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THE PENUMBRA OF IRRADIATIONS IN LINEAR ACCELERATORS, ITS USE IN RADIOTHERAPY OF CANCER DISEASES, NEGATIVE EFFECTS, AND THE POSSIBILITIES OF REDUCING THEM

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Abstract. *The aim of this study is to highlight the understanding of radiation, changes in the radiation of the same type but with different energy, the causes of these changes, the damages caused by their presence in the primary beam, or the reduction of the effectiveness of radiation, compared with the same radiation beam in which the presence of penumbra is higher. Penumbra is the region near the edge of the field margin where the dose falls rapidly. The dose falls off around the geometric beam edge that is sigmoid in shape and extends under the collimator jaws into the penumbral tail region, where there is a small component of the dose due to the transmission through the collimator jaws (transmission penumbra), a component attributed to the finite source size (geometric penumbra) and a significant component due to the in-patient X ray scatter (scatter penumbra). The total penumbra is referred to as the physical penumbra and it is the sum of the three individual penumbras: transmission, geometric and scatter. Without pretending that we can eliminate the negative effects caused by the presence of penumbra in the primary beam, we note that: a part of the quantitative reduction of the radiation dose already performed through the use of high energy of linear accelerators and further reduction of the energy difference between the primary radiation with average beam energy can significantly improve the quality of the beam, including radiation.*

Key words: *Penumbra, irradiation, linear accelerator, effects, dose*

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1. INTRODUCTION

One of the most important qualities of roentgen rays (X-rays) and natural radioactivity, let us say, these radiations was the ability to interact with living human body cells. As it was clarified later, the interaction was selective, because they kill the young ill cells more easily than those of health tissues. This quality of X and γ rays was thought to have been used with the aim to medicate the cancer diseases. Later, in the 1920s, as the use was widely intensified the skin reactions, or so called red skin reactions, began to be evident. Such reactions were more severe as the dose of radiation got higher. As said above, it was verified that X- and γ rays have not been responsible for this erythema caused to patients during the irradiations for therapy, as well as for diagnostic. In the last cases, which means in the diagnostics, the erythema has not been so accentuated because the doses used for X-ray pictures were not so high as in the cases of therapy. Those scientists were almost sure that the causes of erythema were not the X and/or γ irradiations but another radiation, very well known as electrons. Nevertheless, a lot of them had too high energies for regular electrons and it was impossible to link this radiation with such electrons. This radiation did not consist of regular electrons, because it has high energies, it did not include either X- nor γ-rays, since both of them, as we know, are electromagnetic waves, without the electric charge. In such conditions, this radiation consisting of the high energy electrons, or β-electrons, may be responsible for such quantity of energy, which create the erythema reactions in the patient's skin, getting the entry portal of skin in burning. This fact was in the center of discussions, of how to reduce or/and to eliminate at all these negative effects, especially, starting from the 1930s, when accelerators in the industry as well in some hospitals were firstly used for therapy, i.e. in killing of cancer cells.

After such a long introduction, let us speak about the principal aims, to grow the efficiency of β-particles more and more, considering the possibilities and perspectives not to eliminate them from the therapy beams but, on the contrary, to use them directly for therapy as much as possible. In fact, therapy beams are produced by two types of accelerators: 1. which produce X- and γ-rays, and 2.which produce β particles, or as they are called, high energy electrons. Nowadays, many factories are working to build up more and more perfect accelerators, which are able to use not only high energy γ–rays, or so called megavoltage energy γ-rays, but also high energies β-particles. In our Hospital in Pristina, for photons we use energies of 6 *MV* and 15 *MV,* and for electrons we use energies of 5 *MeV*, 7 *MeV*, 8 *MeV*, 10 *MeV*, 12 *MeV* and 14 *MeV*. In our Clinical of Oncology-Department of Radiotherapy in Pristina, we have two Linear

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Accelerators (SIEMENS), one of them with Multi Leaf Collimator (MLC), and another one without MLC. In the first one, we treat the patients using photons and, in second one, we treat the patients using photons and electrons, too. The experimental data are obtained by the measurement of dosimetric parameters, such as the dose profile, relative output factor and percentage depth dose (PDD) [1]. Determination of dosimetric characteristics of all radiation beams is vital so that the most appropriate set of treatment planning parameters is chosen. Data on the percentage of the depth-dose of diagnostic X-rays are important in evaluating the patient dose from medical exposure [2]. In radiotherapy, the quality of a radiation beam is most usefully expressed in terms of its penetrating power, which is mainly a function of the mean photon energy and it may be fully described by its depth dose characteristics in water [3] but an increase in the surface dose with the field size is also noted due to the electron scattering from intervening materials [4]. Data on the dose distribution are almost entirely derived from the measurements in phantoms, and then they are used in a dose calculation system devised to predict the dose distribution in an actual patient [5]. To study the energy and geometrical parameters on the dose distribution in the medium, we will create different field sizes – the Source Skin Distance (SSD) and the photon beam energy. The influence of these parameters will be evaluated by the measurement of Percent Dose Depth (PDD) and Dose Profile (DP).

2. Materials and Methods

The measurements were made through PTW three ionization chambers:

-PTW Pin Point Chamber TM 31010-1046

-PTW Pin Point Chamber TM 30010-0358 (Reference Chamber)

-PTW Markus Chamber TM 23343-3809 (for electrons)

-PTW Water Tank Phantom.

We used MEPHYSTO (PTW) version 7.4 software to analyze beam profile parameters. The parameters analyzed are Homogeneity, Symmetry, Penumbra sizes, Field Size, CAX DEV, Pen left, Pen Right, D_{max}, D_{min} and Quality. We have conducted measurements for all profiles for PDD, Dose Depth Curve, and Open Collimator Factor (OCF) for photons 100 cm SSD, and field size with dimension, (10 × 10) cm^2, (15 × 15) cm^2, (20 × 20) cm^2, with the following wedge angles: 15˚, 30˚, 45˚ and 60˚. We also measured all energies of electrons.

3. Results and Discussion

The depths of measurements are typically at z_{max} and 10 cm for verification of compliance with machine specifications, in addition to other depths required by the particular treatment planning system (TPS) used in the department [6]. Dose profile for 6 MV 15 MV photon energy, field size 10 × 10 together with analyze profile are shown in Figures 1-2, and dose profile for electrons with energy 5 MeV and circle applicator with diameter 5 cm is shown in Figure 3.

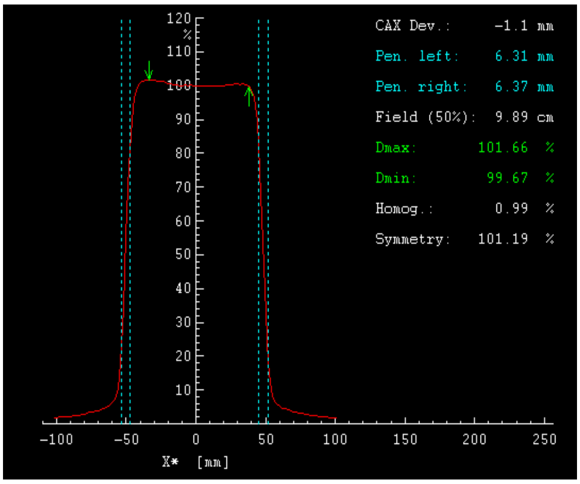

Figure 1. Dose Profile Curve 6 MV, SSD 100 cm, field size (10 × 10) cm2.

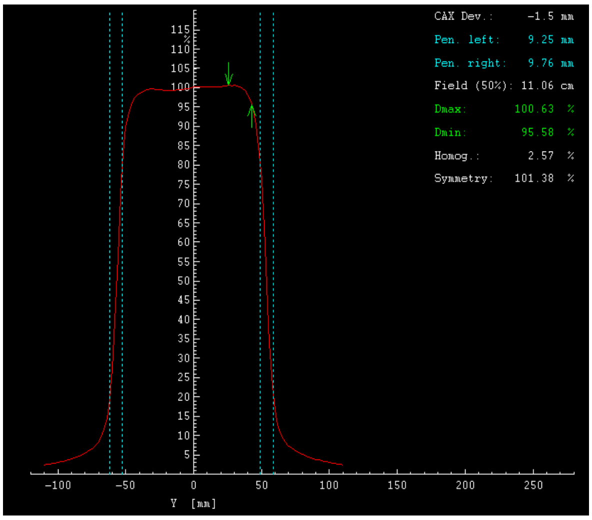

Figure 2. Dose Profile Curve 15 MV, SSD 100 cm, field size (10 × 10) cm^2.

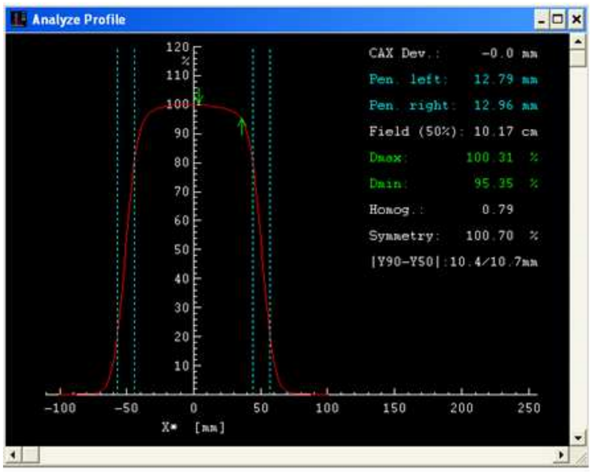

Figure 3. Dose Profile Curve 5 MeV, SSD 100 cm, circle applicator with diameter 5 cm

But the question to discuss is obviously the penumbra, especially for high energy β-particles which, as mentioned above, are electrons and the last one, during the interaction, produces secondary, tertiary and so on other electrons, whose abundance in number as well the abundance in directions creates a considerable diffusion in all directions, creating a penumbra around the primary beam, and into it, covering the exposed zone with the primary beam radiation plus secondary electrons, while outside this zone they create a penumbra, created by diffused electrons, and inside the primary beam, having in, the same, electrons, should have been created a penumbra, around and inside of primary beam. As we know, the radiation of penumbra has lower energy than the primary one.

Looking more attentively at Fig.1, we can see in other plan that the dose distribution of isodose curves falls down almost perpendicular and almost within the last cm. All the curves from 90 % to 10 % are assembled, so the penumbra is too small and, consequently, the radiation beam is too smart. The values of penumbra in radiotherapy are very important especially because the energy values of it, being not able to kill the tumoral cells are at the same time able to cause injuries to health cells. From this point of view, photon beams, as well as electron beams generated in accelerators with high or/and very high energies, being clean, have minimal risks to damage the tissues. Also, it is too easy for the physicists who operate it to exactly calculate the location of two (or more) adjacent beams without any of their interference. Another advantage of high energy radiations, produced in accelerators vs other natural or/and man made radioactive sources of radiations, is that the parasitary radiations, which accompany the radiations used for therapy, are of a small quantity. Thus, penumbra into their beams is substantially smaller than that of natural or/and man made radioactive sources. Penumbra one, as we can see in Figure. 1, for a standard beam 10x10, is in total about 12.5mm (6.31mm left penumbra and 6.37mm right penumbra), and it is consistently smaller than penumbra into radioactive source beams. In Figure 3 left penumbra is 12.79 mm and right penumbra is 12.96, and as a result in this case is higher than penumbra into photon source beams.

4. Conclusion

The study of photon and electron beam characteristic is necessary before the machine calibration is performed. Knowledge of energy and geometrical influence on different dosimetric parameters is indispensable for absorbed dose calculations. We have also conducted the TLD measurements which were audited and accepted by IAEA. After that all of these measurements and profiles for photons and electrons, we have installed our Treatment Planning System XiO, version 4.8, by which we make treatment planning for radiation. For higher energies, β particles are transformed from an obstacle to the proper treatment of tumors into a powerful weapon, ranging from superficial tumors of the skin substrates to the deep tumors (although the deep tumors in our clinic are treated by γ rays of high energies).

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