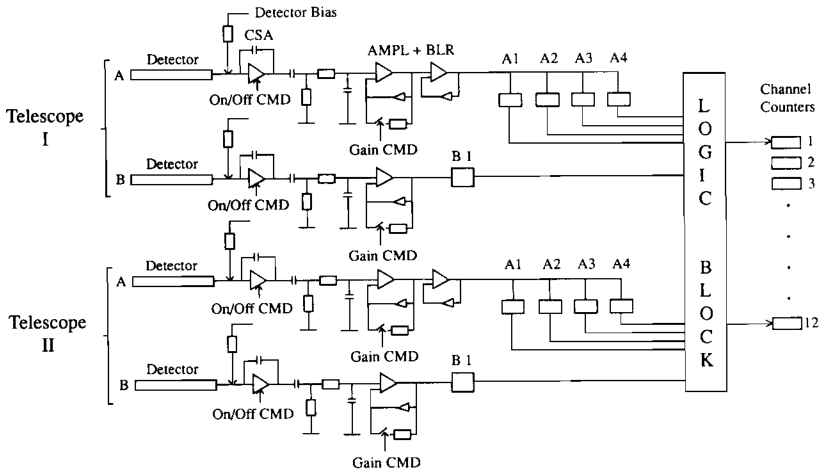

Fig. 4. Functional block diagram showing the analog electronic system.

the threshold at 600 keV effectively excluded electrons, thereby allowing two energy ranges for ions to be defined, namely 0.6–3.2 MeV in Te1 and 0.8–3.2 MeV in Te2.

The detector signals were amplified, following charge-to-voltage conversion, in hybrid amplifier chains with baseline restorer (restoration time < 10 μs) before classification by the discriminators, see fig. 4. The outputs from these discriminators, which comprised normalized pulses, were applied individually to the logic block. In order to handle expected fluxes of up to 10^5 counts/s, it was found necessary to utilise twelve 12-bit counters, the contents of which could be transferred in parallel into serial shift registers under microprocessor control (see fig. 5). The data were finally formatted into frames for transfer to the on-board data processing unit of the ESTER Complex (DPU-B) [5], which handled the eventual transfer of information to the spacecraft data handling and telemetry subsystem. Communication between SLED and the DPU-B was via a fast, bi-directional UART, all connections being made through optocouplers.

5. SLED software

The SLED software system had seven major tasks to perform, namely: (i) collection of scientific data, (ii) formatting these data, (iii) transmission of the data to the DPU-B, (iv) in-flight calibration, (v) memory dump of ROM, (vi) in-flight test procedures and (vii) device switching and control. These various tasks were controlled from the ground using a total of 23 commands, of which four were dedicated to data transmission.

The collection of scientific data entailed the reading of the scientific data cells (SDCs) every 40 ms and successively adding these measurements, over a 230 s integration period, to previous readings in internal memory locations.

A procedure to compress the 25-bit binary code data into a quasi-logarithmic coded 12-bit floating-point word, with a 5-bit exponent and a 7-bit mantissa, was then implemented. This data compression (and subsequent decompression on the ground) incurred a relative error of < 0.39%. The 12-bit compressed data cells (CDCs) were then coded as 8-bit words in SLED data frames (see below). Five such data frames, along with timing information supplied by the DPU-B, formed one data block of 960 bits every 20 minutes.

Fig. 6 shows the structure of a typical formatted SLED data frame, which consisted of 23 8-bit words. The first two words (AA55 HEX) provided a binary data pattern to synchronise the SLED and spacecraft computer serial data link (which ran at 153.6 kbaud). The next 18 words (144 bits) contained the reformatted data from the 12 event counters.

Word number 20 (HK) comprised a housekeeping data word. There were four housekeeping 8-bit measurements which respectively provided information on the electronic box temperature, the sensor housing temperature and on the primary and secondary current consumption. These data and the status byte (Word Number 21) which described the internal (i.e. software-controlled) operations of the instrument were each selected from four values and recurred with a periodicity of four.

In the first frame of a typical set, words 20 and 21 provided the sensor housing temperature and the functional status (FST); in the second frame they provided the box temperature and the command status (CMD); in the third frame, primary power consumption and the eight most significant bits of the experiment frame counter (EFC2) were given and in the fourth frame, the secondary power consumption and the least significant eight bits of the experiment frame counter (EFC1).

EFC1 was incremented every time a SLED data frame was processed by the DPU-B. Finally, word number 22 provided a check sum. If this check sum revealed an error, a command to repeat the readout of the data frame was automatically sent.

6. Hardware control and maintenance

Several diagnostic procedures were built in to test the performance of the instrument during flight. Among these, the In-Flight Calibration Mode involved sending a regular pattern to the counters, using an inbuilt pulse generator; the Memory Dump Mode involved transmitting the contents of the 2K ROM to Earth where it could be checked against a copy of the program in the ground support computer; the Test Mode involved performing five sequential tests on the hardware. All modes

Word #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Word	SYNC I	SYNC II	CH1	CH2		CH3	CH4		CH5	CH6		CH7	CH8		CH9	CH10		CH11	CH12		HK	ST	CK
HEX	AA	55	....																				

Fig. 6. General format of a SLED data frame.

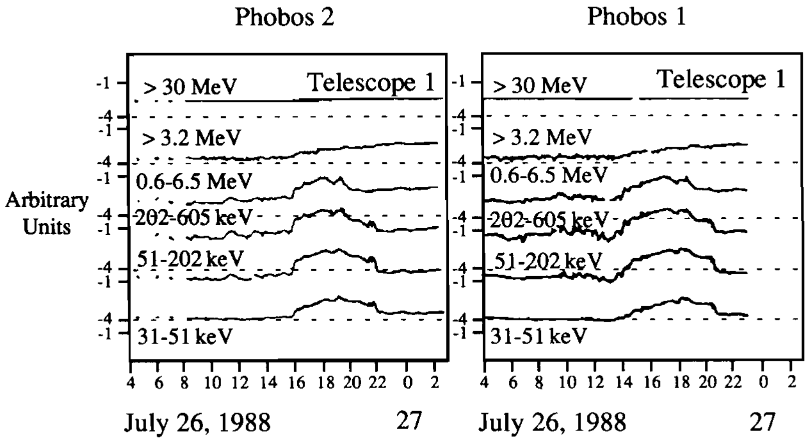

Fig. 7. A solar cosmic ray event recorded in the open telescopes of SLED1 (on Phobos 2) and SLED2 (on Phobos 1) during the Cruise Phase of the Phobos Mission on 26 July, 1988.

used the same basic format of the DTB and the same transmission operations procedure.

An additional task of the experiment software was concerned with the control and switching on/off of various components (amplifiers, discriminators, gain levels, etc.) In particular if, in the course of the experiment, the sensor temperature rose to the danger level for semiconductors (taken to be 28° C), the detector bias voltage would switch off automatically, with switch-on when the temperature fell to 25° C. This later procedure could be overridden by a ground command if necessary. In environmentally cold conditions, such as those pertaining in the shadow of Mars (see section 7), a heater on the telescope platform was similarly programmed to switch on (and off as required) automatically.

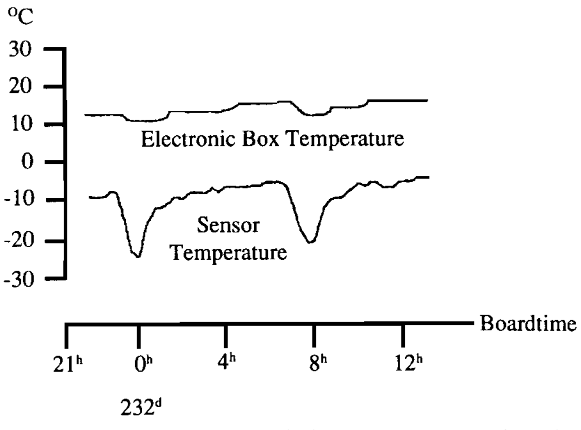

Fig. 8. Record of the electronic box temperature and of the sensor temperature of SLED1 obtained while Phobos 2 was performing circular orbits around Mars on spacecraft day 232 (5 March 1989) The consecutive temperature drops recorded denote successive passages of the instrument through the shadow of the planet.

7. In-flight performance

Two identical SLED instruments were launched on Phobos 1 and Phobos 2. Fig. 7 provides an example from 26 July 1988, in which the same solar cosmic ray event was recorded by each of these instruments in their open telescopes. The traces concerned are closely matched, and differences between the records may be attributed to the different positions in space (five days apart) at which particle sampling was made.

Throughout the mission, monitoring of the sensor temperature and of the electronic box temperature was maintained. Fig. 8 provides an example of these data taken in a circular orbit around Mars at an altitude of about 6330 km. Cyclic temperature decreases characterising each of these records reflect consecutive passages of the instrument through the shadow of Mars.

8. Conclusion

A light-weight dual-telescope particle detector system code-named SLED with the capability to monitor electron and ion fluxes within an energy range spanning several tens of keV to a few MeV has been designed for the Phobos Mission to Mars and its Moons. This instrument operated nominally during both the Cruise Phase and at Mars Encounter and has provided a wealth of high quality scientific data for downstream analysis.

It is presently planned that a further SLED instrument, having a mass of 3 kg, with telescopes viewing in four directions and with an energy range spanning the interval 30 keV–50 MeV will be flown on the Mars-94 Mission to further investigate the magnetospheric phenomena recorded by the highly successful prototype SLED instrument on Phobos.

Acknowledgements

The authors wish to thank the members of the Irish technical team, M. Martin and B. Jordan (electronics), D. Gleeson (mechanical interfacing) and N. Murphy (box fabrication) who input so many hours constructing and integrating the instrument. We also thank K. Fischer of MPAe Lindau, who, in particular, contributed to the design and fabrication of the telescope mount and to the electronic/environmental testing of the instrument. We further express sincere appreciation to K.H. Saeger and A. Loidl of MPAe, for valuable advice and cooperation and acknowledge essential financial support from the Irish National Board for Science and Technology (now incorporated into EOLAS) and from Space Technology Ireland, Ltd.

References

[1] K.A. Anderson, R.P. Lin, D.W. Potter and H.D. Heetderks, IEEE Trans. Geosci. GE-16 (1978) 183.

[2] S.M.P. McKenna-Lawlor et al., Interplanetary Variability in Particle Fluxes Recorded by the Low Energy Charged Particle Detector SLED (30 keV– > 3 MeV) During the Cruise Phase of the PHOBOS Mission to Mars and its Moons, submitted to Ann. Geophys. (1989).

[3] V.V. Afonin et al., Nature 341 (1989) 616.

[4] S.M.P. McKenna-Lawlor et al., Preliminary Results Obtained by the SLED Experiment During the Phobos Mission to Mars and its Moons, submitted to Ann. Geophys. (1989).

[5] V.V. Afonin et al., this issue, Nucl. Instr. and Meth. A290 (1990) 223.