MEASUREMENTS OF LET SPECTRA OF THE JINR PHASOTRON RADIOTHERAPY PROTON BEAM

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Biological action of ionizing radiation can be described using the quantity called the Linear Energy Transfer (LET). The LET belongs to one of most important radiobiological quantities. In our paper, we focused on measurement of the LET spectra in the clinical proton beam of the Laboratory of Nuclear Problems (LNP) of the Joint Institute for Nuclear Research (JINR). The LET was calculated on the base of measurement with the Liulin-4C silicon semiconductor energy deposits spectrometer in several points along the depth-dose curve for different beam setups. Results can be used mainly for obtaining more detailed information about the radiation quality during the radiobiological experiments.

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INTRODUCTION

The mechanism of interaction of ionizing radiation with the biological objects depends on the type and the energy of the ionizing radiation. It can be described using several radiobiological quantities, of which the LET is one of the most important. In case of charged particle beams, the value of the LET depends on the ion charge and ion energy. Because the mean energy decreases and energy spectrum widens when the particle beam passes the target volume, the LET and biological effectiveness of the primary beam changes.

The LET can be determined using several approaches, e.g. with the Tissue Equivalent Proportional Counter (TEPC), solid state track etch detectors or with the semiconductor detectors. Measurement with the TEPC belongs to most conservative and oldest methods for the LET determination. Solid state track etch detectors have a relatively high sensitivity threshold and can be used for measurement of the LET spectra only above about 10 keV/μm. Hence, they can register mainly secondary particles and can be used only for measurements in the Bragg peak area of the primary proton beam (generally they can register protons with energies below 6 MeV). In some cases, a detector size plays important role. If the experiment requires minimize dimensions of the detector, the silicon semiconductors LET spectrometers can be used with advantage. One of such detectors is the Liulin semiconductor energy deposits spectrometer, which measures energy deposits of each interacting particle. Its response can be under certain conditions (mentioned later) recalculated into the LET.

1. LIULIN TYPE DETECTORS

The energy deposits spectrometer Liulin-4C was developed in the Bulgarian Academy of Sciences as a miniature 256 – channel spectrometer-dosimeter (Fig. 1) with dimensions 95×65×24 mm. Sensitive volume of the detector is made of silicon (Si) photodiode with effective area equal to 10×20 mm and thickness of 300 μm.

Thanks to the small dimensions and weight of the detector, the detector is often used as a cosmic rays monitor aboard aircraft and spacecraft [1, 2].

The Liulin spectrometer can be used also for measurement of the LET spectra in the proton and heavy ion beams if the total fluxes are of order of 10^4 of particles per second per square centimetre [3]. The only conditions are that a) the particle must impinge the detector's surface perpendicularly and b) cannot stop inside the photodiode. For charged particles, the LET can be recalculated from silicon into water using the ratio of proton's mass stopping powers in water and silicon. In the range of proton energies from 20 to 200 MeV, the LET in silicon and water are equal to each other by factor 1.24 with uncertainty of 3% [4]. All values presented in this article are corrected using this relationship.

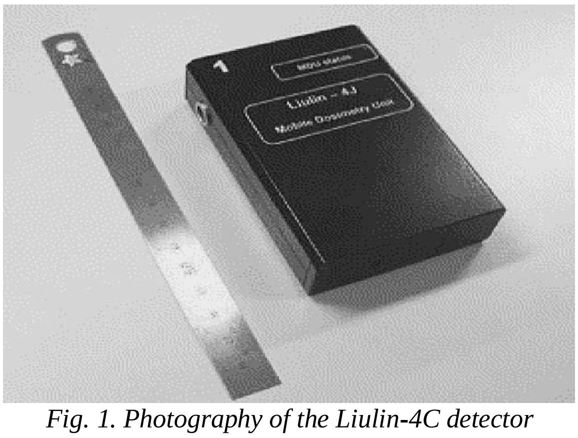

Fig. 1. Photography of the Liulin-4C detector

Simplified principle of the usual Liulin detector is as follows. Electronic signals from the sensitive volume are amplified using the low noise charge sensitive preamplifier, digitized with a fast 12-bit Analogue to Digital Converter (ADC) and analysed using the 2 microcontrollers .Obtained information is stored in a flash memory and can be accessed using the PC with corresponding software [3]. If the particle beam impinges the photodiode surface perpendicularly, the LET in silicon can be calculated from the energy deposit spectra as a ratio of energy deposited in respective channel and the thickness of the photodiode.

2. RESULTS OF THE MEASUREMENTS

Measurements of the LET spectra were performed using the Liulin-4C detector at different positions along the depth dose distribution of the clinical proton beam of the LNP of the JINR. Mean energy of the clinical proton beam at the cabin entrance was equal to 171 MeV and was measured on the base of measurement of the range of the protons in water. Depth dose curves were determined using a miniature Si semiconductor detector. Decrease of energy was achieved by adding additional poly-methyl-methacrylate (PMMA) moderator.

Depth dose distributions of the primary beam as well as of the beams modified with ridge filters (RF11 and RF14) are illustrated in Fig. 2. Points of measurements along these curves are illustrated with triangle markers.

The beam intensity was decreased to the level, in which 3×10^4 of protons were passing the photodiode surface each second. This level assures that the Liulin detector will not saturates.

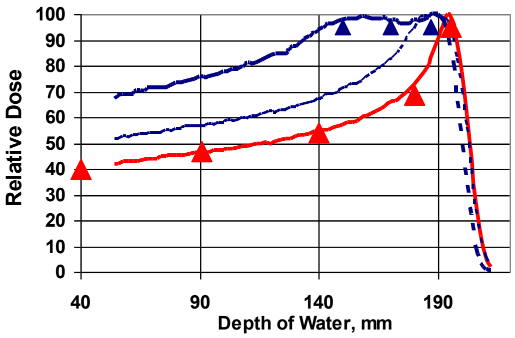

Fig. 2. Depth dose distributions of the primary and modified proton beams

The LET spectra measured in primary beam at different depth along the depth dose curve are presented in Fig. 3. We present the spectrum of number of particles in Fig. 3,a and the energetic spectrum ($E_i = LET_i \times N_i$) in Fig. 3,b. As can be seen from the figures, the LET rises and the spectrum widens with increasing depth inside the target volume.

The LET spectra measured in the proton beam modified with the ridge filters are presented in Fig. 4. As can be seen from the figure, the LET depends on the position of the detector along the spread-out Bragg-peak plateau. This can result into the different biological effectiveness of the beam even if the target is irradiated inside the spread-out Bragg peak and receives the same absorbed dose.

The absorbed dose in water can be determined from the obtained spectra as:

$$D = 1.6\ 10^{-6}\ \Sigma\ LET_i \times N_i/\rho,$$

where D – absorbed dose in water, mGy;

LET_i – LET in *i*-th channel, keV/μm;

N_i – number of particles in bin *I*;

ρ – density of water, g/cm^3.

The absorbed dose calculated from the LET spectra was compared with the absorbed dose measured with the miniature semiconductor detector. It was found that both doses are in good agreement – the comparison is shown in Fig. 5.

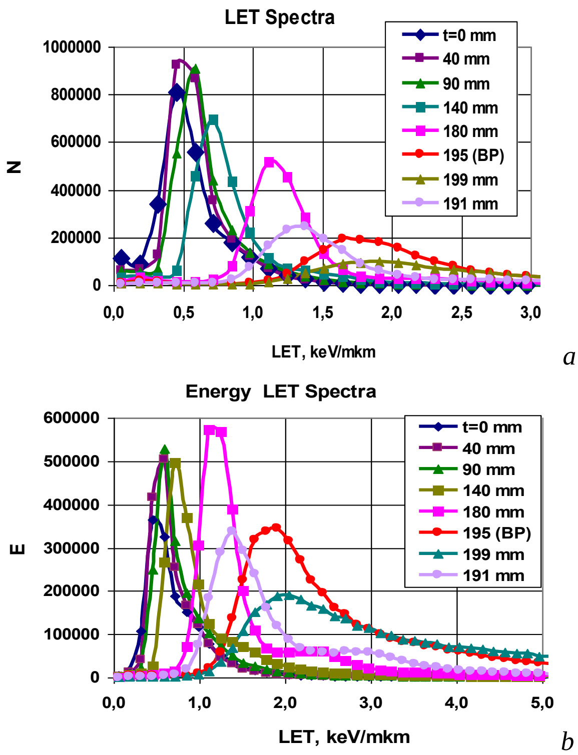

Fig. 3. LET spectra of the primary proton beam

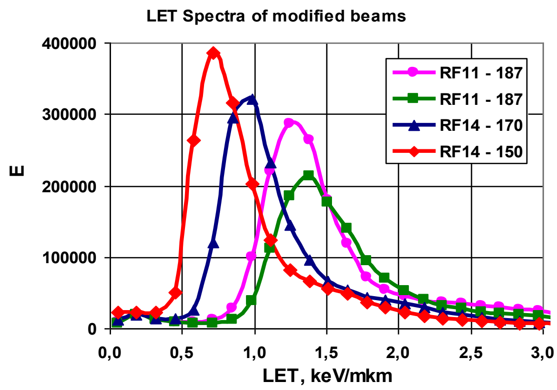

Fig. 4. LET spectra of modified proton beams

The disadvantages of the measurement with the Liulin detector are mainly its tissue non-equivalency, thickness of the sensitive volume (300 μm) and low number of spectrometer's channels.

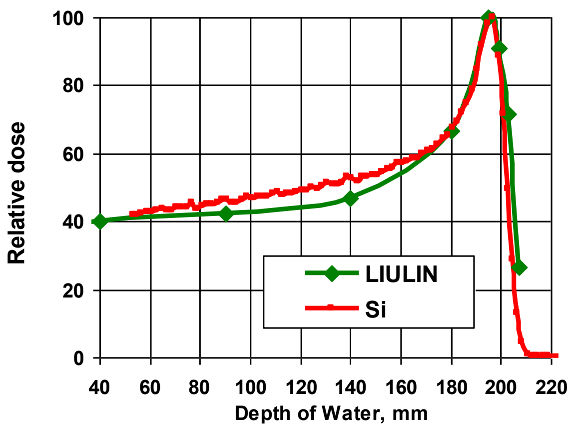

Fig. 5. Depth dose curves of the unmodified proton beam as measured with the Liulin-4C detector and the miniature silicon detector

Moreover, thickness of the sensitive volume corresponds to the range of the protons with energy of 6.3 MeV [5]. All protons with the kinetic energy below 6.3 MeV stop in the detector and hence their LET cannot be determined.

CONCLUSIONS

1. We measured the LET spectra of the clinical proton beam of the LNP of the JINR using the Liulin-4C semiconductor energy deposits spectrometer.
2. Depth dose dependence of absorbed dose measured with the Liulin-4C detector is in good agreement with the measurement with the silicon semiconductor detector.
3. Measured spectra can be used in the radiobiological experiments.

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ИЗМЕРЕНИЕ СПЕКТРОВ ЛПЭ РАДИОТЕРАПЕВТИЧЕСКОГО ПРОТОННОГО ПУЧКА ФАЗОТРОНА ЛЯП ОИЯИ

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Биологическое воздействие ионизирующего излучения определяется величиной линейной передачи энергии (ЛПЭ). От величины ЛПЭ зависит механизм взаимодействия клеток с излучением. Представлены результаты измерений спектров ЛПЭ радиотерапевтического пучка протонов фазотрона ЛЯП ОИЯИ. ЛПЭ рассчитывались на основе измерений кремниевым полупроводниковым спектрометром LIULIN-4C в различных точках глубинного дозного распределения. Результаты могут быть использованы для получения более детальной информации о качестве излучения протонного пучка при радиобиологических исследованиях.

ВИМІР СПЕКТРІВ ЛПЕ РАДІОТЕРАПЕВТИЧНОГО ПРОТОННОГО ПУЧКА ФАЗОТРОНА ЛЯП ОІЯД

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Біологічний вплив іонізуючого випромінювання визначається величиною лінійної передачі енергії (ЛПЕ). Від величини ЛПЕ залежить механізм взаємодії клітин з випромінюванням. Представлено результати вимірювань спектрів ЛПЕ радіотерапевтичного пучка протонів фазотрона ЛЯП ОІЯД. ЛПЕ розраховувалися на основі вимірів кремнієвим напівпровідниковим спектрометром LIULIN-4C у різних точках глибинного дозного розподілу. Результати можуть бути використані для отримання більш детальної інформації про якість випромінювання протонного пучка при радіобіологічних дослідженнях.