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APPLICATION OF A SCINTILLATION DETECTOR FOR PERIODIC MONITORING OF BEAM PARAMETERS AT MEDICAL PROTON THERAPY COMPLEX «PROMETHEUS»

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Abstract

In November 2015 the first domestic complex of proton therapy "Prometheus" start to treat oncology patients. This complex uses a modern technique for irradiation of tumours by scanning with a pencil beam. This technique requires continuous monitoring and regular verification of main beam parameters such as range in water, focusing and lateral dimension. To control these parameters, we developed a waterproof detector for measurements in air and in a water phantom.

The detector system consists of a luminescent screen 5 cm in diameter, a mirror and a CCD camera. When the beam goes through the screen, a glow appears, the reflected image of which is perceived by the camera and analysed. This design is waterproof, which makes it possible to perform measurements in water. To measure the range of protons in water, this detector was fixed on a special positioner, which allows to move the sensor with an accuracy of 0.2 mm. We measured the beams also in comparison with EBT3 dosimetry film for energies from 60 to 250 MeV with a step of 10 MeV. Same measurements of the ranges were carried out using a standard PTW Bragg Peak ionization chamber.

It was shown that this system is a simple and inexpensive tool for conducting regular quality assurance of beam parameters. Unlike the EBT3 dosimetry film, this detector gives an immediate response, which makes it possible to use it when debugging the accelerator and adjusting the beam.

INTRODUCTION

Proton therapy is receiving close attention from radiation oncologists around the world [1]. The research beams of large physics scientific centers adapted for medical purposes have been replaced by specialized medical proton facilities. In November 2015 the first domestic complex of proton therapy "Prometheus" start to treat oncology patients. It is the first specialized medical proton facility put into clinical operation in Russia (Fig. 1). «Prometheus» based on an original synchrotron with a diameter of 5 meters, which makes it possible to obtain proton beams with energy smoothly varying in the range of 30-330 MeV. The active scanning beam of the «Prometheus» synchrotron provides high conformity of the irradiation. This small spots can be used to build intensity modulated proton therapy treatment plans. But this benefit requires accurate tuning and quality assurance procedures of main beam parameters such as range in water, focusing and lateral dimension. For these purposes, a number of special equipment is used in radiation therapy. There are devices for determining the exact range of the particles, such as variable water column “Peakfinder” (PTW) or multi-layer ionisation chamber “Giraffe” (IBA Dosimetry). To assess the size of the beam and its symmetry, film dosimetry or scintillation screen detectors are mainly used [2-7]. All this devices have some limitations. For example, it requires scanning and processing of film dosimetry, which significantly increases the time of the study.

We developed a waterproof detector for measurements in air and in a water phantom that can be used in routine practice.The purpose of this work was to investigate the performances of own development scintillator detector with comparison of PTW Bragg Peak ionisation chamber and EBT3 film dosimetry.

Figure 1: Proton therapy facility «Prometheus».

MATERIALS AND METHODS

For calibration procedures we developed a detection system for measuring the geometric parameters of the beam spot in the energy 50-330 MeV. It consists of 50 mm diameter scintillation screen based on gadolinium oxysulfide, installed perpendicular to the proton beam, a mirror and a CCD camera (Fig. 2). The distance between the camera and the mirror is large enough to minimize the distortion of the

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image. Image resolution 0.12 mm/pix. This design is waterproof to make possible to perform measurements in water. For measuring the proton range in water, this detector were fixed on a special 2D positioner, which allows to move the sensor with accuracy of 0.2 mm. The detector was preliminarily characterized in terms of stability and linearity with the delivered amount of protons in range from 3e+8 to 2e+9 protons per second.

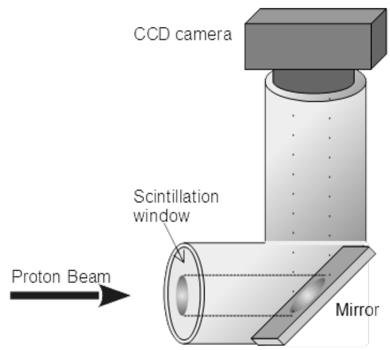

Figure 2: Scheme of scintillation detector.

To minimize induced radioactivity of materials and radiation tarnishing of scintillator and mirror, measurements in each points we performed by single 300ms proton shoot repeated 3 to 5 times to improve accuracy.

CCD camera operation synchronized with beam extraction to maximize image intensity. The signal from the camera is read by a specially developed program. In this program grayscale image is processed by median filter and colored. When the brightness center is found, which coincides with the center of the beam, the signal is approximated by a normal distribution along the horizontal and vertical axes (Fig. 3). The characteristic of the beam size is the sigma parameter of the normal distribution fitted on both axes.

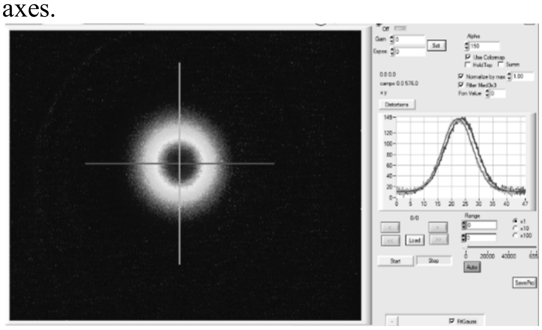

Figure 3: View of the program for beam analysis.

Beam Profile Shaping

One of the important tasks for the device is to help with adjusting the accelerator extraction channel to obtain a focused medical proton beam at the energy range of 30-330 MeV with a step of 10 MeV. Measurements performed in the isocenter of the patient's immobilization system. Figure 4 shows beam with energy 160 MeV before and after this tuning procedure. When launching a new facility and preparing for medical use, it is necessary to adjust the beam release in order to preserve the focus and symmetry of the beam in the entire range of energies used.

Adjustment performs by three quads and two pairs of horizontal and vertical correctors. Configured parameters of magnets current for each energies saved in the config file and restored when the corresponding energy is turned on.

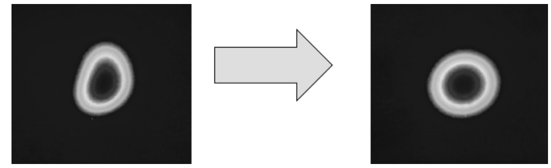

Figure 4: 160 MeV proton beam shape before and after calibration.

Accurate Beam Profile Measurements

Pencil beam technique used in «Prometheus» requires beam characteristics to be carefully assessed and periodically checked to guarantee patient safety. Main task for detector is accurate measurements of beam profile. Due to high sensitivity we can collect important parameters such as spot size in air and in water for further use of this data in the treatment planning system.

RESULTS

We measured beam size both with detector and EBT3 film for proton energies 40 to 200 MeV, see in Table 1. Unlike scintillation detector on which we used single protons shots, EBT3 film were irradiated in dose near 1Gy to have a good signal.

Table 1: Comparison of Scintillation Detector and EBT3 Film Measurements of Beam Size

E,	**Detector**		**EBT3**	
MeV	**σX, mm**	**σY, mm**	**σX, mm**	**σY, mm**
40	8.87	8.85	8.99	9.12
50	7.55	7.04	7.87	7.39
60	6.40	6.20	6.50	6.48
70	5.63	5.18	5.69	5.25
80	5.12	4.78	5.34	4.93
90	5.01	4.36	5.17	4.53
100	4.55	4.47	4.65	4.56
110	4.25	4.10	4.44	4.27
120	3.92	3.98	4.07	4.19
130	3.55	3.61	3.7	3.78
140	3.41	3.43	3.56	3.52
150	3.05	3.00	3.10	3.12
160	2.84	2.89	2.92	2.94
170	2.64	2.68	2.71	2.72
180	2.69	2.84	2.72	2.97
190	2.69	2.75	2.79	2.84
200	2.65	2.68	2.76	2.78

We took the sigma value of the Gaussian as the parameter of the beam size. Measured value ratio is shown in Fig. 5. The ratio of the values of two methods was ≤5%. Thus, size of the beam measured by EBT3 film was bigger at average 3% than the same for scintillation detector. Such

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discrepancy may be associated with the calibration of the film or caused by a higher radiation dose, in contrast to the detector.

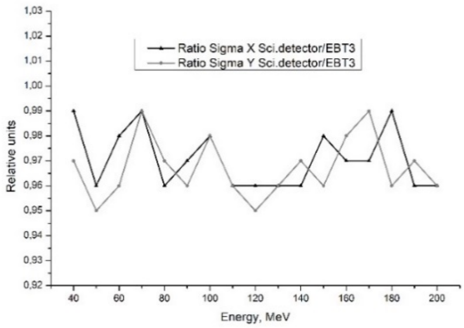

Figure 5: Ratio of measured values for beam σ at X and Y axes.

For measuring the proton range in water, this detector were fixed on 2D positioner, and pictures of the beam were measured as a function of depth in the water. By analyzing the signal amplitude of all pictures, we can determine the proton range in water with high accuracy.

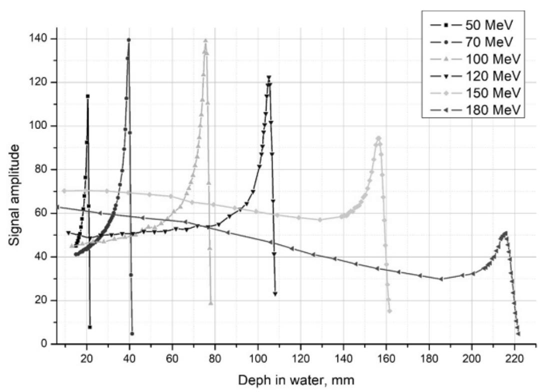

Figure 6: Bragg Peak curves measured by scintillation detector.

Figure 6 shows Bragg curves obtained by analyzing the amplitude of the signal from the scintillation detector for beams with energies 50-180 MeV. We compared this data with the same, received by PTW Bragg Peak chamber in the same water phantom. As the range of protons we used the distance to R80 – the 80 percent level behind the Bragg peak. This distance corresponds to the mean projected range of a proton, i.e. the range at which 50% of the protons have stopped. Thus, the R80 is independent of the initial energy spread of the proton beam. Differences between R80 for detector and Bragg peak ionization chamber were less than 1 mm. Figure 7 shows comparison for 150 MeV proton measurements. For this energy difference was near 0.5 mm.

CONCLUSION

Developed scintillation detector is a simple and inexpensive tool for conducting regular beam quality assurance procedures. Detector combines properties of EBT film dosimeters useful for beam shape analyses and parallel plate ionization chambers used for percentage depth dose measurements in water and proton range verification. Unlike the EBT3 dosimetry film, this detector gives an immediate response, which makes it possible to use for debugging extraction channel and adjusting the beam. The beam parameters obtained during the initial tuning and calibration of the accelerator extraction channel could be used in subsequent beam quality control procedures.

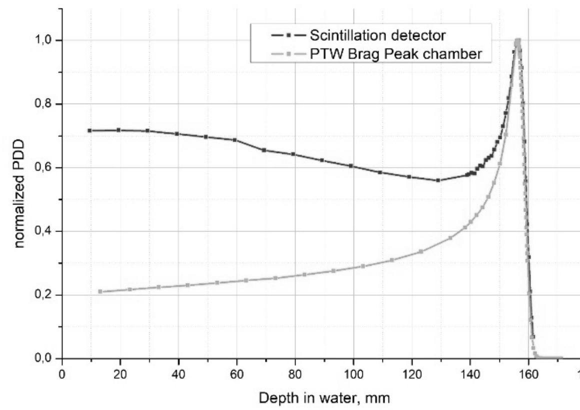

Figure 7: Depth dose curve for 150 MeV proton beam in water measured by scintillation detector and PTW Bragg Peak chamber.

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