E16-2015-32

J. Kubančák [1], A. G. Molokanov,
M. Navrátil [2], B. Vlček [1], V. Vondráček [2]

MEASUREMENT OF OUT-OF-FIELD DOSES IN THE CLINICAL PROTON BEAM AT THE CZECH PROTON THERAPY CENTER

[1] Nuclear Physics Institute of the ASCR, Prague
[2] Czech Proton Therapy Center, Prague

Кубанчак Я. и др. E16-2015-32

Измерения рассеянных дозных полей клинического протонного пучка
в Центре протонной терапии Чехии

В работе приведены результаты измерений дозных полей в Центре протонной терапии в Праге (PTC), где для облучения пациентов применяется техника активного сканирования узким протонным пучком. Полученные данные сравниваются с аналогичными экспериментами, выполненными ранее в Медико-техническом комплексе ЛЯП ОИЯИ в Дубне.

В отличие от PTC для формирования протонного пучка в ЛЯП ОИЯИ применяется пассивная система коллиматоров, дополнительных замедлителей и гребенчатых фильтров. В активных системах сканирования единственным значимым источником вторичного излучения является взаимодействие пучка с телом пациента, в то время как в пассивных системах дополнительный вклад в дозу вносит вторичное излучение, образованное в коллиматорах, дополнительных замедлителях и гребенчатых фильтрах.

В результате измерений было показано, что поглощенные дозы за пределами первичного пучка, измеренные в PTC в Чехии, оказались ниже, чем в Дубне. Основной причиной различий является рассеяние протонов на элементах пассивной системы формирования пучка в кабине.

Работа выполнена в Лаборатории ядерных проблем им. В. П. Джелепова ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2015

Kubančák J. et al. E16-2015-32

Measurement of Out-of-Field Doses in the Clinical Proton Beam
at the Czech Proton Therapy Center

In our paper we describe results of out-of-field doses measurements performed in the clinical proton beam at the Czech Proton Therapy Center (PTC), Prague, using a pencil-beam delivery mode. The obtained data were compared with a similar experiment previously performed at the medical center of the Dzhelepov Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research, Dubna.

Contrary to the PTC experiment, the clinical proton beam at the JINR Phasotron was formed using passive system of collimators, additional degraders and ridge filters. In active scanning systems, beam interactions with the patient's body are the only significant source of secondary radiation, whereas in passive scattering beam lines there are a number of additional collimators, and ridge filters in which secondary radiation is produced.

The out-of-field absorbed doses measured in the Czech PTC were found to be lower and more homogenously distributed than those measured in Dubna. The main cause of the difference is scattering of the primary beam on the elements of beam formation in the therapy room of JINR.

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

Communication of the Joint Institute for Nuclear Research. Dubna, 2015

INTRODUCTION

Radiotherapy is from its beginning connected with the requirement of maximal dose delivery into the target volume and minimal radiation load of surrounding healthy tissues. Naturally, these two conditions are opposite to each other and the latter is dominated by stochastic effects, such as, for example, secondary radiation malignancies induction.

Dose delivered outside the proton field during radiotherapy can potentially lead to secondary cancer development. The work is primarily focused on measurements of absorbed doses delivered outside the target volume. Out-of-field dosimetry was performed in the clinical proton beam at the Czech Proton Therapy Center, s.r.o. (PTC), using a pencil-beam scanning technique.

The obtained data were compared with the similar experiment performed in the medical center of the Dzhelepov Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research, Dubna, Russia. There is a fundamental difference between the different ways of forming the depth dose distributions. Proton beam in the PTC uses active pencil-beam technique to form the spatial depth dose distribution, while the proton beam at the JINR Phasotron applies passive scattering technique, i.e., a system of collimators, additional degraders, and ridge filters. In active scanning systems beam interactions with the patient's body are the only significant source of secondary radiation, whereas in passive scattering beam lines the secondary radiation fields are induced also in interactions of the primary beam with filters, degraders, and shaping collimators.

1. MATERIALS AND METHODS

Out-of-field dosimetry was performed in the clinical proton beam at the Czech Proton Therapy Center, s.r.o. (PTC). The obtained data were compared with the similar experiment performed in the medical center of the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research, Dubna [1, 2].

The out-of-field doses can vary by several orders of magnitude. For this reason, measurements of absorbed dose were performed with thermoluminescent detectors placed in the PMMA phantoms.

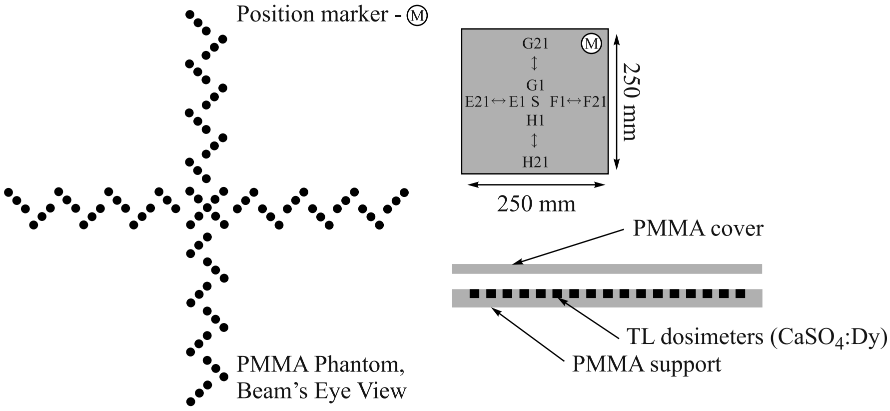

Fig. 1. Schematic drawing of the used phantom. Black dots represent holes for TLDs

This work was focused on measurements of absorbed dose delivered outside the target volume shaped using simple beam profiles. For this purpose, special PMMA phantoms were constructed. They consisted of two parts: the bottom and the top one. The bottom part was made of PMMA glass in the shape of parallelepiped with square base of side 250 mm and depth of 10 mm. The top part was created from another PMMA plate with square base of the same proportions but 4 mm deep.

As detectors, $CaSO_4$:Dy dosimeters in form of powder fixed in aluminum holder were used. They were placed in holes drilled into the bottom part of the PMMA phantom so that they would shadow themselves minimally. Furthermore, emphasis on maximal symmetry was put. Detectors were calibrated individually in ^{137}Cs beam in terms of absorbed dose in water. Individual calibration minimized the uncertainty of measurement. Schematic drawing of the phantom is presented in Fig. 1.

2. EXPOSITIONS IN THE PTC CLINICAL PROTON BEAM

Experiments were performed at the Czech Proton Therapy Center, Prague. Pictures of the experiment are presented in Fig. 2. Measurements were carried out for the target volume produced using scanned beam technique. Depth dose distribution and the lateral beam profile at the center of SOBP are presented in Fig. 3. The maximal range of the beam was 21 g/cm^2, SOBP was 6 g/cm^2, and a lateral width of the beam was 4 cm at 95% isodose level (FWHM = 5.4 cm). Absorbed dose delivered to the target volume at the center of SOBP was 20 Gy. Lateral profiles of the beam were measured with thermoluminescent detectors

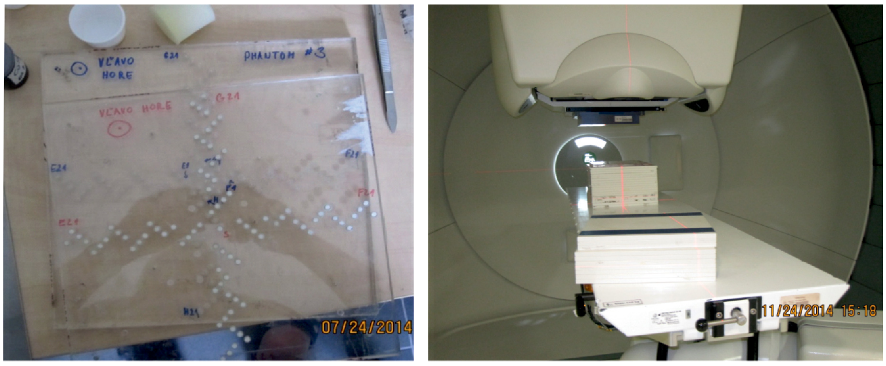

Fig. 2. Pictures of the PMMA phantom with TLDs (left) and gantry with the phantom (right)

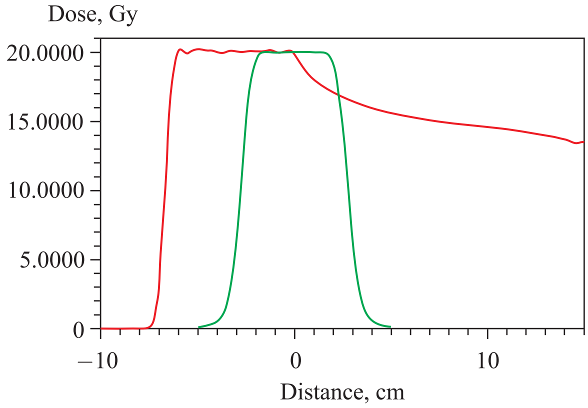

Fig. 3. Depth dose distribution and lateral profile of the PTC proton beam

placed in the PMMA phantoms at two depths — at the beam input (Phantom1) and at the center of the SOBP (Phantom 2).

3. RESULTS

Results of the measurements with the $CaSO_4$:Dy TLDs are presented in Table 1 and Fig. 4. The data in the figure are normalized to the value of the absorbed dose delivered to the target.

As can be seen, the dose measured in the target volume is substantially lower than the prescribed one. The reason is that response of $CaSO_4$:Dy TLDs is strongly saturated and hence the measured dose does not correspond to the actual dose. Response of the detectors located in the target volume and irradiated with a very high dose is nonlinear. Nevertheless, outside the target volume, the

Table 1. **Absorbed doses distribution measured at the PTC proton beam in the PMMA phantoms irradiated with a dose of 20 Gy at the SOBP**

X, Y, mm	Absorbed dose, (mGy)			
	Vertical Ph1	Horizontal Ph1	Vertical Ph2	Horizontal Ph2
105	1.01	1.80	1.89	2.01
90	1.20	2.64	4.51	4.28
75	1.60	3.81	14.65	13.19
60	2.64	7.00	56.52	53.14
45	7.18	16.60	243.09	225.53
30	473.55	600.37	5890.35	4090.98
15	8799.51	9223.65	12921.16	13016.50
0	8529.56	8529.56	11572.57	11572.57
–15	9524.78	9101.00	12070.16	13492.39
–30	257.88	518.56	5078.60	5065.67
–45	6.68	13.61	217.10	263.14
–60	2.49	4.21	51.46	61.45
–75	1.62	2.15	13.32	15.91
–90	1.19	1.32	3.97	5.81
–105	0.93	1.06	1.73	2.82

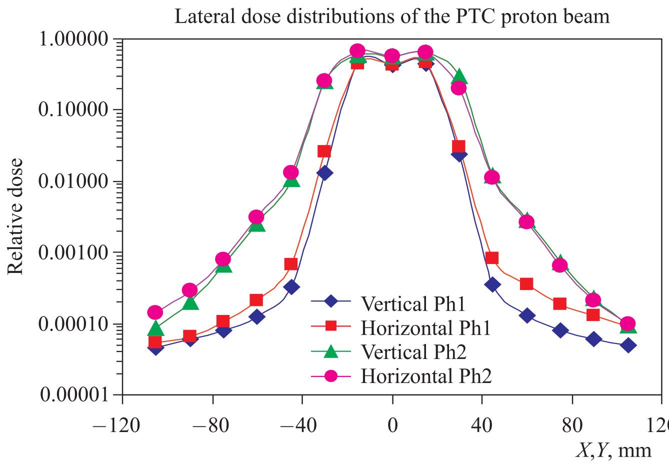

Fig. 4. Horizontal and vertical dose distributions measured in the PTC proton beam with $CaSO_4$:Dy TLDs

secondary particles do not distort measured absorbed dose distributions.

The beam expands with the passage of the proton beam from the entrance to the Bragg peak region due to multiple scattering.

4. COMPARISON WITH THE CLINICAL PROTON BEAM IN DUBNA

Some out-of-field dosimetry measurements were already performed at the Phasotron in the Dzhelepov Laboratory of Nuclear Problems of the Joint Institute for Nuclear Resarch, Dubna, Russia, and are described in [3]. Expositions were realized in the treatment room, which is primarily used for brain radiotherapy and radiosurgery. The average energy of the entering proton beam was 171 MeV. In the room, the beam passed farther through three collimators. Spread out of Bragg peak (SOBP) configuration was also achieved using a passive modulator — ridge filter, consisting of absorbers made from aluminum and polymethyl methacrylate (PMMA). Schematic drawing of the beam collimation system in the treatment room is shown in Figs. 5, 6.

The Bragg peak was spread out to approximately 6 cm of depth, the beam lateral size has a square shape of dimensions 5×5 cm (FWHM). Dose delivered to the target volume was 30 Gy. These techniques necessarily resulted into delivery of some unwanted dose outside the beam [1, 2]. The setup and the experimental irradiation conditions were validated with an ionization chamber and a small silicon detector.

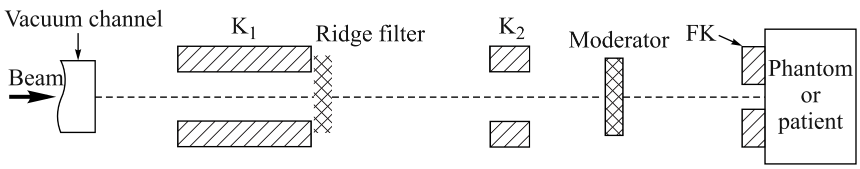

Fig. 5. Beam collimation system in the treatment room. K_1 and K_2 represent primary and intermediate collimators, FK represents the final shaping collimator

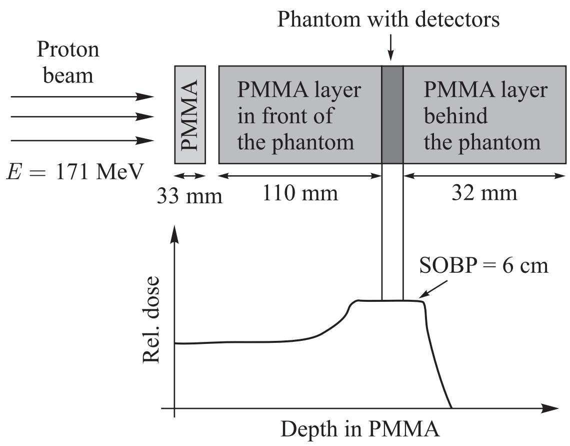

Fig. 6. Schematic drawing of the experiment, in which the phantom was positioned between two PMMA layers, and measuring the dose in the centre of the spread-out Bragg peak area

Results of the measurements of lateral absorbed dose distributions at the center of the SOBP of the JINR proton beam with the $CaSO_4$:Dy TLDs normalized to the value 1 Gy of the absorbed dose delivered to the target are presented in Table 2.

Table 2. **Absorbed doses distributions measured at the spread-out Bragg peak of the JINR proton beam normalized to the value 1 Gy of the absorbed dose delivered to the target**

X, Y, mm	Absorbed dose, mGy	
	Horizontal	Vertical
105	1.317	1.100
90	2.116	1.805
75	2.126	0.615
60	0.661	0.841
45	3.809	4.571
30	43.165	124.948
15	829.951	759.193
0	926.088	926.088
–15	809.314	611.909
–30	104.241	35.198
–45	3.607	3.358
–60	0.719	0.633
–75	0.453	0.213
–90	1.156	0.144
–105	1.044	0.093

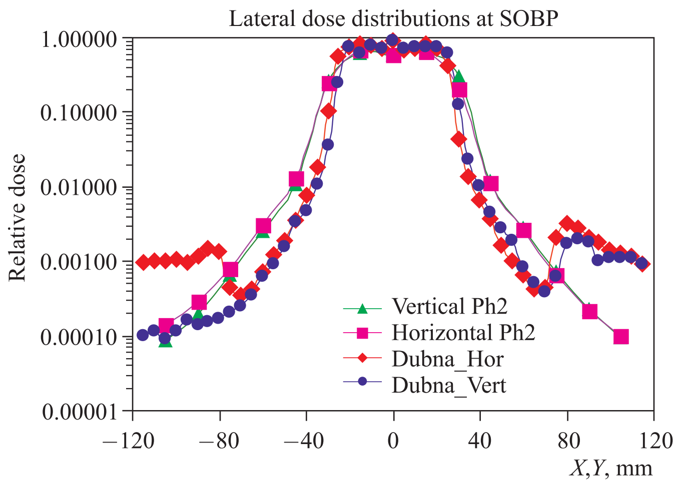

Fig. 7. Horizontal and vertical dose distributions measured in the Czech PTC, Prague, and in JINR, Dubna, at the centre of SOBP proton beams with $CaSO_4$:Dy TLDs

During the experiments in Dubna, it was found that there is an anomalous dose increase in the direction from the center to the edges of the phantom. This anomalous increase was found to be field size independent and was minimized by applying additional shielding around the intermediate and final shaping collimators. In the lower part of vertical profile there is no this effect due to the horizontal platform on which the beam forming system is placed. There is no anomalous increase of absorbed doses observed in the case of the Czech PTC scanning proton beam.

In Fig. 7 we compare relative doses measured in both facilities with $CaSO_4$:Dy detectors. The data in Fig. 7 are normalized to the values of the absorbed dose 1 Gy delivered to the targets in each experiment.

CONCLUSIONS

The out-of-field doses measured in the Czech PTC, s.r.o. were found to be lower and more homogenously distributed than those measured in Dubna. The main cause of the difference is scattering of the primary beam on the shaping collimators of the Dubna beam. Nevertheless, in both cases the out-of-field doses are by one order lower than in the case of analogous target volume shaped by the linac megavoltage photon beams [4].

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Received on May 12, 2015.

Редактор *Е. И. Крупко*

Подписано в печать 8.07.2015.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 0,5. Уч.-изд. л. 0,55. Тираж 195 экз. Заказ № 58592.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@jinr.ru
www.jinr.ru/publish/