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Cosmic Rays

COSMIC RAY STUDIES IN THE FIRST SPACE SHUTTLE—SPACELAB

S. BISWAS, F.N.A.

Tata Institute of Fundamental Research, Bombay 400 005

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Recent studies in spacecrafts in interplanetary and near-earth space revealed the presence of low energy cosmic ray heavy ions of unknown origin with strikingly different properties as compared to high energy cosmic rays. The measurements in the Skylab in the near-earth indicated that these heavy ions are probably in partly ionised states. In order to obtain new information on the origin of this anomalous component of cosmic rays, an experiment is under preparation for the first Space Shuttle, Spacelab Mission to study the ionisation states of low energy heavy ions of cosmic rays, their abundances, intensities and energy spectra. In this experiment, the arrival time and arrival direction of each of the ions of C to Fe in 5–100 MeV/N energy interval and their other properties are determined and from these, lower bounds of their magnetic rigidities are obtained. By combining these data with the momentum of the particles, their ionisation states are determined. In case of a solar event, the ionisation states of the solar particles are also measured. The design, fabrication, assembly and testing of the instrument are being done in India, following which it will be integrated with the First Spacelab for one week's space mission with Space Shuttle. A brief description of the experiment is presented here.

INTRODUCTION

HEAVY nuclei of galactic cosmic rays of energies less than 100 MeV/nucleon have been studied in detail only during the past five years in satellites and space probes and these studies revealed that these low energy cosmic ray nuclei have strikingly different properties as compared to high energy (>100 MeV/N) cosmic rays. This anomalous component, which was first discovered in interplanetary space in IMP and Pioneer 10 and 11 satellites (McDonald *et al.*, 1974; and Hovestadt *et al.*, 1973) was found to be composed of highly enhanced abundances of oxygen, nitrogen and neon ions, relative to carbon, as compared to high energy (>100 MeV/N) cosmic rays. In the interplanetary space, these measurements were made near 1 A.U. in IMP 6, 7 and 8, ISEE-3 satellites (Garcia-Munoz *et al.*, 1977; Hovestadt *et al.*, 1979; Klecker *et al.*, 1977; McKibben, 1977; Mewaldt *et al.*, 1975; and Webber *et al.*, 1975), and in deep interplanetary space from 1 to 19 A.U. in Pioneer 10–11 and Voyager 1–2 space probes (McDonald *et al.*, 1974; and Webber *et al.*, 1975, 1979). In near earth space, the anomalous component of low energy cosmic rays was measured in detail in the Skylab in 8–25 MeV/N interval by Biswas *et al* (1975*a*, *b*; 1977, 1979) and it was found that N, O and Ne abundances are highly enhanced relative to C, similar to those in interplanetary space; in addition Mg and Si ions were depleted. Skylab measurements indicated a very striking feature for the first time, that the ions of this anomalous component are most probably in partly ionised state, e.g., 0^{+1}, 0^{+2}, etc. in interplanetary space and in ion states such as 0^{+4}, 0^{+5}, etc. in the magnetosphere. Because the skylab measurements were made in the inner magnetosphere, the additional properties of the ion states of these anomalous components could be inferred from the rigidity filtering effect of the geomagnetic field. The recent observations and results from the Skylab have been reviewed in the paper by Biswas and Durgaprasad (1979). Fig. 1 shows the energy spectra of the anomalous oxygen ions which are highly enhanced in the low energy cosmic rays, measured in near earth space in Skylab by Biswas *et al.* (1979) and Biswas and Durgaprasad (1979) and in interplanetary space at about 1 A.U. by Klecker *et al.* (1977) and in deep space by McDonald *et al.* (1974). The peak in oxygen spectrum observed in Skylab at about 12 MeV/N is ascribed due to 0^{+4} ions by rigidity filtering effect of the earth's magnetic field.

The general picture which emerges from Skylab measurements seem to indicate that the interplanetary 0^{+1}, 0^{+2}, etc. ions of the low energy anomalous component enter the earth's field at high latitudes and these undergo stripping collisions in the upper atmosphere near the mirror points (Blake & Friesen,

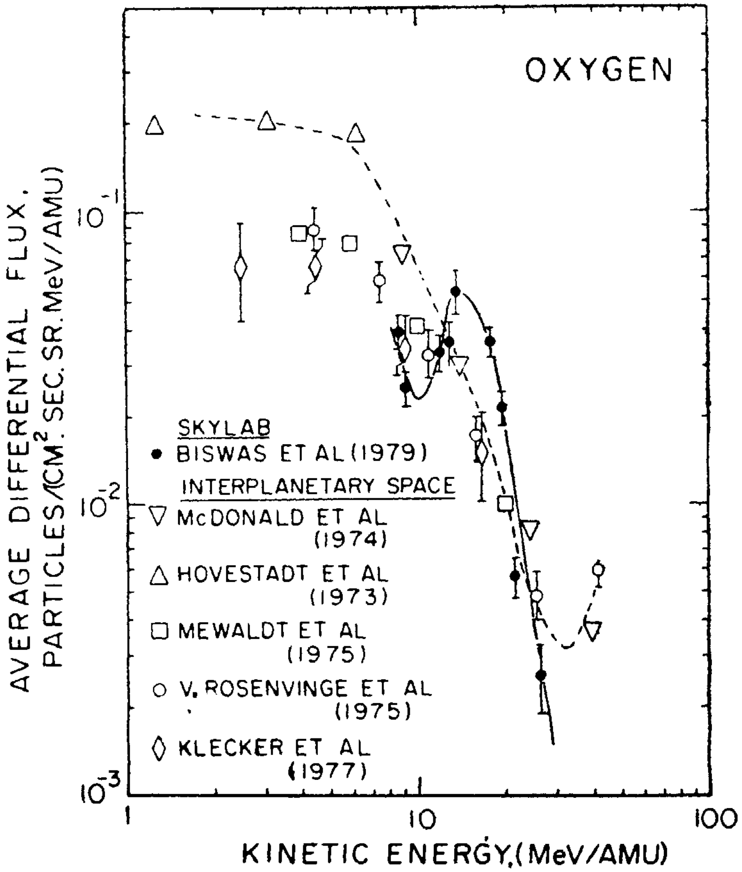


FIG. 1. Oxygen nuclei in the anomalous component of low energy cosmic rays measured in (*a*) Skylab in near earth space, and (*b*) interplanetary space.

1977) leading to temporarily trapped ions of 0^{+3}, 0^{+4}, etc. These have relatively short life time in the inner magnetosphere as these are rapidly lost by ionisation loss process.

The origin of the anomalous component is not fully understood at present. Fisk *et al.* (1974) proposed in 1974 a model to explain the interplanetary anomalous component in terms of neutral interstellar atoms swept into the solar cavity and being photoionised by solar UV and accelerated at the heliospheric boundary. This model predicts that enhanced flux should consist of singly ionised particles. Durgaprasad and Biswas (1977) suggested in 1977 the possibility that stellar objects such as novae having anomalous composition may accelerate C, N, O, etc. ions to $\sim$ 100 KeV/N. These ions having equilibrium charge of 0^{+1}–0^{+2}, etc. may be further accelerated in the heliosphere boundary to 10 MeV/N range.

In order to decide on the origin of the anomalous component, it is necessary to measure directly the ionisation states of the heavy ions in the low energy cosmic rays. The Indian cosmic ray experiment which has been selected by NASA for the First Space Shuttle-Spacelab Mission has been designed to do this for the first time. Another parallel problem in the solar cosmic rays is the measurements of the ionisation states of solar cosmic ray heavy nuclei, which is necessary to understand the acceleration mechanism of heavy ions in the sun. The same experiment will measure these in case of a large solar event.

FIRST SPACE SHUTTLE-SPACELAB MISSION

For the first SPACE SHUTTLE-SPACELAB MISSION, NASA selected a multidisciplinary payload. The list of principal investigators and their areas of studies is shown in Table I. The first five experiments are in the areas of space physics and astronomy, the next six experiments—nos. 6 to 11—are in life science in space and the next six are in space technology and radiation monitoring. The seventeen experiments selected by NASA in different disciplines include fifteen from USA, one from Japan and one from India. European Space Agency (ESA) selected about equal number of experiments from the European experiments. In the multidisciplinary payload of NASA and ESA in Spacelab-1, there are two cosmic ray experiments—the Indian experiment and one from ESA on cosmic ray isotopes by the University of Kiel.

The reusable spacecraft, Space Shuttle-Spacelab-1 is scheduled to be launched in April 1982 in a circular orbit of inclination of 57° at an altitude of 250 km. It will have seven-day mission in space after which it will make re-entry and landing, following which the instruments will be delivered back to the experimenters.

INDIAN COSMIC RAY EXPERIMENT: EXPERIMENTAL METHOD

The Indian cosmic ray experiment has been designed for the following scientific objectives:

(*i*) To study the recently discovered anomalous component of low energy galactic cosmic ray ions of energy 5–100 MeV/N of C, N, O, Ne and Ca to Fe, as regards their ionization states, composition and intensity; and

TABLE I

First Space Shuttle—Spacelab Mission

Principal investigators selected by NASA and their research areas

SPACE PHYSICS AND ASTRONOMY	1.	M. R. Torr	University of Michigan	Atmospheric Sciences
	2.	S. B. Mende	Lockheed Palo Alto Research Laboratories	Atmospheric Sciences
	3.	T. Obayashi	University of Tokyo	Atmospheric & Plasma Physics
	4.	S. Biswas	Tata Institute of Fundamental Research (India)	Cosmic Ray Physics
	5.	C. S. Bowyer	University of California (Berkeley)	Ultraviolet Astronomy
LIFE SCIENCE IN SPACE	6.	L. R. Young	Massachusetts Institute of Technology	Vestibular Studies
	7.	M. F. Reschke	NASA, Johnson Space Center	Vestibular Studies
	8.	S. L. Kimsey	NASA, Johnson Space Center	Blood Kinetics
	9.	F. M. Sulzman	Harvard Medical School	Circadian Rhythms
	10.	E. W. Voss	University of Illinois	Immune Responses
	11.	A. H. Brown	University of Pennsylvania	Plant Growth Studies
SPACE TECHNOLOGY AND RADIATION MON.	12.	E. V. Benton	University of San Francisco	High Energy Particle Dosimetry
	13.	J. Hart	University of Colorado	Atmospheric Sciences
	14.	C. H. T. Pan	Shaker Research Corporation	Lubrication
	15.	K. E. Demorest	NASA, Marshall Space Flight Center	Tribology
	16.	C. B. Farmer	NASA, Jet Propulsion Laboratory	Atmospheric Sciences
	17.	R. C. Wilson	NASA, Jet Propulsion Laboratory	Radiation Measurements

(*ii*) to study the ionization states of low energy heavy elements from oxygen to iron in energetic solar particles emitted during flare events.

The same detector system will serve for both studies, with the second objective being given priority if there are any solar particle events during the mission.

Heavy cosmic ray ions are stripped of their orbital electrons while passing through the protective cover or the uppermost layers of the detector and hence, do not yield any information on their original charge states from the measurements in the detector alone. In order to measure the ionization states of heavy ions, the method by which the earth's magnetic field is used as momentum analyser for each of the ions was adopted and the information thereby obtained was combined with other properties measured in the detector to determine the ionization state. For this purpose, the arrival time and direction of each of the ions are also measured.

In selecting the detector, it was noted that passive detectors such as plastic detectors have large collecting power, low or zero background and can withstand space environment with very little shielding material, but normally these have no resolution in time. Electronic detectors have high resolution in time, but are usually of low collecting power. Therefore, we have combined the advantages of both in our detector system. A fairly large area plastic detector system, combined with resolution in time is used for the experiment. The detector system consists of stacks of thin sheets of special plastics such as cellulose nitrate (CN) and Lexan polycarbonate which are efficient low noise detectors for heavy nuclei. The stacks are made in the shape of a cylindrical module with a diameter of 40 cm and a height of about 4cm. There are two distinct stacks, a major lower stack (4cm thick) which is slowly rotated in steps of 40 sec. of arc once every 10 sec. with respect to a thin, fixed upper stack (0.05 cm thick) with a separation of 0.05 cm.

An energetic particle entering through the top stack and stopping in the bottom stack leaves a damage trail along its path that can be revealed optically by a suitable chemical treatment in the laboratory. The identity and energy of the particle can then be determined from measurements on the geometry of the tracks and the range traversed in the stack. Also, by identifying the segments of the same track in the top and bottom stacks, the arrival time of the particle can be determined from the displacement between the segments. The arrival time can be measured to the nearest 10 sec. in the present design from the output of the shaft angle encoder which is telemetered to the ground together with the Universal Time and Spacelab attitude vectors. These data, coupled with the direction of arrival of the particle, give a lower bound to the magnetic rigidity (momentum/effective charge) of the particle determined by the earth's magnetic field configuration. Thus, by combining these two kinds of information the particle's ionization state is determined.

INSTRUMENT DESIGN

A general view of the instrument is shown in Fig. 2. The structure housing is made of special quality aluminium alloy and consists of approximately cylindrical enclosure of diameter 48 cm and height 53 cm, the top of the enclosure being covered by a thin shell of aluminium foil of thickness about 0.0050 cm, so as to allow very low energy ions to enter the detector (Fig. 3). Inside the housing, a high resolution stepper motor rotates the lower stack with respect to the fixed upper one in steps of 40 sec of arc once in 10 sec through a precision gear assembly so that full 360° rotation is completed in 90 hrs. The main detector stack is mounted on a shaft coupled to a 15-bit absolute shaft angle encoder, whose output is telemetered to ground through spacelab interfaces. There are three separate power supplies; for the motor drive, the encoder LED and the encoder output circuit, to enable pulsed mode operation. The temperature is monitored by an analog data channel. There is a venting valve which allows air to escape from the enclosure during the venting of cargo bay in the ascent phase of the Spacelab till the pressure inside drops to 1/10 of an atmosphere and then is sealed. Another pair of venting valves opens during the re-entry of Spacelab so

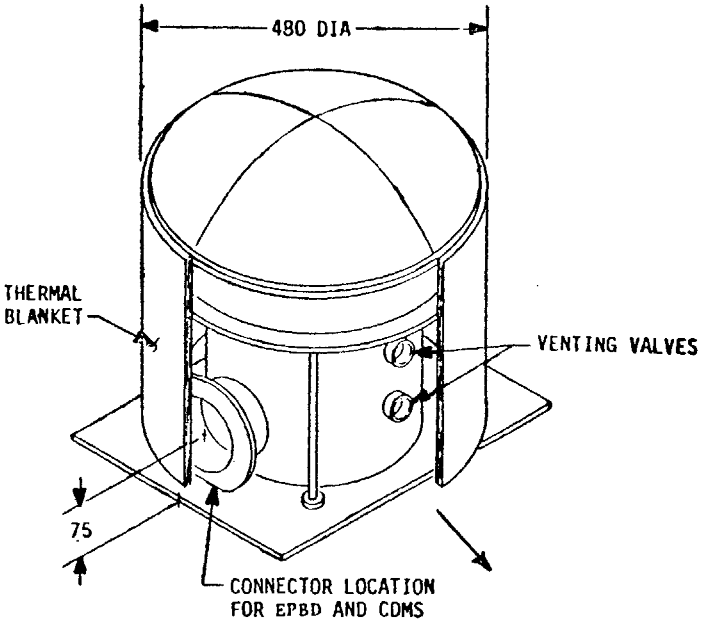


FIG. 2. A general view of the instrument envelope of the Indian cosmic ray experiment in Spacelab-1. The dimensions are in mm.

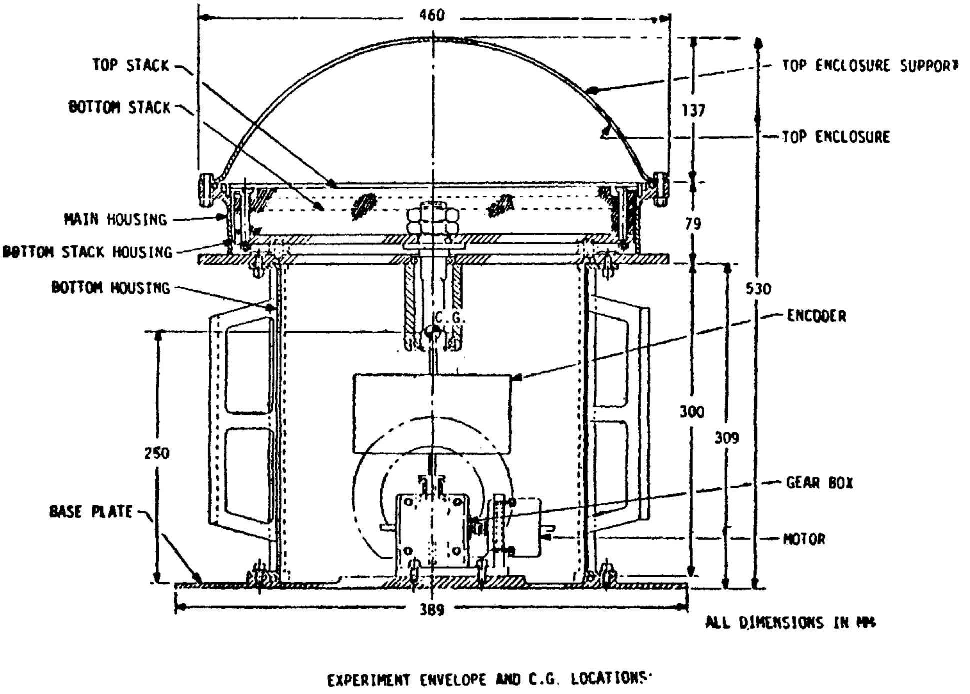


FIG. 3. A sectional view of the Indian cosmic ray instrument.

that it allows air to enter the instrument at the end of the mission and the instrument lands with air at 1 atmospheric pressure. The instrument is mounted in the pallet of the spacelab on a cold plate for thermal control. The external surface of the instrument, excepting the top dome, is shielded by multilayer thermal insulation of appropriate reflectivity so that the instrument is maintained well within the operating range of temperature.

SPACELAB INTERFACES

The instrument weighing about 30 kg is mounted on the pallet of the spacelab and the upper surface is exposed to free space with a viewing cone of 90°. The mechanical interface of the instrument (INS 004) is shown in Fig. 4. The instrument has other interfaces with the spacelab as follows:—

(1) Electrical Power Branch Distributor (EPBD)
(2) Command and Data Management System (CDMS)
(3) Environmental Control System (ECS)

The instrument uses average operating power of about 5 W for about 90 hrs switching being done by on/off commands from the Remote Acquisition Unit (RAU) in pallet. It interfaces with CDMS with 10 on/off command channels, 16 discrete data acquisition channels and 1 analog channel. The thermal control of the instrument is provided by the pallet cold plate (on which the instrument is mounted) and also by multilayer insulation on outer surface of the instrument, excepting the top shell.

EXPERIMENT OPERATION

During the 7 day-mission in space, the instrument for the cosmic ray experiment will be controlled and operated by a software module in the on-board Spacelab computer, according to experiment time-line. The experiment operation will be carried out during the period when the Spacelab Z-axis points towards deep space, or is in the upper hemisphere, and a total period of about 90 hrs will be available for the experiment during the mission. The functional block diagram of the instrument operation is shown in Fig. 5.

For the control of the experiment, the software module is loaded in the computer according to experiment time-line and the experiment operation is carried out through the input/output unit and RAU. The 15-bit output of the encoder is used to monitor and control the rotation of the detector module by the stepper motor and to make corrections, if necessary. The experimental data and the operation status will be periodically displayed and monitored by Spacelab crew in the module during the mission. The encoder output is telemetered to the ground control centre once every 10 sec through high rate multiplexer and these are annotated with U.T., housekeeping data and spacelab position and attitude vectors. The transmitted data are examined in near real time at the Payload Operation and Control Centre and are stored on tape for off-line examination and analysis.

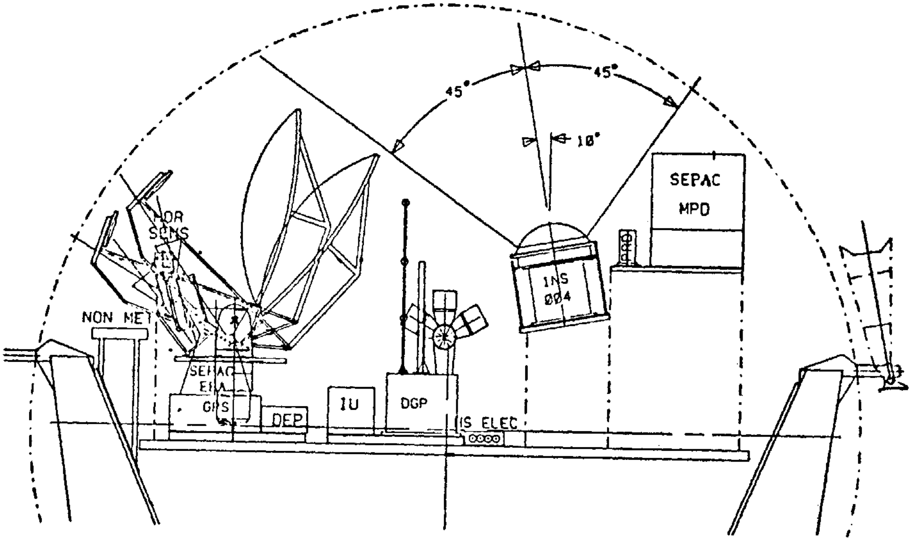
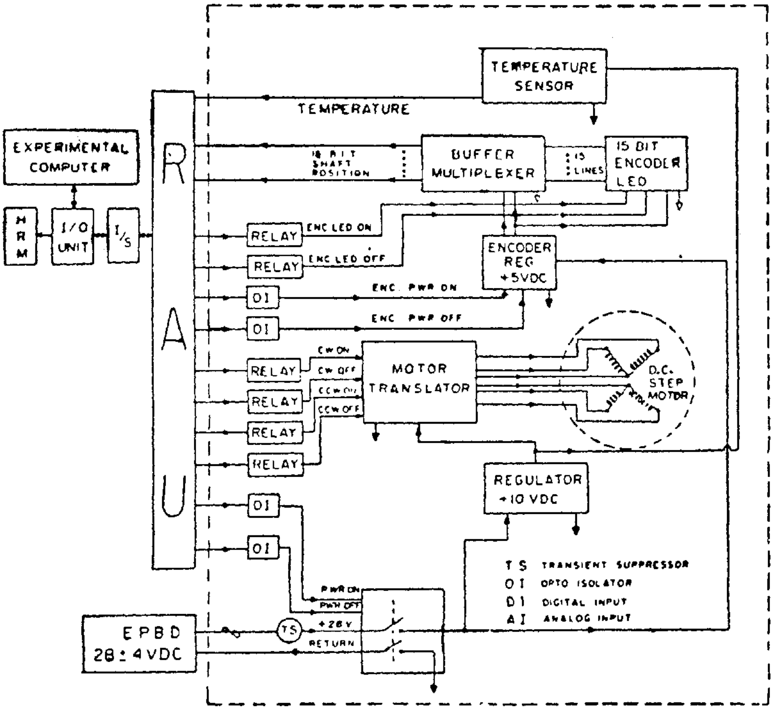


FIG. 4. Location of the instrument in the pallet of Spacelab-1.



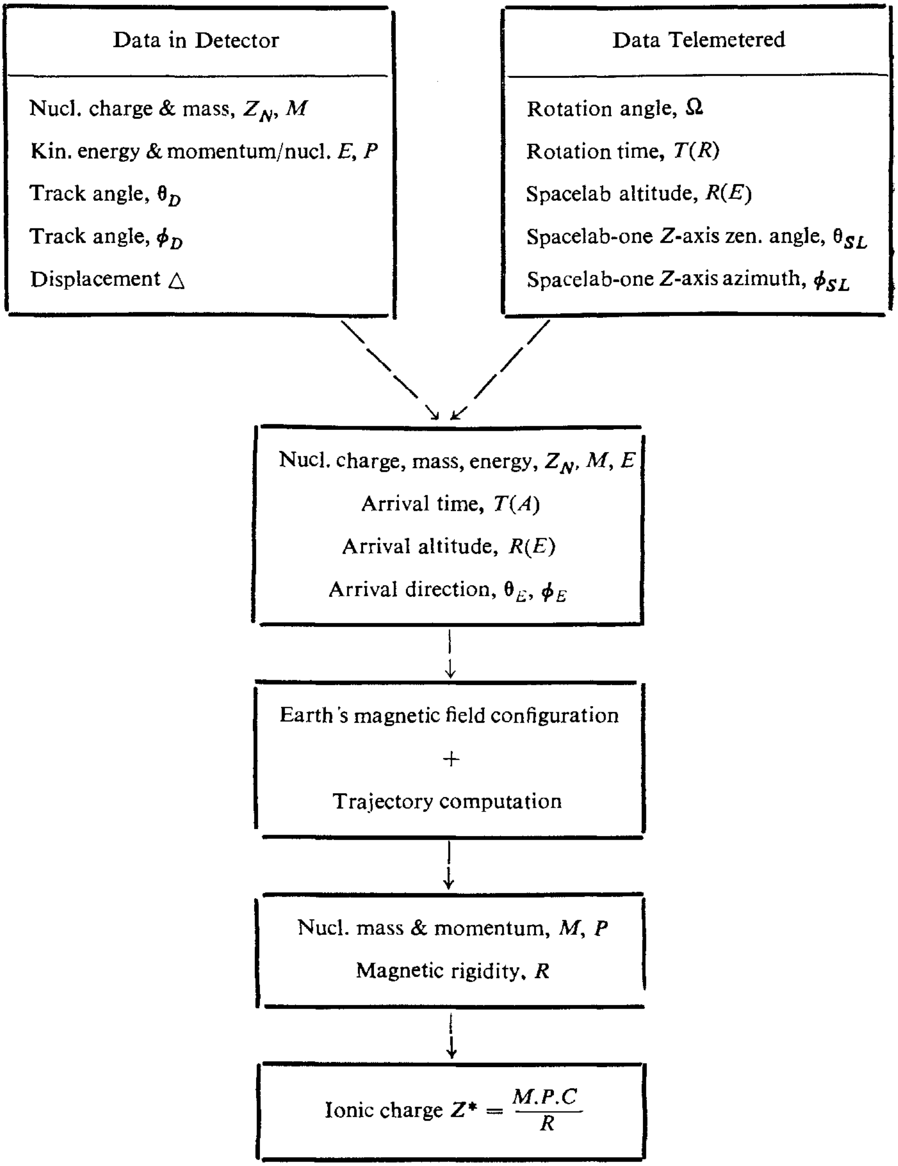
EXPERIMENT BLOCK DIAGRAM

FIG. 5. Functional block diagram of the experiment operation. The components inside the dashed line are constructed by the Indian experimenters and the components outside the dashed line are provided by NASA.

In case of a large solar cosmic ray event during the mission, a command from ground to spacelab will switch the operation of the instrument in solar flare mode. In flare mode, each step of the motor is executed once in 5 sec. The 'flare' mode operation is decided by the investigator team at the Control Centre.

TABLE II

Indian cosmic ray experiment in first space shuttle Spacelab mission : Ion states of solar and galactic cosmic ray experiment : Data acquisition and analysis



DATA ACQUISITION

The experimental data are of two kinds, such as the data telemetered to the ground and the data recorded in the on-board solid state track detector modules. The latter is retrieved by suitable chemical etching in post flight processing. The post flight data acquisition in solid state track detectors will be carried out using digitised optical microscopes. For rapid and reliable track data acquisition the 15-bit absolute shaft angle encoders used in the flight instrument will be employed for laboratory measurements and this, coupled with a linear encoder, will provide digitised r, θ co-ordinates of events which will be recorded on tape. Matching of tracks in upper and lower detector modules will be made by computer with the aid of appropriate software and thus the arrival times of events will be determined from the measurements of angular displacements and telemetered data. Measurements of other track parameters will be carried out in microscopes with digitised x, y and z-coordinates by means of incremental encoders. Suitable electronics will be designed to transfer data directly onto a digital tape recorder or card punch. This will not only speed up the data recording processes, but also will reduce transcription errors. Procedures for the data acquisition and analysis are schematically shown in Table II.

Table III summarises the technical details of the Indian cosmic ray experiment. A brief account of the Indian cosmic ray experiment in Space Shuttle Spacelab-1 is given in Space Research, 1979 (Biswas, 1979)

CONCLUDING REMARKS

The Indian Cosmic ray experiment is being developed and conducted by the team of scientists and engineers of several organisations as shown in Table IV. The

TABLE III

Indian cosmic ray experiment in first space shuttle Spacelab mission : Summary of technical features

Weight	:	30 kg
Volume	:	48 cm diameter 53 cm height
Viewing	:	Deep space F.O.V. = 90°
Power	:	5W av. for 90 hrs
Energy	:	0.45 kWh
Thermal control	:	Cold plate in pallet plus multi-layer insulation
Command and data management	:	8 Discrete on-off command channels 16 Discrete data acquisition channels 1 Analog data channel
Experiment control	:	By stored programme in on-board computer of S/L-1 through I/0 unit and interfacing with Remote Acquisition Unit (R.A.U.)
Data acquisition	:	Multiplexing and telemetry to ground by CDMS 32 bits every 10 sec for 90 hrs track recording in on-board detector; analysis on recovery.

Table IV

Participants in the Indian experiment in the first space shuttle Spacelab mission

Name of Experiment	:	Studies on the ionisation states of solar and galactic cosmic ray heavy nuclei	
Objective category	:	Space Astro-Physics	
Principal Investigator	:	Professor S Biswas	(TIFR)
Principal Co-Investigator	:	Professor D Lal	(PRL)
Co-Investigators	:	Professor R Cowsik	(TIFR)
		Dr N Durgaprasad	(TIFR)
		Dr J N Goswami	(PRL)
		Dr U B Jayanthi	(PRL)
		Mr S Sarkar	(TIFR)
		Dr V S Venkatavaradan	(TIFR)
Engineers	:	Mr S S Kshatriya (Structural & Thermal)	(ISAC)
		Mr R Srivastava (Structural)	(PPED)
		Mr R K Gupta (Structural)	(PPED)
		Mr H S Mazumdar (Electrical)	(PRL)
		Mr K Ramani (Fabrication)	(BARC)
		Mr M D P Gupta (Fabrication)	(BARC)
Technical	:	Mr P J Kajarekar	(TIFR)
		Mr D R Bhandari	(ISAC)
		Mr J Shah	(PRL)
		Mr Sreenath Prasad	(TIFR)
Participating Institutions	:	Tata Institute of Fundamental Research (TIFR), Bombay; Physical Research Laboratory (PRL), Ahmedabad; ISRO Satellite Centre (ISAC), Bangalore; Power Project Engineering Division (PPED, DAE), Bombay; Bhabha Atomic Research Centre (Central Workshop (BARC), Bombay.	

design, development, fabrication, assembly, operation and testing of the instrument are being done in India. Following these the instrument will be delivered to NASA in August 1980 for integration in the Spacelab-1. The results obtained from the studies of the ionisation states of low energy cosmic ray ions and their other properties will give important clues as to the origin of the low energy cosmic rays. These, in turn, will help in deciding the astrophysical questions such as whether there are low energy cosmic rays in interstellar space and whether there are 'soft' sources of cosmic rays in the galaxy.

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