INFLUENCE OF HEAD COVER ON THE NEUTRON DOSE EQUIVALENT IN MONTE CARLO SIMULATIONS OF HIGH ENERGY MEDICAL LINEAR ACCELERATOR

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INFLUENCE OF HEAD COVER ON THE NEUTRON DOSE EQUIVALENT IN MONTE CARLO SIMULATIONS OF HIGH ENERGY MEDICAL LINEAR ACCELERATOR

by

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Neutron contamination of radiotherapeutic photon beam occurs when energies higher than 10 MeV are used in radiotherapy. To correctly assess the neutron doses that medical personnel and patients receive, it is highly important to know the spectra of the produced photoneutrons. One of the most common ways to determine such spectrum is to perform Monte Carlo simulations of the accelerator. Major issue in the Monte Carlo modelling is that the manufacturers often does not provide full specifications of the accelerators head, so some parts of the head are omitted from the simulation. Within this paper we present a model that includes head cover compared to the one where it is omitted, as it can often be found in the references. Neutron fluxes, spectra, mean energies and place of origin are compared in isocenter, at the point 1 m above target and the point 1 m aside from the target, in both models.
In all the considered planes the flux change was found to be more than 20 %, with a significantly change in neutron energy, what is also important in neutron dosimetry. Ignoring the head cover in the Monte Carlo modelling of the high energy electron linear accelerators in radiotherapy, will introduce a large uncertainty of neutron doses assessing a patient, or a medical professional.

Key words: Monte Carlo simulation, neutron detection, head cover, radiotherapy

INTRODUCTION

As it has been reported previously, high energy electron medical linear accelerators can produce undesired neutron contamination of the photon therapeutic beams [1-3]. This occurs due to the photonuclear effect, caused by photons with energies higher than 10 MeV[4]. These photons interact with an atomic nucleus with high atomic number, such as lead and tungsten, that are commonly used for construction of the linear accelerator head [1]. Other elements such as copper, aluminum and iron, that are also present in the accelerators head, have negligible probability for photoneutron production [5]. The photonuclear effect becomes even more clinically significant when intensity modulated radiation therapy (IMRT) is employed, since a higher number of monitor units is used, and production of photoneutrons is proportional to the beam-on time [6].To describe neutron contamination, Monte Carlo (MC) simulations of a medical linear accelerator are frequently used, since they can provide precise information about the photoneutron properties, such as place of origin and spectra [4, 5, 7, 8].

In MC modelling accelerator, some parts are often omitted for several reasons: simplicity of the model, shorter calculation times and the fact that manufacturers often does not provide full specifications of the accelerators head. This is especially true for the head cover, since in some studies it is modelled fully [4, 9-11], and yet, in the majority of the others, it is completely ignored [8, 12-18], regardless what was the primary goal of the simulations. To the best of our knowledge, none of the modelled Siemens accelerators have the head cover included in the simulations and within this study the Siemens Oncor linear accelerator is modelled. Also, there is no study that shows the influence of modelling the head cover on the change in neutron spectra, or mean energies, that would lead to the errors in estimation of the doses that are received by the patients or medical staff.

The aim of this study is to determine the influence of head cover presence on neutron flux around Siemens Oncor medical linear accelerator head, place of origin

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of neutrons, in two different approaches and changes in neutron spectra in both cases. These data are relevant for determining the exact dose that the patients and medical personnel receive from the neutrons, in facilities where high energy medical linear accelerators are installed, especially if these doses are determined using highly dependent passive detectors [3].

MATERIALS AND METHODS

The MC model of the accelerator Siemens Oncor, used at University hospital of Osijek radiotherapy department, was built using MCNP611®[19] code, as it was described in previous studies [3]. That model was built without the head cover (empty model in further text) and in the model presented in this paper, we included the head cover (full model in further text), for comparison of the two models.

The dimensions and the structure of the accelerator head cover was not available from the manufacturer, so we were forced to acquire necessary dimensions for adding the head cover into the MC model, manually. Only the outer dimensions of the head cover were measurable, after disassembling the accelerator lids, and therefore, the head cover was modelled as a rectangular box with dimensions 45 cm 50 cm 30 cm. On the top of the head cover there was a 6 mm thick tungsten plate (20 cm 24 cm), and it was also included in the model (fig. 1). Due to lack of information and geometry specifications of the head cover interior, we modelled it according to the previously published data [20]. The walls of the head cover were 10 cm thick and the region below the tungsten plate was assumed to be filled with lead. Two additional tungsten shields, near the primary collimator, were included in the simulation [20].

Neutron flux detectors within this model were placed in a square, with sides 2 m long, and the intersection of square diagonals was set on the top of the target. Detectors were 1 cm 1 cm 1 cm in size and were placed each 10 cm in three different planes, the patient plane, the plane above the accelerator head, and the plane on a side of the accelerator (fig. 1). DXTRAN spheres, with both inner and outer radius of 1 cm, were set around each detector, to improve the particle sampling in the detector region. Simulations were performed using 10 cm 10 cm photon field.

Neutron spectra were detected in 56 energy bins ranging from 1 10^{-9} to 2 10^{2} MeV in logarithmic scale that corresponds to the NCRP flux to dose conversion factors energy bins [21].

Simulations were performed for at least 3 10^{8} histories (electrons incident on target), or until the R value in all the detectors falls below 0.02 and all 10 statistical checks were satisfied. Continuous energy neutron cross-sections library ENDF/B-VII (Evaluated Nuclear data file B-VII) [22] was used to perform the simulations of photoneutron transport.

RESULTS

Neutron profiles were observed in three planes of interest (square edges). Neutron fluxes normalized per source particle (electron that hits the accelerator target) are shown in fig. 2.

To analyze data shown in fig. 2, the neutron place of origin in both cases was determined (fig. 3).

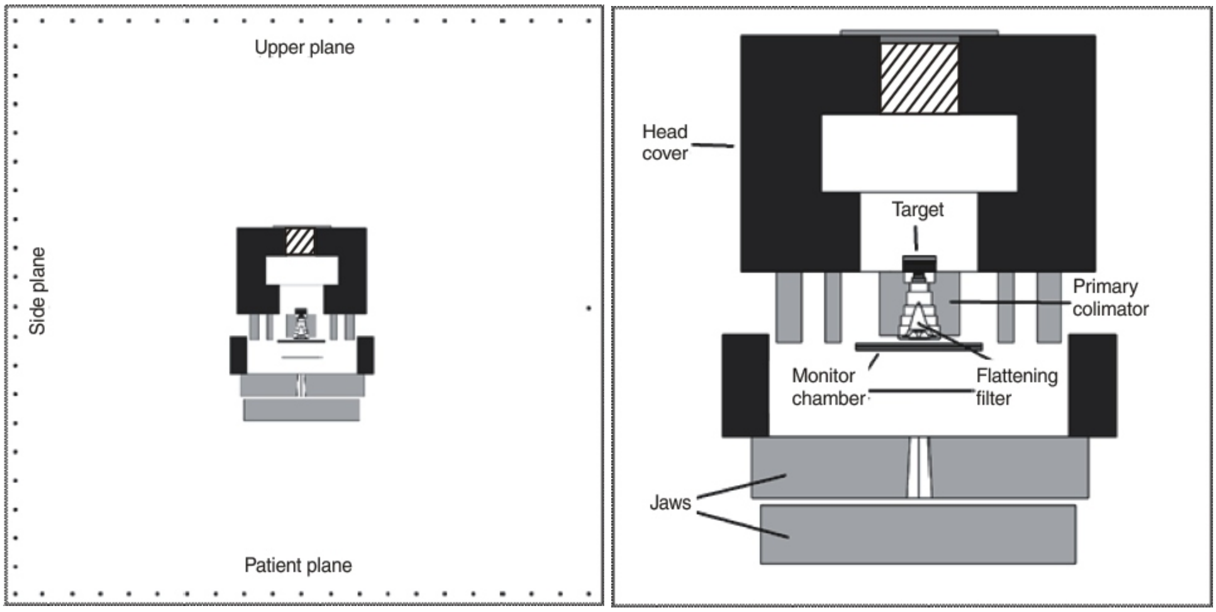

Figure 1. Position of the observed planes (left) and the cross-section of accelerator head (right); black colour represents stainless steel, grey is tungsten and dark grey is lead, small squares around the head are the detectors for neutron flux at three planes

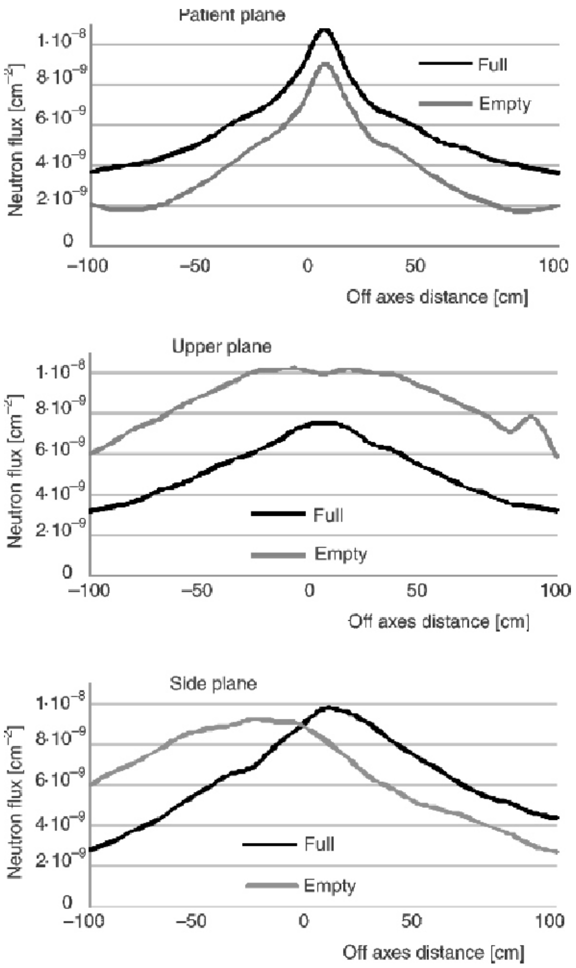

Figure 2. Neutron profiles for three observed planes. Flux is given in neutrons per source particle per square centimetre, and the distance is given in centimetres relatively to the center of each square edge; black line represents full model and light grey line represents empty model

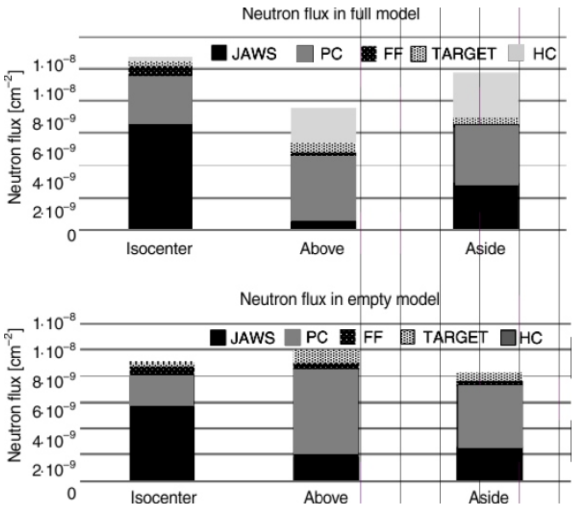

Figure 3. Neutron place of origin for both models where the full model is shown in the upper and the empty model in the lower chart; jaws are represented in dark grey, primary collimator (PC) in grey, flattening filter (FF) in black with white dots pattern, target in white with black dots pattern and head cover (HC) in light grey

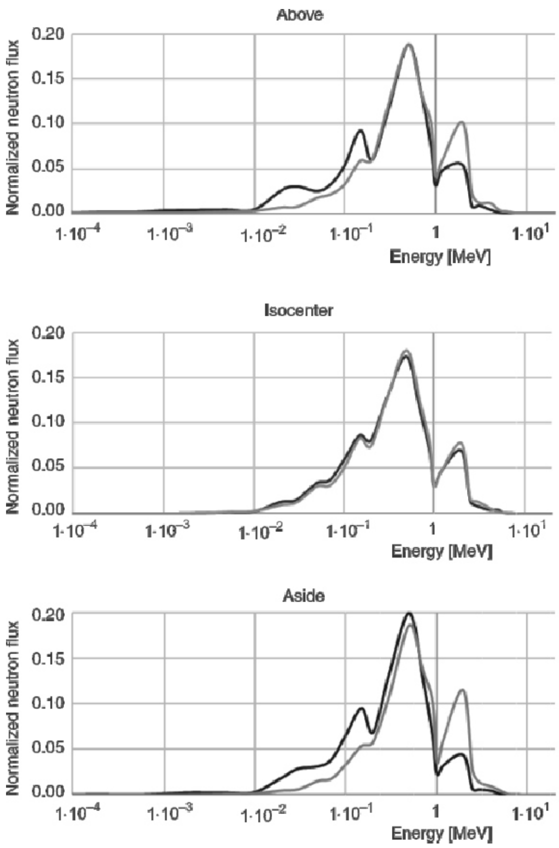

Figure 4. Neutron spectra for two different models in three points of interest; black line represents full model and grey line represents empty model

There is no significant change in neutron place of origin for the neutrons that are coming at the isocenter in both models, but for two other points there is a difference. While in the empty model there is no head cover to become a source of neutrons, in a full model a significant number of neutrons, that come in upper and side detector, are produced in the head cover. The major difference in the origin of neutrons detected in the center of the upper plane comes due the fact that the head cover stops a significant number of neutrons that originate from the jaws and the primary collimator. In the side plane there was only a slight reduction in the number of neutrons produced in the primary collimator, while the number of neutrons that come from the jaws remains constant. When the neutrons produced in the head cover are summed up, the total flux in the side plane is increased by 20 %.

Figure 4 shows neutron spectra in isocenter at the, point 1 m above the head, and 1 m aside. It can be seen, that in the full model lower energies are more present in the than in the empty. All these results can be correlated with the mean energies shown in tab. 1.

The neutrons with highest energies always come from either the flattening filter or the target, followed by the neutrons produced in the accelerators jaws of the primary collimator. Lowest energies always come from either the jaws or the head cover (if present). It is also notable that the presence of the head cover re-

Table 1. Mean energies obtained from both simulated models, energies of neutrons that come from different parts of the accelerators head are shown in the table (head cover (HC), primary collimator (PC), flattening filter (FF), monitor chamber (MC)), and overall mean energy is given in the last column

	Energy [MeV]						
	HC	PC	FF	MC	Jaws	Target	Overall
	Full						
Isocenter	0.27	0.77	1.06	0.29	0.40	1.03	0.55
Above	0.36	0.55	0.79	0.14	0.38	0.69	0.50
Aside	0.38	0.51	0.55	0.19	0.47	0.55	0.46
	Empty						
Isocenter	0.00	0.84	0.90	0.25	0.43	1.10	0.59
Above	0.00	0.74	0.95	0.21	0.42	0.90	0.71
Aside	0.00	0.75	0.89	0.39	0.69	0.96	0.75

duces the overall mean energies in all the observed points, significantly.

DISCUSSION AND CONCLUSIONS

As it can be seen from the presented results, neutron flux that comes from the accelerator head in all directions is not negligible. Neutron profiles, in the plane above the accelerator head and in the plane aside, show that neutron flux drops slower, than in the patient plane, when moving away from the central point, fig. 2(a-c). In other words, neutron contamination is even more significant around the accelerator head than in the patient plane.

In the patient plane the flux is higher when the accelerator head cover is modelled, fig. 2(a), namely at the central point it is 20 % higher, and in at the more distant points the flux is doubled. In the plane above the accelerator, the result is very reasonable since the flux is higher in the empty model, when there is nothing to stop the neutrons, and lower in the full model, when neutrons cannot pass freely to the detectors. In this plane, flux is reduced by 25 % in at the central point and up to 50 % in at more distant points. In the side plane, the explanation is combination of the two previous. In the upper part of the accelerator (distance presented from –100 to 0 in fig. 2(c) the empty model has higher fluxes, which are almost doubled when compared with the full model, since there is no head cover material to stop the neutrons. In the lower part of the accelerator, situation is just the opposite, and the flux in empty is reduced by averagely 30 %.

According to the neutron spectra, shown in the fig. 4, it can be concluded that more neutrons with lower energies appear in the full model for all 3 observed points. Also, at the points above and aside, there is are significantly less energies higher than 1 MeV present in the neutron spectra, after adding the head cover. Reason for this reduction comes from the fact that the head cover stops the neutrons originating from accelerators target and flattening filter, that have higher mean energies than the neutrons produced in other parts of the accelerators head (tab. 1).

If the changes in neutron spectra and flux are both accounted, one can conclude that the absolute number of neutrons in each energy bin will not be the same. This could be very important, especially if the neutrons are detected trough a converter that is highly energy dependent (like ^{10}B) [23, 24]. So, if the neutron spectra, obtained in these three points of interest, are multiplied by boron cross section, the difference in number of the detected neutrons between the full and empty model could be 28 % in isocenter, 24 % in the upper detector and even 74 % in the side detector.

Presented results indicate that the accelerator head cover should not be ignored when performing Monte Carlo calculations. Omitting the head cover will underestimate neutron flux and overestimate neutron energy that comes from the accelerators head. This will be true in the patient plane, but even more pronounced in the planes above and aside of the accelerator head. Hence, ignoring the head cover in the MC modelling, of the high energy electron linear accelerators in radiotherapy, will introduce a large uncertainty assessing a patient, or a medical professional neutron doses. In the future, we will include human phantom in the simulations to determine importance of simulating the head cover in the staff and patients' neutron dose equivalent estimations.

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AUTHORS' CONTRIBUTIONS

The idea for this paper came as a result of discussions of H. Brkić, D. Faj, and A. Ivković. Preparing and conducting the simulations was done by H. Brkić. Data analyses and interpretation was done by D. Agić, M. Kasabašić, and I. Krpan. The manuscript was written, and the figures were prepared by H. Brkić. All the authors have participated in critical review of the manuscript with valuable suggestions and improvement.

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УТИЦАЈ ЗАШТИТЕ ГЛАВЕ АКЦЕЛЕРАТОРА НА НЕУТРОНСКИ ДОЗНИ ЕКВИВАЛЕНТ У МОНТЕ КАРЛО СИМУЛАЦИЈАМА ВИСОКОЕНЕРГЕТСКИХ МЕДИЦИНСКИХ ЛИНЕАРНИХ АКЦЕЛЕРАТОРА

Неутронска контаминација мегаволтних фотонских радиотерапијских снопова појављује се при енергијама већим од 10 MeV и утиче на озрачење медицинског особља и пацијената. Да би се тачно проценила доза коју примају медицинско особље и пацијенти, врло је важно познавати спектар произведених фотонеутрона. Један од уобичајених начина утврђивања спектра и фотонеутронског тока је Монте Карло симулација акцелератора. Чест недостатак при Монте Карло моделовању радиотерапијских снопова је тај што произвођачи најчешће не дају тачне и потпуне спецификације главе акцелератора, па неки делови главе нису укључени у симулације. У овом раду представљен је модел који укључује заштиту главе акцелератора и упоређење с моделом у којем је заштита изостављена, будући да се такви модели врло често могу наћи у публикацијама. Неутронски токови, спектри, средње енергије и место настанка неутрона упоређени су у изоцентру, тачки 1 m изнад мете и тачки 1 m бочно од мете, у оба модела.

У свим размотреним равнима утврђена промена у флуксу износи више од 20 %, са значајном променом у енергији неутрона, што је такође важно у неутронској дозиметрији. Занемаривање заштите главе акцелератора, у Монте Карло моделовању високоенергетских линеарних акцелератора у радиотерапији, уводи велику мерну несигурности при процени доза које примају медицинско особље и пацијенти.

Кључне речи: Монте Карло симулација, детекција неутрона, заштита главе акцелератора, радиотерапија