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LIGHT–HEAVY ION MEASUREMENTS IN CR–39 LOCATED ON THE EARTH SIDE OF LDEF *

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SUMMARY

The azimuthal angle distribution and the charge and energy spectra of selected light–heavy ($5 \leq Z \leq 8$) stopping particles were measured in a single layer of CR-39 plastic nuclear track detector (PNTD) from the stack of the A0015 experiment located on the Earth–end of the LDEF satellite. The directional incidence of the trapped protons is studied by comparing the azimuthal angle distribution of selected recoils, obtained in the LDEF detectors, to that obtained through calibrations of PNTDs with exposures performed with 200 MeV proton beams from different directions.

INTRODUCTION

The purpose of the A0015 Free Flyer Biostack experiment was to measure the total absorbed doses and particle LET spectra as a function of depth in shielding material at different positions on the surface of the LDEF satellite[1,2,3,4,5,6,7].

Cosmic ray charged particles contribute to the health risk of crew members and high LET particles can cause single event upsets (SEUs) in microelectronics. In the present study the charge and energy spectra of selected high LET particles (mostly heavy recoils) were measured in order to compare with model calculations. The contribution of high LET recoils to the LET spectra seems to be more significant than previously thought. Their flux in the inner radiation field is much higher than the flux of the high LET primary cosmic ray particles under the same shielding conditions. To measure the LET spectra, plastic nuclear track detectors are widely used. A standard technique is developed to measure the LET spectra in regular STS flight. This technique, however, has a range threshold about 30–40 μm, therefore recoil particles with a range shorter than that threshold could not be detected. Hence, short range recoils are not included in regular LET spectra measurements performed in STS flights. This range cut–off value, however, is proportional to the etching time which had to be much shorter in the case of the LDEF samples because of the expected high track density. Also, the fluence of these relatively long range recoils is much higher in the case of the LDEF samples because of the long duration exposure. Heavy recoils, satisfying

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certain selection criteria, can be identified in CR–39 PNTDs by measuring the geometrical parameters of their single–surface etched track. Detection efficiency of these particles can be calculated and experimental and theoretical results can be compared in the future. This gives a good opportunity to validate model calculations.

The directionality distribution of these particles was measured and compared with calibration measurements performed with 200 MeV proton beams. Some conclusions about the directionality of the primary trapped proton radiation environment are drawn.

EXPERIMENT

Detector stacks filled two Biostack containers and partially filled a third in the A0015 experiment. Detector stack No. 1 (Earth–side) and No. 2 (non–Earth–side) were positioned in the center of Al canisters. Each canister was sealed from the outside environment by means of an O–ring. The inner wall of each canister was covered by an acrylic layer.

Two layers of CR–39 from the Earth–side stack and two layers from the non–Earth–side stack were selected for analysis. The minimum shielding of these layers was 10.0 g/cm^2 for the Earth–side layers and 4.2 g/cm^2 for the non–Earth–side PNTDs. The layers were etched in a 6.25 N NaOH solution at 50 °C for 36 hours. A thickness of 8–10 μm was removed from each surface.

Measurement of Charge and Energy of "Energetic" Recoil Particles

A layer from the Earth–side stack was selected for these measurements of the charge and energy of selected energetic recoil particles. The minimum shielding distance (from the outer surface of the canister) for this layer was 10.3 g/cm^2. The surface of the layer was parallel with the surface of the Earth. That side of the layer nearest the satellite was scanned. The scanned area was 4.32 cm^2 and was located at the center of the layer. 400 undercut, rounded tracks were measured in the scanned area and 200 of these were selected for charge and energy determination. The range of the particles in the CR–39 layer and the reduced etch rate ratio ($V_T/V_B - 1$) along the particle's tracks were determined from track geometry measurements of etched tracks using the assumption of constant etch rate ratio. The particles were identified using an internal calibration technique and the REL (Restricted Energy Loss) model of track formation with a threshold energy of 200 eV. The internal calibration is based on the assumption that recoil particles with the highest charge are oxygen because there are no particles with larger charge in the composition of the CR–39 material. The corresponding charge distribution is shown in Figure 1.

The track selection criteria were determined in such a way as to ensure that only "energetic" recoil particles were measured, the range of which had to be greater than $\approx$ 15–20 μm depending on the charge of the particles. Currently, a detailed detection efficiency calculation is under way to convert this data into charge, energy and LET fluence spectra.

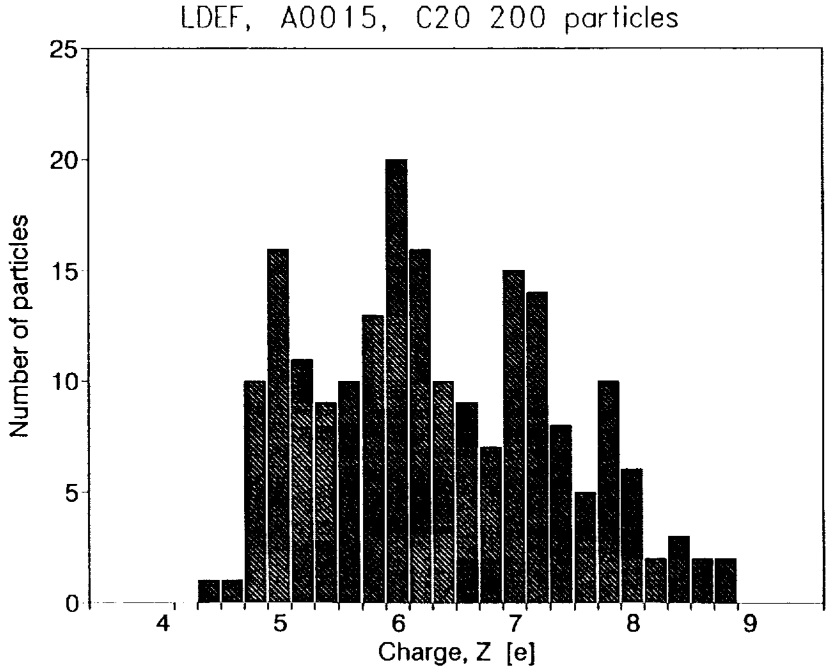

Figure 1: Number of energetic recoil particles as a function of charge measured in a CR-39 layer from the LDEF A0015 Earth–side stack.

Directionality of Recoil Particles

In addition to charge and energy spectra measurements, the directionality distribution of recoil particles was measured. Figure 2 shows the azimuthal angle distribution of the 400 measured tracks. The azimuthal angle in this case is the angle of the projection of the particle trajectory onto the detector surface measured from an arbitrary x–axis on the detector sheet.

Similar measurements have been performed on calibration samples of CR–39 exposed to 200 MeV protons at different angles of incidence. The corresponding azimuthal angle distributions are presented in Figure 3. The comparison of these distributions with that obtained from the LDEF sample confirm the anisotropic nature of the primary proton fluence by which these energetic heavy recoils were produced in the case of the LDEF.

CONCLUSIONS

Charge and energy spectra of selected energetic recoil particles can be measured in CR–39 samples with acceptable charged resolution in the case of the LDEF samples. Together with detailed detection efficiency calculations these spectra can be compared with theoretical results to validate model calculations.

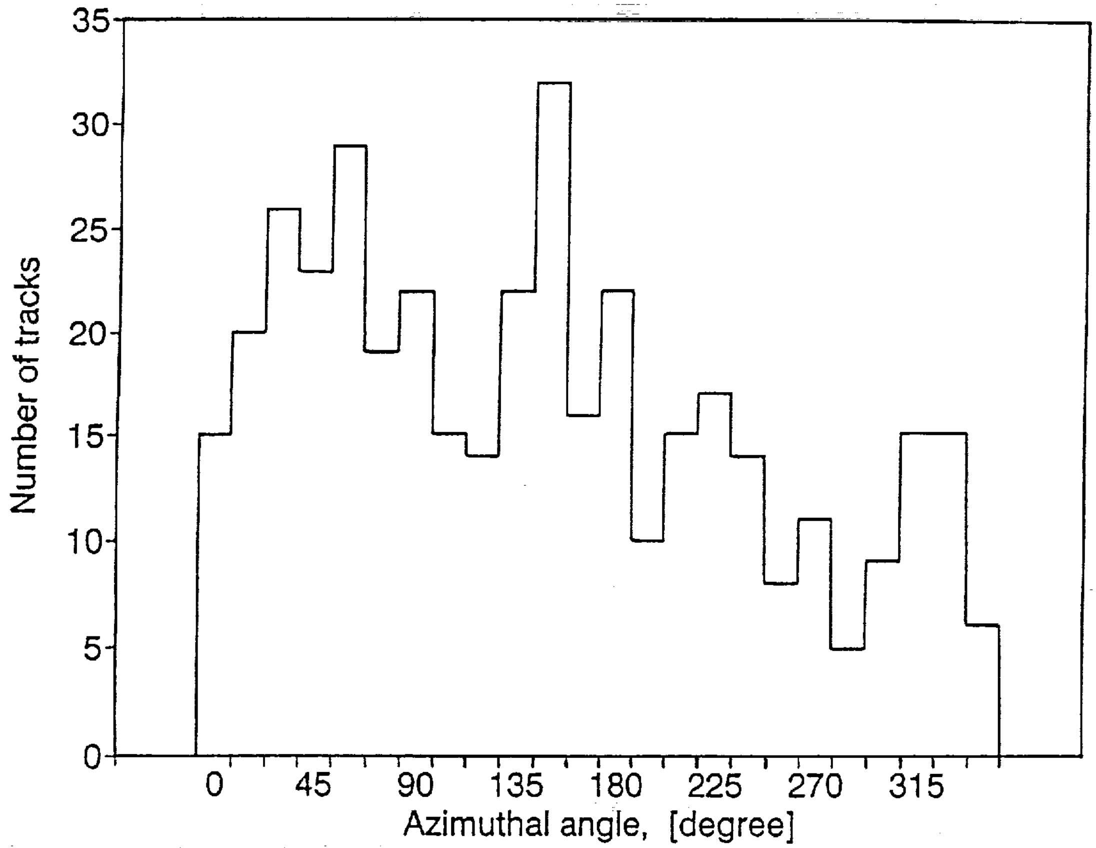

Figure 2: Azimuthal angle distribution of 400 tracks of energetic heavy recoils in a CR–39 layer from the LDEF A0015 Earth–side stack. The anisotropy reflects the anisotropy of the high energy trapped proton fluence by which these recoils were produced.

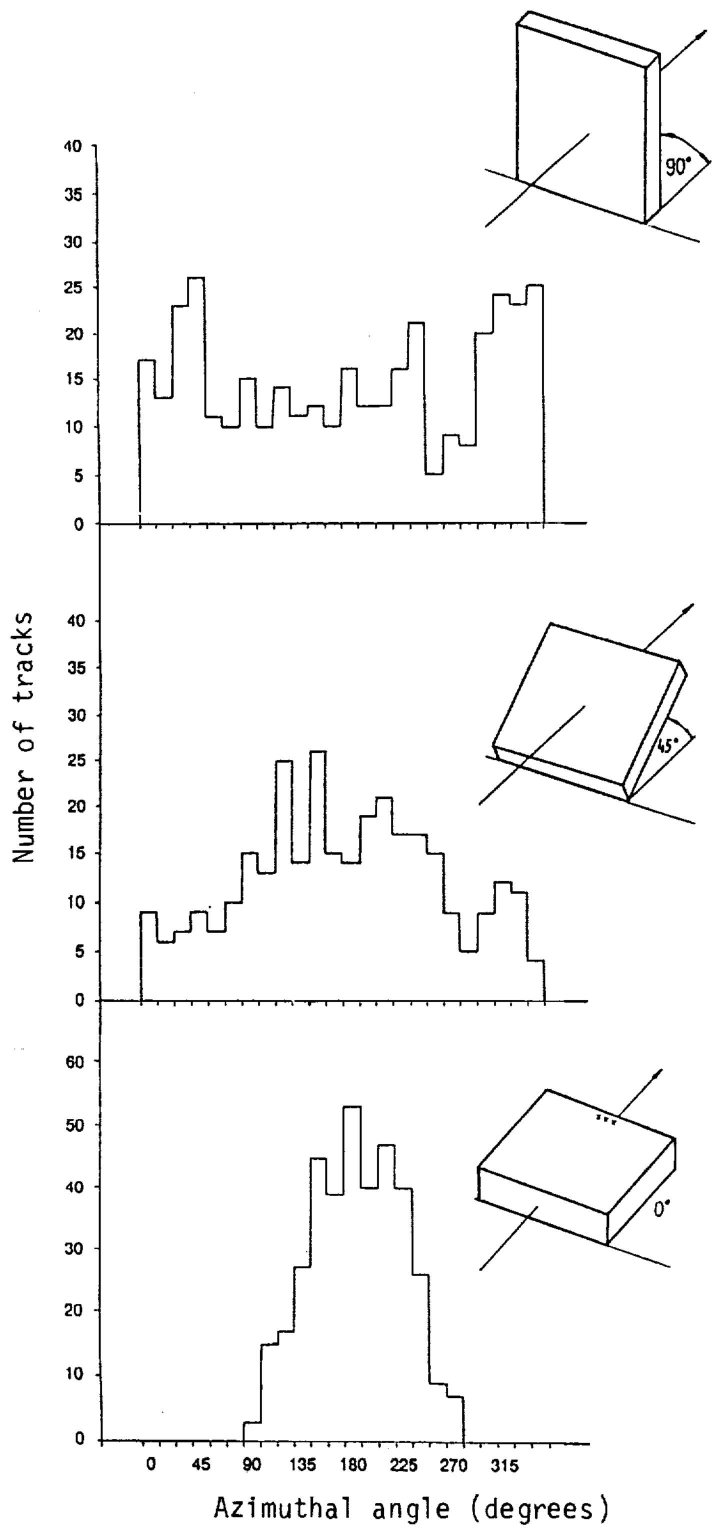

Figure 3: Azimuthal angle distributions of 300 energetic recoils produced by 200 MeV protons incident on CR–39 at various dip angles. Anisotropy of recoils show the directionality of the primary proton beam in the case of 45° and 0° dip angles.

It is found through calibration experiments that the directionality of energetic recoil particles reflects the directionality of the primary high energy proton beam by which the recoils were produced. The analysis of the azimuthal angle distribution of energetic recoils in an LDEF sample confirms the anisotropic nature of the high energy trapped proton fluence in the case of the LDEF.

Similar experiments are under way in a sample from the non–Earth–side stack to study the location dependence of the charge and energy spectra of energetic recoils. Also, a directionality study of energetic recoils is under way in samples with surfaces parallel with the East–West direction. The directionality of recoils in these samples is expected to be more definite as the majority of the trapped protons is expected to have arrived from the West direction. These experiments will be also used for validation of directionality of trapped proton radiation environment models.

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