Nuclear Technology & Radiation Protection: Year 2020, Vol. 35, No. 1, pp. 36-41

BREMSSTRAHLUNG CONVERSION EFFICIENCY AND GAMMA – NEUTRON GENERATION FROM POLYPROPYLENE, ALUMINUM, IRON, AND LEAD BOMBARDED BY 10 MeV ELECTRONS

by

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Scientific paper
https://doi.org/10.2298/NTRP2001036T

An electron beam from the UELR-10-15S2 accelerator (average energy of 9.92 0.48 MeV) was applied to irradiate food and medical items at the Research and Development Center for Radiation Technology, Vietnam Atomic Energy Institute, Vietnam. The materials are under an electron beam window, such as irradiation products, conveyor, magnet and shielding material for the magnet coil, bombarded by electrons and generated X-ray (bremsstrahlung effect). In this article, X-ray conversion efficiency from polypropylene, aluminum, iron, and lead bombarded by an electron beam from the UELR-10-15S2 accelerator is measured by the film dosimeter and simulated by the MCNP4c2 code, and there is good agreement between the calculation and measurement results. The results show that X-ray conversion efficiency is the highest from lead (4.3 %), so the gamma - neutron reaction (Q-value of –6.74 MeV for ^{207}Pb) has to be studied in food and medical items irradiated by a 10 MeV eelectron beam.

Key words: electron beam, food irradiation, bremsstrahlung, X-ray converter, Monte Carlo, MCNP

INTRODUCTION

Food irradiation was permitted in the US for the following type of radiation [1]: gamma radiation from ^{60}Co and ^{137}Cs, an electron beam with the maximum energy of 10 MeV, X-ray (bremsstrahlung) with the maximum energy of 5 MeV, and X-ray with energy up to 7.5 MeV. The permission for – food irradiation was based on three main pathways: induction of radioactivity in food isomeric activation, photo activation, and neutron activation [2]. In the case of food irradiation by an electron beam and X-ray [3], the neutron activation is the largest, so the electron energy should be below the threshold of the (γ, n) reaction threshold for the irradiated products.

The energy thresholds of the (γ, n) reaction [4] for major isotopes in food are ^{12}C (18.74 MeV), ^{16}O (15.67 MeV), and ^{14}N (10.56 MeV) [5]. Thus in the case of food irradiation by electrons with maximum energy of 10 MeV and an X-ray converter with maximum energy of 5 MeV, the neutron production is insignificant [6, 7]. In the case of materials with a low energy threshold of the (γ, n) reaction such as: aluminum, ^{27}Al (13.06 MeV), iron, ^{56}Fe (91.75 %, 11.12 MeV), ^{57}Fe (2.12 %, 7.65 MeV), and lead, ^{206}Pb (24.1 %, 8.09 MeV), ^{207}Pb (22.1 %, 6.74 MeV), and ^{208}Pb (52.4 %, 7.37 MeV) [5] bombarded by an electron beam, the neutron activation should be analysed. In this paper, X-ray conversion efficiency and bremsstrahlung spectra [8, 9] from polypropylene (PP), Al, Fe, and Pb targets bombarded by an electron beam were measured by a film dosimeter [10] and calculated by the MCNP code [11]. The aim of this work is the probability analysis of the (γ, n) reaction in irradiation and shielding materials bombarded by an electron with the average energy of 9.92 0.48 MeV based on measurement and calculation of X-ray conversion efficiency.

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EXPERIMENT AND SIMULATION

The measurement of the dose distribution inside the material

Based on the depth – dose – profile, the penetration of the electron with the average energy of 9.92 0.48 MeV and the thickness of targets is calculated to shield electrons [8, 12] and only photons penetrate. The depth – dose – profile of the electron beam with the average energy of 9.92 0.48 MeV from the accelerator UELR-10-15S2 was measured by a film dosimeter in a homogenous dummy. The homogenous dummy was made of PP plates with a size of 24 cm 20 cm 1 cm and the dosimeter was put in the center of the plates, fig. 1(a). The film dosimeter B3000 was manufactured and supplied by the GEX company, Germany with a response range from 0.5 to 80 kGy, 5 % uncertainty was used in measurements. The darkness of the film dosimeter [13] was measured by spectrometer GENESYS 20, manufactured by Thermo Science, fig. 1(b). The film dosimeter was calibrated by calibration phantoms which have been designed and built to provide a consistent method of presenting dosimeters to a radiation source as detailed in ISO/ASTM 51261 [14] at the electron beam facility.

X-RAY CONVERSION EFFICIENCY EXPERIMENT

The preparation of targets

The results of the depth – dose curve, fig. 2, show that the electron beam is fully shielded by the area density of the target which is more than 5.5 gcm^{-2} for irradiating one side and 11.0 gcm^{-2} for the double sided. The thickness of targets can be calculated for irradiating one side and double side as follows

$$d \quad 5.5/\rho \text{ [cm], for one side} \qquad (1)$$

$$d \quad 11.0/\rho \text{ [cm], for the double side} \qquad (2)$$

Parameters of PP, Al, Fe, and Pb targets for irradiation with 9.92 0.48 MeV electrons are shown in tab. 1.

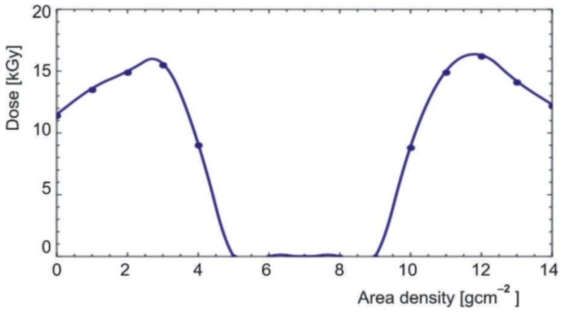

Figure 2. Experimental depth-dose curve in the homogeneous dummy irradiated double sided by the electron beam from accelerator UELR-10-15S2

Table 1. The parameters of X-ray targets

Targets	Density [gcm^{-3}]	Thickness of one side irradiation [cm]	Thickness of double sides irradiation [cm]
PP	0.95	7.0	14.0
Al	2.7	3.0	6.0
Fe	7.8	1.0	2.0
Pb	11.3	0.6	1.2

Irradiated targets by electron beam from accelerator UELR-10-15S2

Targets were put in the middle of the upper and the lower beam window for double sided irradiation, fig. 4(a). In fig. 4(a), (1) is the scanning magnet for the upper beam, (2, 3) is the bending magnet, (4) is the bending and scanning magnet for the lower beam, and (5) is the directory of the electron beam for the lower beam window. The geometry of the beam window and targets is shown in fig. 4(b). The irradiation time, conveyor speed and scanning width are set up so the electron dose and X-ray dose are in the response range of the film dosimeter. The parameters of the irradiation targets are shown in tab. 2. The irradiation targets include

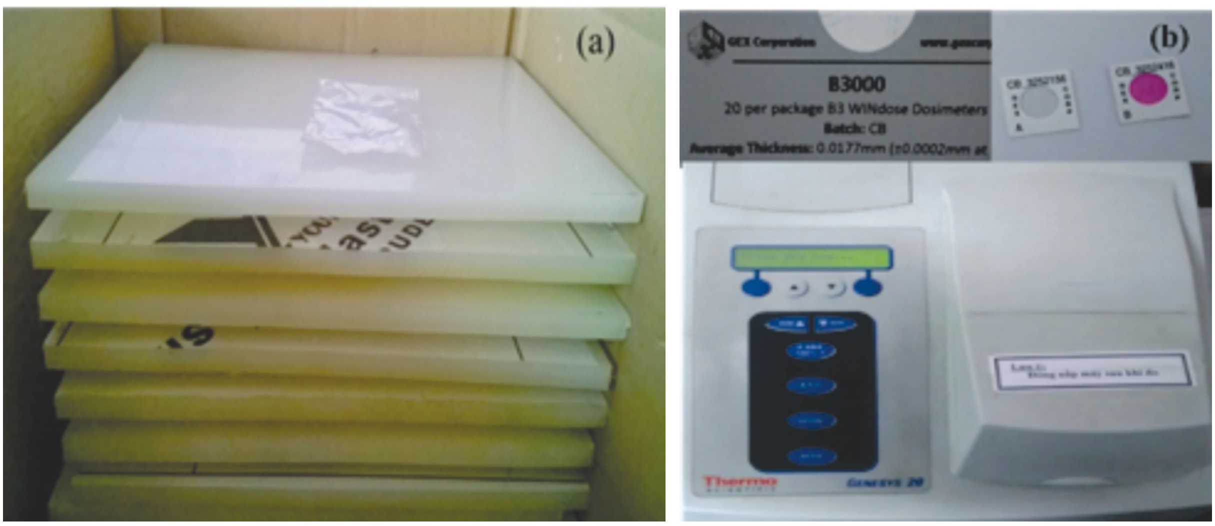

Figure 1. The experiment of the depth – dose – profile of the electron beam from accelerator UELR-101-5S2, (a) the homogeneous dummy and (b) the film dosimeter B3000 and spectrometer GENESYS 20

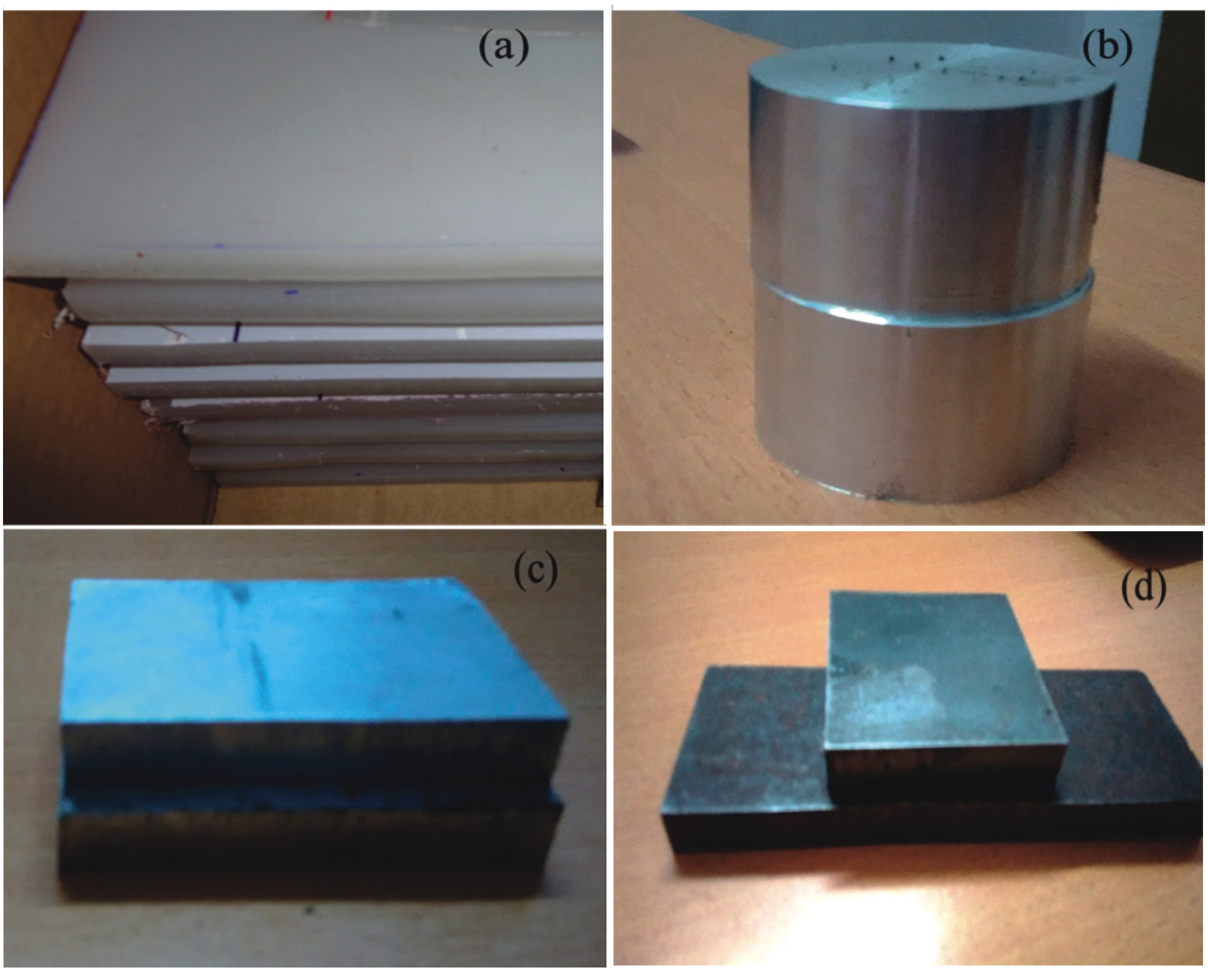

Figure 3. The X-ray targets irradiated by an electron beam from accelerator UELR-10-15S2, (a) PP, (b) Al, (c) Fe, and (d) Pb

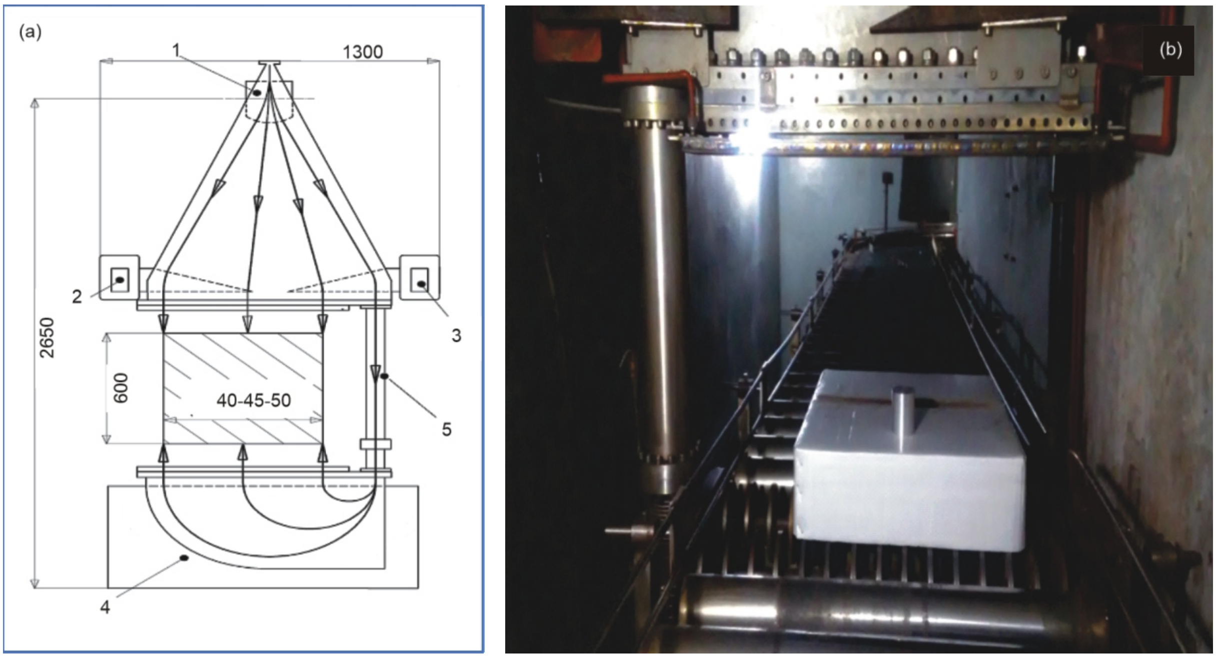

Figure 4. The geometry of the irradiation X-ray converter targets on accelerator UELR-10-15S2, (a) the scanning magnets double sided and (b) the location of targets under the beam window

Table 2. Irradiation parameters were set up for the electron beam accelerator

Irradiation parameters	Values
Electron beam energy [MeV]	9.92 0.48
Beam current [A]	960
Scanning width [cm]	50
Conveyor speed [m min^{-1}]	0.5
Surface dose [kGy]	28.0
Cycle of irradiation to measure the electron dose	1.0
Cycle of irradiation to measure the photon dose	10

PP, Al, Fe, and Pb were prepared as fig. 3 and the film dosimeters B3000 were put in the center of targets.

Simulation and calculation using the MCNP code

The geometry of the X-ray converter and electron beam window were simulated by the MCNP code. Then the surface electron dose and photon dose in the center of the target were calculated. The bremsstrahlung spectrum from the targets bombarded by electron beam 9.92 0.48 MeV was also calculated by the MCNP code.

In the input file of the MCNP code, the size of the electron beam window was 50 cm 2 cm; the distance window to target was 40 cm. Shielding concretes and air were also simulated in the input file of the MCNP code, fig. 5. The running MCNP code was set at 30 000 000 particle histories so that the uncertainty is less than 5 %.

RESULTS AND DISCUSSION

Results of the electron and photon spectrum by the MCNP simulation

Electron spectrums were simulated at distances of 5, 10, 20, 30, and 40 cm from the titanium window

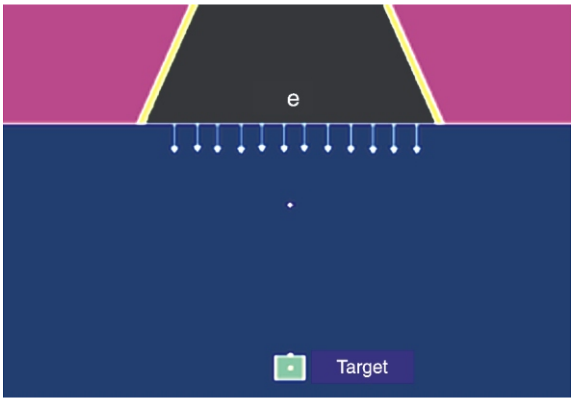

Figure 5. The MCNP simulation of irradiation X-ray converter targets on accelerator UELR-10-15S2

in the air. The result in fig. 6 shows that the peak position of the electron spectrum does not move with the distance from the titanium window. Electron flux decreased with the distance from the beam window due to scattering on the air molecule and unfocused trajectory of high energy electrons fig. 7(b). At a distance of 40 cm from the beam window in the air, the electron flux is only 40 % electron, flux at the window, and it is 60 % in the vacuum, fig. 7(b).

The results of bremsstrahlung from PP, AL, Fe, and Pb targets irradiated by an electron beam with average energy of 9.92 0.48 MeV are presented in fig. 8.

The bremsstrahlung photon spectrum after layers of the target irradiated by the electron beam depends on the density and atomic number of the target material. In the case of the Pb target, the probability of bremsstrahlung at the high energy region is significant. At the region of the energy threshold of the (γ, n) reaction for Pb [5], the probability of bremsstrahlung is about 1.14 % of the total bremsstrahlung generated.

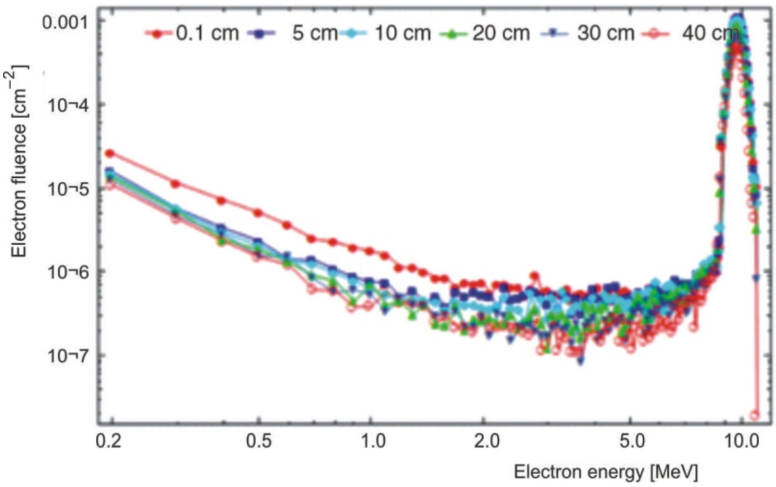

Figure 6. Electron spectra at distances from the beam window of the electron accelerator UELR-10-15S2

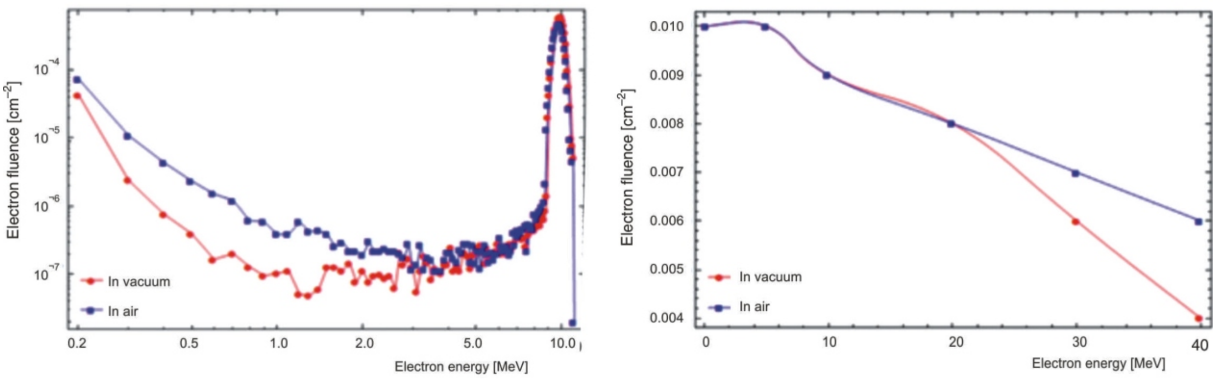

Figure 7(a). Electron spectrum at a distance of 40 cm from LINAC in the air and the vacuum, and (b) electron flux at distances from the beam window in the air and the vacuum

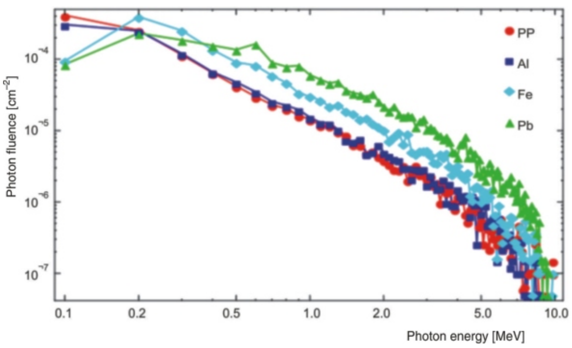

Figure 8. Photon spectrum from PP, Al, Fe, and Pb bombarded by electron beam 9.92 0.48 MeV

X-ray conversion efficiency by experiment and MCNP code

Measurement of the electron dose, photon dose and X-ray conversion efficiency from PP, Al, Fe, and Pb targets irradiated by electron beam 9.92 0.48 MeV from accelerator UELR-10-15S2 were compared with the MCNP in tab. 3.

The results show that X-ray conversion efficiency depends on the density and the atomic number of the targets. In the case of the target with a low atomic number (PP, Al), X-ray with conversion efficiency is less than 1.0 %. In the case of the heavy target (Fe, Pb), X-ray conversion efficiency is significant, so the (γ, n) reaction should be studied.

CONCLUSIONS

The X-ray conversion efficiency from irradiated products (low Z material) is less than 1.0 %. The energy of the (γ, n) reaction for major isotopes in food irradiation is ^{12}C (18.74 MeV), ^{16}O (15.67 MeV), and ^{14}N (10.56 MeV) [2, 5]. Neutron activation could be neglected when food and other medical devices were irradiated by the electron 9.92 0.48 MeV beam directly without an X-ray converter. The X-ray conversion efficiency is significant in shielding materials (4.3 % from Pb) and at the region of the energy threshold of the (γ, n) reaction for ^{207}Pb (6.74 MeV) [5], the probability of bremsstrahlung is about 1.14 % of the total bremsstrahlung generated. Measurement and MCNP calculation results of X-ray conversion efficiency from Fe (the main component of under the beam conveyor) at the region of the energy threshold of the (γ, n) reaction for ^{57}Fe (7.65 MeV) [5] are about 0.20 % of the total bremsstrahlung generated. According to the above given results, the Pb should be removed from the direction of the electron beam, and the Fe conveyor should not be exposed to the electron for a very long time in LINAC with an average energy of 9.92 0.48 MeV.

ACKNOWLEDGMENT

This research was supported by the Research and Development Center for Radiation Technology (VINAGAMMA), Vietnam Atomic Energy Institute, Vietnam.

Table 3. Measurement and MCNP results of X-ray conversion efficiency

Targets	Electron dose D_{e-} [kGy]		X-ray dose $D_{X\text{-}ray}$ [kGy]		Conversion efficiency [%]	
	Measurement	MCNP	Measurement	MCNP	Measurement	MCNP
PP	270.0 13.8	413.1 3.2	1.8 0.1	3.41 0.04	0.7	0.83
Al	230.0 11.8	373.9 2.9	2.0 0.1	3.34 0.05	0.9	0.89
Fe	266.0 13.6	387.3 3.0	4.7 0.2	7.05 0.11	1.8	1.82
Pb	180.0 9.4	251.5 1.8	7.8 0.4	9.01 0.15	4.3	3.58

The authors wish to thank Prof. Chary Rangacharyulu, Faculty of Physics and Engineering Physics, Saskatchewan University, Saskatoon, Canada, who helped us so much and reviewed this article.

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Received on July 14, 2019
Accepted on May 2, 2020

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ЕФИКАСНОСТ КОНВЕРЗИЈЕ ЗАКОЧНОГ ЗРАЧЕЊА И ГЕНЕРИСАЊЕ ГАМА НЕУТРОНА У ПОЛИПРОПИЛЕНУ, АЛУМИНИЈУМУ, ГВОЖЂУ И ОЛОВУ УСЛЕД БОМБАРДОВАЊА ЕЛЕКТРОНИМА ЕНЕРГИЈЕ 10 MeV

Истраживачки и развојни центар за радијациону технологију Вијетнамског института за атомску енергију користи акцелератор UELR-10-15S2 са електронским снопом (средње енергије 9.92 0.48 MeV) за озрачивање хране и медицинске опреме. Материјали који се нађу у снопу, као што су производи који се озрачују, покретна трака, магнет и заштитни материјали магнетног навоја, бомбардовани су електронима и могу произвести X-зрачење (закочно зрачење). У овом раду, ефикасност конверзије X-зрачења из полипропилена, алуминијума, гвожђа и олова бомбардованих електронским снопом акцелератора UELR-10-15S2 мерена је применом филм дозиметара и симулирана применом програмског пакета MCNPc2, при чему је уочено добро слагање измерених и симулираних вредности. Резултати показују да је ефикасност конверзије X-зрачења највећа за олово (4.3 %) тако да гама -неутронске реакције (Q-вредности за ^{207}Pb од 6.74 MeV) морају бити испитане код озрачивања хране и медицинске опреме при енергијама од 10 MeV).

Кључне речи: електронски сноп, озрачивање хране, закочно зрачење, конверзија X*-зрачења, Монте Карло,* MCNP