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Original research article

The determination of a dose deposited in reference medium due to (p,n) reaction occurring during proton therapy

*Anna Dawidowska**, *Monika Paluch Ferszt*, *Adam Konefał*

Department of Nuclear Physics and Its Applications, Institute of Physics, University of Silesia, Katowice, Poland

ARTICLE INFO

Article history:
Received 31 August 2013
Received in revised form
15 November 2013
Accepted 27 February 2014

Keywords:
Neutrons
Proton therapy
Monte Carlo
GEANT4

ABSTRACT

Aim: The aim of the investigation was to determine the undesirable dose coming from neutrons produced in reactions (p,n) in irradiated tissues represented by water.

Background: Production of neutrons in the system of beam collimators and in irradiated tissues is the undesirable phenomenon related to the application of protons in radiotherapy. It makes that proton beams are contaminated by neutrons and patients receive the undesirable neutron dose.

Materials and methods: The investigation was based on the Monte Carlo simulations (GEANT4 code). The calculations were performed for five energies of protons: 50 MeV, 55 MeV, 60 MeV, 65 MeV and 75 MeV. The neutron doses were calculated on the basis of the neutron fluence and neutron energy spectra derived from simulations and by means of the neutron fluence–dose conversion coefficients taken from the ICRP dosimetry protocol no. 74 for the antero-posterior irradiation geometry.

Results: The obtained neutron doses are much less than the proton ones. They do not exceed 0.1%, 0.4%, 0.5%, 0.6% and 0.7% of the total dose at a given depth for the primary protons with energy of 50 MeV, 55 MeV, 60 MeV, 65 MeV and 70 MeV, respectively.

Conclusions: The neutron production takes place mainly along the central axis of the beam. The maximum neutron dose appears at about a half of the depth of the maximum proton dose (Bragg peak), i.e. in the volume of a healthy tissue. The doses of neutrons produced in the irradiated medium (water) are about two orders of magnitude less than the proton doses for the considered range of energy of protons.

* *Corresponding author*. Tel.: +48 510515756.
E-mail addresses: annadawidowska@gazeta.pl, a.dawidowska@us.edu.pl (A. Dawidowska).

http://dx.doi.org/10.1016/j.rpor.2014.02.003
1507-1367/

1. Background

Cancer therapy using protons is a modern method of an external radiation treatment. It is characterized by high precision and efficiency.[1–6] Proton therapy differs from traditional methods of treatment in concentration of radiation dose in the tumor with a reduced load of healthy tissue in the input channel, precise placement of the dose in the target area with a large gradient at the border of healthy tissue and increased biological effectiveness. But this is not a universal method for the treatment of all types of pathological changes. The proton therapy is not used for spread tumors.

The undesirable phenomenon related to emission of protons is a production of neutrons in the system of beam collimators[7,8] and in irradiated tissues. The neutron production occurs in a broad range of proton energy. It causes proton beams to be contaminated by neutron radiation and patients to receive additional undesirable neutron dose. The presented research is associated with proton therapy in the range of relatively low energies from 50 MeV to 75 MeV. Such therapy is applied in a superficial tumor treatment, particularly in radiotherapy of ocular melanoma.[9]

2. Aim

The aim of the presented investigation was to determine the additional undesirable dose coming from neutrons produced in reactions (p,n) in an irradiated tissue represented by water – a medium recommended by dosimetry protocols for a dose determination in radiotherapy.[10] Water has the mass collision stopping powers and linear scattering powers approximately equal to those of biological tissues. The neutron doses were derived by means of the Monte Carlo computer simulations based on the GEANT4 software.

3. Materials and methods

The presented investigation was based on the Monte Carlo computer simulations with the use of the GEANT4 software in the version 4.9.3. The GEANT4 code is recommended by many scientists for application in proton and other kinds of radiotherapy[11,6,12–14] because it provides all physical processes occurring during the emission of proton therapeutic beams, based on extensive data bases of experimental parameters, cross-section, etc. The majority of physical process models is based on experimental data bases which makes it possible to obtain very accurate results. The calculations were performed for five energies of protons: 50 MeV, 55 MeV, 60 MeV, 65 MeV and 75 MeV applied in the proton therapy of the eyes.

The performed simulations made it possible to determine energy spectra, the map of fluence and the distributions of depth-doses for undesirable neutrons produced in the (p,n) reactions inside the irradiated volume, as well as the depth-dose distributions for the therapeutic protons. The created virtual simulated system consisted of a water phantom with logical detectors. The phantom was a cube of 5 cm × 5 cm × 5 cm. Two factors were taken into account for the choice of the size of a phantom. Firstly, the phantom of 5 cm × 5 cm × 5 cm is large enough not to disturb the flow of protons and neutrons. Secondly, the size used does not increase the time of simulations significantly. 201 logical detectors were located along the central axis of the proton beam (Z in Fig. 1). The logical detector system was shifted along the axis X, i.e. in the direction perpendicular to the proton beam central axis, to determine the maps of the neutron fluence. The logical detectors were in the shape of cylinders of 0.05 mm in height, the radius of its base being 5 mm. To obtain an accurate depth-dose distribution with the Bragg peak, the distances between the detectors were set as follows: 0.5 mm in the region of depths up to 3 cm, and 0.15 mm at 3–5 cm. A group of logical detectors was intended to the register of energies of neutrons. In this case, the distances between the

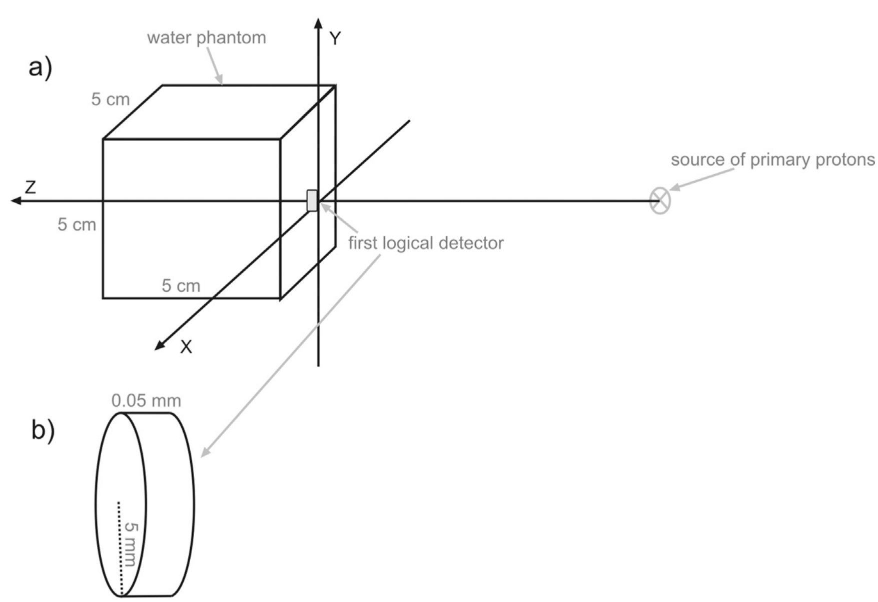

Fig. 1 – Scheme of the simulated system. (a) The full system and (b) a logical detector.