Polish J. of Environ. Stud. Vol. 15 No. 4A (2006), 177-180

Background Neutron Radiation in the Vicinity of Varian Clinac-2300 Medical Accelerator Working in the 20 MV Mode

A. Konefał[1], K. Polaczek-Grelik[1], A. Orlef[2], Z. Maniakowski[2], W. Zipper[1]

[1]Institute of Physics, Department of Nuclear Physics and Its Application, University of Silesia, Katowice
[2]Department of Medical Physics, Centre of Oncology, Gliwice Branch

Abstract

The neutron fluences and the mean energies of neutrons on the treatment couch, on walls in the accelerator bunker were determined for the Varian Clinac-2300 linac working in the 20 MV mode. Measurements as well as Monte Carlo calculations were applied in the investigations. The measured thermal and epithermal fluences normalized to the central-axis maximum 20 MV X-ray dose determined in the water phantom are between 0.7 and $1.8 \cdot 10^6$ cm^{-2} Gy^{-1} in the treatment room whereas the values from the simulation are from $0.46\text{-}1.93 \cdot 10^6$ cm^{-2} Gy^{-1}. The neutron fluence decreases significantly in the maze to be $0.09 \cdot 10^6$ cm^{-2} Gy^{-1} (thermal neutrons) and $0.01 \cdot 10^6$ cm^{-2} Gy^{-1} (epithermal neutrons) on the surface of the door. The mean energy of the undesired neutrons is of the order of some hundred keV and it decreases significantly in the maze to be 0.6eV on the door surface. Additionally, the neutron effective dose to patients was estimated for three values of the source-surface distance (SSD) to be 2.4mSv (SSD=100cm), 1.7mSv (SSD=150cm) and 0.8mSv (SSD=220cm) per Gy at D_{max} determined at SSD = 100cm (radiation field 10x10 cm^2).

Keywords: biomedical accelerators, 20 MV X-rays, undesirable neutrons

Introduction

Modern medical accelerators generating high-energy therapeutic beam are source of neutron radiation undesired in the radiotherapy treatment. The neutrons originate from photonuclear and electronuclear reactions caused by the therapeutic beam. As it was shown in plentiful works, for example [1, 2], the neutron production is particularly high during emission of X-rays with the nominal potential of 20 MV or somewhat greater. In fact, recently many oncology centers have given up the usage of the beams with such nominal potential. However, the 20 MV beam is still in use. There are many undesirable consequences of emission of this beam. Firstly, patients receive the additional total body neutron dose. Secondly, radioisotopes are induced in the accelerator bunker (treatment room and maze), as a result of the photonuclear and electronuclear reactions and the simple capture of thermal and epithermal neutrons. Several radioisotopes with the longer half-life come into existence [2, 3]. They cause the raised radiation level keeping even for tens hours after the beam emission. The components of the accelerator head are particularly strong activated. The activation strongly depends on rate of the neutron production yield.

The first purpose of this work was the determination of the thermal and epithermal neutron fluence in chosen locations in the accelerator bunker i.e. close to walls where many accelerator accessories are placed. The knowledge of the distribution of the thermal and epithermal neutron fluence is important to put massive accessories in lower neutron field. The second purpose was the determination of the neutron energy spectra on the treatment couch for estimation of the neutron effective dose to a patient treated with the 20 MV beam. Measurements as well as calculations were applied in our investigations. The neutron activation method was used to measure the thermal and epithermal neutron fluence whereas the Monte Carlo calculations based on GEANT4 simulation toolkit [4] made it possible to determine the neutron fluence in the whole energy range. The measurements were performed for series of the Varian Clinac-2300 linacs installed in the Center of Oncology in Gliwice (Poland). The calculations were carried out for the full geometry of the Varian accelerator, using the computers in the Institute of Physics of Silesian University in Katowice (Poland) and in the Department of Medical Physics of Centre of Oncology in Gliwice.

Material and methods

The indium foil (^{115}In isotope) was applied as a neutron detector in the neutron activation method. The indium foils were in the shape of a circle with the radius of 0.75 cm. The foil thickness was 100 µm (80 mg/cm^2). The cadmium cover method was applied to separate the activities due to thermal and epithermal neutrons. The detailed description of the applied method was presented in our previous papers which we refer to as [2, 5]. In the calculations, all components affecting the 20 MV beam quality were taken into account in the simulation program i.e. three tungsten components: the target, the primary collimator and the jaws, and the iron-tantalum flattening filter. Moreover, the other major components of the accelerator i.e. the lead secondary collimator, shielding, plastic casing ect., and the concrete accelerator bunker with the maze and the door were simulated.

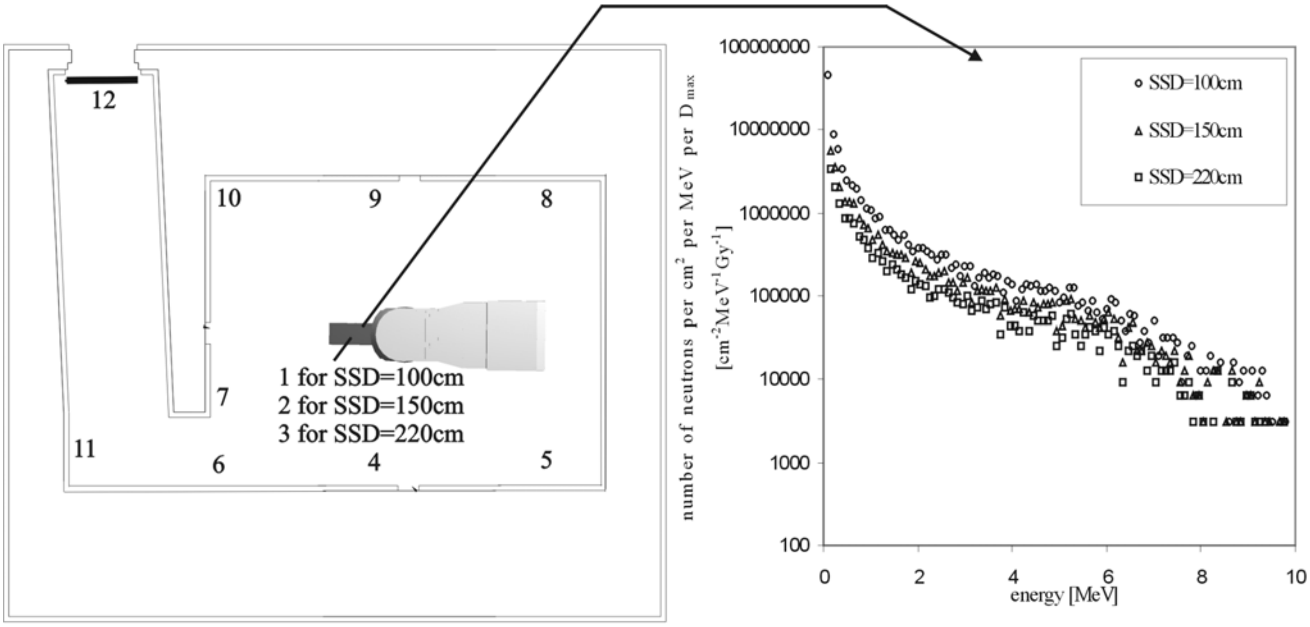
All presented fluences and the effective dose values were normalized to the central-axis 20 MV X-ray maximum dose D_{max} determined in the water phantom for source-surface distance (SSD) equal 100 cm and the radiation field of 10 cm x 10 cm. Such normalization renders the presented values independent of the accelerator output and makes it easy to relate the obtained results to the therapeutic dose. However, it required us to carry out the additional measurements and simulations for determination of the dose D_{max}. The measurements of D_{max} were performed using two types of the ionization chambers i.e. the Markus and the M31002 ionization chambers recommended by dosimetry protocols. In the case of the simulations, the dose D_{max} was calculated as energy given by radiation to a volume of water phantom for the described above geometry of the accelerator. The calculated dose values were recorded in logic detectors (called bins, following Mohan at al [6]). Verifications of the X-ray beam simulation was performed by the comparison of the calculated central-axis depth-dose curves and the measured ones. The good agreement was observed. The exemplary results of this verification and the obtained X-ray energy spectrum of the 20 MV beam were presented in the paper [7]. The neutron energy spectra were recorded in the 2-dimensional bins. These bins scored energies of neutrons passing through them. The sizes of the bins were determined taking into account four factors: insignificant changes of photon and neutron flux in the bin volume, good statistic, computer power and relatively short time of simulations. The neutron fluence was determined in 12 chosen places inside the treatment room (see Figure 1): on the treatment couch (for three distances of the couch from the target, characterized by the parameter SSD = 100 cm, 150 cm and 220 cm -locations signed as 1 ,2 and 3 in Figure 1), for 8 places on the walls (about 1.5 m over the floor) – locations 4-11 and on the door surface (location 12). The neutron spectra obtained in the first three locations were used for estimation of the neutron effective dose D_{eff}. The estimation was performed with the use of conversion coefficients (for antero-posterior irradiation geometry) presented in ICRP Publication 74 [8], according to the following dependence: $D_{eff} = \Phi_{total} \cdot Q_{Eo}$, where Φ_{total} is the total neutron fluence (see table of results in Figure 1), Q_{Eo} is the conversion coefficient defined as effective dose per unit neutron fluence (in units of pSv cm^2) for monoenergetic neutrons. The neutrons have broad energy spectrum on the treatment couch. We decide to take the mean neutron energy E_0 for the estimation of D_{eff}.

Results

All obtained results are presented in Figure 1.

Discussion and conclusions

The measurements have given the neutron fluences with uncertainty of about 15 %. The statistical fluctuations in values from our Monte Carlo calculations did not exceed 5 %. The measured and the calculated thermal and epithermal fluences are the same order of magnitude. The thermal as well as epithermal fluence decreases significantly in the maze. In general, the highest thermal and epithermal neutron radiation is on the treatment couch. The neutron effective dose decrease about 3 times as the SSD parameter changes from 100 cm to 220 cm. It is caused, mainly, by the decrease in the total neutron fluence and in the mean energy of neutron radiation for greater distance between the target and the treatment couch. Secondly, the neutron fluence was normalized to the central-axis 20 MV beam maximum dose D_{max} for SSD = 100 cm, independently of the place of the determination. Of course, the value of D_{max} for SSD = 100 cm is greater than for SSD = 150 cm and 220 cm. Thus, the greater differences between the effective dose values will disappear after renormalization to the therapeutic dose. The obtained thermal neutron fluences are between those measured by Gudowska and Brahme [1] for various type accelerators with the similar nominal potential. However, the fast neutron fluence is somewhat less then the values derived by Gudowska and Brahme [1] for the 21 MV Mictrotron. The fast neutron measurement method used by Gudowska and Brahme does not separate the epithermal



Measuring places	$\Phi_{thermal}/D_{\max}\cdot 10^6$ [cm^{-2} Gy^{-1}]		$\Phi_{epithermal}/D_{\max}\cdot 10^6$ [cm^{-2} Gy^{-1}]		**E_0 [MeV]**
	measured	**calculated**	**measured**	**calculated**	**calculated**
1	1.3	1.80	0.9	1.41	0.55
2	1.4	1.86	0.8	1.22	0.47
3	1.5	1.93	0.8	1.15	0.37
4	1.8	1.81	1.2	0.94	0.23
5	1.3	1.46	0.9	0.64	0.21
6	1.0	1.06	0.7	0.42	0.17
7	1.1	1.47	0.8	0.65	0.13
8	1.3	1.46	0.9	0.64	0.20
9	1.7	1.87	1.2	0.99	0.23
10	1.7	1.31	1.2	0.46	0.17
11	0.1	0.51	0.1	0.19	0.12
12	-	0.09	-	0.01	$6.1 \cdot 10^{-4}$

	$\Phi_{fast}/D_{\max}\cdot 10^6$ [cm^{-2} Gy^{-1}]	$\Phi_{total}/D_{\max}\cdot 10^6$ [cm^{-2} Gy^{-1}]	$D_{eff}/D_{\max}$ [mSv Gy^{-1}]
1	8.82	12.02	2.4
2	6.57	9.65	1.7
3	2.17	5.25	0.8

Fig. 1. Scheme of the accelerator bunker with the numbered locations where the fluences were determined. The measured and the calculated thermal and epithermal neutron fluences ($\Phi_{thermal}$ and $\Phi_{epithermal}$), the calculated fast neuron fluences Φ_{fast}, the calculated total neutron fluences Φ_{total} and the neutron effective doses are related to D_{max}. The fluences are determined as a number of neutrons per squared centimeter

neutrons and the fast ones. It seems to be the main reason that their values are greater than ours. The calculated total neutron fluence was compared with results (measured and calculated with the EGS4 and MORSE codes) presented by Mao et al. [9] to be in a good agreement with them. The small difference is only in the mean energy value i.e. those obtained by us are about 0.2 MeV greater. This disagreement can be caused by the differences in the construction of the accelerators and the sizes of the treatment couch.

References

1. Gudowska J. and Brahme A.: Neutron radiation from high-energy X-ray medical accelerators. Nukleonika **41**, 2, p. 105-118, **1996**.
2. Konefał A., Dybek M., Zipper W., Łobodziec W., Szczucka K.: Thermal and epithermal neutrons In the vicinity of the Primus Siemens biomedical accelerator. Nukleonika **50**(2):73-81, **2005**.

3. Fasso A., Silari M., Ulrici L.: Predicting induced radiotherapy at high-energy electron accelerators. Journal of Nuclear Science and Technology. 37; Suppl. **1**, 827-834, **2000**.
4. GEANT4homepage2006 http://wwwinfo.cern.ch/asd/geant4/geant4.html/support/gettingstarted.shtml
5. Konefał A., Orlef A., Zipper W., Dorda J., Łobodziec W.: Undesired neutron radiation generated by biomedical accelerators during high-energy X-ray and electron beam emission. Pol J Med Phys **2**, 7(4), 291-304, **2001**.
6. Mohan R., Chui C. and Lidofsky L.: Energy and angular distributions of photons from medical linear accelerators. Med. Phys. **12**, 592-597, **1985**.
7. Konefał A.: Symulacje komputerowe metodą Monte Carlo przy pomocy nowoczesnego oprogramowania GEANT4 (The Monte Carlo komputer simulations with the use of the modern software GEANT4). Postępy Fizyki, in preparation **2006**.
8. ICRP Publication 74. Conversion coefficients for use in radiological protection against external radiation, p. 199, table A 41, **1995**.
9. Mao X.S., Kase K.R., Liu J.C., Nelson W.R., Kleck J. H., Johnsen S. Neutron sources in the Varian Clinac 2100C/2300C medical accelerator calculated by the EGS4 code. Health Physics **72** (4): 524-529, **1997**.