

Comparison of the Light Charged Particles on Scatter Radiation Dose in Thyroid Hadron Therapy

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ABSTRACT

Background: Hadron therapy is a novel technique of cancer radiation therapy which employs charged particles beams, ¹H and light ions in particular. Due to their physical and radiobiological properties, they allow one to obtain a more conformal treatment, sparing better the healthy tissues located in proximity of the tumor and allowing a higher control of the disease.

Objective: As it is well known, these light particles can interact with nuclei in the tissue, and produce the different secondary particles such as neutron and photon. These particles can damage specially the critical organs behind of thyroid gland.

Methods: In this research, we simulated neck geometry by MCNPX code and calculated the light particles dose at distance of 2.14 cm in thyroid gland, for different particles beam: ¹H, ²H, ³He, and ⁴He. Thyroid treatment is important because the spine and vertebrae is situated right behind to the thyroid gland on the posterior side.

Results: The results show that ²H has the most total flux for photon and neutron, 1.944E-3 and 1.7666E-2, respectively. Whereas ¹H and ³He have best conditions, 8.88609E-4 and 1.35431E-3 for photon, 4.90506E-4 and 4.34057E-3 for neutron, respectively. The same calculation has obtained for energy depositions for these particles.

Conclusion: In this research, we investigated that which of these light particles can deliver the maximum dose to the normal tissues and the minimum dose to the tumor. By comparing these results for the mentioned light particles, we find out ¹H and ³He is the best therapy choices for thyroid glands whereas ²H is the worst.

Keywords

Hadron therapy, Thyroid gland, Secondary particles, Photon and neutron flux, Energy deposition

Introduction

Cancer is a major social problem, and it is the main cause of death between the ages 45–65 years. In the treatment of cancer, radiotherapy plays an essential role. Hadron therapy, thus, has great prospects for being used in early stages of tumor disease not amenable to surgery [1]. Light particles are often used for radiation therapy because they have a well-defined penetration in tissue, the depth being dependent on the incident energy of the particles and the nature of the irradiated tissue. The other main reason for using these particles in radiation therapy lies in their physical, the ability to deliver the dose to the interest target [2]. Beams of charged particles have specific dose distribution, exhibiting a flat entrance dose relatively (plateau), followed by a sharp dose peak, the Bragg peak, in which

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the particles lose rest of their energy. Due to their physical and radiobiological properties, they allow one to obtain a more conformal treatment, sparing better the healthy tissues located in proximity of the tumor and allowing a higher control of the disease. Indeed, its relative biological effectiveness (RBE) does depend on the linear energy transfer (LET) and can become substantially large at the falling edge of the Bragg peak [3, 4]. Treatment planning in radiation therapy uses mathematical and physical formalisms to optimize the delivering a high and conformal dose to the target and limiting the doses to critical structures. The dose tolerance levels for critical structures, as well as the required doses for various tumor types, are typically defined on the basis of decades of clinical experience [5]. Then by proper choosing of different types of particles like ^1H and the other light particles can be reduced the relevant dose to critical organs. It is well recognized that ^1H are extremely valuable to treat tumors close to critical structures such head and neck [6], brain stem, prostate [7], spinal cord, eye [8] or optic nerves [9].

The main types of radiation therapy induced fatalities that have been widely reported are secondary cancers. It is primarily related to the amount of dose deposited in the specific organs. So, the most efficient way to prevent these secondary cancers is reducing the amount of dose scattered to the internal organs; for example choosing a radiation technique or proper particle that minimizes the scattered dose to the other organs. In the regards to the secondary cancers, a recent review showed that secondary tumors occur more frequently in organs that are close to radiation fields, in the high/intermediate dose areas, and that is important to evaluate the scattered dose to those the internal organs along with their secondary cancer [10]. All these light particles deliver different lev-

els of scattered dose to the internal organs and hence may induce different risks of secondary cancers. The aim of this study is to evaluate the amount of the scattered dose to the internal organs situated in the intermediate/high dose region including the spine and nerves, etc.

Recently, Orecchia has been reported that the potential indications for proton therapy to treatment of thyroid cancer is about 50 patients per year in the national center for oncological hadron therapy in Pavia, Italy [8]. Taheri has investigated the potential advantages of intensity modulated ^1H therapy (IMPT) compared with intensity modulated radiation therapy (IMRT) in nasopharyngeal carcinoma [11]. They found that IMPT plans reduced the averaged mean dose of the thyroid gland by a factor of two related to IMRT.

In this study, we have calculated the light particles energy deposition in the thyroid gland, for different particles such ^1H , ^2H , ^3He , and ^4He by MCNPX Monte Carlo code, and estimation of the total photon and neutron production due to interaction of incident particles by tissue, that is very important in order to evaluate the risk of secondary cancers [12]. One of the major concerns in hadron therapy is due to the neutrons and photons. Because of their long rang, they can damage the critical organs and increase the probability the secondary cancers[13].

Material and Methods

MCNPX is a general purpose Monte Carlo radiation transport code designed to track many particles over broad ranges of energies. The code deals with transport of more than 40 particles, and coupled transport, such transport of secondary gamma rays and neutrons resulting from different interactions in hadron therapy[14]. It is important that a dose calculation algorithm to be able

to model complex and heterogeneous density mediums, as well as, calculating of the primary and secondary particles dose. MC-NPX code has this ability which we applied it in this research[15].

A cylindrical geometry was used to describe the neck phantom, having 6 cm of length and 6 cm of diameter. The layers of the phantom include 0.12 cm skin, 0.4 cm adipose and 0.6 cm skeletal muscle, after these layers we consider the thyroid gland as cylindrical with 0.6 cm of diameter, vertebrae and spine with 0.4 cm diameters, respectively. Figure 1 shows the geometry of the neck phantom and we derived their material compositions and densities from ICRP publications[16]. Four light particles including ^1H , ^2H , ^3He and ^4He are used in our simulation. We have applied a mono energetic pencil beam perpendicular to the phantom surface.

Results and Discussion

We have calculated the energy deposition variation with depth for the same range particles to compare their Bragg peaks in the target organ. As well as, the suitable energy interval for scanning of the thyroid organ with step of 1 MeV have been obtained: 37 - 53 MeV for ^1H , 50 - 71 MeV for ^2H , 128 - 190 MeV for ^3He and finally 146 - 214 MeV

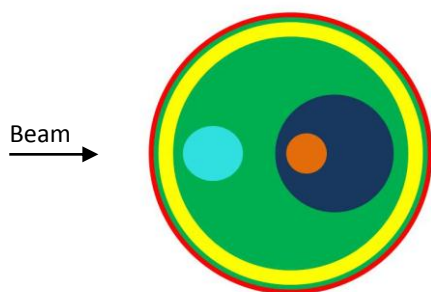


Figure 1: Geometry of the neck phantom including layers from left to right: 0.12 cm skin, 0.4 adipose, 0.6cm skeletal muscle, 0.6 thyroid, 1cm vertebrae, 0.4 spine.

for ^4He . Light particles slow down in tissue, mainly through myriad Coulomb interaction with electrons of atoms. As it is well known, the dominant interactions in tissue are ionization and excitation processes in more 99.9% of energy loss and the rest is belong to the nuclear interactions. In the treatment plan of hadron therapy, the main side effects come from the unwanted secondary particles like neutrons and photons. They may induce any second cancers or affect the critical organs functionality. The energy of light particles with the same range of 50 MeV for ^1H (2.14 cm) in thyroid organ are, 68 MeV, 176MeV, and 200 MeV for ^2H , ^3He , ^4He , respectively. Figure 2 shows the variation energy deposition with depth in the neck phantom for these particles.

Variation of the energy deposition with depth in the neck phantom for any particles with the same range is shown in figure 2. The sharper peak with less width, have more concentration for adjusting beam on the tumor and also beam energy spread [4]. It is well known that the FWHM and peak to plateau ratio (PTPR) are two significant factors that can be studied in treatment planning. These

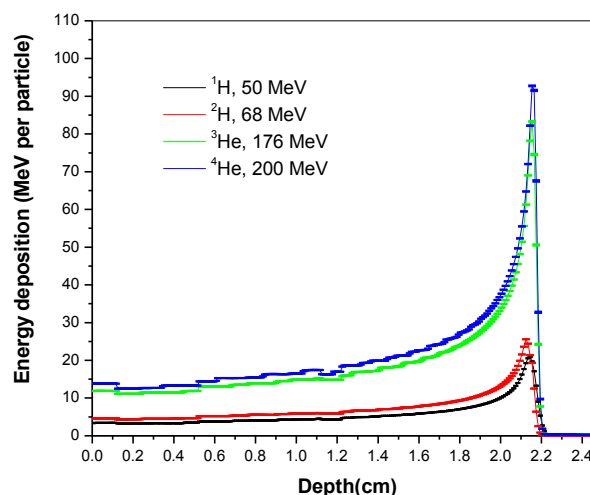


Figure 2: Variation of energy deposition with depth in the neck phantom.

results have been listed in table 1 and show that ^4He with the highest value for PTPR and the minimum value for FWHM factor is a good choice. According to the figure 2, with comparing the particles with same range can be understand the energy deposition in peak rises by increasing of the particle mass and atomic number.

In hadron therapy of thyroid gland, vertebrae, spine and nerve can be considered as

Table 1: Peak to Plateau ratio and FWHM.

Particle	Peak to Plateau ratio	FWHM
^1H	5.55	0.107
^2H	6.18	0.053
^3He	6.88	0.014
^4He	7.04	0.006

the critical organs which maybe damaged by the exposure of neutrons and photons secondary particles. We have evaluated the total flux of the secondary particles as recorded in table 2.

As it is well known, presence of neutron and photon secondary particles in hadron

Table 2: Total flux for photons and neutrons secondary particles per one particle of beam.

Particle	Total flux for photon	Total flux for neutron
^1H	8.88609 E-4	4.90506 E-4
^2H	1.9444 E-3	1.76666 E-2
^3He	1.35431E-3	4.34057 E-3
^4He	1.39082 E-3	4.57347 E-3

therapy, a fraction of dose can be deposited inside the thyroid gland and other far organs. Tables 3 and 4 indicate that how much energy fractions of neutrons and photons deposited in the tumor and other important healthy organs in the phantom. The obtained results in table 3 and 4 indicated that secondary particles of ^1H beam deposits maximum percentage dose in thyroid gland but the maximum damage for other sensitive organs

Table 3: Energy deposition for neutron in critical organs.

Particle	Spine	Vertebrae	Thyroid
^1H	5.43%	8.58%	39.88%
^2H	9.17%	15.55%	38.74%
^3He	8.13%	13.4%	39.5%
^4He	8.95%	13.74%	38.93%

Table 4: Energy deposition for photon in critical organs.

Particle	Spine	Vertebrae	Thyroid
^1H	2.57%	3.89%	42.37%
^2H	3.23%	5.12%	43.58%
^3He	3.14%	4.65%	41.94%
^4He	3.17%	5.05%	43%

is related to the ^2H beam. Figure 3 shows the neutron and photon dose for the all beams. The results illustrated that we have the maximum absorption in thyroid region and then in spine and vertebrae, respectively.

Consequently, when assessing the impact of neutron and photon doses, not only the absorbed dose is important but also the neutron and photon energy distribution spectra are essential in radiobiological effects evaluation. The secondary neutrons may have energies up to the primary particle beams energy. Based on the hadronic model, neutrons with energy in excess of 10 MeV produced by an intranuclear cascade processes are mainly forward-peaked and below 10 MeV neutrons produced by an evaporation process, and are emitted more isotropically.

Neutron energy distributions in patients have calculated using Monte Carlo simulations. Figure 4 shows the simulated energy distribution of neutrons entering the neck by light particle beams. The results show that neutrons produced by ^1H interactions in the patient body have an average energy lower than the neutrons produced by other hadron

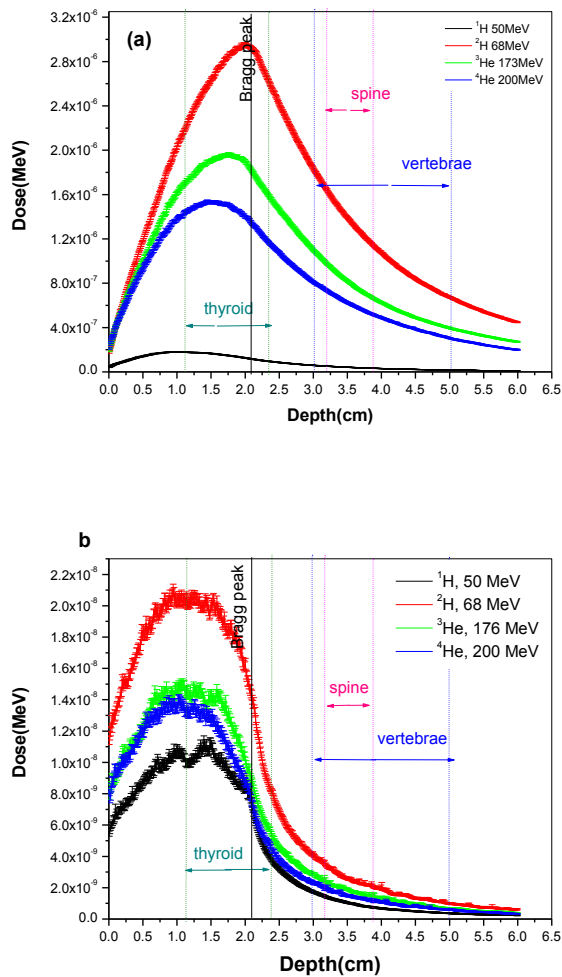


Figure 3: (a) Dose curves for neutron in sensitive organs and (b) dose curves for photons in sensitive organs.

beams with also wider energy distribution. Because of neutron elastic scattering in the soft tissue, there is a prevailing field of low energy. Furthermore of low energy neutron dose, a large fraction of the neutron dose is induced by fast neutrons.

For low energies neutrons, γ -rays are produced in (n, γ) neutron capture reaction. The most likely interaction in the body, because of the presence of hydrogen, is elastic scattering. In the low/thermal energy region, there is a decreasing probability of neutrons slowing down, as low-energy neutrons sparsely interact with the body's material. As a result, an extensive part of the patient's body may be exposed to the secondary photon and neutron radiation fields. The small amount of dose from uncharged particles - neutrons and photons- measurement or simulation is difficult and may be time consuming. In this research, two types of have been done: first, calculation of the secondary particle flux according to the energy of secondary particle, and the second is evaluation of the secondary particle flux according to the primary particle energy. The neutron and photon energy spectra have been illustrated in figures 4 and 5, respectively.

The neutron spectra for these particles

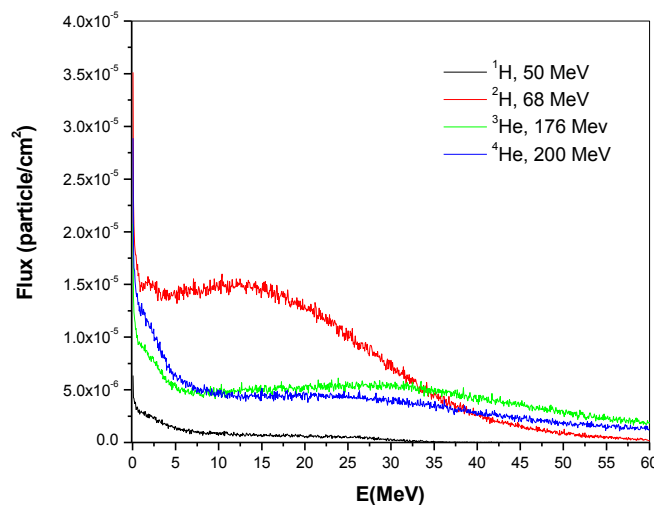


Figure 4: Neutron spectra produced by ^1H , ^2H , ^3He , and ^4He beams.

have significant high intensity smooth peak in low energy region. Thermal neutrons have a different and often much larger effective neutron absorption cross section for a nuclides in tissue than fast neutrons, and can therefore often be absorbed more easily by an atomic nucleus, creating a heavier, often unstable isotope as a neutron activation process. After the peak, there is a continuum flat that the intensity is decreased smoothly by increase in neutron energy. The results show that ^2H generates the highest thermal neutron flux.

The photons flux spectra are important remarkable quantity need to study, deeply. According to the results of simulation, there are some peaks which related to elements that have been specified in figure 5. Some peaks are known very well, 4.43 MeV from ^{12}C excitation, 5.22 from ^{35}Cl , 6.13 and 6.92 from

^{16}O .

Total neutron and photon production for different energies of ^1H , ^2H , ^3He , and ^4He primary beams have been illustrated in figures 6-9. Photon production result is fitted by polynomial third order function for ^2H energy, whereas for other beams it is described by a linear function. The figures show that the neutron total flux increased for ^4He , ^3He , ^1H and ^2H , respectively. The total photon flux production due to ^2H , ^3He , ^4He and ^1H are increasing.

Conclusion

In this research, we simulated simplified neck phantom involving a tumor placed in 2.14 cm depth with MCNPX Monte Carlo code for ^1H , ^2H , ^3He and ^4He . First we obtained proper energy for these incident particles and calculated the energy deposition.

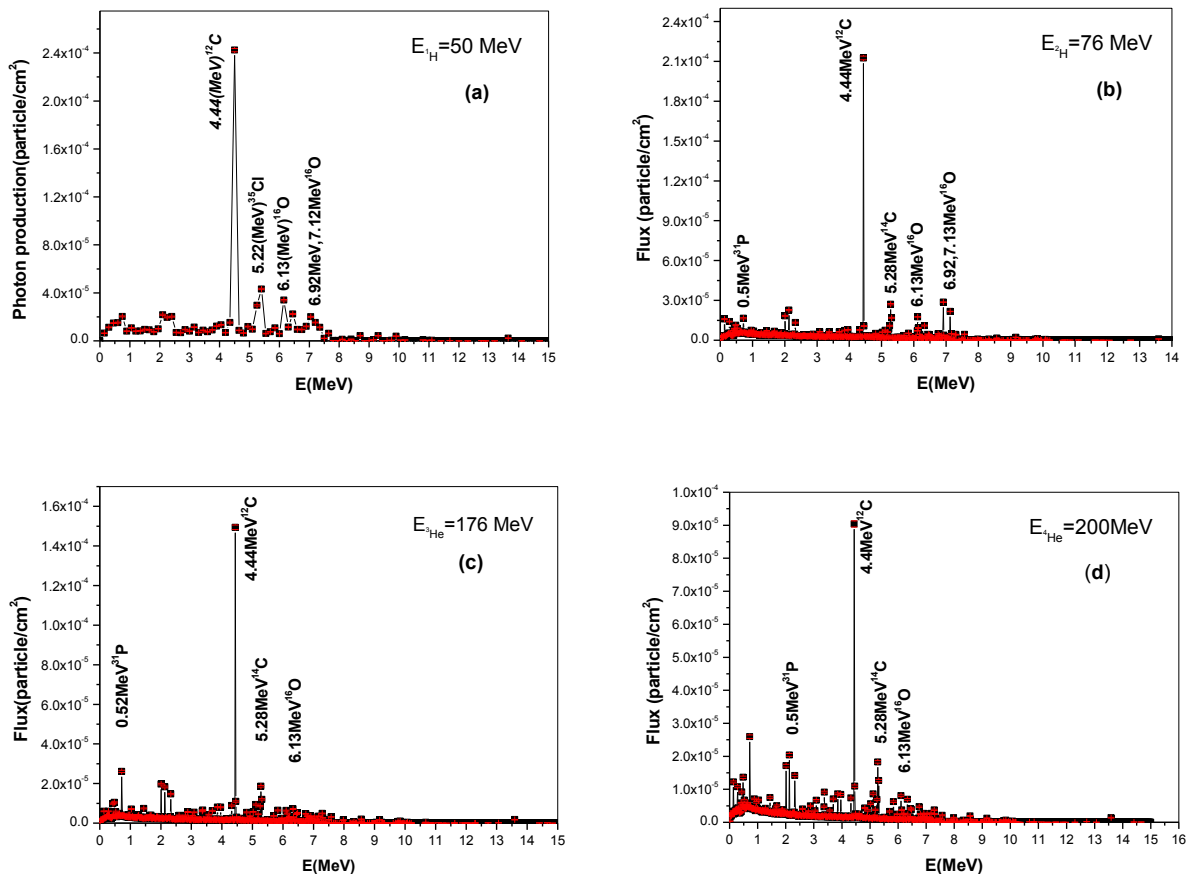


Figure 5: Spectra of photon flux for (a) ^1H , (b) ^2H , (c) ^3He , and (d) ^4He .

The results show that by increasing the atomic number, the Bragg peak becomes sharper and the incident beam can deposit more energy in tumor. As mentioned before, one of the important factor in external therapy is secondary particles that produced by

nuclear interaction with tissue. We evaluated the flux and energy deposition of the secondary particles including neutron and photon in critical organs such spine and vertebrae placed after thyroid gland. Based on the dose of secondary particles, it can be concluded

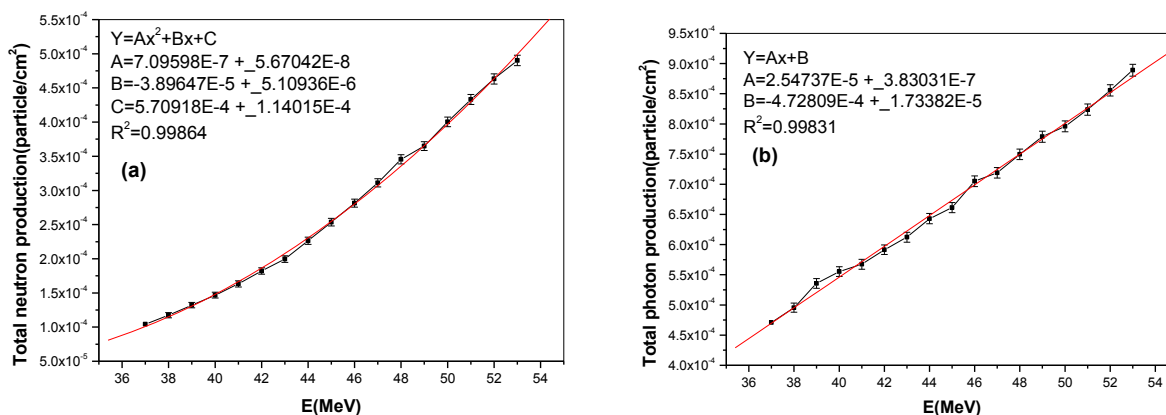


Figure 6: Variation of (a) neutron and (b) photon flux in terms of ¹H energy.

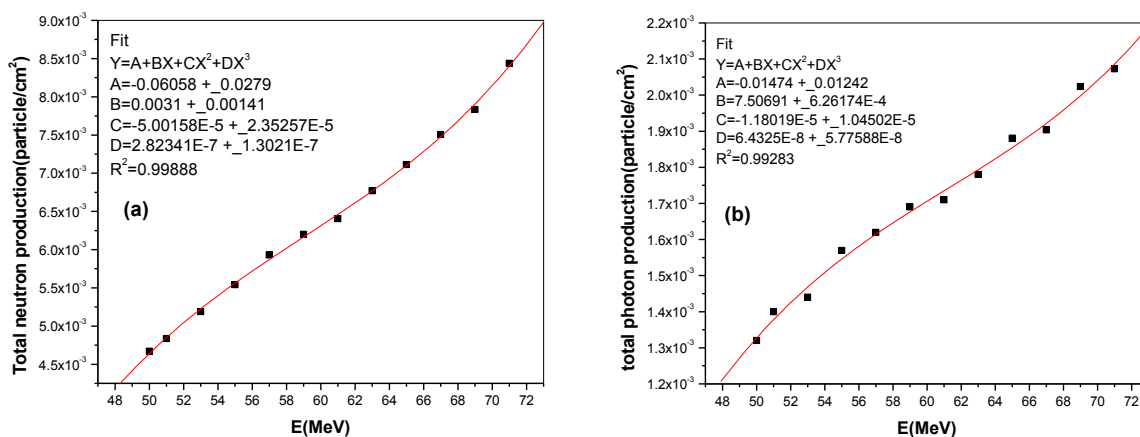


Figure 7: Variation of (a) neutron and (b) photon flux in terms of ²H energy.

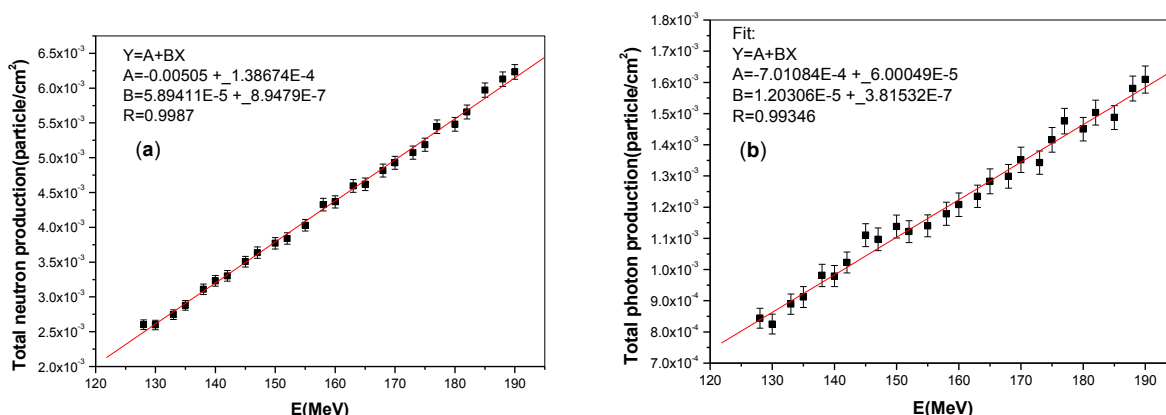


Figure 8: Variation of (a) neutron and (b) photon flux in terms of ³He energy.

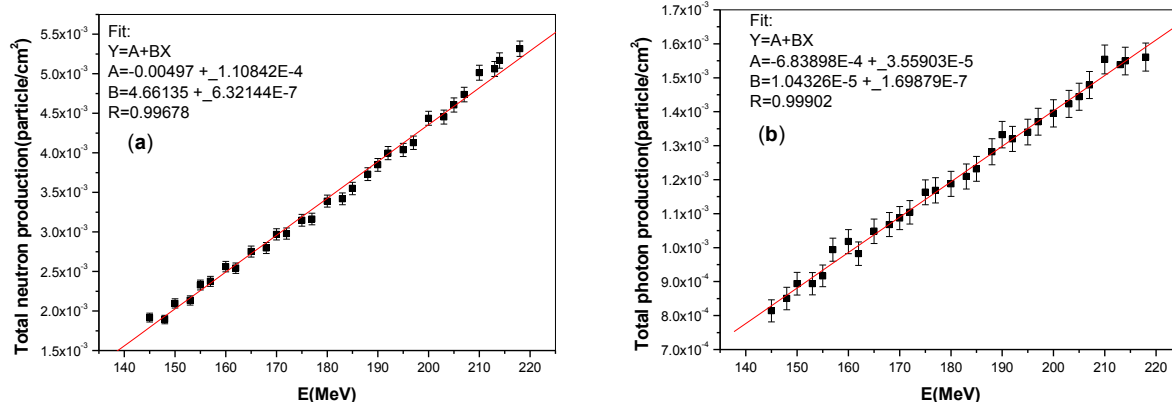


Figure 9: Variation of (a) neutron and (b) photon flux in terms of ^4He energy.

that ^1H and ^3He are the best therapy choices for thyroid glands whereas ^2H is the worse particle.

Conflict of Interest

None

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