International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

MONTE CARLO Simulation of Photon Beams for Various Effects on Energy and Angular Distribution using PRIMO

Prashant Ranjan[1], Nitin K. Puri[1]
Department of Applied Physics,
Delhi Technological University,
Delhi, India

***Abstract* - The Monte Carlo code PENELOPE has been used to simulate different models of LINACS with the presence and absence of air and variation of radius of ring using PRIMO for medical applications. The patient model is selected as water phantoms and its dimension is 16.20*16.20*31.00 with bin size of 0.25 cm having source to phantoms surface distance (SSD) 100cm. For that Nominal energy is set at 6 MV with initial energy 5.900 MeV. The field geometry is set at 20*20 with parameter X1, X2, Y1, Y2 as 10 cm. Implication from the simulation shows that the effect of air is only in the Elekta model of LINACS. There is also a large variation in the energy due to change in radius of ring of LINACS**

Keywords: PRIMO, PENELOPE, Phantoms PSF

1. INTRODUCTION

According to the latest estimation done by The International Agency for Research on Cancer (ICRA), Cancer is a major cause of disability and fatality with approximately 14 million new case and 8 million cancer related deaths in 2012 which will reach about 22.2 million till 2030 affecting population in all countries and regions. To confront with such fatal disease, an innovative way is to use linear accelerator which was made 56 years ago. But, as large numbers of people are being affected by it, new technology with more sensitive equipment is required so that the people can be cured of the diseases. There are many parameters which are related to the treatment of cancer such as amount of radiation required to cure the disease, effects of radiation on the healthy cells of the patient's body etc. which are still a major concern for scientific community. It requires more accurate equipment so that healthy cells are not affected from the radiation. Therefore, the greatest challenge of the 21st century is to treat the cancer and to accomplish this task, Radiotherapy is the most commonly used technique [1] which uses ionizing radiation to irradiate the affected areas of the human body. Linear Accelerators (LINACS) are the devices which produce the required radiation (X-ray beams) [3]. Rapid development in the last decades has led to user friendly specialized codes which are clinically applicable to various ranges of parameters. Various effects are being put in the biomedical context which focuses on modeling radiation transport and damage induced in the tissues of the patient's body. The radiotherapy planning systems uses various computer algorithms to model the dose distribution and among them Monte Carlo (MC) has proven to be very favourable in terms of accuracy, providing more genuine results [2] and started to be used for the simulation of radiation transport [5-8].

In the present paper, we describe the MC simulation of photon beam using different models of Linacs like Elekta SL, Varian 600C, Varian Unique, Varian Clinac 2100, and Varian Clinac 2300 implemented on the MC code PENELOPE using PRIMO software. The aim is to study the effects of air and radius of ring on the spatial distribution of energy. We would like to stress that the present paper is primarily related with the variation of energy with change in model of linacs.

The rest of the paper is organized as follows. In section 2, the main characteristics of the Monte Carlo simulation are described. A graphical environment for the Monte Carlo simulation of Varian and Elekta linacs, PRIMO is presented in section 3. Section 4 is devoted to important features of the PENELOPE code system. Simulation with both measurements and phase space file are described in section 5. Results and conclusions are drawn in section 6 and 7 respectively.

2. MONTE CARLO Simulation

In application of radiotherapy, the MC simulation is divided into two parts. In first part, produced radiated beam is simulated by the LINAC and then the phase space of millions of particles is generated. The phase contains information such as energy, location, orientation etc. In second part, transport of particles (sampled phase space) is simulated in certain configurations of irradiation field. This is performed to assess the dose distribution in the patient. [3]

Earlier, Simulation in MC algorithm was incompatible with clinical routine. However, with the onset of faster CPUs and lateral arrangement it is now possible to use MC algorithms for clinical purposes. In a complete MC Simulation, most of the CPU time is consumed by the transport of photon beams through the Target, the Flattening Filter and the Multi Leaf Collimator (MLC) [4].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

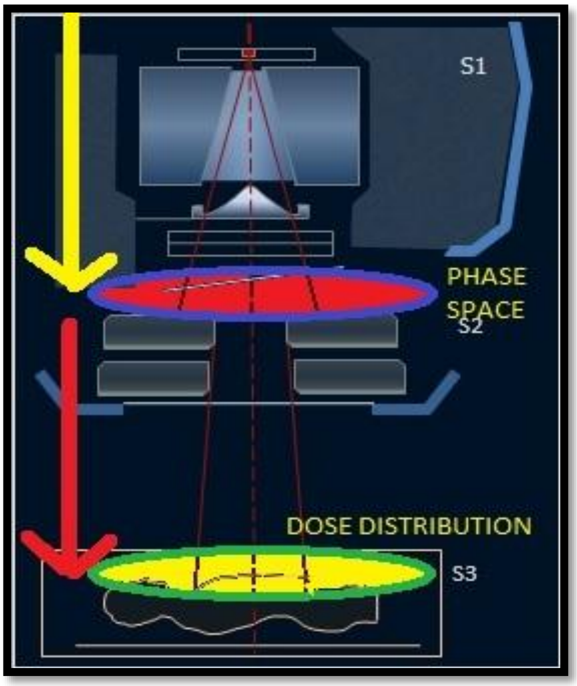


Figure 1: Representation of the MC simulation model

There are different methods in which MC techniques can be applied to irradiation treatment designing. MC pre-calculated radiative flux can be used as the core of geometrical algorithms such as pencil shaft helix [9], the aeolotropic geometrical algorithm [10] or the topple cone helix class [11]. Use of semi-geometrical algorithms or conglomerate fount form which produces Phase Space Files(PSF) and are able to reproduce certain related fields in water phantoms[12-13] tells the drawbacks of using pre-determined PSF's[14]; latent change due to the statistical fluctuations in a confined PSF is transferred and added to the variety of the consumed dose in a 3D geometry. There is no way out from the latent change but to increase the particle density of the PSF. If a source form is derived from this PSF, the earlier will tend to cover out local peaks in the variance resulting in variation in the calculated quantities and an accurate estimation of the statistical uncertainty will not be attained. [14]

To overcome the drawbacks of using source form, MC Simulation of the whole accelerator is performed. It is done from the exit of the electron acceleration stage to the patient or water phantom, following all emission in each primary drizzle. This Simulation allows exact calculation of statistical unpredictability and this can be reduced to any desired level providing ample computing time for simulation. MC Simulation technique is free from errors except the ones that are related to differential cross sections and electron multiple-scattering techniques. Thus radiation transport can be performed by Geant4 [15] or PENELOPE [16] codes through any analytical structure such as clinical linear accelerators and voxelized phantoms. [17].

3. PRIMO

PRIMO creates the necessary input files which are used for simulating variety of Varian and Elekta Linacs with the help of Monte Carlo code and PENELOPE. PRIMO computes the dose distribution in phantoms and computerized topographies. It can be designed as a layered software structure which is shown in the figure given below

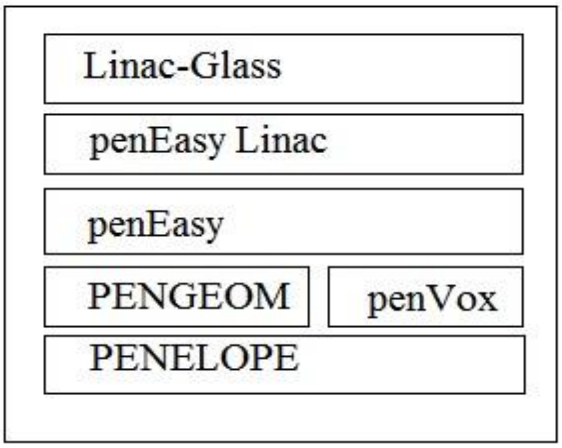


Figure 2: Software structure of PRIMO

The linac model and its configuration, is determined by: [18]

- Whether the machine is operated in the electron or photon mode.
- The nominal beam energy.
- The position of the jaws.
- The configuration of the multileaf collimator.

4. The PENELOPE code system

PENELOPE, a MC method and computer code for the simulation of coupled electron-photon transport. The name is an acronym that stands for PENetration and Energy LOss of Positrons and Electron. It is the lowermost layer of the PRIMO software structure which is formed by set of functions that model the physics of the electromagnetic avalanche. It performs Monte Carlo simulation of linked electron-photon transport in random materials for a wide energy range, from 1keV to about 1 GeV [16]. A diverse method is used for the simulation of electron, photon and positron interactions, in which 'Strong' events i.e. those with energy loss larger than pre-selected cutoffs are simulated in a detailed way, while 'moderate' interactions are calculated from multiple scattering way. [16]

5. SIMULATION

Simulation is done on two different parameters which are as:

- Effect of Air
- Variation of Radius of Ring

For the simulation, Nominal energy is set at 6 MV with initial energy 5.900 MeV. The field geometry is set at 20*20 cm^2 with parameter X1, X2, Y1, Y2 as 10cm. The patient model is selected as water phantoms and its geometry 16.20*16.20*31.00 cm^3 with bin size 0.25 cm. Photon mode is used in all the models of Linacs for variation in the radius of ring and to check the effect of presence and absence of air on spatial distribution of energy, energy distribution and angular distribution.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

5.1 The Phase-Space Files

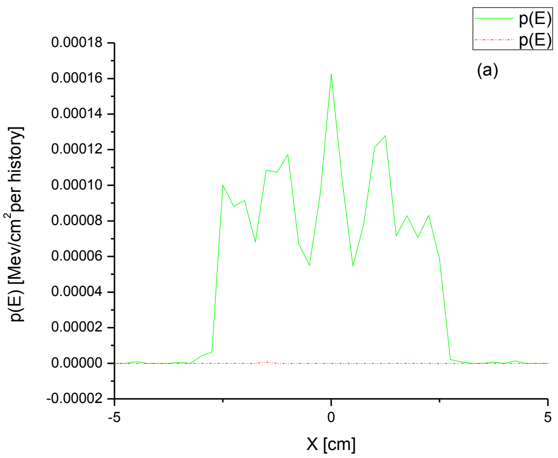
While simulating the radiation transport using Monte Carlo method, it is possible to define a surface, which is generally a plane and can be at any location in the geometry. Particles that traverse this plane are stopped and their states such as energy, position, direction of flight etc. are recorded on a file which is called Phase-Space File (PSF). When a Phase-Space File is sufficiently rich i.e. it contains a 'large number' of particles then it is possible to neglect the geometry upstream of the Phase-Space Surface and to consider the Phase-Space File as the radiation source for subsequent Monte Carlo Simulations [14]. Only particles that belong from a rectangular region of the Phase-Space Plane are included in the analysis. This region can be determined by the values which are entered in X1, X2, Y1 and Y2. It is possible to select the intervals and bin sizes of the angular and energy probability distributions. If the phase-space file has been tallied with PRIMO, then it is also possible to filter the particles by the material where they were produced. This feature has no effect on imported Phase-Space Files agreed with other Monte Carlo codes.

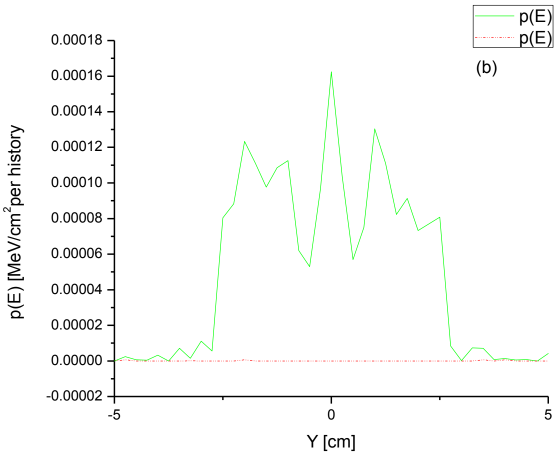
If the option analysis in rings is checked, the analysis is performed by subdividing the whole phase space plane into concentric rings centered at the central axis. The number of rings is determined by the values of the maximum radius and the radial increment set in the dialog.

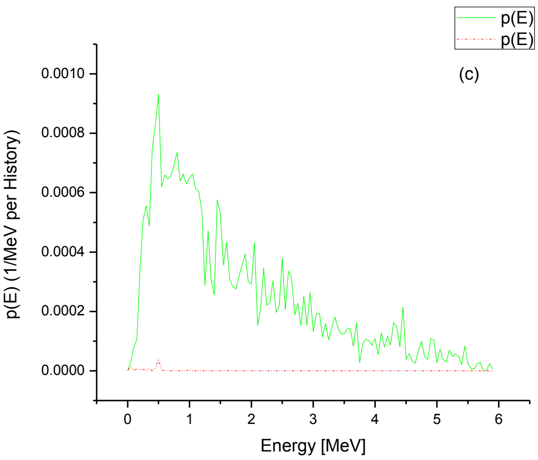
6. RESULTS

6.1 Effect of Air

PSF measurements were analyzed in plane dimensions of X1, Y1 as -10 cm and X2, Y2 as 10cm with the bin size of spatial 0.25cm, energy 0.05MeV and angle 1 deg in photon mode. For the sake of completeness, it is also interesting to compare diverse features of the PSFs generated with PENELOPE using Elekta SL and Varian models of linacs. To this end, spatial distribution of energy, energy distribution and angular distribution of photons are displayed in figure 3 to 7.







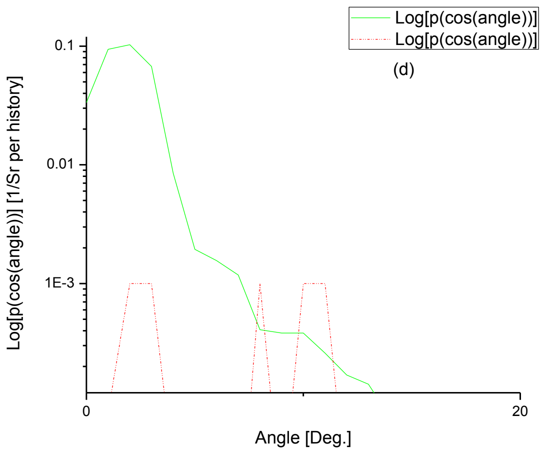
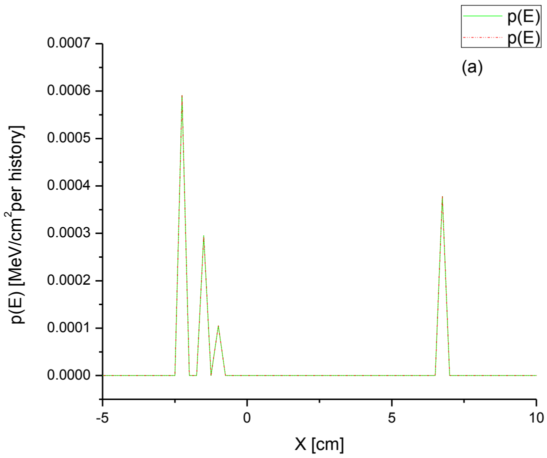
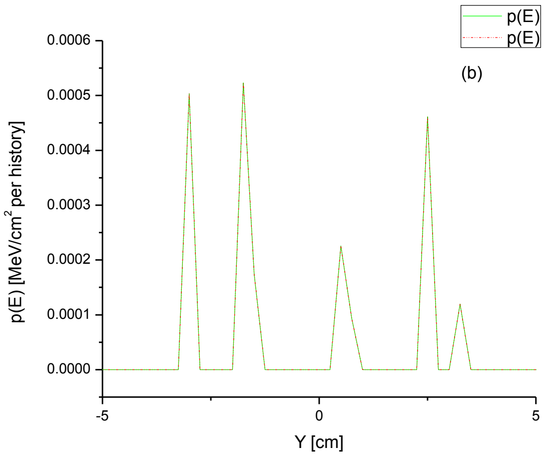
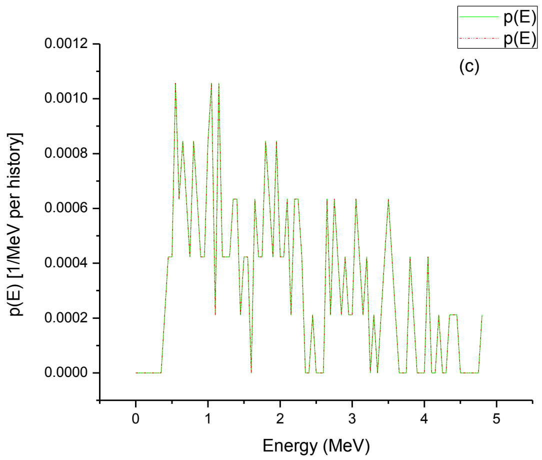


Figure 3: PSF photon probability density for X and Y in (a) and (b) respectively. Energy distribution and angular distribution for 6 MeV beams in (c) and (d) respectively. Full and dashed curves correspond to presence and absence of primary particles air respectively in Elekta Linacs.

An interesting feature of the photon spectra in figure 3(c) is the presence of several prominent peaks in the presence of air in the Elekta model of linacs. The one at lowest energy between 50 and 100 KeV corresponds to the x-rays produced in the parts of the accelerator. The highest peak is at energy around 511 KeV is caused by annihilation photons produced after the generation of an electron –positron pair by a bremsstrahlung photon. While in the absence of primary particles i.e. air there are no such peaks. So we can conclude from the figure 3(c) that in case of absence of air in the Elekta model of linacs the process such as x-rays production, annihilation, bremsstrahlung doesn't occur.







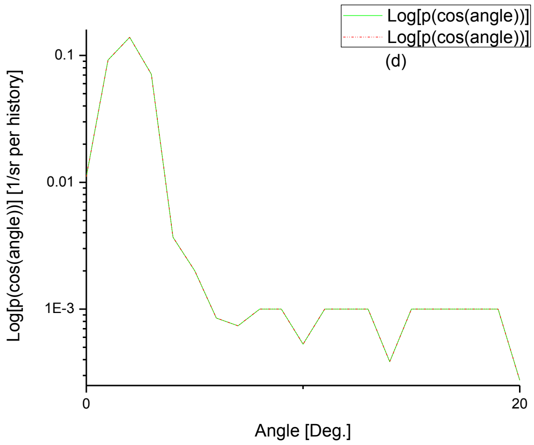
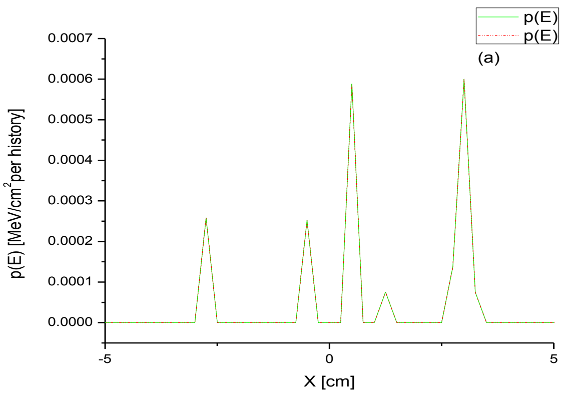


Figure 4: PSF photon probability density for X and Y in (a) and (b) respectively. Energy distribution and angular distribution for 6 MeV beams in (c) and (d) respectively. Full and dashed curves correspond to presence and absence of primary particles air respectively in Varian 600c Linacs.

In figure 4(c), the feature of the photon spectra is the presence of several prominent peaks in the presence and absence of air in the Varian 600c model of linacs. At lowest energy between 50 and 100 KeV, prominent peaks are not present which corresponds to the absence of the x-rays produced in the parts of the accelerator. The highest peak is at energy around 511 KeV and 1.022 MeV which is caused by annihilation photons produced after the generation of an electron –positron pair by a bremsstrahlung photon. So we can conclude from the figure 4(c) that x-rays doesn't produce here and there is no effect in the presence and absence of primary particles i.e. air in Varian 600c model of linacs.



International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

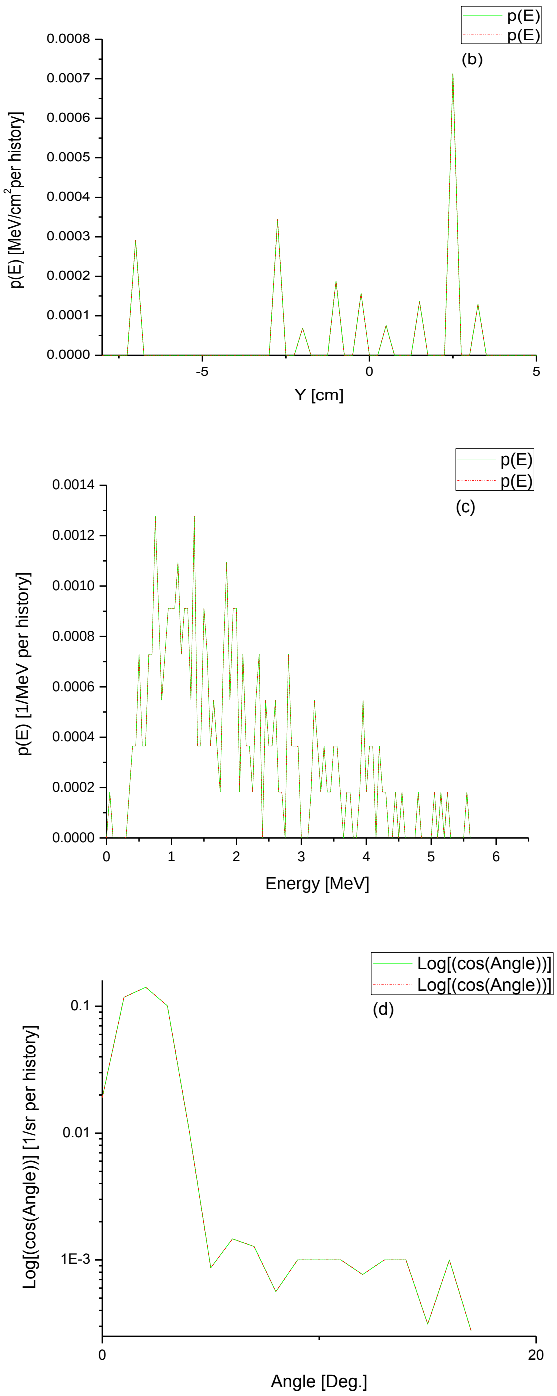
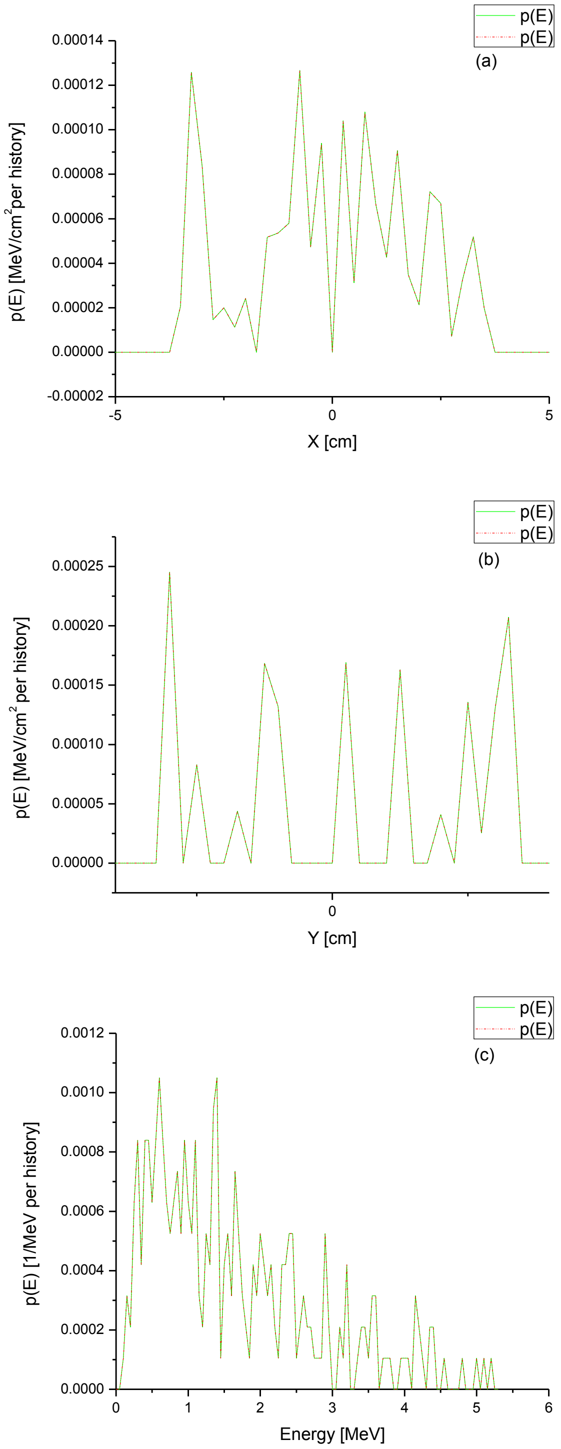


Figure 5: PSF photon probability density for X and Y in (a) and (b) respectively. Energy distribution and angular distribution for 6 MeV beams in (c) and (d) respectively. Full and dashed curves correspond to presence and absence of primary particles air respectively in Varian unique Linacs.

In figure 5(c), the feature of the photon spectra is the presence of several prominent peaks in the presence and absence of air in the Varian unique model of linacs. At lowest energy between 0 and 50 KeV, prominent peaks are present corresponds to the x-rays produced in the parts of the accelerator. The highest peak is at energy slightly greater than 511 KeV and 1.022 MeV which is caused by annihilation photons produced after the generation of an electron – positron pair by a bremsstrahlung photon. So we can conclude from the figure 5(c) that there is no effect in the presence and absence of primary particles air in the Varian unique model of linacs. Also, the process such as x-rays production occurs at slightly lower energy compared to Elekta SL model of linacs and annihilation, bremsstrahlung occurs at slightly greater energy compared to Elekta SL model of linacs and Varian 600c linacs.



International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

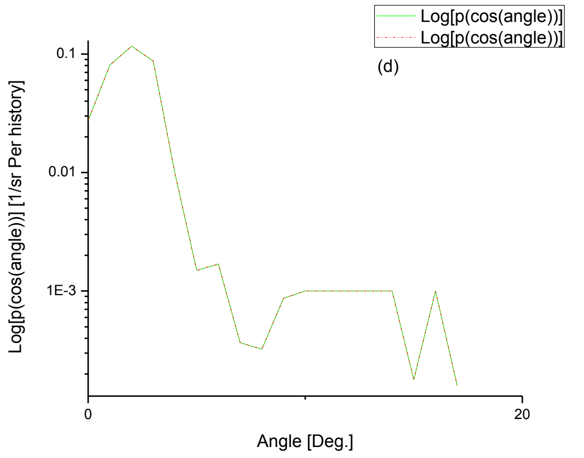
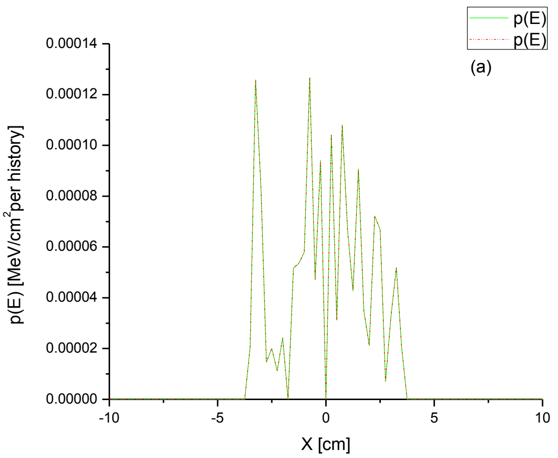
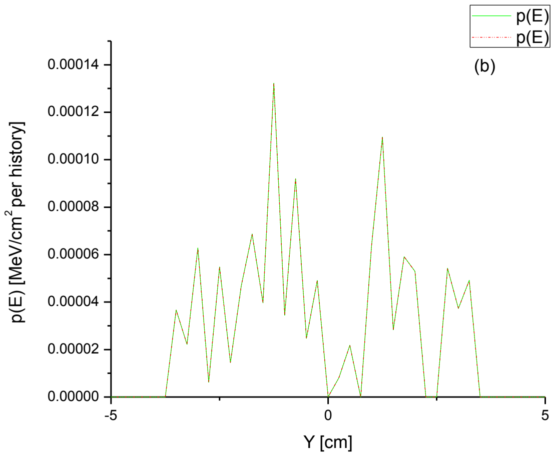
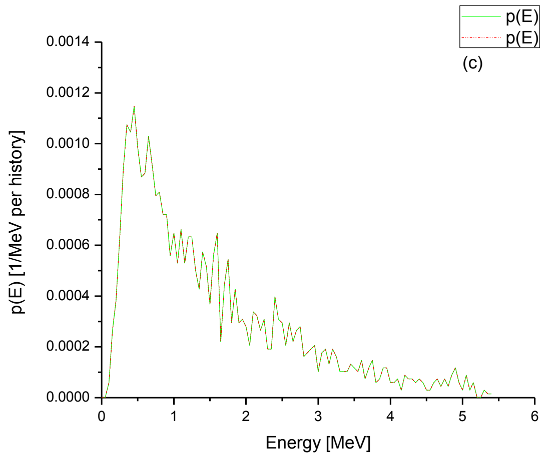


Figure 6: PSF photon probability density for X and Y in (a) and (b) respectively. Energy distribution and angular distribution for 6 MeV beams in (c) and (d) respectively. Full and dashed curves correspond to presence and absence of primary particles air respectively in Varian clinic 2100 Linacs.

In figure 6 (c), the feature of the photon spectra in the presence of several prominent peaks in the presence and absence of air in the Varian clinac 2100 model of linacs. At lowest energy between 50 and 100 KeV, prominent peaks are present which corresponds to the x-rays produced in the parts of the accelerator. The highest peak is at energy around 511 KeV and slightly greater than 1.022 MeV which is caused by annihilation photons produced after the generation of an electron –positron pair by a bremsstrahlung photon. So we can conclude from the figure 6(c) that there is no effect in the presence and absence of air in the Varian clinic 2100 model of linacs.







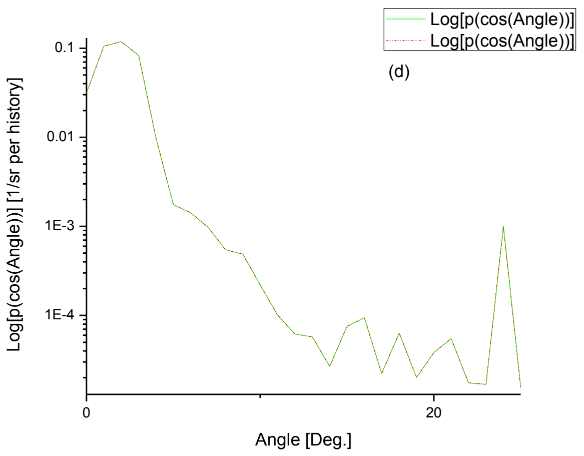


Figure 7: PSF photon probability density for X and Y in (a) and (b) respectively. Energy distribution and angular distribution for 6 MeV beams in c and d respectively. Full and dashed curves correspond to presence and absence of primary particles air respectively in Varian clinic 2300 Linacs.

In figure 7 (c), the feature of the photon spectra in the presence of several prominent peaks in the presence and absence of air in the Varian clinac 2300 model of linacs. At lowest energy between 50 and 100 KeV, prominent peaks are present which corresponds to the x-rays produced in the parts of the accelerator. The highest peak is at energy around 511

KeV is caused by annihilation photons produced after the generation of an electron –positron pair by a bremsstrahlung photon. So we can conclude from the figure 7(c) that there is no effect in the presence and absence of air in the Varian clinic 2300 model of linacs.

6.2 Variation of Radius Of Ring

The radius of ring is varied from 0 cm to 5 cm with variation of 0.50 cm in all the models to check the variation of energy with the change of radius of ring. Simulated results are tabulated in the following table.

MODELS	RADIUS	MIN.E	MAX.E
ELEKTA SL	3.00-3.50	-	5.876
	3.50-4.00	0.022	-
VARIAN 600C	3.00-3.50	-	4.775
	2.50-3.00	0.399	-
VARIAN UNIQUE	2.50-3.00	-	5.573
	4.00-4.50	0.074	-
VARIAN CLINAC	4.50-5.00	-	5.202
	2.00-2.50	0.131	-
VARIAN CLINAC	2.50-3.00	-	5.376
	3.50-4.00	0.106	-

7. CONCLUSION

In the present work, different models of Linacs have been investigated for the impact of air and variation of radius of ring. It has been observed and shown that only Elekta SL model of Linacs has the effect in the presence and absence of air while other models have no effects. It is also observed that maximum and minimum energy is achieved in case of Elekta SL model for the radius range 3.00 cm to 3.50 cm and 3.50 cm to 4.00 cm respectively while other models have variation of energy with the change of radius of ring. It is also necessary to implement method of error analysis to make the analysis more accurate and reliable using different MC codes like Geant4, FLUKA codes etc. This is what is intended to do for the publication of the next jobs.

REFERENCES

[1] Eucard- European Coordination For Accelerator Research And Development "Advances In Conformal Radiotherapy-Using Monte Carlo Code To Design New IMRT And IORT Accelerators And Interpret CT Numbers",Eucard Editorial Series On Accelerator Science And Technology,17,(2013) .
[2] M Rodriguez, J Sempau and L Brualla 2012 :"A combined approach of variance-reduction techniques for the efficient Monte Carlo simulation of linacs".Phys. Med. Biol. 57 10
[3] Alex C.H.Oliveria, Jose W.Vieira, Marcelo G.Santana, Fernando R.A.Lima Monte Carlo Simulation of a medical linear accelerator for generation of phase spaces INAC 2013.
[4] Siebers J, Keall P, Kim J and Mohan R 2002 A method for photon beam Monte Carlo multileaf collimator particle transport Phys. Med. Biol. 47 3225–49.
[5] R.R. Wilson Phys. Rev. 86, 261–269 (1952).
[6] J.C.Butcher, H.Messel, Phys Rev 112,2096–2106 (1958).
[7] J.C. Butcher, H. Messel Electron number distribution in electron-photon showers in air and aluminium absorbers. Nucl Phys 20, 15–128, (1960).
[8] A.A. Varfolomeev, I.A. Svetlolobov, Sov Phys JETP 36, 1263–1270 (1959).
[9] Ulmer W and Harder D I 1995 A triple Gaussian pencil beam model for photon beam treatment planning Z. Med.Phys. 5 25–30.
[10] UlmerW, Pyyry J and KaisslW2005 A 3D photon superposition/convolution algorithm and its foundation on results of Monte Carlo calculations Phys. Med. Biol. 50 1767-90.
[11] Ahnesj¨o A 1989 Collapsed cone convolution of radiant energy for photon dose calculation in heterogeneous media Med. Phys. 16 577-92.
[12] Fippel M, Haryanto F, Dohm O, Nusslin F and Kriesen S 2003 A virtual photon energy fluence model for Monte Carlo dose calculation Med. Phys. 30 301–11.
[13] Chetty I J et al 2007 Report of the AAPM Task Group No. 105: issues associated with clinical implementation of Monte Carlo-based photon and electron external beam treatment planning Med. Phys. 34 4818–53.
[14] Sempau J, S´anchez-Reyes A, Salvat F, Oulad ben Tahar H, Jiang S B and Fern´andez-Varea J M 2001 Monte Carlo simulation of electron beams from an accelerator head using PENELOPE Phys. Med. Biol. 46 1163–86.
[15] Agostinelli S et al 2003 Geant4—a simulation toolkit Nucl. Instrum. Method A 506 250–303.
[16] Salvat F, Fern´andez-Varea J M and Sempau J 2006 PENELOPE—A code system for Monte Carlo simulation of electron and photon transport (Issy-les-Moulineaux: OECD Nuclear Energy Agency).
[17] Lewis R, Ryde S, Hancock D and Evans C 1999 An MCNP-based model of a linear accelerator x-ray beam Phys.Med. Biol. 44 1219–30.
[18] M Rodriguez, J Sempau and L Brualla 2013: A graphical environment for monte carlo simulation of varian and elekta linacs. Strahlentherapie und Onkologie 189 10 881-886.