

Development of a shielding to protect patients against photoneutrons produced by linacs in radiotherapy treatments

Desenvolvimento de uma blindagem para proteger pacientes contra fotonêutrons produzidos por aceleradores de partículas lineares em tratamentos radioterápicos

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Abstract

This work focused on radiological protection of patients submitted to radiotherapy using high energy linear accelerators, in which their healthy tissues receive undesirable doses due to photoneutrons. For that, a shield against the produced photoneutrons was developed using the computer code Monte Carlo N-Particle version X (MCNP-X). This shield showed to be positioned in a simple way, at the outside part of the linear accelerator's head, reducing the doses. This shield was named external shielding. The simulation was performed using a computational model of the head of a Varian 2300 C/D linear accelerator, plus the external shield. In order to verify the effects of this shielding, the values of ambient dose equivalent were calculated. These values were compared with the accelerator operating with and without the external shielding. The results of this study indicated that the external shielding showed great efficiency in reducing the ambient dose equivalent due to photoneutron, resulting in an average reduction above 60% for the various simulated configuration, without increasing the ambient dose equivalent due to the photos at the plane of the patient. It was concluded that the implementation of an external shield at the accelerator's head increases the protection of the patients against undesirable photoneutrons doses and may avoid new focus of cancer produced by the radiotherapy.

Keywords: simulation, MCNPX, linear accelerator, shielding against radiation.

Resumo

Este trabalho teve como objetivo a proteção radiológica de pacientes submetidos à radioterapia utilizando aceleradores lineares de alta energia, nos quais os tecidos saudáveis recebem doses indesejáveis devido aos fotonêutrons. Para isso, uma blindagem contra os fotonêutrons produzidos foi desenvolvida, usando o código de computador Monte Carlo *N-Particle*, versão X (MCNP-X). Tal blindagem mostrou que é posicionada facilmente na parte de fora do cabeçote do acelerador linear, reduzindo as doses. Essa camada protetora foi chamada de blindagem externa. A simulação foi realizada utilizando um modelo computacional do cabeçote de um acelerador linear Varian 2300 C/D mais a blindagem externa. Para verificar os efeitos dessa blindagem, os valores de equivalente de dose ambiente foram calculados. Esses valores foram comparados com o acelerador operando com e sem a blindagem externa. Os resultados deste estudo indicaram que a blindagem externa mostrou grande eficácia em reduzir o equivalente da dose do ambiente devido ao fotonêutron, resultando em uma média de redução acima de 60% para as diversas configurações simuladas, sem aumentar o equivalente da dose do ambiente devido às fotos no plano do paciente. Concluiu-se que a implementação de uma blindagem externa no cabeçote do acelerador aumenta a proteção dos pacientes contra doses de fotonêutrons indesejados e pode prevenir novos focos de câncer produzidos pela radioterapia.

Palavras-chave: simulação, MCNPX, acelerador linear, blindagem contra radiação.

Introduction

The production of unwanted neutrons has been a major problem for patients undergoing radiotherapy, particularly when the equipment operates at energies greater than 7 MV and/or IMRT mode. Also, 60% of the patients which undergo some type of treatment against cancer, submitting to radiotherapy¹, note a disturbing and important enough issue to be addressed. In order to minimize the undesirable doses due to neutrons produced in the sections of the treatment, it was developed by Silva and colleagues² a shielding against these photon neutrons that could reduce considerably the ambient dose equivalent due to neutron $H^*(10)_n$. With the use of collimators Jaws and multi-leaf (MLC) to model and conform the therapeutic beam, the ambient dose equivalent due to photons $H^*(10)_f$ greatly reduces at the patient's plan, but, for the ambient dose equivalent due to neutron $H^*(10)_n$, the calculated values remain almost constant. Therefore, it is observed that the primary shielding, Jaws and MLC, provide excellent electromagnetic radiation shielding, however have no satisfactory shielding for neutrons, instead, end up producing more neutrons, especially when the therapeutic beam is higher than 7 MV. Figure 1 shows the calculated values in the computational model of the head of the linear accelerator Varian 2300 C/D operating at 18 MV for $H^*(10)_n$ and $H^*(10)_f$ ³.

Methodology

The external shielding, consisting of borated polyethylene, was developed using computational simulation. It was idealized and implemented using the Monte Carlo N-Particle version X code (MCNP-X). For this, the external shielding was simulated at the head of Varian 2100 C/D operating at 18 MV, assuming a beam with 1E15 electrons of 18.8 MeV each focused on a target consisting of tungsten and copper⁴; the gantry was simulated at 0°, with therapeutic beam focused on the perpendicular plane of the patient. The simulation was conducted in three configurations, regarding to the opening of the fields. These settings are presented in Table 1². It was used the MCNP F5 command to simulate point detectors and calculate $H^*(10)_n$. The detectors were placed at coordinates A (0,0,0), B (0,20,0), C (0,40,0), D (0,60,0), E (0,80,0), F (0,100,0), G (0,120,0), H (20,0,0), I (40,0,0) and J (60,0,0) of this code. Figure 2 illustrates the calculated points⁵. To evaluate the effect of shielding, the calculated values of $H^*(10)_n$ were compared with values obtained by Rebello and colleagues⁶, also by computer simulation, with the equipment operating without external shielding.

Results

For the first configuration, Figures 3 and 4 present the values of $H^*(10)_n$ in the axis Y (longitudinal direction to

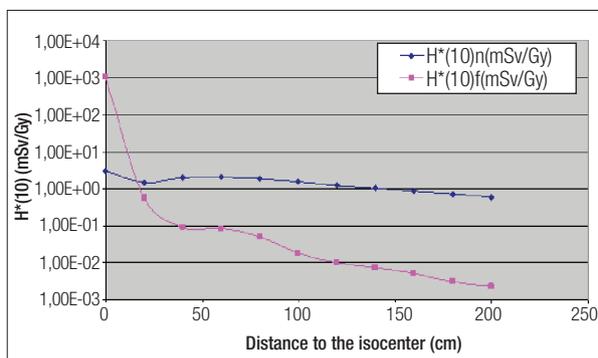


Figure 1. Comparison of the calculated values of ambient dose equivalent due to neutrons and photons, given in mSv for each dose in Gy deposited at the isocenter. (All for the Varian 2300 C/D).

Table 1. Settings of the simulations related to the fields of apertures of collimators JAWS and MLC

Configuration	Jaws	MLC	External shielding
1 ^a $H^*(10)_n$	5 x 5 cm ²	5 x 5 cm ²	5 x 5 cm ²
2 ^a $H^*(10)_n$	30 x 30 cm ²	5 x 5 cm ²	5 x 5 cm ²
3 ^a $H^*(10)_n$	5 x 5 cm ²	5 x 5 cm ²	40 x 40 cm ²

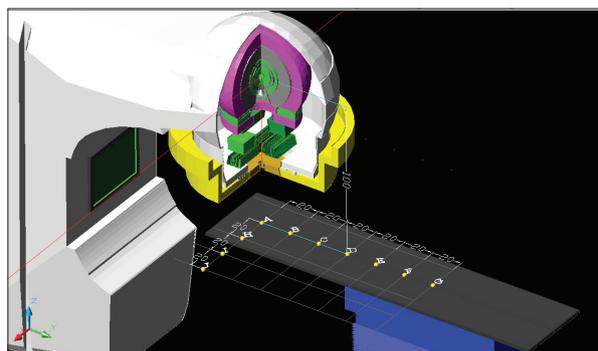


Figure 2. Coordinates of the simulations in terms of patient.

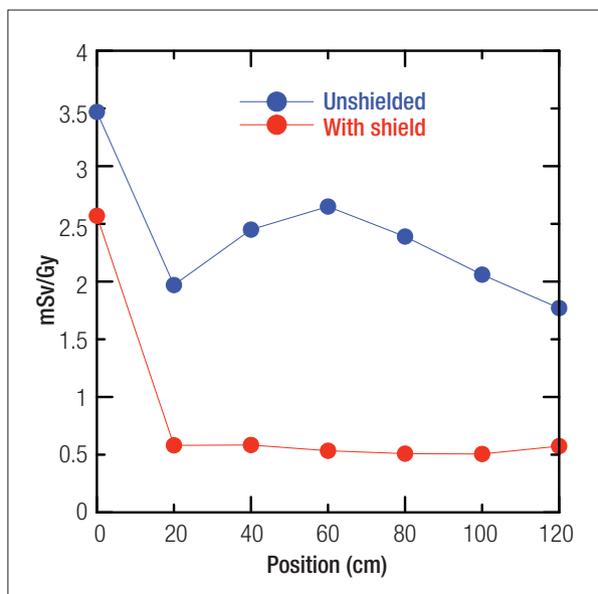


Figure 3. First configuration, $H^*(10)_n$ at points along the Y axis.

the patient) and X (transverse direction to the patient), respectively, calculated by MCNP-X with fields: JAWS $5 \times 5 \text{ cm}^2$, MLC $5 \times 5 \text{ cm}^2$ and external shielding $5 \times 5 \text{ cm}^2$, with the head of the linear accelerator operating with (this work) and without shielding⁶.

For the second configuration, Figures 5 and 6 present the values of $H^*(10)_n$ in the axis Y (longitudinal direction to the patient) and X (transverse direction to the patient), respectively, calculated by MCNP-X with fields: JAWS $30 \times 30 \text{ cm}^2$, MLC $5 \times 5 \text{ cm}^2$ and

external shielding $5 \times 5 \text{ cm}^2$, with the head of the linear accelerator operating with (this work) and without shielding⁶.

For the third configuration, Figures 7 and 8 present the values of $H^*(10)_n$ in the axis Y (longitudinal direction to the patient) and X (transverse direction to the patient), respectively, calculated by MCNP-X with fields: JAWS $5 \times 5 \text{ cm}^2$, MLC $5 \times 5 \text{ cm}^2$ and external shielding $40 \times 40 \text{ cm}^2$, with the head of the linear accelerator operating with (this work) and without shielding⁶.

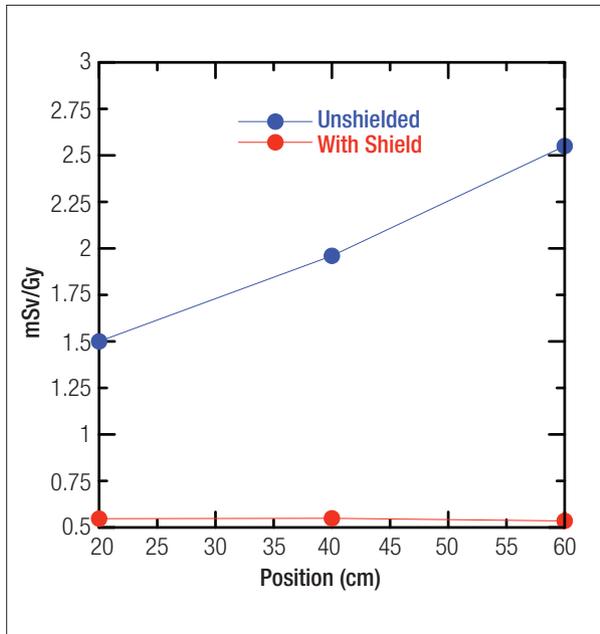


Figure 4. First configuration, $H^*(10)_n$ at points along the X axis.

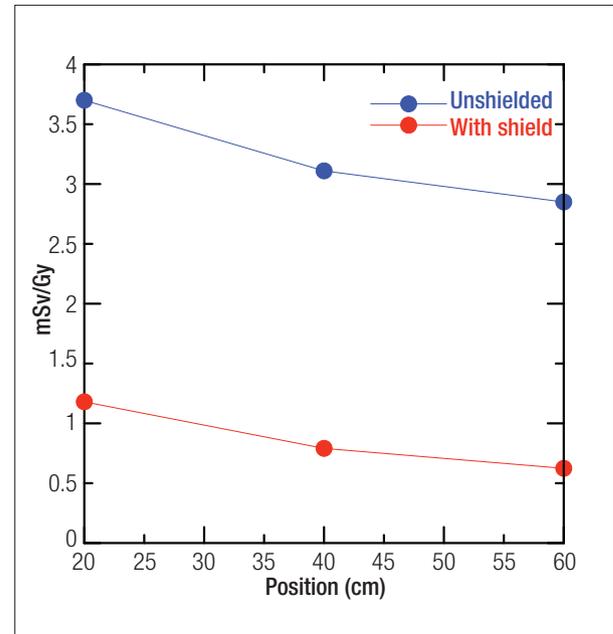


Figure 6. Second configuration, $H^*(10)_n$ at points along the X axis.

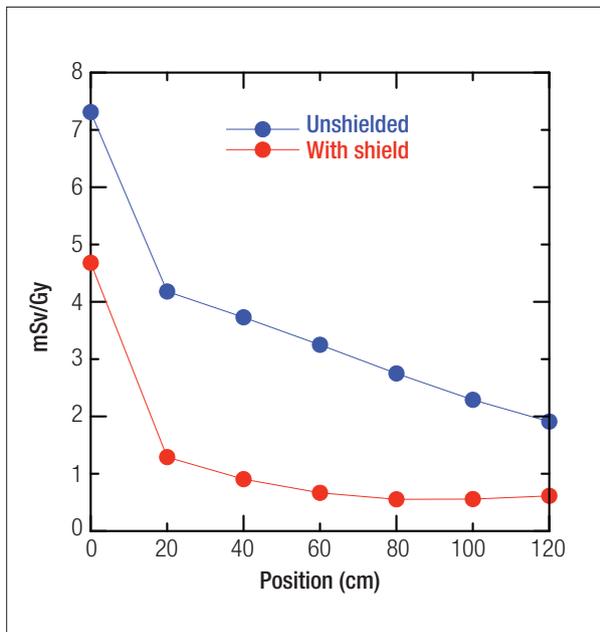


Figure 5. Second configuration, $H^*(10)_n$ at points along the Y axis.

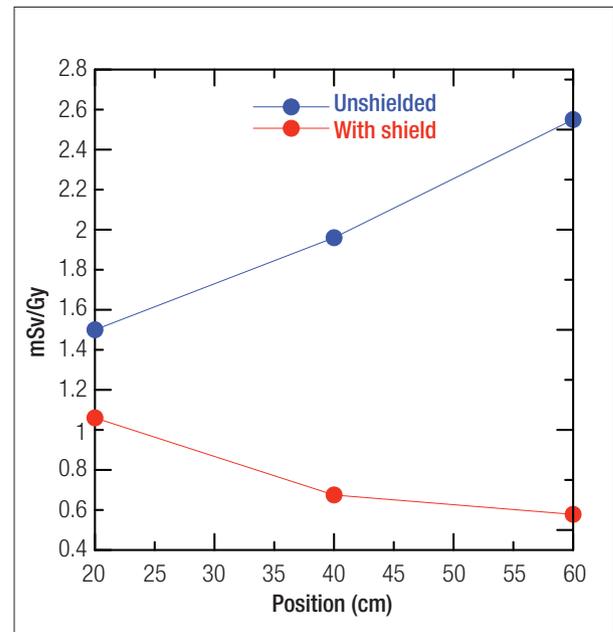


Figure 7. Third configuration, $H^*(10)_n$ at points along the Y axis.

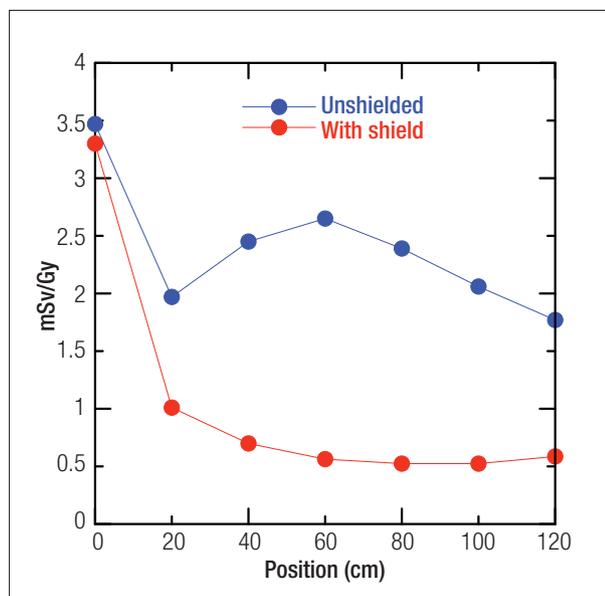


Figure 8. Third configuration, $H^*(10)_n$ at points along the X axis.

Conclusions

At points away from the isocenter, the effect by external shielding was very satisfactory for the three configurations. It was observed at the points evaluated the reducing of the ambient dose equivalent with an average of 70% for the first configuration (Jaws, MLC and external shielding $5 \times 5 \text{ cm}^2$), 78.34% for the second configuration (Jaws $30 \times 30 \text{ cm}^2$, MLC and external shielding $5 \times 5 \text{ cm}^2$) and 60.23% for the third configuration (Jaws, MLC $5 \times 5 \text{ cm}^2$ and external shielding $40 \times 40 \text{ cm}^2$). In the first and second configuration, there was a greater reduction in the values of $H^*(10)_n$, which is explained by the fact that the external shielding was set with the same size of fields for opening the Jaws and/or MLC, allowing an improvement to shield the neutrons. Instead, in the third configuration, in which the field opening external shield was up, there was a smaller reduction of $H^*(10)_n$ when compared with other settings; however, it can be considered not less significant since

it has reached an average value reduction of around 60%. The analysis of this last configuration is extremely important, because it demonstrates that the simple installation of the external shielding, with its single opening of $40 \times 40 \text{ cm}^2$ (this opening represents the greatest possible opening of the primary beam and, therefore, does not interfere with treatment), would generate a significant reduction of $H^*(10)_n$, ensuring less patient exposure to neutrons generated.

After these results, it can be considered, initially, that the external shielding is able to reduce the dose absorbed by healthy tissues of the patients, indicating a positive way in order to stimulate a deeper study of this new system. The external shielding can be further considered as an important safety item to be used in linear accelerators. For future work, it will be suggest an analysis of the effect of external shielding in internal dosimetry of organs close to the isocenter and the evaluation of the influence of shielding effects in regions far from the plane of the patient, particularly in the area of the maze, considering, inclusive, multiple angles of gantry inclination.

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