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SPECTRA OF THE LINEAR ENERGY TRANSFER MEASURED WITH A TRACK ETCH SPECTROMETER IN THE BEAM OF 1 GeV PROTONS AND THE CONTRIBUTION OF SECONDARY CHARGED PARTICLES TO THE DOSE

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1. INTRODUCTION

A spectrometer of the linear energy transfer (LET) based on the chemically etched polyallyldiglycolcarbonate (PADC) nuclear track detector (NTD) has been recently developed /1-3/. It has already been used to determine LET spectra in several radiation beams and fields /4-8/.

This report presents, discusses and analyzes the LET spectra established in the detectors irradiated by the beam of 1 GeV protons. The goal of experiments was to enlarge the studies already performed with the protons of energies of few hundred MeV /5-7/ and, also, to obtain new data on the dosimetric characteristics of beams supposed to be used for the programme of the «accelerator driven transmutation technologies» (ADTT) /9/.

2. EXPERIMENT

2.1. Irradiation

The irradiation has been carried out by the beam of 1 GeV protons of the LHE synchrophasotron. The monitoring of irradiation conditions has been ensured through the beam ionization chamber measurements. The proton flux during the irradiation was about 1.65×10^{8} cm^{-2}, that corresponded to the tissue kerma value about 50 mGy.The particle fluences have been determined by the sets of activation detectors (reactions $^{12}C \rightarrow {}^{11}C$; $^{27}Al \rightarrow {}^{24}Na$ or ^{18}F). placed perpendicularly to the beam simultaneously with the NTD. In total, five sets of detectors have been exposed.

2.2. LET Spectrometer Based on Chemically Etched PADC NTD

Polyallyldiglycolcarbonate available from Pershore Moulding, England (curing time 32 hours, thickness 0.5 mm) has been used. The detector samples have been etched in a 5N NaOH at 70°C after irradiation. Each sample was irradiated before etching in a corner with ^{252}Cf fission fragments, in another one with ^{241}Am alpha particles to check exact etching conditions and to determine the bulk etching. The optimal condition was corresponded to 18 hours of etching (one-side removed layer about 17 μm).

To determine LET-value of a particle, the etch rate ratio $V = V_T/V_B$ (where V_B is bulk etching rate and V_T is track etching rate) has been primarily established through the determination of track parameters. The track parameters have been measured by means of an automatic optical image analyzer LUCIA II based on a Leitz microscope /1-3/. The value of V was calculated by at least two ways of track parameter combination, the final optimization is performed through the comparison of the removed layer thickness recalculated from V-value and directly measured through fission fragment track diameter. The obtained V-spectra were corrected for the critical angle of the registration and transformed to LET spectra on the basis of the heavy charged particles calibration checked through high dose electron irradiation. The spectrometer permits to estimation LET of a track between 100 and 7000 $MeV.cm^2.g^{-1}$ in tissue.

Two sheets of PADC NTD 30x30 mm^2 covered by one half with 2 mm of polyethylene (PE) represent an irradiation set. It is always irradiated being sealed in an aluminized foil. The sheets combination gives the possibility to have four radiator positions: bare, under PE, under the first of PADC sheet (bare-CR) and under PADC covered with PE (CR-PE).

3. RESULTS AND DISCUSSION

3.1. LET spectra

The LET spectrometer permits to establish the distributions in LET of both the absorbed dose D and the equivalent dose H. For these purposes quality factors from both recent ICRP Recommendations /10,11/ have been used. First, we have observed that there is a minimal influence of the radiator on both absolute values of linear energy transfer as well as their spectral shape. Typical examples of the obtained results are for the absorbed dose and the equivalent dose with ICRP 60 quality factors presented in Figures 1 and 2. One can see there that the both spectra as well as absolute values of differential dose quantities are quite similar for all four radiators. A good agreement has been also observed for the exposed five detector sets.

More information on the contribution of secondary charged particles with the different LET values to the total LET value can be obtained from so-called microdosimetric distributions L*D(L) and L*H(L) respectively. These distributions are presented in Figure 3, for the absorbed dose as well as for the equivalent doses with both sets of quality factors.

One can see that all three spectra are peaked in the region about 2000 $MeV.cm^2.g^{-1}$, the average values of LET with respect to the energy delivery can be estimated to about 1600 $MeV.cm^2.g^{-1}$ for the absorbed dose and the equivalent dose (ICRP 21). It is a little less in the case of the equivalent dose with ICRP 60 quality factors.

3.2. Integral dosimetry and microdosimetry characteristics

The LET absorbed dose and equivalent dose distributions enable us to calculate the integral values of the absorbed dose D and equivalent dose H,

corresponding to the secondary particle tracks which are revealed. These integral values are obtained as:

$$D = \int (dN/dL) \cdot L \cdot dL ; \qquad (1)$$

$$H = \int (dN/dL) \cdot L \cdot Q(L) \cdot dL ; \qquad (2)$$

where dN/dL is the number of tracks in a LET interval; L is the value of LET; and Q(L) is the quality factor corresponding to the value of L.

The integral characteristics obtained from the LET distributions through the equations (1) and (2) are presented in Table 1. As discussed in previous papers /7/, the values presented in Table 1 could represent the total contribution of high LET particles to the tissue dose characteristics in the beam of high energy protons. One can see that these contributions increase regularly with the proton energy, going for the tissue kerma and 1 GeV protons up to about 6.8 %

Table 1: Total dose and dose equivalents due to track forming secondary particles created in the PADC LET spectrometer under high energy proton irradiation (primary proton tissue kerma = 1 Gy).

Quantity; unit	E_p, GeV			
	1.0	0.2	0.16	0.085
D, mGy	68.2±6.2	27.2±2.1	22.5±2.0	12.2±0.6
H (ICRP21), mSv	782±80	277±25	187±21	140±6
H (ICRP60), mSv	944±92	327±28	225±24	175±7

Of course, the quality factors defined for radiation protection purposes are not appropriate to appreciate, for example, relative biological efficiency in the radiotherapy. Nevertheless, the values of obtained «equivalent doses» are high enough (up to 90 % of tissue kerma due to ionization losses for 1 GeV protons) to be considered in the relation to possible differences in the efficiency of high energy protons as compared with photons and/or electrons with comparable microdosimetric characteristics for primary radiation. It is well known, for example, that the relative radiotherapy biological efficiency of few hundred MeV protons is estimated up to about 1.2 /12/. Nevertheless at radiobiological irradiation by a high energy particle beam even with thin biological samples it is very important to know the secondary charged particle contributions to the doses. The described technique of experimental estimation of LET –spectra in solid matter (the composition of CR-39 detector is tissue-equivalent roughly) allows one to define more exactly dosimetric characteristics and corresponding biological efficiencies at radiobiological experiments.

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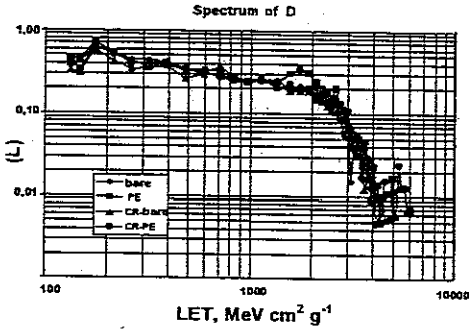

Fig.1. LET spectra of the absorbed dose due to the secondary particles in the 1 GeV proton beam

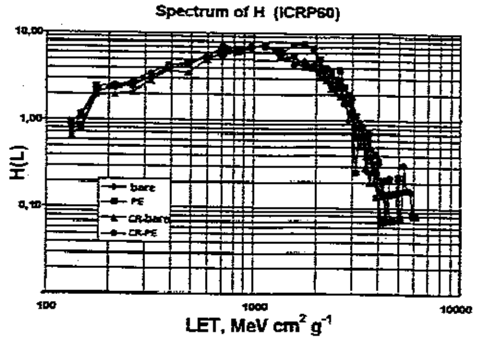

Fig.2. LET spectra of the equivalent dose (ICRP60) due to the secondary particles in the 1 GeV proton beam

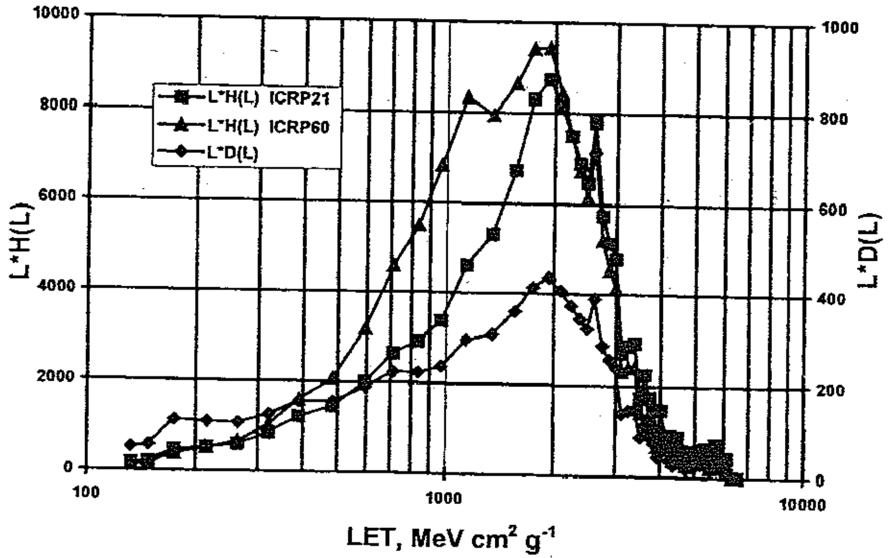

Fig.3. Microdosimetric distributions of the absorbed and equivalent doses due to the secondary particles in the 1 GeV proton beam

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