Incident-Angle Dependency Found in Track Formation Sensitivity of a Plastic Nuclear Track Detector (TD-1)

Hiroshi Yasuda*,†,*1,*2

(Received June 16, 1999)
(Revised August 23, 1999)

KEY WORDS: plastic nuclear track detector, TD-l, CR-39, incident angle, LET, heavy ion, NIRS-HIMAC, space radiation

I INTRODUCTION

Plastic nuclear track detector (PNTD), which can make visible the track of an ionizing charged particle, has been used widely as a radiation detector. Particularly, with the advantage of its smallness and simplicity, this detector has been applied to space radiation dosimetry in past low-earth-orbit missions. Space radiation consists mainly of heavy charged particles and the PNTD is considered to be suitable for detection of high LET components with LET greater than several keV µm⁻¹.

When an ionizing particle passed through the PNTD, the energy will be transferred to the electrons along the track, which results in the trail of damaged molecules. This trail will form a pit on the PNTD surface by being etched in a strong base or acid solution. The pit can be made large enough to be visible with a microscope. The PNTD, however, cannot detect entire particles having the LET of more than the threshold value. A track that makes a low angle on the surface can be erased in etching process; the incident angle must exceed a critical angle (θc) to be detected. Although the θc value can be theoretically derived through geometric approximation, it is hoped to confirm the validity of this θc through ground experiments. Also, we need to recognize that the observed shape of an etchpit could change for a particle having low incident angle close to the θc. The image of an etchpit ellipse is affected by experimental conditions such as the normal-surface damage of PNTD, the adjusted condition of a microscope, and the mathematical program used for image analysis. However, very limited experimental data are available on the incident-angle dependency of the PNTD track formation sensitivity.

II MATERIALS AND METHODS

Examined in this study was an antioxidant-doped CR-39 (HARZLAS, Fukuvi Chemical Industry) of which the product name is TD-1. CR-39 (diethyleglycol bis allylcarbonate) is well known for its high sensitivity to charged particles and have been used widely as a high-LET radiation detector. Before heavy ion exposure, a plate
of TD-1 was cut to chips of $3.2 \times 16 \times 0.9$ mm$^3$. Four chips were exposed in 1-atm free air to C, Ne, and Si beams in Heavy Ion Medical Accelerator in Chiba of National Institute of Radiological Sciences (NIRS-HIMAC). The energy, the unrestricted LET in water, and the fluence of each beam are shown in Table 1. The chips were set in the beam line being inclined in intervals of 5 degrees from 0° to 90°.

At one or two days after exposure, the TD-1 chips were etched in 6N NaOH at 60°C for 12 hours and its surface was observed with an optical microscope (OLYMPUS BX50) and a program for image analysis. The track formation sensitivity ($S$) was calculated from the shape of an etchpit observed as:

$$S = \frac{VT}{VB} - 1$$

$$(16DA^2B^2/(4B^2-DB^2)^2+1)^{0.5} - 1$$

where $VT$ is the etching rate along the damaged track; $VB$ is the normal (bulk) etching rate of non-damaged surface; $DA$ is the major axis of the ellipse; $DB$ is the minor axis; and $B$ is the bulk-etching thickness. The $B$ was measured with a micrometer as the difference of thickness before and after etching. The incident angle ($\theta$) was estimated as follows:

$$\sin \theta = (4B^2+DB^2) \times \left(16B^2D_A^2+(4B^2-DB^2)^2\right)^{0.5}$$

The critical angle ($\theta_c$) was calculated by:

$$\theta_c = \arcsin \left(\frac{V_B}{V_T}\right) = \arcsin \left(\frac{1}{(S+1)}\right)$$

### III RESULTS AND DISCUSSION

The track formation sensitivity ($S$) calculated

![Fig. 1 Plots of the TD-1 track-formation sensitivity ($S$) versus the incident angles of heavy ion beams. No etchpit was observed below the theoretical critical angle ($\theta_c$) which was derived from eq. (3).](image-url)
Incident-Angle Dependency of a Plastic Nuclear Track Detector

The incident-angle dependency of the LET is shown in Fig. 1 as a function of the beam incident angle ($\theta_i$). No etchpit was observed below the O under these conditions. Thus, it is considered that the theoretical O derived from eq. (3) and the S value obtained for a vertical beam could be applied to calculation of detection efficiency. However, the S values became remarkably lower for the beams having low incident angles. These results agree with those obtained by Doke et al.9): they found that the S values decreased with lowering their incident angles for C, N, and Si beams.

In order to discuss the effect of this incident-angle dependency of S in LET determination, the S values were converted to the unrestricted LET in water according to the regression curve of S-LET relationship (Fig. 2A) obtained for the beams having vertical incident angles. In Fig. 2B, the LET values normalized to that for the vertical incident beam are shown as a function of LET. As seen in this figure, the incident-angle dependency appeared more strongly for lower LET particles. The LET value estimated for carbon beam of 11 keV $\mu$m$^{-1}$ decreased to about half at 75° incident angle, whereas Si beam of 110 keV $\mu$m$^{-1}$ showed about 20% decrease at 30° incident angle.

In the past space radiation dosimetry2-7), the LET spectra has been estimated from the S values obtained for vertical incident beams. However, the results shown in this study suggest that such LET values could have significant errors for low-incident-angle particles. This error should be larger for lower LET particles. A practical method for this correction is now being investigated.

**IV CONCLUSION**

A plastic nuclear track detector (TD-1) was exposed to heavy ion beams under different incident angles. The S values calculated from eq.(1) became smaller for the beams having lower incident angles. Accordingly, the LET values estimated from an S-LET relationship obtained for vertical incident beams showed large reduction for low incident-angle particles. Incident-angle dependency of the estimated LET appeared more strongly for lower LET particles; about 50% underestimation was found for carbon beam of 11 keV $\mu$m$^{-1}$. Such potential errors should be quantified and corrected.
accurately in determination of the LET spectra in space.

ACKNOWLEDGEMENTS: Sincere appreciation is expressed to Ms. Ayuchi NAKAMURA, Chiba Univ., Mr. Atsushi KYAN, Ibaraki Univ., for their help in the image analysis. Heavy ion exposure was carried out as part of the NIRS-HIMAC Research Project.

REFERENCES


