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ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

ОТДЕЛ РАДИАЦИОННОЙ БЕЗОПАСНОСТИ

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Introduction

The parameters as DE , QE (dose equivalent, quality factor), used in radiation protection, in the radiation field of high energy protons have been more frequently a subject of a theoretical than experimental studies.

The ICRP recommendations[1] concerning QF values for high energy protons and neutrons are also based on the data calculated by Neary and Mulvey[2]. The calculations of radiation dose from high energy nucleons, published in a recent few years[3-8], have given more exact data for QF and DE in the phantoms. An experimental determination of QF in the field of high energy nucleons was an object of the investigations of Baarli and Sullivan[9] and Zielczynski et al.[10] based on ion columnar recombination phenomenon in gases of an ionization chamber. Dependence of the specific luminescence of the organic scintillators upon LET of charged particles allows to realize a new detector for an experimental determination of QF of mixed radiation[11].

In the paper an attempt is made to determine experimentally the QF depth distribution in the tissue-equivalent phantom in the 200 MeV proton beam using this method.

Experimental Technique

The double detector system consisting of a tissue equivalent (TE) ionization chamber and an organic scintillation detector was used. The ionization chamber made of TE electrically conducting plastic is cylidrical in shape (40 mm dia x 140 mm) with 3 mm thick wall. The NE 102A scintillation detector (8 mm dia x 80 mm) is located inside the ionization chamber and coupled to EMI 9524S photomultiplier through the light pipe. The cross section of the double detector system is shown in Fig.1.

The detector response in mixed (n,γ) radiation field was analysed/12/ and empirical expression was derived:

$$Q = 11\left(1-0{,}91\,\frac{I_s}{K I_k}\right)\ldots\ldots, \qquad (1)$$

where

Q - quality of radiation, measured by the double detector system,

I_s - output current of the scintillation detector,

I_k - current of the ionization chamber,

K - normalization-factor, which normalizes the ratio $\frac{I_s}{K I_k}$ to 1 for γ rays of ^{60}Co .

Factor Q is calculated from expression (1) according to measured I_k and I_s values and within ± 15% agree with recommended QF values for gamma radiation and neutrons with energy from thermal up to 14.8 MeV.

A narrow beam of 196 ± 10 MeV protons was obtained by moderating 660 MeV proton beam from JINR synchrocyclotron in polythene thick slab. The energy (momentum) of protons, leaving the absorber, was estimated according to magnetic density of the sweep magnet. A "slab" phantom, 100 x 100 x 30 cm thick, was filled with a tissue equivalent liquid (mixture of water, glycerin, urea and sucrose) as suggested in[13]. An experimental arrangement is illustrated in Fig. 2. The position of the double detector inside the phantom was adjusted remotely. The output signals (i.e. current of an ionization chamber and current from a scintillation detector) were simultaneously measured by Ekco electrometers and recorded on tape. The ionization chamber was used as a monitor of proton beam stability during the experiment.

Experimental Results

The currents of the ionization chamber (dose rate) and the scintillation detector were measured along the beam axis as a function of depth in the tissue equivalent phantom. Quality of radiations, Q , was calculated from expression (1). The dose rate and quality of radiation, Q , along the beam axis as a function of depth in the phantom, are shown in Fig.3. The Bragg peak, which appears at the end of the proton range in the phantom, is not pronounced because of the energy dispersion of protons, passing through a thick slab of polythene[14], and dose rate integration over the ionization chamber volume.

At 5 cm depth in the phantom, the dose rate and radiation quality in the plane perpendicular to beam axis were estimated. The results are shown in Fig.4.

The quality of radiation, Q , for the broad beam of protons were calculated from:

$$Q = \frac{\sum_i P_i(\Delta r) Q_i(\Delta r) r_i \Delta r}{\sum_i P_i(\Delta r) r_i \Delta r} ; \qquad (2)$$

where:

$P_i(\Delta r)$ - dose rate measured by the detector in the point r_i ,

$Q_i(\Delta r)$ - quality of radiation measured by the detector in the point r_i ,

Δr - cross section dimension of the detector in the phantom (perpendicular to the beam direction)

r_i - distance from the center of detector to the beam axis in the plane perpendicular to the beam axis.

The Q value at 5 cm depth in the phantom for broad beam irradiation was obtained to be 1.55 ± 0.25. For the Q value, when compared with quality factor , QF , theoretically determined by Zerby and Kinney/4/, a 15% overestimation has been observed. The difference between Q and QF can occur due to nonidentity in relation of a specific luminescence of NE 102A scintillator upon LET and QF upon LET (aspecially for particles with low LET), and possible contamination of incident proton beam by neutrons. The experimental results are consistent with the theoretical calculations when an accuracy of latter is taken into consideration. The accuracy of Q determination is ± 20% and for the most part is a composite of the accuracies of reading of the ionization chamber currents and a scintillation detector.

The application of the discussed method for QF determination is charged not only by the experimental errors but also by a systematic error of the method. The error, which is introduced by the method itself, is determined mainly by the relation of specific luminescence of the NE 102A scintillator upon the LET of radiation. The evaluation of this error is difficult as the value of specific luminescence of the used scintillator for high LET (heavy recoil particles) is not known with good accuracy.

The comparison of QF values, which were obtained by the method described above, with those determined by a recombination chamber/15/ for the same energy of protons indicates to a good accordance of the results.

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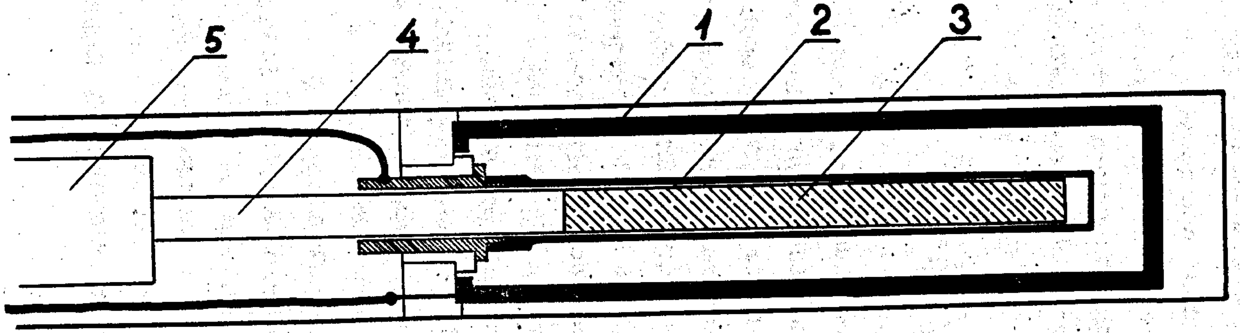

Fig.1. Schematic diagram of the detector system used in the experiment:

1,2 – electrodes of an ionization chamber,
3 – organic scintillator,
4 – light pipe,
5 – photomultiplier,

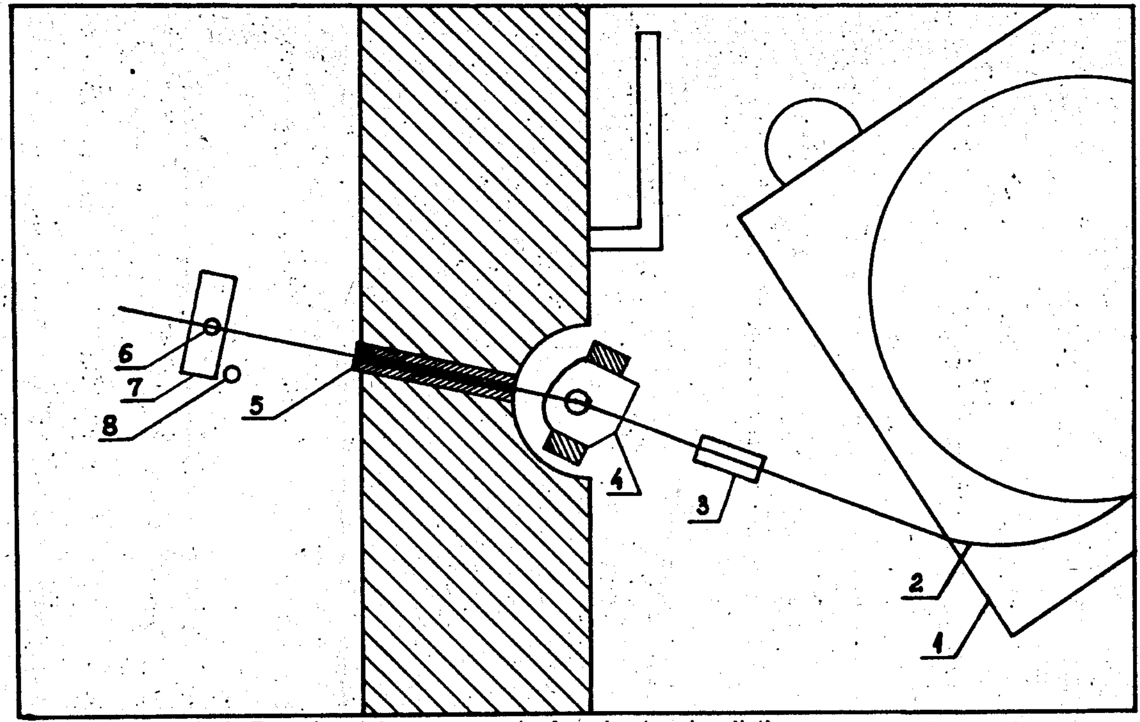

Fig.2. Experimental arrangement of a phantom irradiation:

1 - synchrocyclotron,
2 - beam path,
3 - polythene absorber,
4 - bending magnet,
5 - collimator of proton beam,
6 - investigated detectors,
7 - phantom,
8 - ionization monitor,

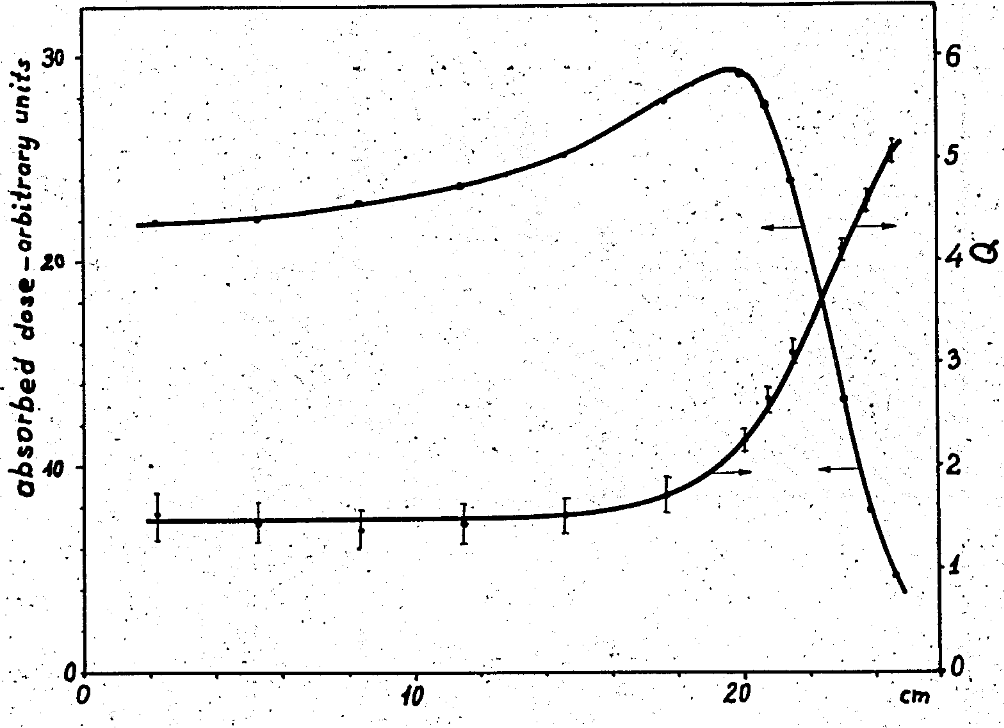

Fig.3. Center line depth dose and quality of radiation Q curves for 196 MeV proton beam.

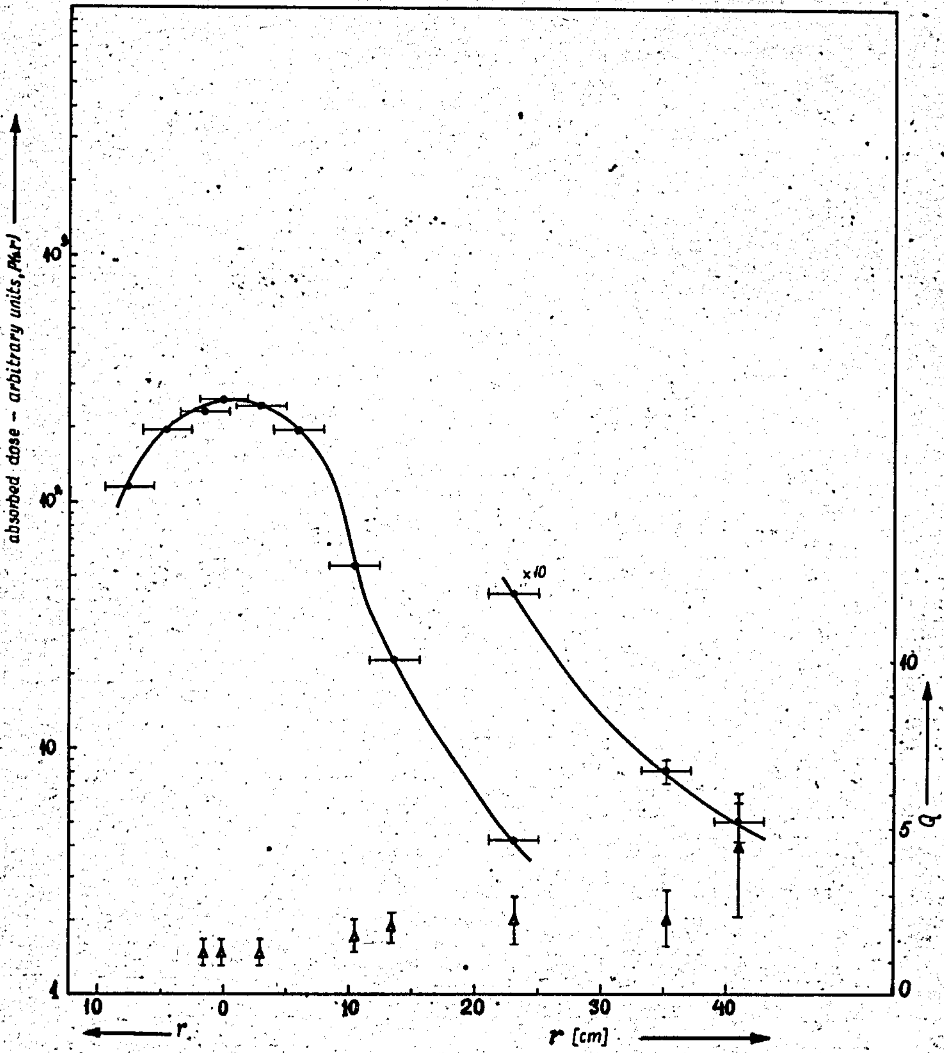

Fig.4. Dose rate (integrated over the volume of the ionization chamber) and quality of radiation across the beam at the depth of 5 cm - in the phantom

● - dose rate
Δ - quality of radiation.