DOSIMETRY OF PROTON BEAMS AT THE MEDICAL FACILITY OF THE JINR PHASOTRON IN DUBNA.

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Radiation therapy with a proton beam has a number of important advantages over conventional radiation therapy. The proton beam allows the maximum dose to be confined to the treatment volume while the dose to surrounding normal tissues is minimized. Realization of these advantages requires higher precision of the proton beam dosimetry.

For absorbed dose rate measurements of therapeutic proton beams we use the KD-27012 clinical dosimeters with thimble air–filled ionization chambers VAK-251 (volume 50 mm^3) and VAK-253 (volume 1.5 cm^3) with air–equivalent walls. The dosimeter calibration was made with the ^{60}Co source of the therapeutic γ-unit, placed in one of the cabins of the clinico–physical facility in accordance with the recommendations of the "Code of practice for clinical proton dosimetry"[1]. The ^{60}Co source was calibrated against the primary standard of the Prague Institute of Radiation Dosimetry with the accuracy of 1.3% [10]. Using the γ–unit as a calibrated stand for ionization chambers of our clinical dosimeters was described in [3,4].

The absorbed dose calibration factor for the proton beams A_{cal} may be obtained from the calibration of the ionization chamber in the ^{60}Co source using the relations:

$$A_{cal} = N_k * C_p = N_x * (W_{air}/e)_\gamma/(1-g) * C_p \ ,$$

where N_k (Gy/reading) is the air kerma calibration factor and N_x (R/reading) is the exposure calibration factor in the ^{60}Co beam.

The proton conversion factor C_p may be obtained using the formulae from [1]:

$$C_p = A_{wall} * [(\bar{S}/\rho)_{air}^{tissue}]_p * k \ ,$$

where

$$k = (1-g) * \frac{(W_{air}/e)_p}{(W_{air}/e)_\gamma} * \frac{[(\bar{\mu}_{en}/\rho)_{air}^{wall}]_\gamma}{[(L/\rho)_{air}^{wall}]_\gamma} .$$

The following coefficients were used for our dosimeter calibration:

- A_{wall} is the wall perturbation factor that takes into account absorption and scattering of γ-rays produced in the ionization chamber walls. The value A_{wall} = 0.99 ± 0.01 is in accordance with these values for all chambers with similar geometrical dimensions.

- $[(\bar{S}/\rho)_{air}^{tissue}]_p$ is the ratio of the mass stopping powers of tissue to air for the proton beam - may be obtained from [5,6]. The "Supplement to the Code of Practice for Clinical Proton Dosimetry" [2] incorporates the new stopping power data from [6]. Differences in the ratios calculated from these two compilations are less than 2%. For proton energies 50 - 1000 MeV this ratio varies very slowly and in [3] it was used as a constant value 1.136 ± 0.016 (1.4%). Table 1 also presents A_{cal} calculated for proton energies 10 MeV and 200 MeV. As we can see A_{cal} very slightly depends on the energy of protons;

- (1 - g) - correction to bremsstrahlung in the air in the ^{60}Co beam (g = 0.003) [1];
- $(W_{air}/e)_p = 35.2eV$ (4.0%) $(W_{air}/e)_\gamma = 33.97eV$ (0.2%) - the average energy required to produce an ion pair in dry air for γ-rays and protons [1]. These values are recommended in [1,2] for all proton energies. But this value of $(W_{air}/e)_p$ is based on measurements at a proton energy of 1.8 MeV [7]. Recently many investigations of the energy required to produce an ion pair for heavy charged particles and in particular a correlation between $(W_{air}/e)_p$ and the LET of particles were performed. For example, in the paper [9] values of $(W_{air}/e)_p/(W_{air}/e)_\gamma$ for different heavy charged particles with different energies from the published data were plotted versus the unrestricted LET. This plot shows that for protons with energy higher than 10 MeV $(W_{air}/e)_p/(W_{air}/e)_\gamma$ is equal to 1.0 and increases with increasing LET (or decreasing proton energy). This value is in agreement with the $(W_{air}/e)_p$ obtained in [8]. This plot also confirms the value $(W_{air}/e)_p/(W_{air}/e)_\gamma$ measured at a 1.8 Mev in [7] and recommended in [1,2];

  The $(W_{air}/e)_p$ value of 34.2 ± 0.5 for the dry air found in latest measurements [11] by using a water calorimeter to calibrate an ionization chamber in proton and ^{60}Co beams also confirmed this plot. This value undoubtedly has to be recommended for determination of the dose in therapeutic proton beams.
- $[(\bar{\mu}_{en}/\rho)_{air}^{wall}]_\gamma = 1.0227$ (1%) - the ratio between the mean mass energy absorption coefficients of the chamber wall material and the air for γ-rays for our ionization chambers [4];
- $[(\bar{L}/\rho)_{air}^{wall}]_\gamma = 1.0076$ (1%) - the ratio between the mean restricted collision mass stopping powers of the chamber wall material and the air for γ-rays [4].

The results of the ionization chamber calibration with different parameters are presented in Table 1.

The full estimated uncertainty of the A_{cal} value with $(W_{air}/e)_p = 1.007$ from [11] is about 3% (one standard deviation).

CONCLUSIONS

- The method for determination of the dose rate absorbed by tissues for the JINR medical proton beam on the basis of clinical dosimeter calibration with the ^{60}Co γ–source is described. The results of the ionization chamber calibration using different parameters are presented. The basic parameters used for calculations were taken from various papers.
- The energy dependence of the calibrated factor is very slight and influence of the proton beam energy distribution is negligible.

Table 1. Calculation of the absorbed dose rate for the therapeutic proton beam at the JINR phasotron in Dubna

A_{wall}	0.99±0.01 [3]				
(1 - g)	0.997 [1]				
$[(\bar{\mu}_{en}/\rho)_{air}^{wall}]_\gamma$	1.0227 (1%) [4]				
$[(\bar{L}/\rho)_{air}^{wall}]_\gamma$	1.0076 (1%) [4]				
$(W_{air}/e)_p, eV$	35.2 (4 %) [1]			34.1 (2 %) [8]	34.2 ±0.5[11]
$(W_{air}/e)_p/(W_{air}/e)_\gamma$	1.0362 [1]			1.01 [8]	1.007 [11]
Energy,MeV	50 – 1000 MeV	200 MeV	10 Mev	200 MeV	250 MeV
$[(\bar{S}/\rho)_{air}^{tissue}]_p$	1.136 [5]	1.130 [6]	1.139 [6]	1.130 [6]	1.130 [6]
K	1.049	1.049	1.052	1.022	1.019
C_p	1.18	1.1735	1.183	1.1433	1.1396
A_{cal}	1.031	1.025	1.034	0.999	0.996

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