MONITORING OF THE EARTH AND MOON RADIATION ENVIRONMENT BY THE RADOM INSTRUMENT ON INDIAN CHANDRAYYAN-1 SATELLITE. PRELIMINARY RESULTS.

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Introduction: This paper describes preliminary scientific results from the measurements of the Earth and Moon radiation environment by RADOM instrument since 22nd October 2008. The instrument is a miniature (98 grams, 100 mW) 256 channels spectrometer of the deposited energy (dose) in a single 2 cm^2 0.3 mm thick silicon detector.

Instrument description: The RADOM spectrometer (see Fig.1.) main tasks are to measure the spectrum (split into 256 channels) of the deposited energy from primary and secondary particles onboard the Indian Chandrayaan-1 mission [1] and to transmit these data to the Earth. RADOM is a miniature spectrometer-dosimeter containing a semiconductor detector. Pulse analysis technique is used for obtaining the deposited energy spectrum, which is further converted to absorbed dose and flux in the silicon detector. The unit is managed by microcontrollers through specially developed firmware. RS232 interface provide the transmission of the data stored in the buffer memory to the Chandrayaan-1 telemetry. The instrument is very similar to: 1) The Liulin-E094 4 Mobile dosimetry units flown in 2001 on American Destiny module of International Space Station (ISS) [2]; 2) R3D-B2/B3 instruments flown on the Foton M2/M3 spacecrafts in 2005/2007; 3) R3DE/R3DR instruments launched February/October 2008 toward the EuTEF platform of the European Columbus module of ISS and the Zvezda module of ISS Russian Segment respectively [3].

Fig. 1. RADOM instrument

Preliminary results and discussion: The solid state detector of RADOM instrument is behind ~ 0.45 g/cm^2 shielding from angle of 2π, which allows direct hits on the detector by electrons with energies in the range 0.85-10 MeV. The protons range is 17.5-200 MeV. On other 2π angle where the satellite is the shielding is larger but not known exactly.

RADOM instrument was switched on about 2 hours after the launch of the Chandrayaan-1 satellite on 22nd October 2008. The preliminary results are shown on Figure 2, obtained by overlapping the 2- and 3- dimensional graphics of the "RADOM-FM.exe" software. On the X axis is plotted the Universal Time between 18:25 and 20:55 UT on 22nd October 2008. On the Y axis on the right side are the 256 channels of each spectrum obtained by the RADOM spectrometer. Totally there are 1800 spectra obtained for 1.5 hours with a 10-second resolution. The count rate for 10 sec in each channel is logarithmically colour coded by the colour bar shown in the right-down part of the figure.

The vertical axis on the left side of the figure shows the variations of 3 parameters: the measured dose in $\mu Gy.h^{-1}$, the flux in particles per square cm per second ($cm^{-2}.s^{-1}$) and the ratio of the dose to flux in ($nGy.cm^{-2}.particle^{-1}$). The last parameter is known also as specific dose per particle. A proton in the energy range 17.5-200 MeV can deposit in the matter between 6.5 and 1.08 nGy, while one electron because of much smaller mass in the range 1-10 MeV can deposit between 0.3 and 0.35 nGy [4].

On the left part of Figure 2 are relative short spectra (up to 30th channel) and high doses and fluxes. We interpret these spectra as generated by electrons in the outer radiation belt, because the specific doses are less than 1 nGy per particle. The specific doses here are higher than expected by Heffner [4] 0.3-0.35 $nGy.cm^{-2}.particle^{-1}$ because the population is not purely by

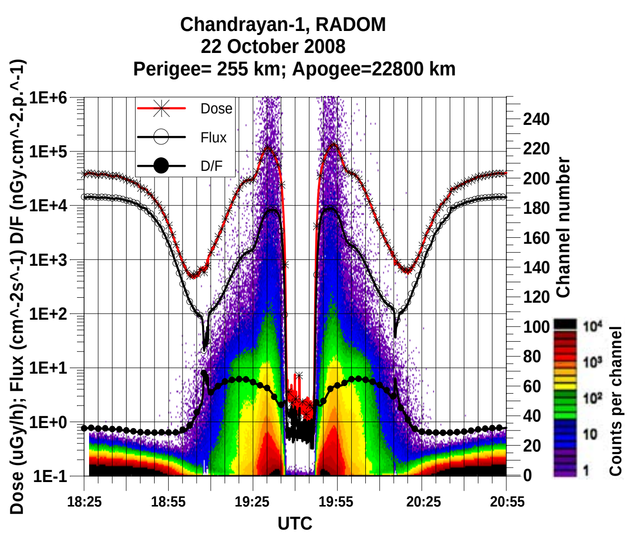

Fig. 2. Overlap of 2 and 3 dimensional presentation of RADOM data for 22800 km altitude

electrons - counts from GCR counts exists in the range above 30th channel. These single counts are not seen because of logarithmic coding of the count rate in the spectra. The doses here reach 4.10^4 µGy.h^{-1}, while the fluxes are $1.5.10^4$ cm^{-2}.s^{-1}.

Gradually from left to right in Figure 2 the spectra first shortened when the satellite moves toward the slot region and next reached highest channels in the region of the inner radiation belt where high energy protons exists. In same time the doses reached about the 3 times higher values of $1.2.10^5$ µGy.h^{-1} nevertheless the fluxes here are smaller than in the outer belt. Here in the middle of the inner belt the highest values of the specific doses are seen of about 5.8 nGy.cm^{-2}.particle^{-1}. This means that protons with energies about 13 MeV are detected. Further motion of the satellite toward the perigee brings a drastic decrease of doses and fluxes to the minimal observed values in the centre of the figure. This happen when satellite moves below the proton radiation belt. The spectra here are composed mainly by GCR particles and the doses are very similar to the observed (by us) doses of 12 µGy.h^{-1} on ISS in 2008 and on Foton M3 satellite in 2007 [3].

After the crossing of the perigee region at about 250 km altitude the satellite starts to move back to the proton belt and to the region between the two belts at about 12000 km altitude. The slot region radiation is mixed between protons, electrons and GCR particles and the dose rates are only few tens of µGy.h^{-1}. Later the doses rise up again in the electron belt and are similar to the observed at the left part of the figure.

Similar features to those on Figure 2 were observed at any time when Chandrayaan-1 was on Earth orbits till 7th November 2008. The doses out of radiation belts are dominated by the GCR particles. Because of the very low solar activity no solar proton events were registered during the whole period till 24th December 2008. The GCR doses were very stable around 12 µGy.h^{-1} [3]. The maximal observed GCR doses of 12.2 µGy.h^{-1} by RADOM instrument were when the Chandrayaan-1 satellite was away from both Earth and Moon during the lunar transfer orbits from 7th to 12th November 2008. When on 13th November 2008 the satellite entered a 100 km circular orbit around the Moon the GCR doses fall down because of the Moon surface shielding to about 8.8 µGy/h and stayed stable around this value. The flux is 2.29 cm^{-2}.s^{-1}.

For the purposes of confirmation of the RADOM data on Figure 3 is presented a comparison between the spectra obtained by RADOM instrument on 22ndOctober 2008 with data from R3DE instrument on ISS in February-March 2008. Three pairs of curves are seen on the figure. At the bottom the two GCR spectra overlap one over another, because the measured GCR dose rates are very similar. 11.4 µGy.h^{-1} is the measured dose rate by averaging of 9951 spectra the R3DE instrument, while the averaged over 46591 spectra dose rate from RADOM is 11.8 µGy.h^{-1}. The second pair of averaged spectra by each instrument is obtained inside of the inner (proton) radiation belt (PRB). Because of the large difference of measured dose rates the triangle denoted spectrum from R3DE (D=931 µGy.h^{-1}) is 2 orders of magnitude below than asterisks line from RADOM (D=93549 µGy.h^{-1}). The better statistics of the RADOM spectrum allows more precise determination of the elbow location at 6.2 MeV deposited energy. Similar is the situation with the other (electron) radiation belt (ERB) spectra. RADOM dose rate is 37615 µGy.h^{-1}, while the R3DE dose rate is 8994 µGy.h^{-1}.

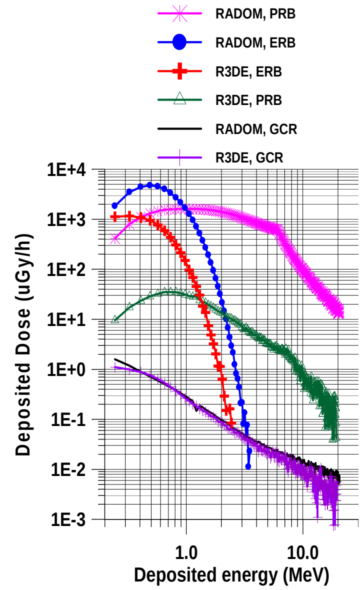

Fig. 3. Comparison of spectra obtained by the R3DE on ISS and RADOM instruments.

Comparison between the RADOM radiation environment results and computational models are shown in a separate LPSC 2009 paper by G. De Angelis.

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