Paradoxical Effect of Neutron Shields on Neutron Dose from LINACs

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Abstract- A Monte-Carlo study was carried out to investigate the efficiency of different materials to shield the photo-neutrons emitted from radiotherapy LINACs. Several materials were tried at different thickness. Though neutron fluence decreased using all the tried neutron shields, paradoxically they increased the neutron dose to the patient. This is probably due to thermalization of the photoneutrons in the shields, increasing their capture rate in patient's tissue.

Index Terms- LINAC, Photoneutrons, Neutron dose, Neutron shield

I. INTRODUCTION

When operating LINACs of clinical use at energies greater than 8 MeV, neutrons are produced due to the interactions of the energetic photons with the high-Z materials present in the accelerator head (Alfuraih et al, 2008). At 14 MeV X-ray, the main reactions of gamma rays which lead to emission of photo-neutrons are the (gamma, neutron) reactions with: Fe-56, Cu-63, and Cu-65 (in target), W-184 (in target and flattener), and Pb-208 (in collimator) (Amber et al, 2014).

Because of their high relative biological effectiveness, photo-neutrons are a particular source of unwanted exposure to patients (ICRP, 2008).

Martínez (Martínez, 2013) investigated the neutron flux inside a patient's phantom and observed a significant decrease of fast neutrons and increase in thermal and epithermal neutrons inside the phantom. He explained that the phantom behaved as a neutron moderator due to its high content of low Z materials.

In this research, several neutron absorbing materials were used as neutron shields. Neutron and X-ray doses received by the patient were calculated before and after adding the shield.

II. MATERIALS (MODEL DESCRIPTION)

Siemens HPD X-ray LINAC was modeled using MCNPX 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.

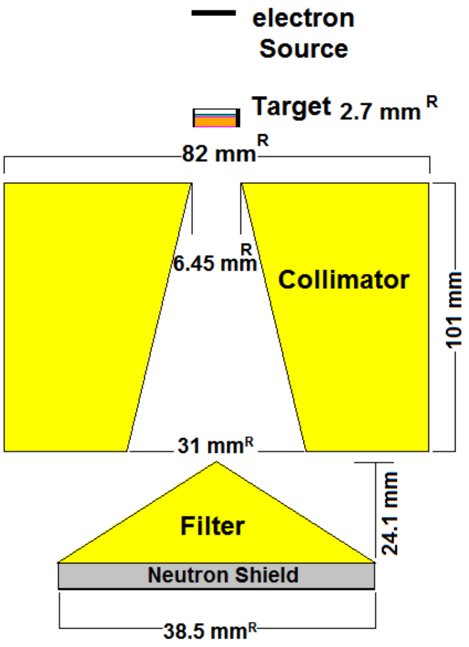

Figure 1. LINAC Head

2.1 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.

2.2. 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.

Component		**Materials**	**Thickness (mm)**
Target	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
	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

2.3. 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).

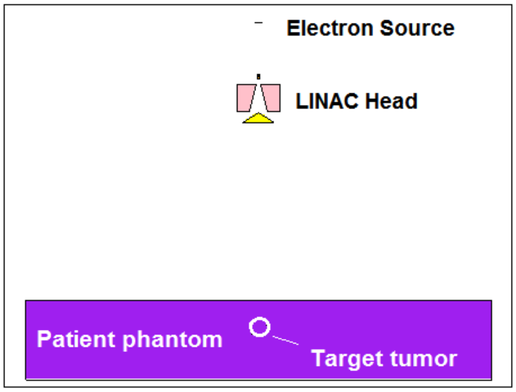

Figure 2. LINAC and patient phantom.

III. METHODS

A spherical, 5 cm radius, volume of the patient phantom was considered as the targeted tumor. X-ray (photon) dose to the target tumor and neutron dose to the whole patient phantom were tallied using MCNPX code. MCNPX code is run in (n p e) mode Several neutron absorbing materials were added, once a time, as neutron shields. Shields were placed just below the flattener. With each neutron shield, photon dose to the target tumor and neutron doses to the patient were recalculated. The tried shields were as in table 2.

IV. RESULTS

Without neutron shield, photon dose to the tumor and neutron dose to the patient were 1.28701 and $4.10935x10^{-4}$ $\mu Sv/10^{10}$ source electrons, respectively.

For all tried neutron shielding materials, photon dose to the target tumor was slightly changed as seen in figure 3 and in table 3. Neutron fluence emitting the LINAC port was markedly reduced using all the tried neutron shields, however, paradoxically, neutron dose to the patient was markedly increased, as seen in figures 4 & 5, and in table 2.

Table 2. Shielding materials with their thicknesses, photon dose to tumor, neutron dose to the patient, and neutron fluence emitting the shield.

Shielding Material	Shield Thickness	X-Ray Dose to Tumor	Neutron Dose to Whole Patient	Neutron surface current traversing the shield
		μSv/10^{10} electrons from source		Per10^{10} source electrons
No Shield	-	1.28701	4.10935E-4	2.44225E+04
High Density Poly Ethylene with 5 $^{w}/_{o}$ Natural Boron	3 mm	1.24458	12.1E-4	1.57549E+04
High Density Poly Ethylene with 5 $^{w}/_{o}$ Boron-10	3 mm	1.30774	9.73200E-4	1.00665E+04
High Density Poly Ethylene with 5 $^{w}/_{o}$ Boron-10	5 mm	1.28369	11.3216E-04	4.80723E+03
Boron-10	5 mm	1.26906	8.54929E-4	5.00000E+03
Boron-10	10 mm	1.22885	9.06580E-4	7.02346E+03
Boron-10	15 mm	0.987851	10.0580E-04	5.55556E+03
Cadmium	5 mm	1.30230	10.2254E-04	5.55556E+03
Cadmium	10 mm	1.28044	10.2254E-04	5.55556E+03
Boron-10 then Cadmium	10 mm B-10 5 mm Cd	1.18005	9.75886E-4	1.33582E+04

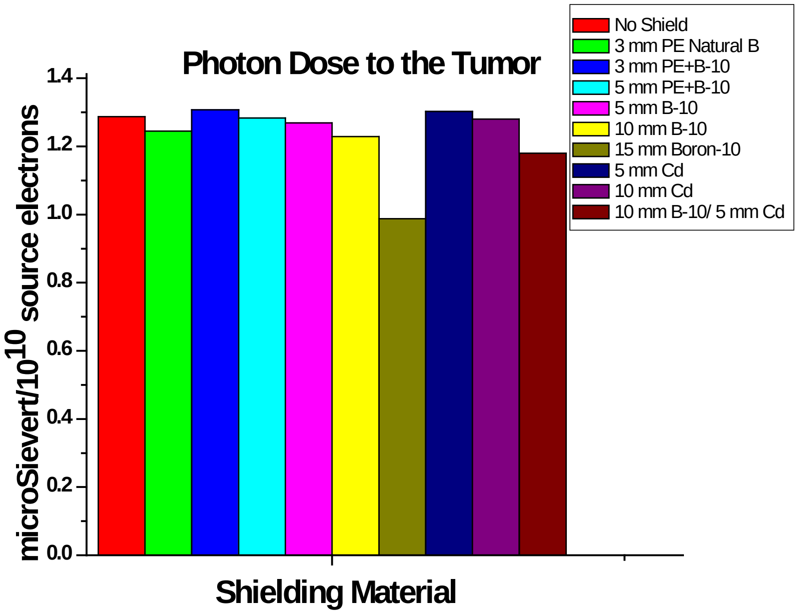

Figure 3. Photon dose to the tumor using different neutron shields.

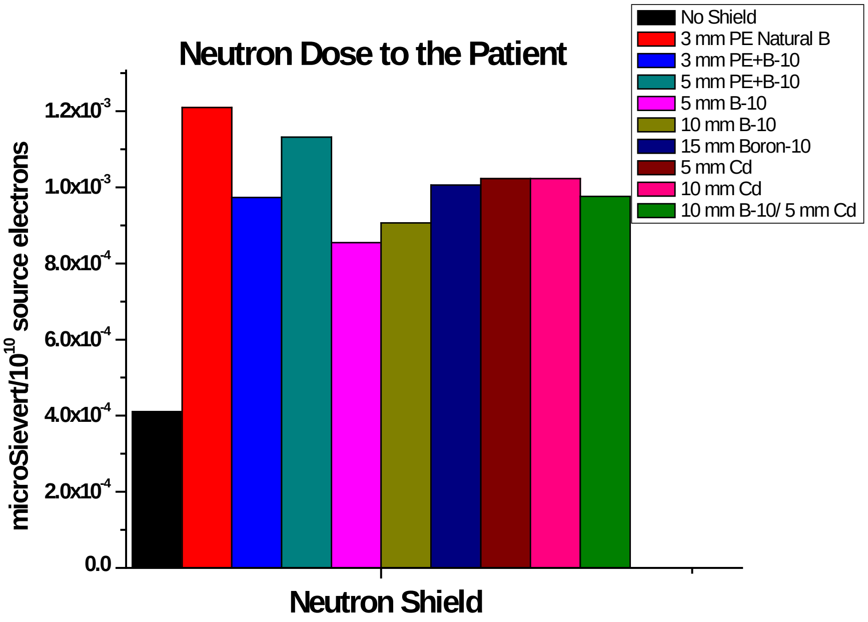

Figure 4. Neutron dose to the patient using different neutron shields.

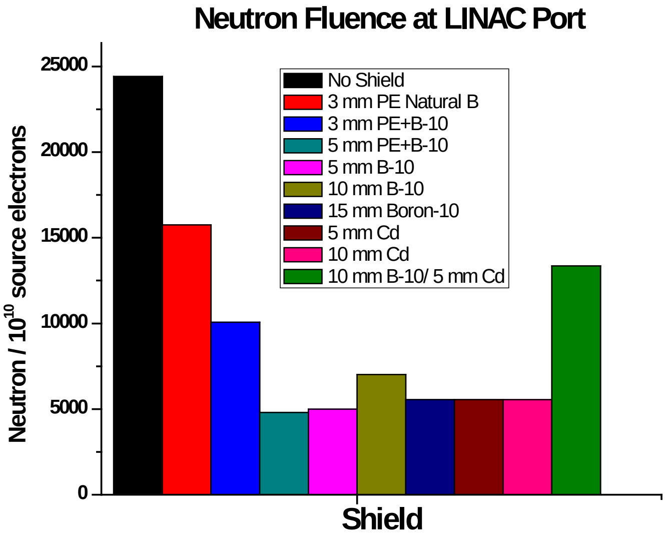

Figure 5. Neutron fluence at LINAC port using different neutron shields.

V. DISCUSSION

Despite the decrease in neutron fluence traversing the neutron shield, neutron dose to the patient was increased probably due to in shield thermalization of the fast neutrons emitted by photo-neutron interactions of the energetic X-rays with the LINAC materials. Thermalization of the neutrons traversing the neutron shield increases their capture cross sections in patient's tissues, thus increasing the absorbed dose, hence increasing the total equivalent dose to the patient.

Exact determination of the neutron spectrum below the neutron shield would take very long MCNPX runs using very large number of electron histories to get the neutron energy spectrum at acceptable precision. However, it should have verified the thermalization explanation of the increase in neutron dose to the patient. It is planned to be done in future work.

VI. CONCLUSIONS

A Monte-Carlo study was carried out to investigate the efficacy of different materials to shield the photo-neutrons emitted from LINACs. Several materials were tried at different thickness. Though neutron fluence reaching the patient position was reduced by all the tried neutron shields, neutron dose to the patient was markedly increased. This is probably due to thermalization of the photo-neutrons in the shield, increasing their capture rate inside the patient's tissue, and increasing their dose.

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