

Monitoring lunar radiation environment: RADOM instrument on Chandrayaan-1

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This paper describes the RADOM instrument on Chandrayaan-1 spacecraft to monitor the radiation environment en-route to Moon and in lunar orbit. The instrument is a miniature (98 g; 100 mW) 256 channels spectrometer for the measurement of energy deposited (dose) due to incident primary and secondary energetic particles using a single 0.3 mm thick 2 cm² silicon detector. The science objectives, instrument details and operation sequence as well as the data analysis procedure and instrument calibration results are presented.

Keywords: Galactic cosmic rays, radiation environment, RADOM instrument, solar wind.

Introduction

THE dominant radiation components at Chandrayaan-1 orbit at 100 km above the surface of the Moon are the galactic cosmic rays (GCR), modulated by the magnetic fields associated with the low energy solar wind (SW) ions and the sporadic solar energetic particles (SEP) events associated with solar flares during solar active periods. The GCR are charged particles that originate from sources beyond our solar system. The distribution of GCR is believed to be isotropic throughout interstellar space. The energies of GCR particles range from several tens up to 10^{12} MeV nucleon⁻¹, although SW modulation restricts entry of the low-energy (<100 MeV nucleon⁻¹) GCR into the inner solar system. The GCR consists of 98% protons and heavier ions (baryon component) and 2% electrons and positrons (lepton component). The baryon component is composed of 87% protons, 12% helium ions (alpha particles) and 1% heavy ions¹. Highly energetic particles in the heavy ion component, typically referred to as high Z and energy (HZE) particles, play a particularly important role in space dosimetry. HZE particles, especially iron, possess high-LET and are highly penetrating, and have a large potential for radiobiological damage².

The SEP are produced during solar flares, the sudden sporadic eruptions of the chromosphere of the Sun. High fluxes of charged particles (mostly protons, some helium and heavier ions) released during flares are accelerated

both at flare site and subsequently in interplanetary space and can have energies up to several GeV. The time profile of a typical SEP events starts off with a rapid exponential increase in flux, reaching a peak in minutes to hours and can last for hours to days. The energy of SEP lies typically between 10 and 500 MeV nucleon⁻¹ and the intensity can reach 10^4 particle cm⁻² s⁻¹ sr⁻¹. SEP events are relatively rare and occur most often during the solar maximum phase of the 11-year solar cycle. The number of such events could be ten per year during the solar maximum phase, while during solar minimum only one such event per year can be seen on an average³.

The lunar albedo radiation (principally neutrons) is produced by the interactions of GCR and SEP ions with the lunar surface materials. The neutron albedo can contribute as much as ~20% to the effective dose when the radiation environment is dominated by GCRs. When SEPs dominate, the neutrons may contribute an additional ~2% to the total dose.

Science objectives

The basic objective of the RADOM experiment is to monitor the radiation environment, both en-route and in lunar orbit, onboard the Chandrayaan-1 mission. The main goal is the measurement of total absorbed radiation dose due to energetic particles of both galactic and solar origin and monitor effect of solar particles events to assess the dose received by the spacecraft and estimate the same for future long-duration missions to the Moon.

Instrument description

The RADOM spectrometer (see Figure 1) is designed to measure the spectrum (in 256 channels) of the deposited energy from primary and secondary particles on board the Chandrayaan-1 mission. It is a miniature spectrometer-dosimeter containing a single 0.3 mm thick semiconductor detector with 2 cm² area, one low noise hybrid charge-sensitive preamplifier A225F type of AMPTEK Inc.; a fast 12 channel ADC; 2 microcontrollers and buffer memory. Pulse analysis technique is used for obtaining the spectrum of the energy deposited in the silicon detector, which is then analysed and further converted to deposited dose and flux. The unit is managed by the microcontrol-

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lers through specially developed firmware. RS232 interface facilitates transmission of the data stored in the buffer memory to the Chandrayaan-1 telemetry. RADOM is similar to some of the earlier instruments such as the Liulin-E094 4 MDUs flown in 2001 on American Destiny module of International Space Station (ISS)^{4,5}; R3D-B2/B3 instruments flown on the Foton M2/M3 spacecrafts in 2005/2007 (refs 6, 7) and R3DE instrument launched in February 2008 to EuTEF platform of European Columbus module of ISS⁸. After switching on, the RADOM starts measuring the spectrum of the deposited energy (in 256 channels) with a fixed exposure time of 30 s for a given spectrum. After each cycle of measurement, the data are stored in the buffer memory and the accumulated data are transmitted to the telemetry by activating the RS232 interface. Pulse height analysis technique is used for measurement of the energy losses in the detector. A block schematic of the RADOM spectrometer-dosimeter is presented in Figure 2.

The solid state detector of RADOM instrument is shielded by 1.0 mm aluminium + 0.1 mm cooper + 0.2 mm plastic material and 15 layers of aluminized capton with MLI (with total Al thickness of ~150 microns) amounting to equivalent shielding of about 0.45 g/cm². Thus, direct hits on the detector is possible for electrons with energies ≥ 0.85 MeV and for protons with energies ≥ 17.5 MeV.

Dose estimation

The dose D in Grays (Gy: one Joule deposited in 1 kg of matter) can be expressed as:

$$D = K \sum_{i=1}^{256} A_i k_i / MD,$$

where MD is the mass of the detector (in kg) and A_i the count or intensity in channel i . K and k_i are coefficients to be determined from calibration experiment.

On the basis of calibrations of the Liulin type spectrometers in CERN and comparisons with TEPC (Tissue Equivalent Proportional Counter) measurements, a method was developed^{9,10} to evaluate Ambient dose equivalent, H^* .



Figure 1. External view of RADOM-FM instrument.

For the GCR radiation, the H^* values are calculated using the relation¹⁰:

$$H_{\text{GCR}}^*(10) = K \left\{ \sum_{i=1}^{14} k_i A_i + 5 \sum_{i=15}^{256} k_i A_i \right\} / MD.$$

For the SEP radiation, the H^* values are calculated using the relation¹⁰:

$$H_{\text{SEP}}^*(10) = 1.3K \left\{ \sum_{i=1}^{14} k_i A_i + \sum_{i=15}^{256} k_i A_i \right\} / MD.$$

Calculations of the absorbed dose, flux and ambient dose equivalent, H^* , are performed automatically by RADOM-FM software product during the reading of the file transferred through the telemetry.

The RADOM-FM software product (RADOM-FM.exe) is used for the management of the spectrometer and express analysis of the results. The program includes subprograms for data listing and data visualizations.

Calibration results

Calibrations of RADOM precursors were performed with proton beams in collaboration with J. Lemaire and Gh. Gregoire from Institut de Physique, Universite Catholique de Louvain, Belgique⁴. Calibrations using alphas and heavy ion beams were performed in collaboration with K. Fujitaka and Yukio Uchihori from National Institute of Radiological Sciences, Chiba, Japan¹⁰. Calibrations of the different models of Liulin-4 type spectrometers using gamma and neutron sources and CERN reference field were performed in collaboration with F. Spurny from Nuclear Physics Institute of Academy of Sciences of the Czech Republic¹¹. RADOM instrument was built practically with the same mechanical and electrical characteristics as the above-mentioned instruments and thus detail calibration studies using gamma, neutron, proton and heavy ions sources were not performed (except for a limited cases, see next paragraph) and data from earlier studies were considered adequate.

Figure 3 shows the energy-time diagram of the calibrations performed in the laboratory of STIL-BAS with the RADOM-FM instrument using natural radiation sources ²⁴¹Am and ¹³⁷Cs. The top panel shows the colour coded energy-time diagram for the first 32 channels, which displays the counts in each channel by the colour defined in the colour-bar on the right. Of the two maxima in the time series, the first maximum having the most counts in first channel, where energy loss is between 40 and 120 keV, is due to ²⁴¹Am source which emits 60 keV gamma ray line. The second maximum with wider spectra (up to the 8th channel with maximum count rate in the second channel) is due to ¹³⁷Cs source which emits 667 keV gamma ray line. The lower panel of Figure 3 shows the time series of total events in each spectrum.

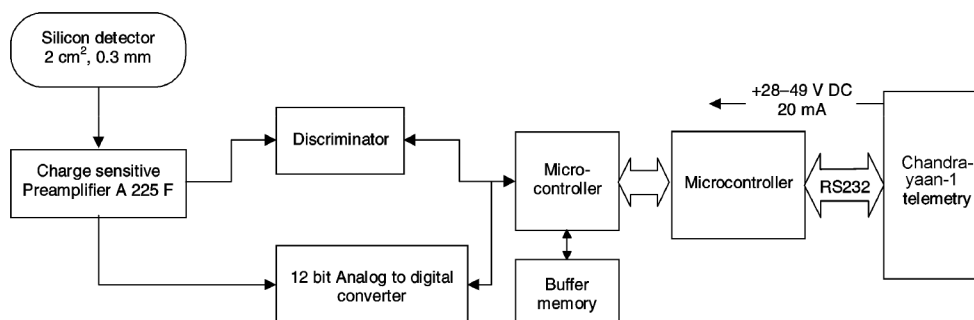


Figure 2. Block-schematics of the RADOM-FM spectrometer.

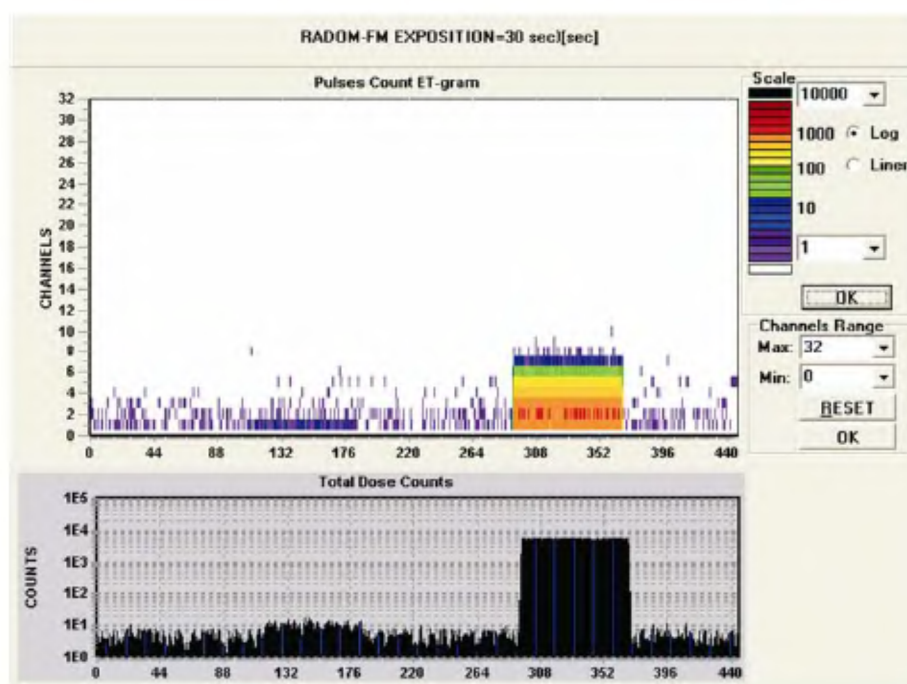


Figure 3. Calibration results of the RADOM-FM spectrometer.

Conclusion

The general objective of the RADOM experiment onboard the Chandrayaan-1 mission is to monitor the radiation environment around the Earth and Moon. Data obtained from this instrument will allow better estimation of the total absorbed dose due to both galactic and solar energetic particles in the lunar environment and help in planning of future long duration missions to Moon.

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