Dose Equivalent, Absorbed Dose and Charge Spectrum Measurements Made in the International Space Station Orbit

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Abstract

Particle intensity, dose equivalent and absorbed dose have been measured on board the space shuttles during their visit to the International Space Station (ISS) on STS-108 and STS-112. The dose estimates are based on very accurate measurements of recoils produced in CR-39 by cosmic ray primary and secondary protons and heavier nuclei and by secondary neutrons. The corresponding LET spectra were used to determine dose equivalent and absorbed dose values for both missions. Estimates of the total flux of Z≥2 nuclei have been undertaken and a charge spectrum was measured for both missions. Comparisons are made with the predictions of a cosmic ray transport model.

1. Introduction

In low earth orbit astronauts are exposed to the radiation fields of galactic cosmic rays (GCR), solar particles, electrons and protons in the Earth's radiation belts, albedo neutrons and protons coming from interactions in the Earth's atmosphere. When particles traverse the spacecraft walls, internal structures and equipment, secondary charged particles and neutral particles are produced and a very complex radiation field is then created. Dose contributions for astronauts depend on the orbital inclination and altitude and the stage of solar cycle. LET (Linear Energy Transfer) spectra and charge spectra for STS-108 and STS-112 missions were measured by CR-39 detectors calibrated with heavy ions and at the CERF radiation field at CERN. This paper describes the approach used and presents the observed results and the comparison with theoretical predictions.

2. Experimental Approach and Data Analysis

The CR-39 material used by DIAS (Dublin Institute for Advanced Studies) for STS missions was manufactured by American Technical Plastics. The detector thickness is about 600 μm and is covered by a thin plastic film to protect the detector from exposure to radon. A stack of 20 detectors was used for STS-108 and each detector had an area of 7 cm × 7 cm. Because of the limited

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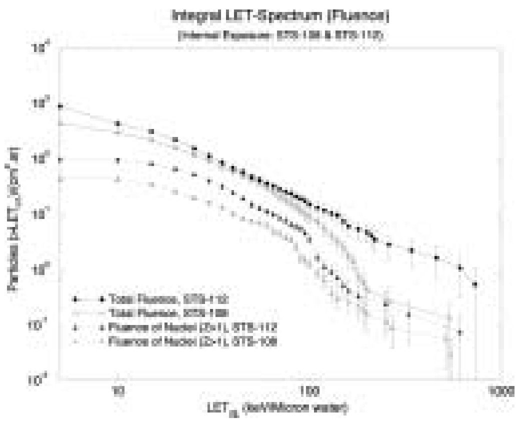

Fig. 1. Integral LET-spectra of fluence for cosmic rays in low Earth orbit.

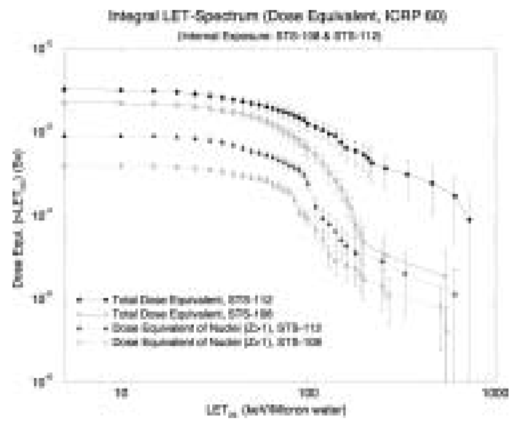

Fig. 2. Integral LET-spectra of dose equivalent for cosmic rays in low Earth orbit.

available space the stacks of CR-39 detectors for STS-112 were smaller. The orbital inclination was 51.6° and the orbital altitude was 390 km for ISS, while the flight times of STS-108 (Dec. 2001) and STS-112 (Oct. 2002) were 284 and 260 hours respectively. Following chemical etching at 60° C for 52 hours and 23 hours in 6.25N NaOH, the track parameters (major and minor axes of track surface) were measured using microscope. The signals observed were due to short range recoils from the nuclear interactions of protons, neutrons and heavy nucleons in the detectors as well as tracks due to the passage of the primary and secondary cosmic ray particles. These two types of events can be easily separated since the secondary particles produce short tracks on only one surface of detectors while GCR can be observed in two or more sheets depending on their charge and energy. Full details of the technique and analysis can be found in O'Sullivan (O'Sullivan et al., 1999, 2002) and Zhou (Zhou, 1999a).

3. LET Spectra and Dose Equivalent

LET values were calculated and binned and the differential fluence spectrum obtained as described in O'Sullivan (O'Sullivan et al., 1999). The observed dose (Gy) is

$$4\pi \times 1.6 \times 10^{-9} \times LET_{\infty} \times F$$

where LET_{∞} is the linear energy transfer (keV/μm) in water and F is the differential fluence in particles $cm^{-2}sr^{-1}(keV/\mu m)^{-1}$. The integral spectrum is generated by summing the differential spectrum from high LET to low LET. The relationship between LET in CR-39 and etch rate was determined by calibration with heavy ions. Figures 1 and 2 show the integral LET spectra (fluence and dose equivalent ICRP 60 respectively). The upper two curves represent the combined sample of short range recoils and tracks produced by primary and secondary Z>1

Table 1. Comparison of dose rate and dose equivalent rate of cosmic rays for STS missions

Mission	Altitude/ Inclination	LET Threshold	Absorbed Dose Rate	Dose Equivalent Rate (ICRP 60)	Quality Factor
Date	Km/Degree	(keV/µm water)	µGy/d	µSv/d	
STS-108 (Dec. 01)	390/51.6°				
Total		5	17.17 ± 0.61	199.84 ± 10.99	11.66
HZE		5	2.51 ± 0.12	33.60 ± 1.57	13.38
HZE		20	2.05 ± 0.11	32.25 ± 1.70	15.75
STS-112 (Oct. 02)	390/51.6°				
Total		5	21.72 ± 3.08	201.70 ± 19.77	9.49
HZE		5	6.37 ± 0.32	83.99 ± 4.17	13.19
HZE		20	5.45 ± 0.30	81.53 ± 4.43	14.95
ISS Expedition (May-Aug. 01) Total	398/51.6°	10	27.3 ± 0.89	231 ± 8.08	8.47

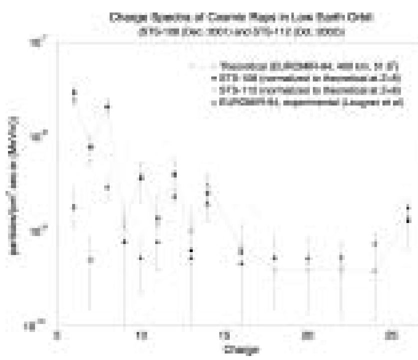

Fig. 3. Charge distribution of cosmic rays (Z≥6) in low Earth orbit.

cosmic ray particles in the detectors. The lower two curves represent Z>1 primary and secondary cosmic rays only. The details of the method to identify nuclei with Z>1 by CR-39 detectors can be found in Zhou et al (Zhou, 1999a, 1999b).

Table 1 summarises results of absorbed dose (μGy/d), dose equivalent (μSv/d) and quality factors for STS-108 and STS-112. Results obtained by Benton et al (Benton et al., 2002) on the ISS Expedition (May–Aug. 2001) are also shown for comparison.

The difference of dose and dose equivalent values for the three space missions may result from different exposure locations and different stage of solar cycle. The quality factor results for STS-108 and STS-112 high Z particles are close to the theoretical values calculated by Heinrich (ICRP 21) namely 14.1 (20 g/cm^2) and 13.3 (40 g/cm^2) (Heinrich, 1977). The measured values 13.38 and 15.75 (STS-108) and 13.19 and 14.95 (STS-112) for the two LET thresholds shown are in good agreement.

4. Charge Spectra for 6 ≤ Z ≤ 26 Nuclei

The charge spectrum of Z≥6 nuclei was determined for nuclei that stopped in the 1.2 cm thick stack. All particles penetrating one or more sheets were noted and followed to the end of their range. HZE particles can be identified by measuring effective etch rate ratio S_{eff} and fractional etch rate gradient G (g^{-1}cm^2) as described in Fowler (Fowler et al., 1976) and Zhou (Zhou et al., 1999a, 1999b). Figure 3 shows the relative abundance of nuclei for 6≤Z≤26 observed during STS-108 and STS-112 missions.

The results of this work are compared with theoretical estimates calculated by Leugner et al (Leugner et al., 1998) ($6 \leq Z \leq 26$) and that group's measurement results for a mission near solar minimum with similar orbital inclination, and at 400 km altitude (EUROMIR-94), using a stack of CR-39 detectors of similar thickness. The results measured by DIAS and the calculated abundances show excellent agreement over the whole range of values. The unique advantage of high efficiency of manual scanning over automatic scanning is clearly indicated in figure 3 especially for lower charge nuclei.

5. Conclusions

LET spectra of particle intensity, absorbed dose, dose equivalent, radiation quality factors and charge distribution of cosmic rays were measured for STS-108 and 112 by CR-39 detectors. The observed results indicate that the DIAS method for radiation measurement by CR-39 detectors based on the calibration of heavy ions and manual scanning is successful, reliable and suitable for space radiation research. The measurement method for HZE cosmic rays, based on Seff and gradient analysis, along with manual scanning can provide precise charge spectra and their dose contributions at low Earth orbit. The experimental results for the charge distribution of HZE particles from CR-39 detectors are in good agreement with the results calculated by theoretical models developed in Siegen group.

6. Acknowledgements

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7. References

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