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Calibration of solid state nuclear track detectors at high energy ion beams for cosmic radiation measurements: HAMLET results

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ABSTRACT

The MATROSHKA experiments and the related HAMLET project funded by the European Commission aimed to study the dose burden of the crew working on the International Space Station (ISS). During these experiments a human phantom equipped with several thousands of radiation detectors was exposed to cosmic rays inside and outside the ISS. Besides the measurements realized in Earth orbit, the HAMLET project included also a ground-based program of calibration and intercomparison of the different detectors applied by the participating groups using high-energy ion beams. The Space Dosimetry Group of the Centre for Energy Research (formerly Atomic Energy Research Institute) participated in these experiments with passive solid state nuclear track detectors (SSNTDs). The paper presents the results of the calibration experiments performed in the years 2008–2011 at the Heavy Ion Medical Accelerator (HIMAC) of the National Institute of Radiological Sciences (NIRS), Chiba, Japan. The data obtained serve as update and improvement for the previous calibration curves which are necessary for the evaluation of the SSNTDs exposed in unknown space radiation fields.

1. Introduction

In the framework of the MATROSHKA experiment all the proposing investigators worked together applying different passive and active radiation detector systems for the joint evaluation of skin and organ dose using an anthropomorphic head/torso phantom onboard the International Space Station [1]. Due to the fact that especially for the passive detector systems different read out and data analysis methods, etc. are applied by the various groups, the consolidation of the data from space is only possible if the different detectors are properly calibrated and intercalibrated.

The particle space radiation is a composition of high and low LET particles. The SSNTD technique, described in detail in Ref. [2], permits to determine the radiation dose above a given LET threshold, depending on type of the detector material and the evaluation method. The LET stands for the infinite Linear Energy Transfer in water, more precisely can be written as $LET_\infty \cdot H_2O$. To visualize the latent tracks induced in the detector sheets by the different ionizing particles a chemical etching procedure is applied. The detectors are evaluated after etching by an image analyzer system, which recognizes the tracks and measures their geometrical and optical parameters. From these the track etch rate ratio (V) is calculated for each particle. V is converted into LET using the appropriate calibration functions. Then the dose can be calculated from the LET spectra. It is important to note that the high LET (LET $> \sim 100$ keV μm^{-1}) mostly short ranged or secondary particles are revealed within a short etching time and after long, prolonged etching they become over etched, their geometrical parameters cannot be related to their properties any more, or they completely disappear. In the contrary, the low LET particles (LET $< \sim 30$ keV μm^{-1}) can be observed only after long etching time [3]. To obtain the realistic LET distribution (spectrum) of the cosmic radiation by SSNTD technique two etching regimes and an adequate combination method of the short and long etched LET spectra are recommended [4,5]. This means that two calibration functions need to be established, one for each etching regime. A calibration function can be obtained by exposing detectors with particles of known charge Z, mass M, energy E and LET.

For these purposes several exposures to heavy ions were performed during the years 2008–2011 at the Heavy Ion Medical Accelerator (HIMAC) of the National Institute of Radiological Sciences (NIRS), Chiba, Japan.

2. Experimental runs, detector stacks

For all the investigations presented here 1 mm thick detectors were used, made of a thermoset polymer, Polyallyl–Diglycol–Carbonate (PADC, $C_{12}H_{18}O_7$, density: 1.30 g cm^{-3}, called TASTRAK, produced by TASL Ltd. Bristol, UK). This material is in use since our first dose measurements on the ISS [6]. The quality of the

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TASTRAK detectors has been being continuously monitored by testing the bulk etch rate. It was found nearly constant, within 8%, during the last 12 years. This allowed us to improve the previous calibration curves [4], by keeping the old measurement points and adding the new ones obtained during the recent calibration regime. The LET interval above $\sim$160 keV μm^{-1} was not well covered by experiments when the old calibration curves were determined, between 240 and 428 keV μm^{-1} there were no calibration points. Our aim was to increase the reliability of the calibration curves by adding new points and, if possible, fill the gaps at the same time.

In the frame of the HIMAC calibration runs 5 beam times were organized between May 2008 and February 2011. The ions and energies are presented in Table 1.

For the 1st beam time our group sent 9 detector stacks, each of them was made of two PADC sheets. The stacks were exposed in different incident angles: 0°, 30° and 45° in the case of each ion.

For the 2nd run we provided two He stacks, two Fe stacks and two cubical detector stacks to be exposed to both ions. The He and the Fe stacks were assembled of two PADC sheets. The cubical stacks were different: "cube" and "sliced cube". Fig. 1 shows the "sliced cube". The other one was similar but without detectors inside the carbon block.

During the 3rd beam time a "sliced cube" stack (same composition as in the previous experiment), was exposed to both ions.

Table 1
Ions and energies used in the HAMLET–HIMAC experimental runs.

HIMAC run	Ion	Energy (MeV/n)
May 2008	Helium	150
	Carbon	400
	Iron	500
February 2009	Helium	150
	Iron	500
February 2010	Silicon	490
	Carbon	400
June 2010	Iron	500
January–February 2011	Neon	230
	Argon	500

In the case of the 4th beam time a "sliced cube" stack was irradiated by the bare beam. 4 other stacks were exposed after "Binary Filter" (BF) thicknesses of 0, 46.99, 63.26 and 68.91 mm. The BFs were applied to increase the Linear Energy Transfer of the iron ions for the calibration. The filters actually used were made of PMMA, but the thicknesses presented here are the equivalent in water.

In the last run our group participated with two "sliced cube" stacks, one for each ion. The Ne exposure was effectuated after 30.05 mm "Binary Filter", while the Ar exposure after 70.22 mm.

3. Determination of the calibration curves

3.1. General considerations

The calibration makes relationship between the track etch rate ratio (V) obtained from track parameter measurements and the LET_∞ in water values of the particles. The $LET_\infty(V)$ function was established through the following steps:

- It is assumed that the incident calibration particles are monoenergetic and the etched track area is strongly correlated with the particle type and energy.

- To separate the tracks of the calibration particles from the tracks of the possible secondary particles the track area distribution is investigated and a lower and upper threshold is selected. It is based on the analysis of the track area distribution curve. Tracks out of the limits are due to recoils and fragmentation, which should not be considered when obtaining the calibration curve (see an example in Fig. 2).

- From the track parameter measurements the V for each track is calculated by the following formula [2]:

$$V = \frac{\sqrt{(1-B^2)^2+4A^2}}{1-B^2}, \tag{1}$$

where $A = a/2\Delta h$ and $B = b/2\Delta h$ (a is the measured major, b is the minor axis of the track opening on the surface of the detector sheet, Δh is the etched off layer thickness, this latter one is always to be determined for each etching by control exposures applying a ^{210}Po alpha source. Details of the method obtaining Δh are given in Appendix A). This results in a distribution curve from which the

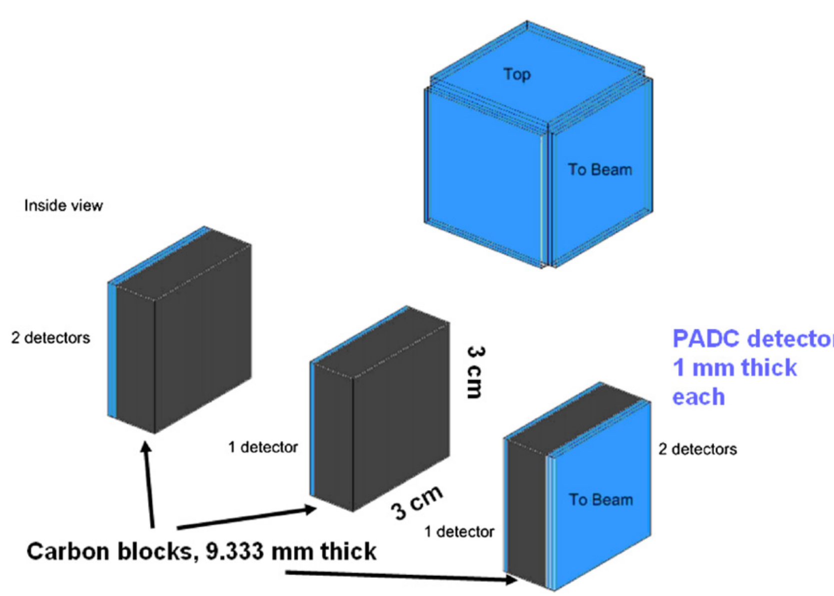

Fig. 1. Composition of the "sliced cube" stack.