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Monte Carlo Simulation of a Theratron Elite100 Telecobalt Machine Using Beamnrc Code.

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ABSTRACT

Realistic computational simulation of the treatment head of a Theratron Elite100 telecobalt machine has been carried out using BEAMnrc Monte Carlo simulation code. The virtual model of the machine is obtained by the complete simulation of all the complex structures in the treatment head including secondary collimators and trimmers. The phase space file obtained at the bottom end of primary collimator in the first step of simulation is being used as the source for the second step. Photon energy spectrum is obtained at the bottom end of the primary collimator as well as at the top of the water phantom surface which is kept at 100cm away from the radiation source. Dosemetric parameters such as percentage depth dose and peak scatter factors are obtained for different field sizes and compared with measurement values. A graph is plotted for showing the variation of electron contamination of particles reaching at phantom surface with field size.

Key words: BEAMnrc code, Monte Carlo Simulation , Teletherapy, Theratron Elite100

I. INTRODUCTION

Monte Carlo simulation codes are found to be a wide range of application in radiation transport studies and becoming a supplement to dose measurement in clinical radiotherapy dosemetry.Treatment head simulation of different commercially available Telecobalt machines using Monte Carlo simulation method has been reported by several authors in the past. Rogers *et al*[1] reported calculations of electron contamination in a cobalt 60 beam from an AECL therapy unit using EGS4 code. [2] Their study was limited to broad beam conditions and made several approximations to reduce the computing time. Burns *et al,* [3] by using EGS4 Monte Carlo code, have claimed that the calculated tissue–air ratios (TAR), for a range of depths and field sizes in ^{60}Co gamma radiation therapy, show 2–3% higher values compared to the published data in BJR suppl. 17. [4] Mora *et al* [5] used BEAM Monte Carlo code to simulate the cobalt 60 beam from an Eldorado 6 cobalt unit. They have presented the build up region of depth dose curve to predict the effect of electron contamination from the surface to dose maximum. MCNP simulation[6] of Theratron 780 telecobalt machine was carried out by R.Miro *et al* [7] and have calculated the spectra as a function of field size. Characterization of Siemens Gammatron1 Telecobalt unit at a secondary standard dosemetry laboratory was done by Åsa Carlsson Tedgren *et al*[8] using BEAMnrc code[9]. Most of the previous works in the past have shown that the radiation from a Telecobalt machine reaching the patient body consists of a spectrum of energy and hence its dosemetry parameters depends on the cross sectional details of that typical machine. Hence it is necessary to have characterize any new Telecobalt machine in terms of their energy spectra and dosimetric parameters to use it for radiation treatment.

In this work , we have used the BEAMnrc Monte Carlo simulation code to simulate the treatment head of a Theratron Elite100 telecobalt unit to obtain the energy spectrum and different dosemetry parameters used for radiation treatment. Many of the previous authors have carried out the simulation of Telecobalt machines by making several simple approximations for the complex structures of the treatment head for reducing the computation time. But we have carried out the complete simulation of all the components of treatment head even without any approximations of complex structures of secondary collimators and trimmers.

II. MATERIALS AND METHODS

2.1 Theratron Elite100 teletherapy machine

The Theratron Elite100 is a new generation telecobalt machine which is being used in many countries all around the world for radiation treatment of cancer patients. The machine is completely microprocessor controlled and have two hand controls separately for table and gantry movements. The treatment head of the unit is mainly consists of a radiation source capsule, lead and depleted uranium shielding ,fixed and adjustable collimators, stainless steel plate and trimmer bars. The source capsule consists of nickel plated ^{60}Co pellets which are embedded in two co-axial cylinders made of stainless steel (no. 316L). Above the ^{60}Co pellets the space is filled with stainless steel spacers and tungsten plates and at the bottom there is a thin stainless steel window, which allows more particles to emerge in the downward direction.Figure1 shows the cross sectional diagram of source capsule which is simulated in the study.

There is an air gap of 1.5cm between source capsule and primary collimator(fixed collimator).The primary collimator is made up of tungsten with thickness 6cm and has a conically shaped hole at the centre. The secondary collimator which comes after the fixed collimator is constructed of four sets of interleaved lead vanes. The field size can be defined by means of the adjustable collimator which are always move in the xy –plane and are perpendicular to the beam direction. The inner edges of the collimator vanes are angulated to follow the beam divergence for all field sizes. Below the secondary collimator there is a 1.8cm thick steel plate with a 14 x14 cm^2 opening. Under that there is another set of collimator bars, called trimmer bars which includes two set of tungsten vanes, which extends the total source to diaphragm distance to 45cm.The source capsule and collimation system are enclosed in an ellipsoidal steel shell filled with lead.

2.2 The Monte Carlo simulation

Monte Carlo modelling of the machine was carried out with BEAMnrc code in the LINUX operating system platform. BEAMnrc is a Monte Carlo simulation code for modelling radiotherapy sources which was developed as part of the OMEGA(Ottawa Madison Electron Gamma Algorithm) project to develop 3-D treatment planning for radiotherapy. BEAMnrc is built on the EGSnrc Code System.

In BEAMnrc code the geometry of the Telecobalt machine to be simulated is built up from a series of predefined “component modules” (CMs). The CMs are designed to aid in the creation of certain geometries and some examples of CM names are SLAB, JAWS, CHAMBER, etc. In the present study the following CMs are used to define the different geometrical structures of the machine.

CONESTAK - source capsule
SLAB - Air gaps
PYRAMID- Primary collimator and Stainless steel plate
JAWS - secondary collimator and trimmers
CHAMBER - water phantom

In order to reduce the computation time the simulation procedure was carried out in two steps as suggested by Mora *et al.* First step includes the simulation of fixed part of the treatment head, ie; source capsule ,air gap, primary collimator and the surrounding lead housing. Figure 2 shows the preview of head simulation in the first step which was directly obtained from the BEAMnrc simulation code using the input preview tool. Second step includes the adjustable collimator ,steel window ,trimmer bars ,air gap and water phantom. The simulation output from the first step, in the form of phase space file was stored and used as the source for second step. The second step was repeated for different field sizes 5x5 cm^2 , 10x10 cm^2 , 20x20 cm^2 ,30x30 cm^{2}and 35x35 cm^2. In second step we included a water phantom of diameter 50cm and thickness 30cm and kept at a distance 100cm from the original source point to get the dose parameters in water. The water phantom was modelled using the component module CHAMBER with 1cm radius dose scoring region at the centre. The output option was given such as to score the spectrum at the bottom end of primary collimator in the first step and in second step spectrum was scored at the top surface of the water phantom.

We used the code PEGS4[10] to create all the material data used for simulation.The PEGS4 code (Pre-processor for EGS) is a stand alone utility program written in Mortran language. PEGS’s purpose is to generate material data for the EGS code. A new material data file “Elite521.pegs4dat” was created using the PEGS4 code and saved in the PEGS4/data directory. The following energy cut off’s were used in PEGS4 to create the material data. AE=0.521MeV, AP=0.01MeV, UE=55.511MeV , UP=55MeV.

We have used the variable LATCH for tracking the particle history during the first and second step of the simulation. The LATCH variable, associated to each photon and particle in a simulation, is a 32-bit variable used to store the history of the particles in BEAMnrc code. The standard LATCH option we used is 2 ie; ‘inherited latch- set by passage‘ option available with the BEAMnrc code.The general Monte Carlo transport parameters used in common to all simulations of present study are given below:

Global ECUT= 0.521MeV
Global PCUT= 0.01MeV
Global SMAX= 5
ESTEPE= 0.25
XIMAX= 0.5
Boundary crossing algorithm= EXACT
Skin depth for BCA= 0
Electron-step algorithm= PRESTA-II
Spin effects= On
Brems angular sampling= Simple
Brems cross sections= BH
Bound Compton scattering= On
Pair angular sampling= Simple
Photoelectron angular sampling= Off
Rayleigh scattering= Off
Atomic relaxations= Off
Electron impact ionization= Off

In order to save the computation time we used the variance reduction technique “range rejection of electrons” with a standard option “on with varying ECUTRR”. “If the range corresponding to the energy ECUTRR is less than the perpendicular distance to the nearest region boundary, the history is terminated and energy is deposited in the current region" (Rogers and Kawrakow[11]). The ECUTRR values for different geometrical regions were selected very carefully in order to minimize the inaccuracies resulting from this approximation. The global electron cut off energy ESAVE_GLOBAL for range rejection was selected as 1MeV which makes sure that the range rejection is not preformed on particles above this energy.

The statistical uncertainty of the simulation is directly depend upon the number of particle histories used in the simulation. Hence in order to improve the accuracy of the calculations ,more particle histories has to be simulated (Francescon *et al* [12]).We have used $2x10^9$ number of particle histories in the first step of simulation and $1x10^9$ particle histories in the second step.

We have used the tool BEAMDP (BEAM Data Processor) [13] for analyzing the phase space files obtained in both steps of the simulation. BEAMDP is an interactive program, developed for the OMEGA project. The spectral distribution from the phase space file was obtained using this tool and graphs were plotted with the 2D graph plotting software GRACE.

III. RESULTS

3.1 Spectral distribution at the bottom end of the primary collimator

In the first step of the head simulation we obtained the output in a plane at the bottom end of the primary collimator. The simulation output obtained was in the form of a phase space file of size 1.6GB. On analysing the file using BEAMDP we found that out of $2x10^9$ photons emitted uniformly in all directions from the source, the total particles reached at the bottom end of primary collimator was only 5, 52, 87, 732 which includes photons of 5, 45, 43, 359 numbers and electrons of 7,44, 373 numbers. The total electron contamination of the obtained spectrum was 1.346%. The photon spectrum extracted from the phase space file using BEAMDP was plotted as figure 3.

3.2 Spectral distribution at water phantom surface at 100cm SSD

In the second step of simulation we have obtained the phase space file at the water phantom surface which was kept at 100cm from the original source point. Figure 4 shows the photon energy spectrum at water phantom surface derived from the phase space file for a broad beam ($35x35cm^2$ field size) and compares with the previous published Mora *et al* [5] spectrum. Energy spectrum of electrons were obtained from the phase space file for the field sizes 10x10 cm^2 and 35x 35cm^2 and shown in figures 5 & 6 respectively. Percentage electron contamination of total particles reaching at phantom surface was calculated for different field sizes from 5x5 cm^2 to $35cmx35cm^2$ and a graph was plotted in figure 7 which shows the variation of percentage electron contamination with field sizes. From the graph it can be seen that percentage electron contamination increases with field size.

3.3 Peak scatter factor

Peak scatter factor (PSF) is defined as the ratio of the dose in the phantom to the dose in free space at a point of dose maximum. We have evaluated the variation of PSF with field size in the same manner suggested by Teimouri *et al*[14]. The water phantom in step 2 was replaced with a mini phantom of same material with a size of 5mm which was surrounded by air. Simulation was repeated for different field sizes. In table 1 PSF values for different field sizes were calculated and compared with that of measurement values (BJR 25 Supplement[15]**)**. We have got a deviation of maximum 0.5% between the calculated and measured values.

3.4 Percentage Depth dose

Percentage depth dose (PDD) values were calculated from dose/fluence obtained at different depths in water phantom for different field sizes using the equation:

$$PDD(\%)= \frac{dose\,/fluence\ \ at\ a\ given\ depth}{dose\,/fluence\ \ at\ \ dmax\ \ depth}\,X\ 100$$

where dmax is the depth of maximum dose. Comparative graphs for MC simulated and BJR25 values were plotted with PDD along X-axis and depth along Y-axis for the field sizes 5x5 cm^2, 10x10 cm^2 and 30x30 cm^2 and shown in figures 8, 9 and 10 respectively. Comparative plots shows well matching between experimental and MC simulation values.

3.5 Discussion

The spectrum shown in figure 3 is the photon spectrum obtained at the bottom end of the primary collimator. In the spectrum there are two major photon peaks corresponds to 1.17MeV and 1.33MeV photons which are originally emitted from the source. The other photons are low energy scattered photons from different parts of the machine head. The energy and quantity of scattered photons reaching at the scoring plane depends on the design of treatment head of the particular machine.

The comparative plot of photon energy spectra obtained at the water phantom surface for broad beam(figure 4) shows that the fluence for primary photon energies (1.17MeV and 1.33MeV) are in agreement with Mora *et al* spectrum. However there are discrepancies in the scattered photon parts of the spectra. The scattered photon intensity obtained is lesser in present study. The difference in spectra may be due to the following facts: (1)Difference between the head cross sections of the two Telecobalt machines ,Theratron Elite100 and Eldorado 6 . (2)The presents of steel plate with opening in the treatment head of Theratron Elite100 to absorb low energy scattered radiation , which is realistically simulated in the study. The electrons spectra shown in figure 5&6 for the field sizes 10x10cm^2 and 35X35cm^2 are identical in shape but fluence is more for35X35cm^2 . This is due to the presents of increased Compton scattered electrons for large field openings. The dosimetric parameters such as PSF and PDD obtained in the present study using the Monte Carlo Simulation is in well agreement with the measurement values which shows the accuracy of the simulation method and inputs we followed in the study.

IV. CONCLUSION

Monte Carlo simulation of the treatment head of a Theratron Elite 100 tele cobalt machine was successfully done using BEAMnrc code. The phase space file obtained in the simulation was used as an input source for dosemetric studies in water phantom. The dosemetric parameters obtained in the simulation studies such as PDD, PSF etc are well matching with the published measurement values which shows the accuracy of obtained phase space file in the present study. In future studies we can use the obtained phase space file as an input source for dosemetric studies using the other codes also such as DOSXYZnrc or DOSRZnrc available with the EGSnrc Monte Carlo Simulation code system.

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Table 1 : Peak scatter factor for different field sizes

Field size cm x cm	Peak scatter Factor(PSF) MC Simulated Value +/-σ	Measured Value (BJR 25 supplement)	Deviation (%)
5x5	1.0348+/-0.006	1.036	0.12
10x10	1.0533+/-0.004	1.054	0.07
20x20	1.073+/-0.005	1.078	0.50
35x35	1.090+/-0.006	1.093	0.30

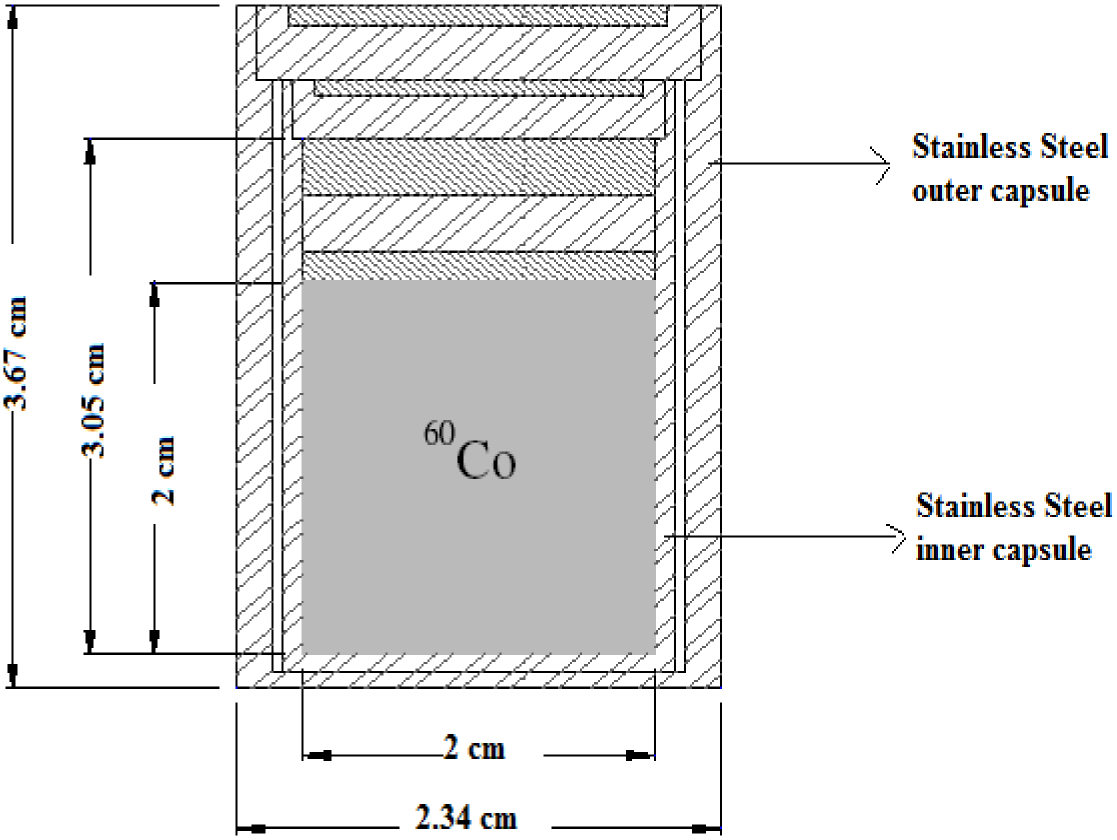
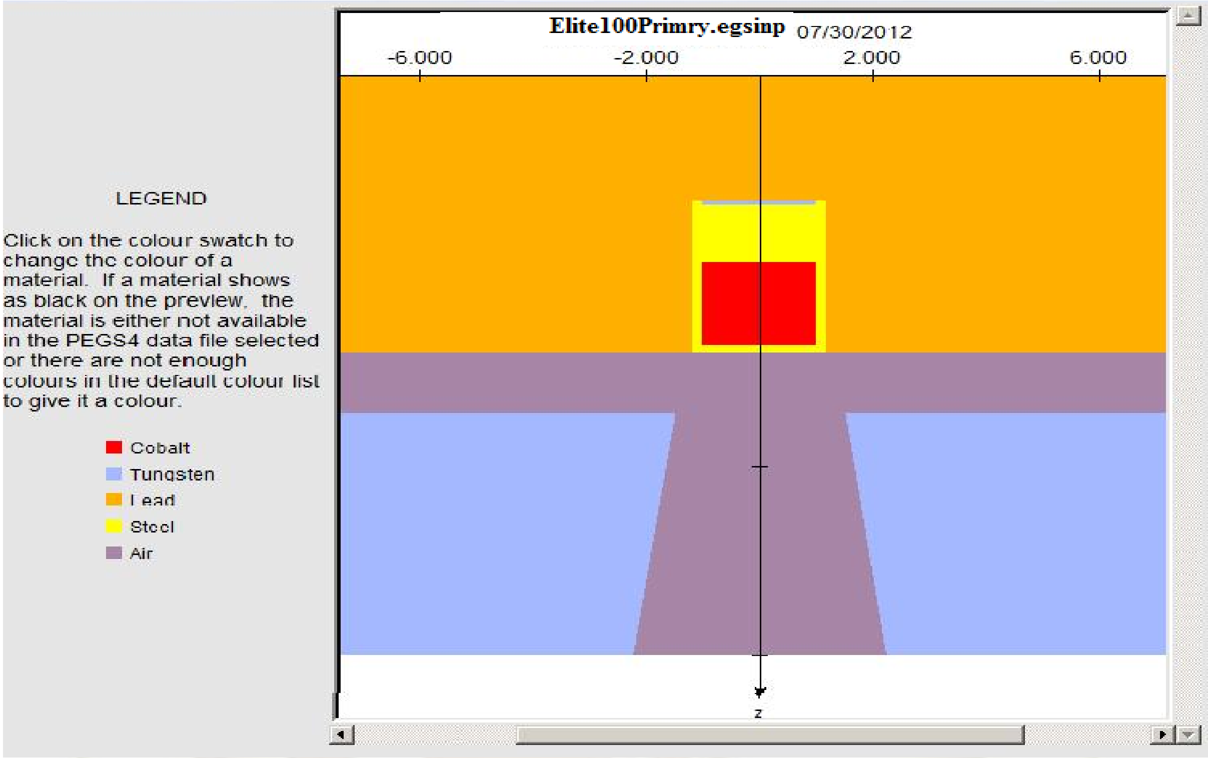


Figure 1: Cross sectional view of Source capsule used in the Simulation of Theratron Elite100 machine.



LEGEND

Click on the colour swatch to change the colour of a material. If a material shows as black on the preview, the material is either not available in the PEGS4 data file selected or there are not enough colours in the default colour list to give it a colour.

- 🟥 Cobalt
- 🟦 Tungsten
- 🟧 Lead
- 🟨 Steel
- 🟪 Air

Figure 2: Figure shows the Source housing and Primary collimator modeled in Step 1 of simulation (Obtained directly from the BEAMnrc input preview tool)

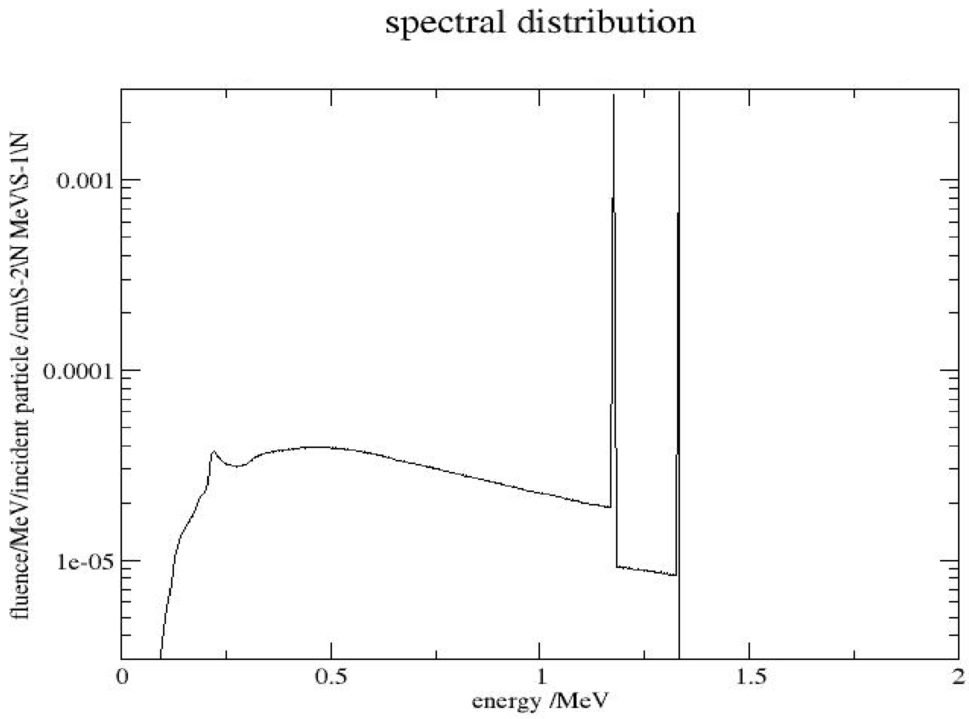


Figure 3: Energy spectrum of particles reaching at the bottom end of Primary collimator

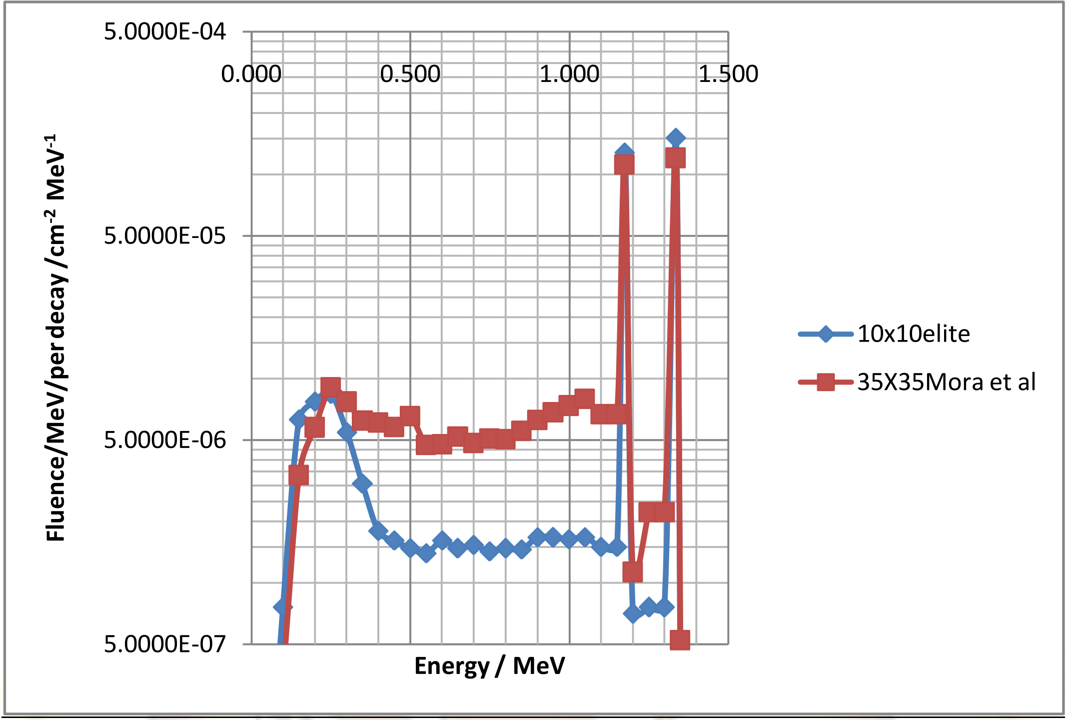


Figure 4: Photon energy spectral distribution at water phantom surface for35X 35cm^2 field size at 100cm SSD is compared with previously published spectrum by Mora et al

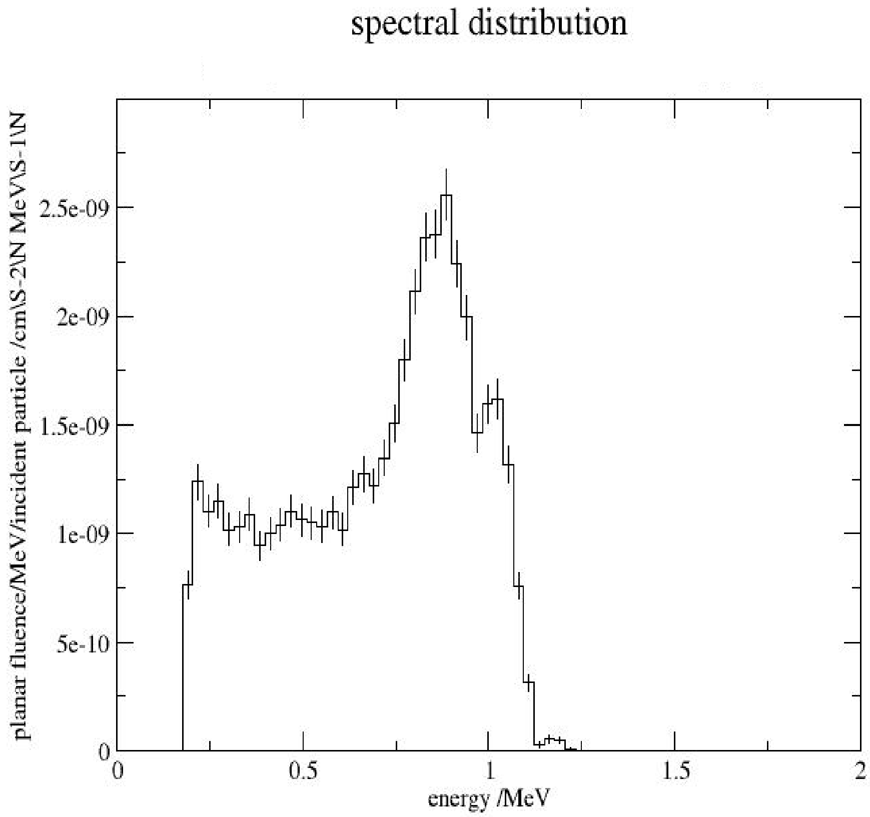


Figure 5 : Spectral distribution of electrons at water phantom surface for 10x10cm^2 field

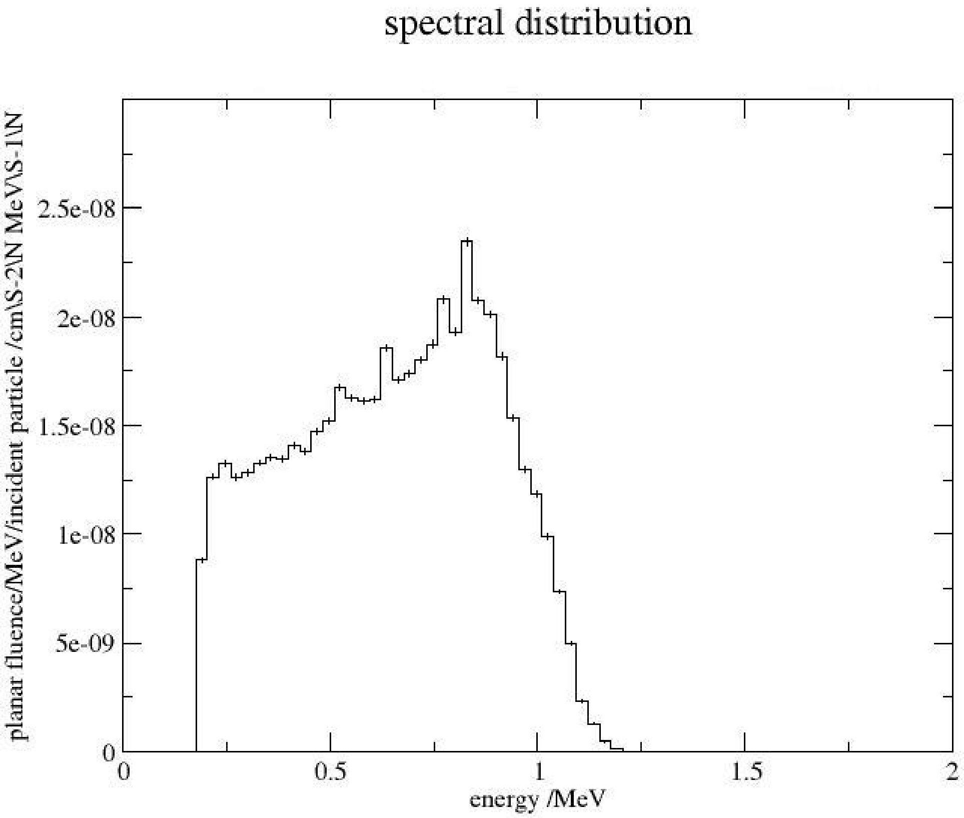


Figure 6: Spectral distribution of electrons at phantom surface for 35x35 cm^2 at 100cm SSD

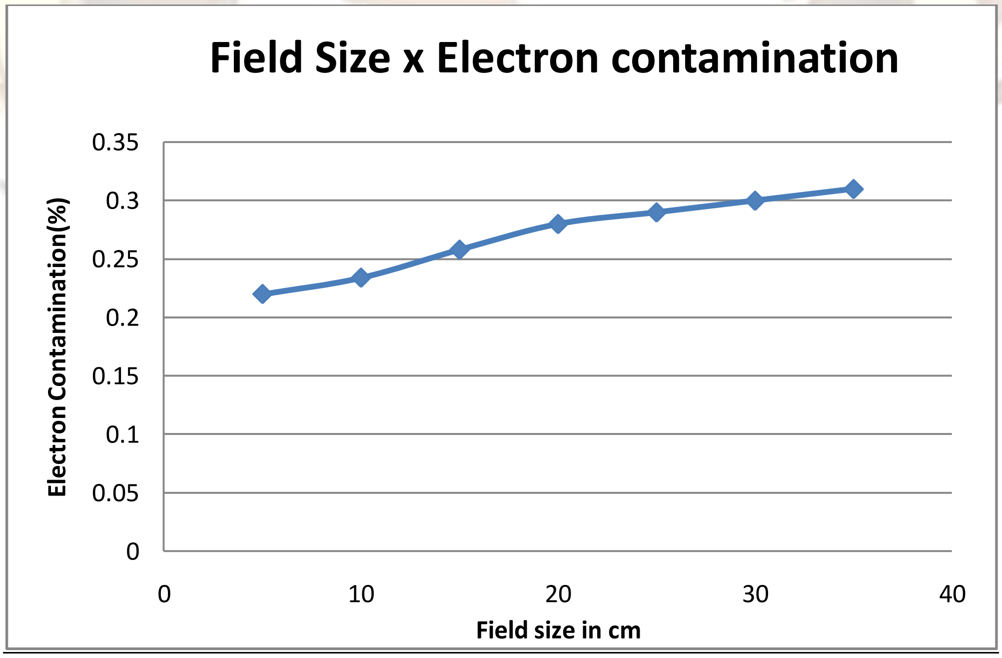


Figure 7: Variation of Electron contamination with field size

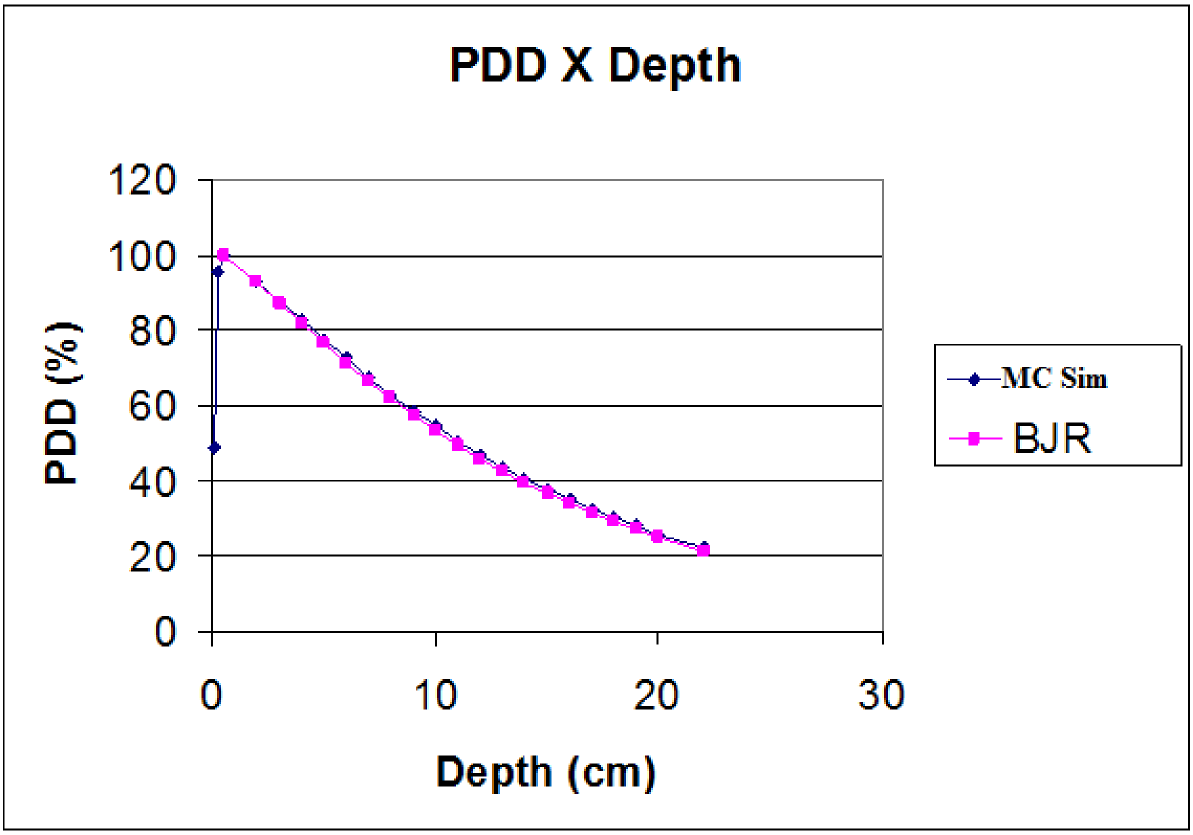


Figure 8: Central axis depth dose distribution for 5cmx5cm field size-comparison of Monte Carlo simulated and measurement (BJR 25 Supplement) values.

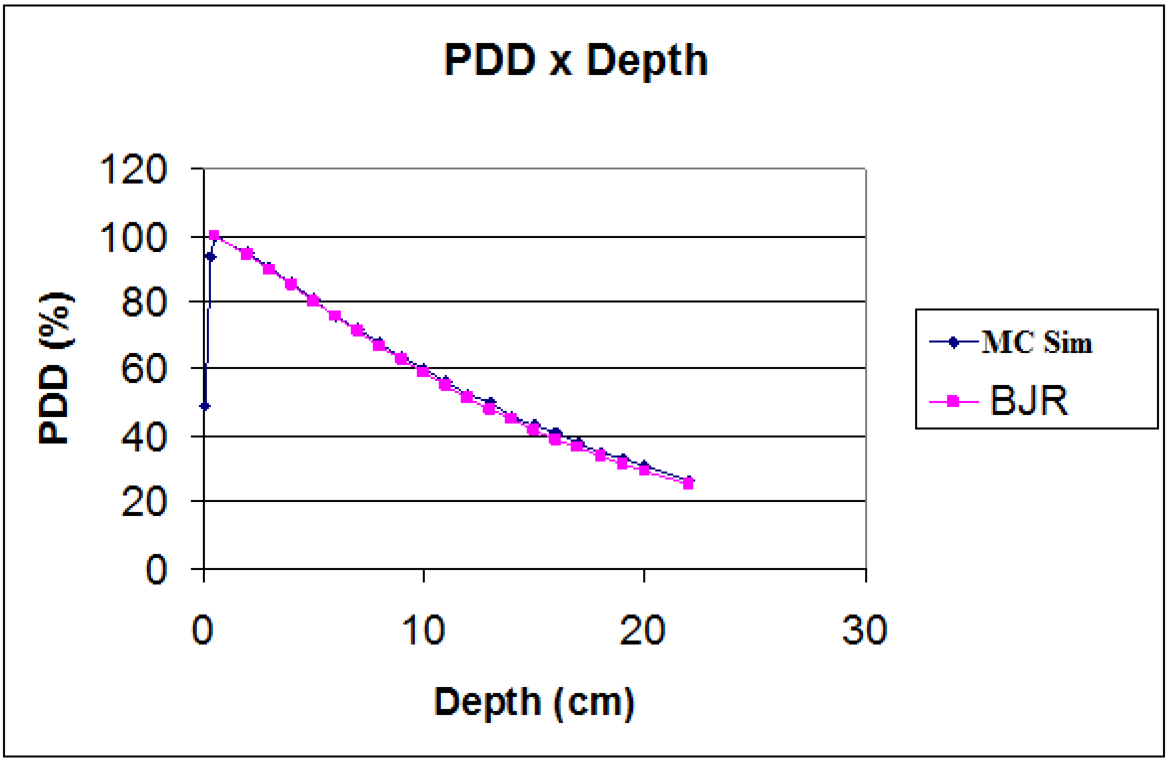


Figure 9: Central axis depth dose distribution for 10cmx10cm field size-comparison of Monte Carlo simulated and measurement (BJR 25 Supplement) values.

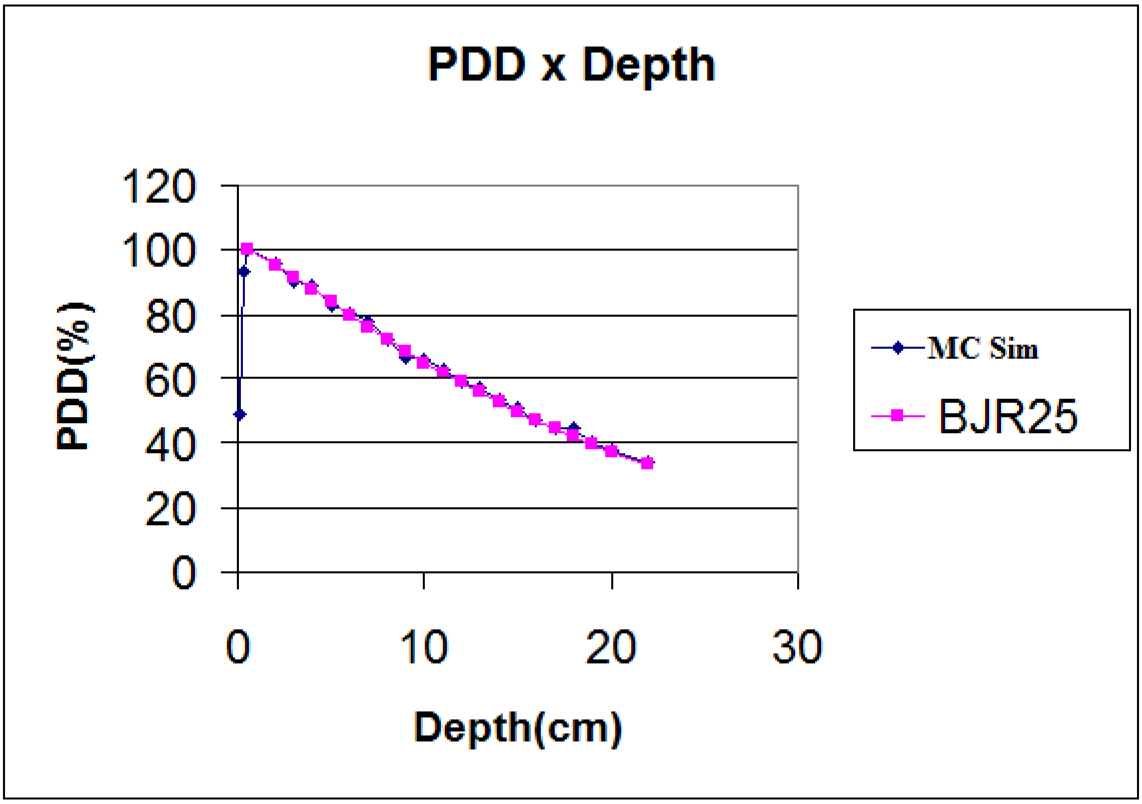


Figure 10: Central axis depth dose distribution for 30cmx30cm field size-comparison of Monte Carlo simulated and measurement (BJR 25 Supplement) values.