ISSN: 2456-9348
Vol (04) _Issue (01) Impact Factor: 4.520

iJETRM

International Journal of Engineering Technology Research & Management

NEUTRON ACTIVATION IN PATIENT'S TISSUES DUE TO PHOTONEUTRONS FROM LINAC

Mahmoud E. Dorrah
Afaf A. Ateya
Nuclear and Radiological Regulatory Authority, 3 Ahmed El-Zomor Street, El- Zohour Region, Nasr City-Cairo, Egypt
mahmoud.dorrah@gmail.com
afaf_ateya@yahoo.com

ABSTRACT
A Monte-Carlo simulation study was carried out to evaluate neutron activation in patient's tissue phantom from exposure to photo-neutrons emitted from medical LINACs during radiotherapy. The LINAC and the patient's phantom were modeled and calculations were carried out using MCNP code. Photo-neutron beam from LINAC was low, and the expected radiation dose imposed by neutron activated nuclides in patient's tissues was insignificant compared to the total radiotherapy dose. Even for 45 Gy X-ray dose, the internal dose due to neutron activation was too low to be warrant consideration.

KEYWORDS:
LINAC, Photoneutrons, Neutron Activation, MCNP, Internal Dose

INTRODUCTION
Radiation therapy is a way of treating cancer in which radiation is used to kill the cancer cells by delivering to the tumor high radiation energy. LINACs are machines that produce high energy X-rays via bremsstrahlung process in which high energy electrons collide with a high Z material target producing X-ray photons in the MeV energy range. However, LINAC operating at energies greater than the photo-neutron production threshold for its components will produce photo-neutrons (Alfuraih et al, 2008). Such photo-neutrons are highly penetrating and cannot be stopped by the conventional X-ray collimators or filters of LINACs. Therefore, those photo-neutrons will inevitably reach the patient's tissue and interact with different nuclides in it. The interaction of interest in the present study is the neutron capture since it will produce new isotopes of the capturing nuclide that might be unstable and emit unpredictable radiation.

Photo-neutrons can diffuse randomly in patient's tissues reaching virtually any part of the patient's body. Hence, radiation from neutron activated nuclides might be produced anywhere in the patient's body, exposing unintended tissues and organs to unpredictable radiation doses.

OBJECTIVES
The present study aims to investigate the neutron activation induced by photo-neutrons produced from LINAC. Specifically, the rate of neutron activation induced in various patient nuclides was estimated. Also, the expected total internal radiation dose from the activation formed radio-nuclides was calculated.

MATERIAL (MODEL DESCRIPTION)
Siemens HPD X-ray LINAC was modeled using MCNP code. The dimensions and materials of the components were according to the data published in the physics primer titled "Digital Linear Accelerator" (Siemens medical, 2008). See figure 1. The LINAC materials modeled by MCNP in the present research are shown in table 1.

ISSN: 2456-9348
Vol (04) _Issue (01) Impact Factor: 4.520

iJETRM
International Journal of Engineering Technology Research & Management

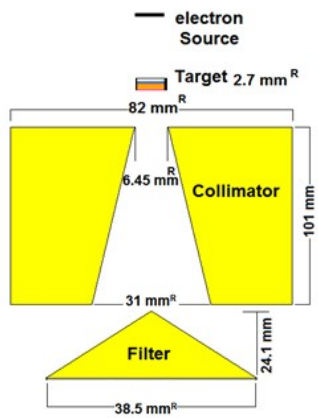

Fig. 1. *LINAC Head.*

Electron Source

It was a planar circular source of radius = 2.7 mm. Energy of the emitted electrons follow a Gaussian distribution, with average energy = 14 MeV, and width = 1MeV.

Neutron Shield

Different neutron shields at different thicknesses were applied just below the filter. The neutron shields materials and thicknesses were as presented in table 2.

Table 1. *LINAC materials modeled (Siemens medical, 2008).*

Component		**Materials**	**Thickness (mm)**
	Titanium	Ti	0.05
	Water	H_2O	0.66
	Titanium	Ti	0.05
	Air	Void	3.53
	Tungsten	W	0.64
	Nicoro (BAu-3) 11 g/cm^3	Au 35 $^{w}/_{o}$ Cu 62 $^{w}/_{o}$ Ni 3 $^{w}/_{o}$	0.15
Target	Copper	Cu	1.65
	Nicoro (BAu-3) 11 g/cm^3	See above	0.05
	Stainless Steel GOST08X18H10T	C 0.08 $^{w}/_{o}$ Cr 18 $^{w}/_{o}$ Ni 10 $^{w}/_{o}$ Ti 0.6 $^{w}/_{o}$ Si 0.8 $^{w}/_{o}$ Mn 2 $^{w}/_{o}$ Cu 0.3 $^{w}/_{o}$ Fe 68.22 $^{w}/_{o}$	1.02
	Graphite	C	10.16
	Stainless Steel GOST08X18H10T	See above	0.04
Collimator		Pb 96 $^{w}/_{o}$ Sb 4 $^{w}/_{o}$	See Figure 1
Flattener		Tungsten	See Figure 1

Patient Phantom

It was a cylinder 180 cm long and 15 cm in radius, horizontally lying 80 cm below the base of the flattener, see Figure 2. Its material was according to ICRP Publication 23 (ICRP, 1975). Table 1 presents the element composition of patient phantom, (density = 1.04 g/cm^3, mass = 79.9824 kg), and presents the activatable nuclides in it.

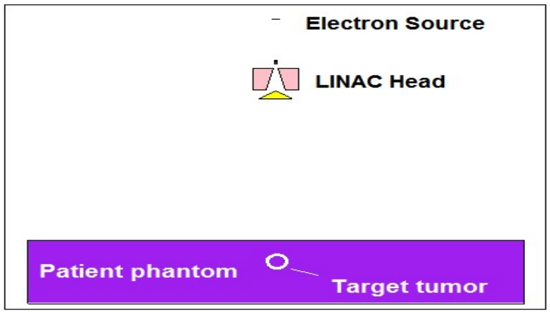

Figure 2. *LINAC and patient phantom.*

Table 1. *Element composition of patient phantom with the activatable nuclides (BÉ et al, 2010).*

Element	Weight %	Activatable Isotopes	Element	Weight %	Activatable Isotopes
H	10.454	H-2	S	0.204	S-34
C	22.663	C-13	Cl	0.133	Cl-35 Cl-37
N	2.490	N-15	K	0.208	K-39 K-41
O	63.525	-	Ca	0.024	Ca-41 Ca-44 Ca-46 Ca-48
Na	0.112	Na-23	Fe	0.005	Fe-54 Fe-58
Mg	0.013	Mg-26	Zn	0.003	Zn-64 Zn-68 Zn-70
Si	0.030	Si-30	Rb	0.001	Rb-85 Rb-87
P	0.134	P-31	Zr	0.001	Zr-92 Zr-94 Zr-96

METHODOLOGY

A spherical, 5 cm radius, volume of the patient phantom was considered targeted tumor. Neutron capture rates in all phantom nuclides were tallied. The product nuclide from neutron capture were investigated, specially the unstable ones. It was found that almost all the produced radio-nuclides were mainly beta emitters. Hence, it was assumed that all beta energy emitted by these radionuclides inside the patient's phantom are absorbed in phantom.

However, It should be considered that some radio-nuclides will be eliminated by a patient's body via excretion before they decay (Burnham., 2011). Also, when calculating internal radiation dose rates, half life of each of the produced radionuclides should be considered. Therefore, all of the physical, biological, and effective half lives of each radionuclide were considered.

Some of the activation produced radionuclides were also gamma emitters. However, internal gamma exposure is usually much less significant than internal beta exposure, since most of the internally produced gamma will escape the body before being absorbed (DOE Standard, 2013).

RESULTS AND DISCUSSION

Table 2 presents the nuclides that were actually activated into Beta emitters isotopes and the produced quantities in phantom, and some of their radioactivity properties.

iJETRM
International Journal of Engineering Technology Research & Management

Table 2. Nuclides activated into Beta emitters isotopes.

Nuclide	Mass of Nuclide in phantom / g	Activation Product[a]	Number of Atoms Produced by Activation /1.8 Gy X-ray	Beta Energy / keV[a]	Physical Half Life / s[a]	Effective Half Life /s[b]	Cumulative Beta Dose over 50 Years/25 X-Ray sessions 45Gy X-ray
Deuterium	191.9578	H-3	3.7882E7	18.6	3.8816E8	7.33E5	1.19777E-10
Sodium-23	8958.033	Na-24	7.806E9	1390	5.3856E4	5.223E4	9.47265E-4
Silicon-30	79.057	Si-31	1.115E8	1500	9.432E3	8.289E3	1.32331E-5
Chlorine-35	8034.6276	Cl-36	8.717E11	251	9.499E12	8.64E5	1.79146E-9
Chlorine-37	2603.0364	Cl-38	3.049E9	1638.93	2.232E3	2.22625E3	4.4868E-4
Potassium-41	1126.2807	K-42	1.307E9	1564	4.4496E4	4.311E4	1.78296E-4
Iron-58	1.169903	Fe-59	6.8165E6	115	3.9321E6	2.31277E6	4.15057E-8

[a]BÉ et al, 2010, [b]Grupen, 2010.

Beta energy that would be deposited in patient tissues over the next 50 years, following 25 sessions of -ray from LINAC, 1.8 Gy each (total = 45 Gy X-ray) were calculated as follows:
The number of atoms left after time (t) un-eliminated by excretion

$$N = N_o e^{-\lambda_{eff} t}$$

Of these, Number of atoms that will decay inside the body:

$$N\lambda_{phys} = N_o \lambda_{phys} e^{-\lambda_{eff} t}$$

Where:
N_o = Number of nuclide atoms produced by photon-neutron activation.
λ_{eff} = Effective decay constant s^{-1}
λ_{phys} = Physical decay constant s^{-1}
Total Number of atoms that will decay inside the body over the next 50 years = 1.57788E9 s

$$\int_0^{1.57788E9} N_o \lambda_{phys} e^{-\lambda_{eff} t} dt = -N_o \times \lambda_{phys} \frac{1}{\lambda_{eff}} \left[e^{-\lambda_{eff} t} \right]_0^{1.57788E9}$$

$$= \frac{N_o \times \lambda_{phys}}{\lambda_{eff}} \left[e^{-\lambda_{eff} \times 0} - e^{-\lambda_{eff} \times 1.57788E9} \right]$$

$$= \frac{N_o \times \lambda_{Phys}}{\lambda_{eff}} \left[1 - e^{-\lambda_{eff} \times 1.57788E9} \right] \approx \frac{N_o \times \lambda_{Phys}}{\lambda_{eff}}$$

From calculations, it was found that only ^{24}Na, ^{38}Cl, ^{42}K of all the activation products that imposed countable Beta internal doses over the next 50 years. None of these deposited any significant dose, maximum was ^{24}Na depositing less than 1 mSv over 50 years, that's too low to warrant any consideration. See figure 3.

iJETRM
International Journal of Engineering Technology Research & Management

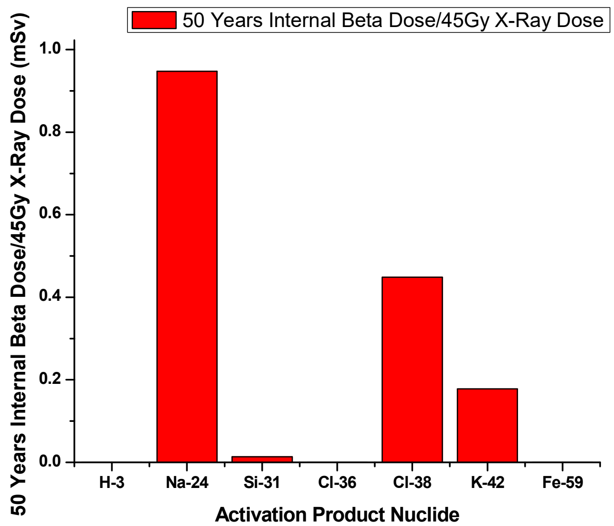

Fig. 3. *Beta doses from activation produced nuclides over 50 years following 25 X-ray sessions, 1.8 Gy each.*

CONCLUSION

Despite the high energy of the photo-neutrons emitted from LINACs operating at radiotherapy energies, the neutron activation in patient's phantom, even following 25 X-ray sessions, 1.8 Gy each (total of 45 Gy X-ray) was negligible, and the total internal beta dose deposited by photoneutron activated nuclides, even over 50 years, was far below any level of significance. No further investigation of this subject is recommended.

REFERENCES

[1] Alfuraih, A., Chin, M., Spyrou, N., 2008. Measurements of the photonuclear neutron yield of 15 MV medical linear accelerator, J. Radioanal. Nucl. Chem. 278 681-684.

[2] Amber, A., James, C., James, L., 2014. *Neutron production and transport at a medical linear accelerator. Master of science thesis.* Department of Environmental and Radiological Health Sciences. Colorado State University.

[3] BÉ, M et al., 2010. *Table of Radionuclides (Comments on Evaluation)*. Bureau International de Poids et Mesures, Pavillon de Breteuile F-92310, Sèvres. Volumes 1-5.

[4] Burnham, J., 2011. Radiation Protection ("Green Book"). Point Lepreau generating station, New Brunswick Power Corporation. St. Andrews NB, Canada. Retrieved from https://www.bipm.org/utils/common/pdf/monographieRI/Monographie_BIPM-5_Comments_Vol1-5.pdf

[5] Claus, G., 2010. Introduction to radiation protection: practical knowledge for handling radioactive sources. Springer. ISBN 978-3-642-02586-0, p.p. 355-358.

[6] DOE Standard, 2013. Internal Dosimetry. DOE-STD-1121-2008, U.S. Department of Energy, Washington, D.C. 20585 October 2013. Retrieved from http://energy.gov/hss/information-center/department-energytechnical-standards-program

[7] International Commission on Radiological Protection, 1975. Report of the task group on Reference Man. ICRP Publication 23. Oxford: Pergamon Press.

[8] International Commission of Radiation Protection, 2008. Publication 103: 2007 recommendations of the ICRP, including Annexes on Quantities used in radiation protection, Biological effects of radiation, and Bases for judging the significance of the effects of radiation. Ann ICRP 37: issues 2-4, 1-332.

[9] Martínez, S, 2013. Frontiers in Radiation Oncology, Chapter 6, Neutron Dose Equivalent in Tissue Due to Linacs of Clinical Use.

[10] Siemens Medical Solutions USA, Inc. Oncology Care Systems, 2008. Digital Linear Accelerator. Physics Primer. Print No.: T2-000.621.01.03.02.