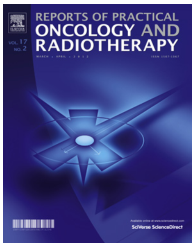
REPORTS OF PRACTICAL ONCOLOGY AND RADIOTHERAPY 19 (2014) 30–36

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor



Original research article

Monte Carlo characterizations mapping of the (γ,n) and (n,γ) photonuclear reactions in the high energy X-ray radiation therapy

Hosein Ghiasi[*]

University of Medical Sciences, Department of Medical Physics, Iran

ARTICLE INFO

Article history:
Received 6 February 2013
Received in revised form
13 April 2013
Accepted 7 July 2013

Keywords:
Photoneutron
Monte Carlo
Shielding
Capture gamma ray

ABSTRACT

Aim: The aim of this work was to map the characteristics of (n,γ) and (γ,n) reactions in a high energy photon radiation therapy.

Background: Photoneutrons produced in the high energy X-Ray radiation therapy may damage patients and staff. It is due to high RBE of the produced neutrons according to their energy and isotropic emission. Characterization of the photoneutrons can help us in appropriate shielding.

Materials and methods: This study focused on the photoneutron and capture gamma ray phenomena. Characteristics such as dose value, fluence and spectra of both the neutrons and the by produced prompt gamma ray were described.

Results and discussion: Neutron and prompt gamma spectra in different points showed the neutrons to be thermalized when increasing the distance from the linac. Energy of the neutrons changed from about 0.6 MeV at the isocentre to around 10^{-08} MeV at the outer door position. Although the neutrons were found as fast neutrons, their spectra showed they were thermal neutrons at the outer door position. Additionally, it was seen that the energy of the gamma rays is higher than the scattered X-ray energy. The energy of gamma rays was seen to be up to 10 MeV while the linac photons had energy lower than 1 MeV. Neutron source strength obtained in this work was in good agreement with the published data, which may be a confirmation of our simulation accuracy.

Conclusion: The study showed that the Monte Carlo simulation can be applied in the radiotherapy and industrial radiation works as a useful and precise estimator. We also concluded that the dose from the prompt gamma ray at the outer door location is higher than the scattered radiation from the linac and should be considered in the shielding.

---

[*] Tel.: +98 4127292564; fax: +98 04127292564.
E-mail addresses: hoseinghiasi62@gmail.com, h_ghyasy@yahoo.com

1507-1367/$ – see front matter © 2013 Greater Poland Cancer Centre. Published by Elsevier Urban & Partner Sp. z o.o. All rights reserved.
http://dx.doi.org/10.1016/j.rpor.2013.07.003

1. Background

Photonuclear reactions become important in the X-Ray radiation therapies with energies higher than 8–10 MV[1]. When a photon has energy higher than the threshold energy of reaction (7–10 MeV), secondary particles emission can occur[2]. Giant dipole resonance (GDR) in which the target material nucleus undergoes instability in the nucleus energy levels is the cause for the secondary particles emission by the nucleus to achieve a stable energy state. The emitted particle may be a neutron, proton, alpha particle and heavy ions[3–5]. However, the neutrons are uncharged and are not absorbed with the LINAC head materials[6]. And this is the key why we study only photoneutrons? For this substantial matter, photoneutron production is a concern and a problem in terms of radiation protection. For example, a proton is absorbed at several millimeters away from the produced origin because of its electrical charge and the Columbus reaction[7]. However, a produced photoneutron is able to go to the maze and outside of the treatment room. The propagation of photoneutrons in the treatment room can lead to an increase in the patients' and staff's exposure to dose equivalent[8–11]. Useful beams and the entire room and maze are contaminated with photoneutron production. Patient body and organs may be a source of photoneutron production and the produced neutrons may be absorbed in or outside of the patient's body. On the other hand, the photoneutrons are produced in a range of energy associated with higher radiobiological damages[3]. The radiobiological effects were reported to be up to 20 times higher those of a photon with any energy[3]. Secondary malignancies reported as the late effects of the produced photoneutrons and capture gamma.

2. Aim

These hazardous effects of neutrons in a high energy radiation therapy were the reason to perform this study and mapping the characteristics of the secondary photoneutrons produced and gamma rays. In this study, we tried to characterize the secondary photoneutrons produced and consequent capture gamma rays.

3. Materials and methods

MCNPX code of the Monte Carlo (MC)[12] method was used in the entire the study. The code has capabilities such as to simulate very complex and rolled geometries. Additionally, physical phenomena such as photon–neutron–electron and coupled particles transport can be achieved using the code and its data libraries. With the usage of the code, Varian 2100 Clinac geometry and physical aspects of the LINAC were simulated according to the manufacturer provided data. Our modeling was validated in our previous works. A typical treatment room according to International Atomic Energy Agency (IAEA No. 47)[1] recommendation on the radiotherapy facilities designing was simulated, made of ordinary concrete. Running the simulated program for short times, BNUM (which controls the number of photons produced per incident primary electron) of electron phys card was optimized and the number of 5 was attributed to the BNUM value. Then, code for any primary electron, transports 5 photons per initial primary incident electron and reduces the running time more than 14 times and statistical error around 1.86 times. With inserted other variance reduction options, produced neutrons energy, fluence, flux, spectra and dose equivalent in different points in the simulated room were scored using different tallies. Photon, neutron and neutron capture gamma ray characteristics were tallied in the isocentre and different points at the isocentre plane, in the room and position of the inside and outside of the maze door. For this, tally of F4 in an air filled spherical cell in diameter of 1 cm was applied and tallied the particles per cm^2. Obtained results were discussed and compared with the published data and commissioned. Dose equivalent was scored in water filled small spherical cell inside and outside of the door and also at the isocentre. Additionally, we calculated and compared the photoneutrons and capture gamma ray dose equivalent using the method we proposed in our previous work. Other analytical methods were used to compare the data, such as Kersey, French, McCall and Wu-McGinley methods[13–17]. The shielding performance and the results were evaluated and the results discussed. In the previous work[18] we proposed an analytical method and sensitized the analytical methods to walls and room material compositions. In this work, we tried to evaluate the proposed methods. Additionally, full mapping of the photoneutron and capture gamma ray characteristics was done in the context of the radiological protection issues.

4. Results and discussion

The results of this work were presented in several sections. The first section presents our results and some discussions on the photoneutron, photon and neutron capture gamma ray spectra. The trend of the spectra with differing distance is discussed. Published data on the neutron, gamma and LINACs photon spectra were considered and discussed. A good agreement was found between the published data and our results in dosed, fluence and spectra in this section. Obtained data is close to the results in the literature. The results and comparisons are presented in the tables.

4.1. *Spectra (photon, neutron, gamma)*

Figs. 2–4 show photoneutron spectra at the isocentre, point A and maze door position. Fig. 5 also shows the neutron spectra outside the door. The two Figs. 6 and 7 show the spectra of neutron at the primary and secondary barrier positions. Door modification is obviously seen from the spectra at the outside of the door. It is shown in Fig. 2 that the fast portion of the photoneutrons is dominant at the isocentre. From an analytical characterization of the photoneutrons at the point it can be deduced that about 89% of the produced neutrons are thermal neutrons with lower energy and unfortunately highest biological effect among the other energies of neutrons. Eq. (1) defines photoneutrons distribution and its thermal and fast components. First term is thermal portion and the second