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MEASUREMENTS OF SPATIAL DOSE DISTRIBUTIONS OF PROTON BEAM WITH THE USE OF RADIOCHROMIC FILMS

Мумот М., Мицын Г. В., Молоканов А. Г. E18-2006-62
Измерения распределения доз протонного пучка с использованием радиохромных пленок

Исследовалась возможность использования радиохромных пленок (РХП) для дозиметрии протонного пучка в водном фантоме. Измерялась чувствительность пленки и ее зависимость от меняющейся энергии пучка и линейной передачи энергии (ЛПЭ). Измерения проводились как с немодифицированным протонным пучком, так и с модифицированным.

Результаты измерений показывают, что чувствительность РХП уменьшается с увеличением значения ЛПЭ, и этот эффект приводит к росту погрешности измерений с уменьшением энергии пучка. Тем не менее РХП является крайне удобным детектором для дозиметрии в фантомных измерениях, где требуется высокое пространственное разрешение. При этом необходимо проводить коррекцию чувствительности пленки в области пика Брэгга.

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Mumot M., Mytsin G. V., Molokanov A. G. E18-2006-62
Measurements of Spatial Dose Distributions of Proton Beam with the Use of Radiochromic Films

A radiochromic film (RCF) is investigated for use in proton beam dosimetry in a water phantom. Investigations have been performed to measure the sensitivity of the RCF and its dependence on changing energy of the beam and on linear energy transfer (LET). Experiments were carried out with both unmodulated and modulated proton beams.

The results show that the sensitivity of the RCF decreases with increasing LET and this effect increases errors of measurements for lower energies of the beam. Nevertheless, the radiochromic film seems to be an adequate detector for dosimetry in phantom measurements where high spatial resolution is required. The correction of the film sensitivity in the Bragg peak region is advisable.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2006

INTRODUCTION

Advantages of proton therapy have been investigated for fifty years. Protons have an advantage over photons and electrons: they allow delivering a maximum dose to the deep located targets (tumours). This is especially important for some kind of tumours, e. g., brain tumours. With minimizing the dose for the surrounding tissues, proton therapy allows delivering a higher dose to the tumour, which increases a probability of local tumour control and has the consequences for patients. But because of higher doses, this kind of radiotherapy requires very precise dosimetry and positioning of a patient. Reliable, but easy-in-use methods have to be pointed out in connection with an increasing number of radiotherapy patients. Dosimetry of the proton beam, because of the nature of its depth distribution, usually requires gathering the doses in the entire plane along the beam axis. High dose gradients in the Bragg peak region and high LET dependence of the detector sensitivity make measurements by some standard methods (radiographic films, TLD) inaccurate or impossible.

The radiochromic film (RCF) seems to be a suitable material for the dosimetry in phantoms for a proton beam [1, 7]. The RCF is one of the best detectors for treatment plan verification dosimetry. It can be immersed in water. Its energy dependence for a photon beam is below 5%. It allows gathering the doses from an entire plane and its response is almost proportional to the dose obtained. It does not require chemical processing but only a scanner for digitizing of the image obtained. The analysis of the collected data is simple and accurate with the use of modern software.

Radiochromic film dosimetry gave good results in a photon beam. However, the studies of the RCF response in a proton beam showed that the use of this method for protons requires careful analysis and taking into account the effects typical of protons alone [2, 3].

The aim of this work is to verify the dose response of radiochromic films for a proton beam of 175 MeV energy. We used the proton beam of the Medico-Technical Complex of the Joint Institute for Nuclear Research (JINR) in Dubna. Regular sessions of proton therapy of cancer and some other diseases are carried out there (about 100 patients per year) [6].

In this paper we try to compare dose distributions measured with RC films and a Si-semiconductor detector. We measured the doses with the RCF positioned along the beam central axis because that configuration is especially attractive for our goals.

1. MATERIAL AND METHOD

For measurements we used MD-55 films manufactured by International Specialty Products, USA (all films from one batch — M2108MD55). The film consists of an active layer sandwiched between two sheets of transparent polyester. Our films were $5' \times 5'$ (12.7×12.7 cm^2) film sheets.

From one sheet of the MD-55 film 8 pieces 2×2 cm^2 in size were cut. These pieces were used for the calibration. We irradiated them with different doses (10, 20, 30, 40, 50, 60 and 70 Gy). Calibration doses were controlled with a clinical dosimeter KD-27012 with the air-filled ionization chamber VAK-253. The pieces were positioned perpendicular to the proton beam axis at the depth of 77 mm of water equivalent. All the optical density (OD) readouts were performed with a Vidar VXR-16 scanner 48 h after film exposure. The scanner has a relatively low sensitivity as a result of its waveband [4], so we used high doses.

Our measurements were performed in the water phantom. The RCF can be immersed in water for a few hours without any consequences [1]. Water affects only the edges of the RCF. The penetrating rate of the water leaking into a film is small and depends on time. In our experiment, contact with water lasted for less than one hour, so we omitted in our analysis the area of 1 mm along the film edges.

After the calibration a film of about 12.7×10.7 cm^2 was irradiated. The RCF was attached to the specially prepared Plexiglas (PMMA) support and it was tiled 5° away from the beam axis to eliminate artifacts that might be produced on the medium border. The PMMA support contacted only with the edges of the film. In front of the water phantom a collimator of 6×6 cm^2 in cross section was placed. Because of limited film size, it was impossible to cover the entire Bragg curve for the beam used (the beam range was about 20.4 cm of water), so the RCF was placed so as to cover the area of the Bragg peak. The maximum absorbed dose at the Bragg peak was 60 Gy (dose measured with the ionization chamber).

The RCF was scanned with a resolution 75 pixels/inch (29.5 pixels/cm) 48 h after irradiation. From the resulting bitmap file the optical density values were read out. On the basis of the preliminary irradiated and scanned pieces the calibration curve was constructed (Fig. 1) and used to convert the optical densities into absorbed dose values. The dose matrix was drawn in the form of isodoses, lines of 10, 20, 30, 40, 50, 60, 70, 80, and 90%.

In identical conditions the doses were measured with a Si-semiconductor detector in a water phantom. Our Si detector was routinely used for water phantom measurements, its dosimetry calibration was determined with the use of our ionization chamber. The profiles of the beam were measured for the same plane as with the RCF for different depths. The Si detector measured doses with an interval of 1 mm along the horizontal profile, and then it moved 5 mm deeper

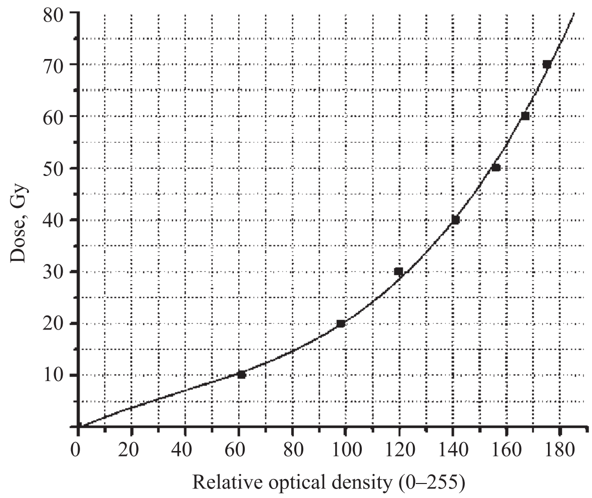

Fig. 1. Calibration curve of type MD-55 radiochromic film obtained with a Vidar-16 scanner

and gathered doses of the next profile. The collected data allow creating a matrix of doses. The isodoses were drawn and overlaid on the isodoses from the RCF.

The next experiment was done to evaluate influence of the devices which moderate the proton beam and are routinely used in radiotherapy sessions: ridge filters, individual collimators and boluses. Boluses are calculated with a dedicated computer program and manufactured for each direction from which the beam is delivered to the patient. They make the beam conformal to the back side of a tumour. The ridge filter is used to spread out the Bragg peak to cover the entire tumour in depth. It is reached by modifying the energy spectrum of the beam.

The RCF from the same batch was irradiated with the modulated beam of protons. The film was put into water in the same manner. The ridge filter and the bolus were placed in the beam. The RCF was irradiated to 50 Gy in maximum. After 48 h the RCF was scanned and digitized to obtain the matrix of doses. For the same system of beam modifiers the dose distribution was measured with the Si detector in water.

The films used were exposed to standard incandescent light only for the time of preparing them for the measurements.

2. RESULTS AND DISCUSSION

Figure 2, *a* shows isodoses obtained from the RCF and the Si-semiconductor detector for an unmodulated beam, the isodoses were drawn at every 10%. Horizontal profiles measured in the Bragg peak region are compared in Fig. 3. The profiles were gathered with the RCF and the Si detector. For the same data set the Bragg curves along central axis were compared (Fig. 4). The maximum difference for the Bragg peak amounts to 12%. In the plateau region differences between two types of dosimeters were less than 5%.

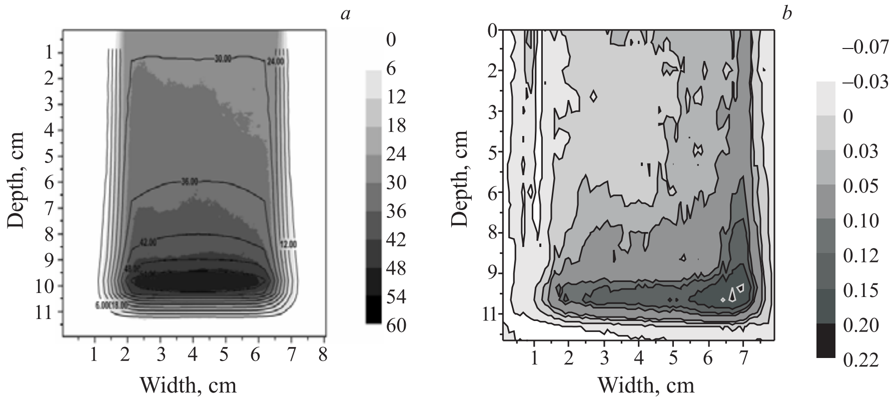

Fig. 2. Isodoses obtained from the radiochromic film (in gray-scale representation) and with the Si-semiconductor detector (in lines) for an unmodulated beam (*a*) and differences between the RCF and the Si detector on the plane (*b*)

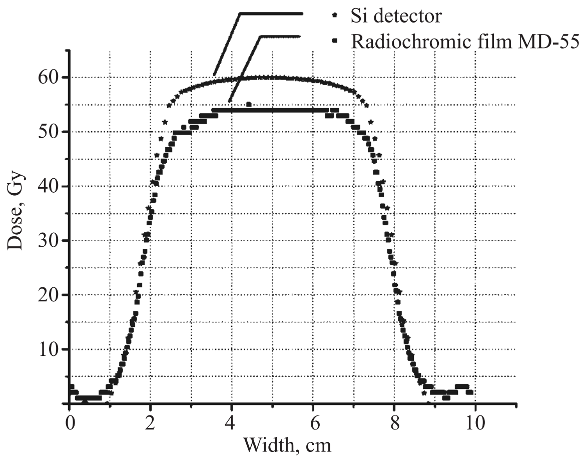

Fig. 3. Comparison of horizontal profiles measured in the Bragg peak region

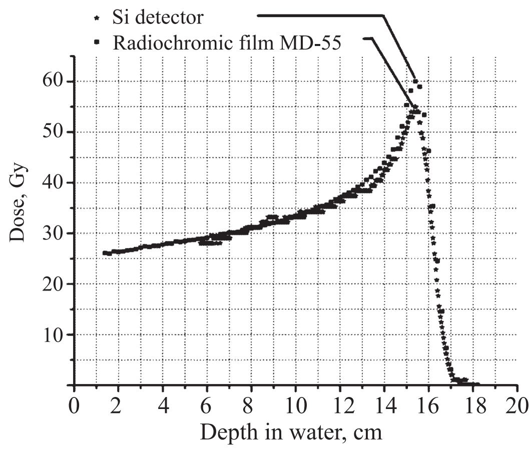

Fig. 4. Comparison of the Bragg curves along the central axis

Comparative analysis of the matrices of doses collected with the RCF and the Si detector was done: we wanted to obtain detailed information about dose disagreement in different regions of dose distributions. The doses obtained with the RCF were subtracted from the doses measured with the Si-semiconductor detector and the result was divided by the dose value at the maximum. The differences between the measurements with the RCF and the Si detector in particular regions are presented in Fig. 2, *b*. As we can see, the maximum difference between the doses is about 20% and it was presented behind the Bragg peak. It can be explained by the fact that in this region the dose gradient has a maximum value and the RCF has a better spatial accuracy than 2D measurements with the Si detector. In Fig. 5 there is a histogram of regions, where the differences are in percent at a given level.

The other pictures show the results of measurements with a beam with modification devices (ridge filter and bolus). Figure 6, *a* demonstrates isodoses collected with the Si-semiconductor detector overlaid on isodoses from the RCF given in Gy. The differences for the maximum dose level in the spread-out Bragg peak region amount to 4%. Figures 6, *b* and 7 show the results of comparative analysis of dose matrices in the form of differences on the plane and the histogram.

We tried to compare the results obtained for the modulated and unmodulated beams. The Table shows the results of this analysis. For the unmodulated beam the mean difference between the measurement with the RCF and the Si detector is higher, especially in the Bragg peak region. Also, the size of the region is larger where the dose measured with the Si detector is higher. We can conclude that there is underdosage for the measurement with the RCF and that the underdosage

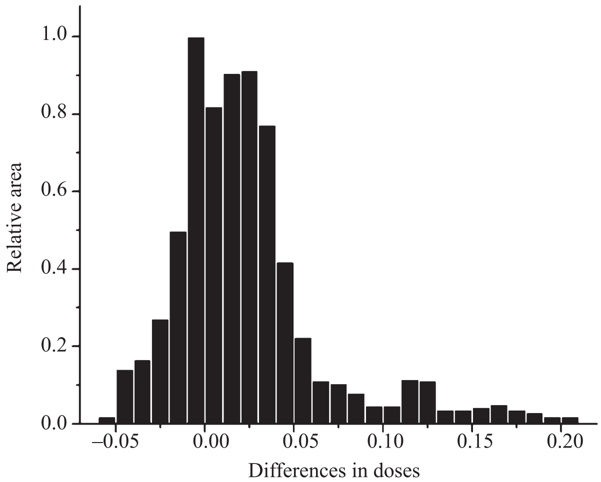

Fig. 5. Histogram of differences between doses measured with the RCF and the Si detector

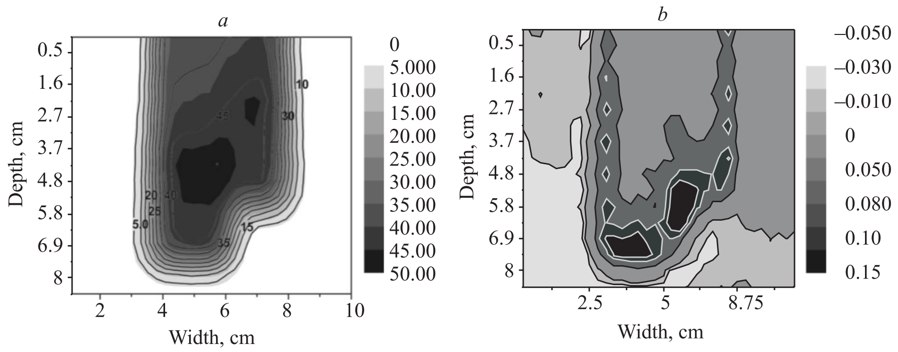

Fig. 6. Isodoses obtained from the radiochromic film (gray-scale representation) and with the Si-semiconductor detector (lines) for a beam modulated with a ridge filter and a bolus (*a*) and differences between the measurements with the RCF and the Si detector on the plane (*b*)

is larger for the unmodulated beam. It could be connected with higher LET values in the Bragg peak region of the unmodulated proton beam. Probably, the underdosage in the Bragg peak is caused by decreasing RCF sensitivity for higher LET. For precise evaluation of dose in the Bragg peak, the dosimetry calibration

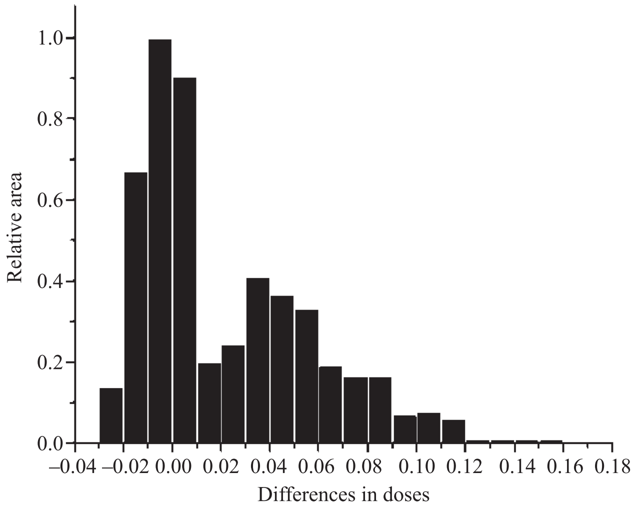

Fig. 7. Histogram of differences between doses obtained with the RCF and the Si detector for a modulated beam

Comparison of results for modulated and unmodulated beams

Difference between RCF and Si detector	Unmodulated beam	Modulated beam
Mean	3.2%	2.1%
Median	2.5%	0.7%
Standard deviation of the mean	4.3%	3.5%
Size of region where differences are $< 5\,\%$	80%	79%
Size of region where differences are $> 5\%$ and $< 10\%$	12%	18%
Size of region where differences are $> 10\%$	8%	3%
Size of region where dose measured with Si detector is higher	83%	65%
Difference in maximum dose	12%	4%

of the RCF should be carried out in the Bragg peak region. For evaluation of the dose in the whole plane the best solution seems to be correction factors, which take into account LET variation with depth. This kind of factors were proposed by Pierrmatei et al. [2]. The difference in uniformity for a single RCF sheet is less than 6% [5]. It can explain differences outside the Bragg peak region.

The results of our experiments are in agreement with the experiments done in other therapy centres (Loma Linda [3], Catania [2]). However, the differences observed by different authors are different. Vatnisky [3] reported underdosage up to 20% (energy 100–250 MeV), Pierrmatei [2] up to 40% (21.5 MeV). It can be explained by the fact that the beams of lower energies have a narrower energy spectrum because of lower straggling and accordingly higher LET. The underestimation effect seems to be better visible for lower energies, which confirms that the underdosage showed by the RCF is caused by high LET.

Radiochromic films are suitable for doses ranging from 2 to 100 Gy. It is important to remember that for lower doses the results could slightly differ from the expected ones, e. g., in region outside the beam, where the dose should be very low, we can observe the noise.

CONCLUSIONS

The results of measurements with radiochromic films are in good agreement with the expectations. The differences outside the Bragg region in the measurements with the RCF and the Si detector are mainly caused by unhomogeneity of radiochromic emulsion. In the Bragg peak region the dose measured with the RCF is lower as a result of LET-dependence of the RCF sensitivity. For dosimetry with this kind of film, the correction of doses in the Bragg peak region is advisable.

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