NOVEL DESIGN OF RADIOTHERAPY ROOM SUGGESTION – THREE-BAND MAZE

by

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Scientific paper
https://doi.org/10.2298/NTRP2104371T

The objective of this study was to analyze the dependence of the neutron dose from the geometry of the second band of the maze using dosimetric measurements of neutrons and Monte Carlo simulations, and based on those results to design a novel radiotherapy room layout. Measurements of the neutron dose at a two-band maze therapy room were performed for a 15 MeV photon beam only. Monte Carlo simulations were performed using the GEANT4 toolkit. In order to obtain the geometry dependence, we were changing the second band angle while we kept the length, height, and width the same as in reality. Results show that the highest calculated dose was obtained for the 60° angle of the second maze. It is 17 % higher than for standard 0° angle. For 30° it was 30 % smaller and for 90° was 10 % smaller. Although the lowest dose was obtained for 30° band angle with calculations, it is not very practical for clinical use. Clinically the most interesting would be the 90° angle which is practically a short three-band maze, which could be promising from the perspective of neutron radiation protection since it could offer a compact constructional solution, and better optimization of the available space.

Key words: radiotherapy, radiation protection, Monte Carlo method

INTRODUCTION

Medical therapy accelerators working at energies higher than the energy threshold for (γ, n) nuclear reactions, produce a measurable number of neutrons [1]. These neutrons are mainly produced in primary, secondary collimators, jaws, and other materials with high Z which can be found in the accelerator head [2]. Neutrons are produced via different reaction mechanisms like giant dipole resonance (GDR), quasi-deuteron (QD), delta resonance (DR), *etc*. Neutrons produced through the GDR mechanism are similar to evaporation neutrons from the compound nucleus [3]. Lead is one of the materials commonly used in accelerator heads, and the energy threshold for (γ, n) reaction is 6.7 MeV for isotope 208Pb [1]. The neutrons are uncharged and are not absorbed with the accelerator's head materials [4]. Produced neutrons undergo scattering with low Z material: treatment vault walls until they are thermalized and finally captured [2].

To reduce the radiation dose near the entrance door and protect staff at radiotherapy departments accelerators are installed in the maze-designed bunkers [1]. Standard geometry is with one band maze. Occasionally two-band maze rooms are used [5]. There are a number of publications considering standard one-band maze design which is extensively investigated [6-10]. Publications with two-band maze are not so common [11-12].

According to Amgarou *et al*., [13] the produced photoneutrons spectra have a strong dependence on accelerator design, operating energy, and head components (target, flattening filter, jaws, collimator, and bending magnet). As the aim of this manuscript was to investigate the dependence of the dose at the entrance door and not the neutron spectra, therefore for simulations verified measured neutron spectra were used.

The purpose of this study was to analyze the dependence of the equivalent neutron dose from the geometry of the second band of the maze using dosimetric measurements of neutrons and Monte Carlo (MC) simulations and based on the results to propose a novel design of the treatment room.

MATERIALS AND METHODS

Neutron equivalent dose was measured in the therapy room at Radiotherapy department, Institute of

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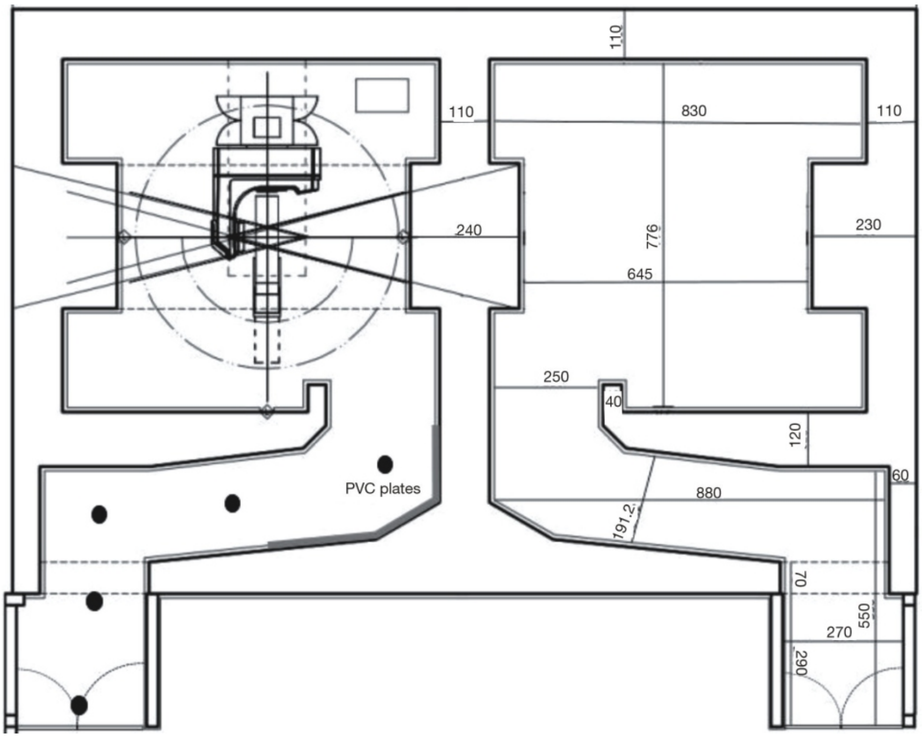

Figure 1. Scheme of therapy room (all dimensions in cm) and neutron dose measurement points

Oncology Vojvodina, Sremska Kamenica, Serbia. The scheme of the therapy room with all the dimensions is presented in fig. 1. Inside the room, Elekta Versa HD (Elekta, Crawley, UK) accelerator is installed, which produces 6 MV, 10 MV, and 15 MV photon energies. The height of the vault is 3.95 m. The inner walls of the room are covered by 2 cm decorative wooden plates. Part of the wall is covered by a 2 cm thick layer of PVC (polyvinyl chloride) to moderate neutrons. Approximately this area is 20.3 m^2.

Neutron equivalent dose was measured for 15 MV photon energy since it produces the highest number of neutrons and therefore the highest dose. Orientation of gantry was 0°. Field size at the isocenter was 10×10 cm^2. For each measurement, the delivered dose was 3 Gy, since Elekta Versa HD operates at the dose rate of ~600 MU per minute the measuring time was 30 seconds.

Measurement of the neutron dose at a two-band maze therapy room was conducted using the Meridian model 5085 survey meter (Health Physics Instrument, Goleta, Cal., USA). The dosimeter was positioned 1 m above the floor. The natural background in the therapy room is significantly lower than the instrument threshold, therefore it can be neglected. The detector has 15 % declared accuracy in the user manual. Before any use of the survey meter, the calibration factor was checked in our laboratory using a ^{252}Cf source [1].

The MC simulations were performed using an internally developed solution based on GEANT4 toolkit.

The GEANT4 was originally developed for the high-energy physics community, but over the years, its physics models have been constantly expanded to cover applications at lower energy. In recent years it has been successfully used also to describe the transport of neutrons from thermal energy to GeV energies [14].

Most publications found in literature used to reconstruct the whole accelerator head and to use produced neutrons in form of phase space for further simulations [2, 15-18]. This method is computational power and time-consuming. Since the full simulation of the whole accelerator head was not the focus of this paper and to overcome this problem, an external verified neutron spectrum was used. The exact geometry of the therapy room was reconstructed using constructive solid geometry (CSG), which is easy to use and normally gives superior performance. The CSG solids are defined directly as three-dimensional primitives. They are described by a minimal set of parameters necessary to define the shape and size of the solid. The NIST compound database materials were used for MC simulations, according to manufacturer specifications. All dimensions of the vault were reconstructed using data provided by detailed construction drawings. General particle source was used as a primary generator of neutrons with externally measured spectra [19]. Neutrons were emitted isotropically from a sphere with 60 cm diameter which was positioned at the isocenter. All simulations were performed using HadronPhysicsQGSP_BIC_HP and EMStandard Physics physics lists [20]. The default energy cut in range value was 0.1 mm. As a dosimeter, a PMMA sphere with a 30 cm diameter was used, fig. 2. A measured dose at the entrance door was used to obtain simulation parameters (number of primaries, *etc.*). The number of primaries

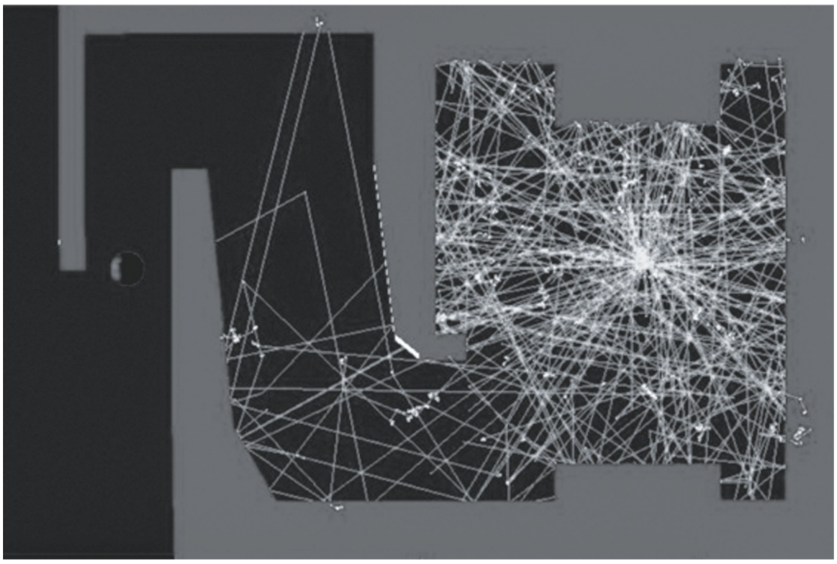

Figure 2. Reconstructed therapy vault in MC simulations and novel three-band maze layout

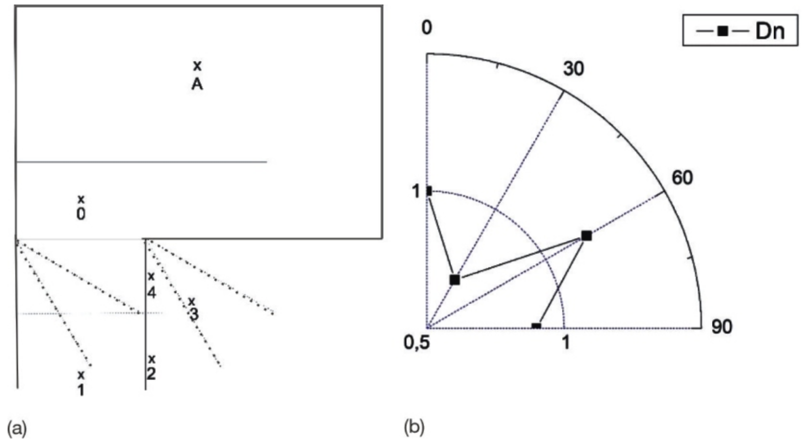

Figure 3. (a) Scheme of the two-band maze therapy room. A is the isocenter position. Measurement was conducted at position 1. The MC simulation was performed for positions 1-4. Dashed lines represent wall positions for different angles in MC simulations, and (b) normalized neutron dose obtained from MC simulations

was 1010 and it was estimated to obtain statistical uncertainty below 2 %. To obtain the geometry dependence we were changing the second band angle keeping the length, height, and width the same as in reality. Dashed lines represent wall positions for different angles in MC simulations in fig. 3(a).

RESULTS

Measured neutron dose at the entrance door was 0.0027 Sv, fig. 3(a) [1]. At several control points inside the maze of the room, neutron dose was measured. These control points were placed at the beginning of the first band, middle, and end of the first band. Also, one control point was placed in the middle of the second maze, fig. 1. Those points were used to check the agreement between calculation and measured neutron doses. The difference was up to 5 % for all points. We normalized the doses obtained from MC simulations, to the measured one. Normalized neutron doses are depicted in fig. 3(b). Our results show that the highest calculated dose was obtained for the 60° angle of the second maze. It is 17 % higher than for standard 0° angle. A possible explanation for this is the fact that the differential dose albedo (wall reflection coefficient) is highest for this angle. For 30° it was 30 % smaller and for 90° was 10 % smaller.

DISCUSSION

In our work, MC simulations gave good agreement with measured data. Therefore, MC simulations may be a very powerful method for testing the new design of the treatment room. The only issue that authors found is that they are quite a time and computational power-consuming, even if the simplified simulations setup is used. Although it is time-consuming it allows evaluation of different bunker geometries to define the most optimal solutions for the available space.

Although the lowest dose was obtained for 30° band angle with calculations, it was not very practical for clinical use. Clinically the most interesting would be the 90° angle which is practically a short three-band maze. This geometry could be very promising as it could offer a compact constructional solution, and better optimization of the available space (resources).

With this significant dose reduction, even a doorless system may be used, which improves patient access, the safety of the radiation therapists and reduce the cost of a heavy shielding door in comparison with a standard one band maze or additional door shielding in case of two band maze bunker. The position of the door in three-band maze could be towards the control console, which allows constant live monitoring of access of the doorless system, which significantly improves the safety of patients and staff.

CONCLUSIONS

In this paper, the measurement of the neutron equivalent was performed in two-band maze room. Based on this measurement results MC simulation was performed to analyze the dependence of the equivalent neutron dose from the geometry of the second band. Although MC simulations are time and computational power-consuming, they are very powerful methods for treatment room design and radiation protection. It allows testing and optimization of the new design before construction.

In our case, the lowest dose was obtained for 30° band angle, which is not very practical for clinical use. Clinically the most optimal solution would be the 90° angle which is practically a short three-band maze. This geometry may provide the most optimal use of available space; also, it could provide a doorless solution that may reduce the costs, increase patient flow, and improve the safety of patients and staff.

AUTHORS' CONTRIBUTIONS

The idea of this paper was suggested by A. A. Toth. Measurements were performed by A. A. Toth, M. S. Marjanović, I. V. Gencel, and B. S. Petrović. Monte Carlo simulation was performed by A. A. Toth. Data analysis and article writing was performed by A. A. Toth and B. S. Petrović.

ACKNOWLEDGMENTS

This work was partially supported by the Delvidekert "Kiss" Foundation.

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Received on August 25, 2021
Accepted on January 18, 2022

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НОВИ ДИЗАЈН РАДИОТЕРАПИЈСКЕ СОБЕ – ПРЕДЛОГ СА ТРИ КРИВИНЕ ХОДНИКА

Анализирана је доза неутрона у зависности од геометрије друге кривине радиотерапијске собе уз помоћ дозиметријских мерења и Монте Карло симулација и на основу резултата дизајнирана је нова соба. Мерење неутронске дозе у радиотерапијској соби са две кривине изведено је за енергију од 15 MeV. Монте Карло симулације изведене су уз помоћ софтвера GEANT4. Да би добили геометријску зависност мењан је угао друге кривине, при томе дужина, висина и ширина другог ходника су остале исте. Резултати показују да је највећа доза добијена за угао друге кривине од 60°, која је 17 % већа од стандардне геометрије са 0°. За угао од 30° доза је 30 % мања, а за 90° је 10 % мања. Иако је најмања доза добијена за угао друге кривине од 30°, она клинички није занимљива. Клинички је најинтересантнији угао кривине другог ходника од 90°, што практично представља собу са три кривине, која може бити важна са аспекта заштите од неутрона будући да нуди компактно конструкцијско решење и бољу оптимизацију расположивог простора.

Кључне речи: радиотерапија, заштита од зрачења, Монте Карло метода