International Journal of Environmental Sciences Vol. 4 No. 3. 2015. Pp. 114-117

Full Length Research Paper

Analysis of Dose Distribution for the Gamma Cobalt Irradiation Therapy Unit in Normal and Emergency Conditions

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Abstract

The dose distribution inside the Gamma Cobalt irradiation therapy unit at Egyptian Atomic Energy Authority (EAEA) was determined both experimentally and theoretically. MCNP computer code, based on Monte Carlo method, was used to model the unit and calculate the dose distributions in both normal and emergency situation of the unit. The dose distribution inside the unit was also measured during the unit in operation. The maximum gamma dose distribution measured around the gamma device during operation (the source in position ON) using TLD and AD6-6150 was 2.21 and 2.010 mSv/h respectively, while the maximum gamma dose distribution calculated by MCNP computer code at the same point was 1.952 ± 0.026 mSv/h. The results indicate good agreement between the measurements and theoretical model of MCNP computer code. In case of emergency, and at 50 cm distance from the unit head the dose rate increases to 7000 µSv/h at the nearest point to the unit.

Key words: Dose distribution, Radiation therapy, Dose rate, MCNP computer code, Co-60 unit

Introduction

Radiation therapy is a method of treating cancer, brain tumors, vascular malformations and trigeminal neuralgia with beams of radiation delivered by machines or by radioactive particles. Radiation therapy works by damaging cells to disrupt their growth (Lawrence, et. al, 2008). Although radiation therapy affects normal and tumor cells, normal cells are able to repair themselves after treatment and function properly, while tumors cells are destroyed by the treatment. X rays, gamma rays, and charged particles are types of radiation used for cancer treatment. The radiation may be delivered by a machine outside the body (external-beam radiation therapy), or it may come from radioactive material placed in the body near cancer cells (internal radiation therapy, also called brachytherapy). Systemic radiation therapy uses radioactive substances, such as radioactive iodine, that travel in the blood to kill cancer cells. About half of all cancer patients receive some type of radiation therapy sometime during the course of their treatment. Radiation used for cancer treatment is called ionizing radiation because it forms ions (electrically charged particles) in the cells of the tissues it passes through. It creates ions by removing electrons from atoms and molecules. This can kill cells or change genes so the cells stop growing.

Some types of ionizing radiation have more energy than others. The more energy, the more deeply the radiation can penetrate (get into) the tissues. The way each type of radiation behaves is important in planning radiation treatments. The radiation oncologist (a doctor specially trained to treat cancer with radiation) selects the type of radiation that’s most suitable for each patient’s cancer type and location.

Cobalt 60 is a radioactive isotope of Cobalt with a halflife of 5.27 years. ^{60}Co decays by negative beta decay to the stable isotope nickel-60. In the process of decay, ^{60}Co. emits one electron with energy of up to 0.315 Mev and then two gamma rays with energies of 1.17 and 1.33 Mev respectively. Radiation doses for cancer treatment are measured in a unit called a gray (Gy), which is a measure of the amount of radiation energy absorbed by 1 kilogram of human tissue. Different doses of radiation are needed to kill different types of cancer cells.

One of the most common types of external-beam radiation therapy is called 3-dimensional conformal radiation therapy (3D-CRT). 3D conformal radiation is a radiation therapy technique that sculpts radiation beams to the shape of a tumor. 3D-CRT uses very sophisticated computer software and advanced treatment machines to deliver radiation to very precisely shaped target areas (Gaspar, et. al, 2008). This is ideal for tumors that have irregular shapes or that lay close to healthy tissues and organs.

The development of high resolution imaging techniques has allowed the physicians to accurately map a target in three dimensions and precisely pinpoint its location to minimize the dose radiation delivered to surrounding normal tissues (Detorie, et. al 2008).
One of the treatment methods is Gamma kniffe. Gamma knife differs from conventional radiation therapy because patients are injected with such low doses of radiation, they don’t experience the side effects associated with traditional radiation therapy. In fact several shots of therapy can be given during the same session and treatment. Sessions can be repeated every few weeks if necessary. Gamma knife can be used to treat a variety of conditions. it is most often used on tumors , either cancerous or benign.

Benign tumors such as meningiomas and acoustic neuromas and malignant tumors that have metastasized can all be effectively treated. Doctors typically use the gamma knife to treat tumors that are smaller than four centimeters in size. Gamma knife is able to stop tumors from growing in 90 to 95 % of all cases . It also causes tumors to shrink in the majority of cases. Radiation therapy uses high energy beams to damage the DNA of tumor cells or lesions. If enough damage is done to the chromosome of a cell , it will die spontaneously or it will die in the next time. Tumors are poorly vascularized tissues that are deprived of oxygen. Radiation therapy controls tumors by splitting the Oxygen molecules it finds in and around tumors into harmful oxygen radicals that destroy tumors cells (Bemiller, et. al, 1995, IAEA Publication 1296, 2008).

The purpose of this research is to model theoretically Gamma Cobalt irradiation therapy unit at EAEA, which is used to treat tumors and different diseases. MCNP computer code based on Monte Carlo method is used to perform this analysis. The dose rate distribution inside the therapy room is determined (through operation mode) using MCNP code and also is measured experimentally. The dose rate through the entrance line during operation of the unit is also calculated which can be used to assess the dose rate at emergency conditions.

Gamma Therapy Device

Gamma Cobalt irradiation therapy unit at EAEA is of type TERDI 800 Cobalt therapy unit [INVAP- ARGENTINA] which can load Cobalt 60 sources for a maximum yield of 12,000 RHM. The source is center distance is 800 mm. The unit consists of Radiation head, Collimator, Rotary arm, mainframe, coach and base. The radiation head houses the source in its interior in double tungsten and lead shielding. The radiation head can rotate around its assembly axis, so as to locate it in such a way that the radiation beam is not intercepted by the beam stopper. The collimator is mounted on the lower part of the radiation head, located in such away that the beam is intercepted by the beam stopper. It contains beam regulation systems in order to obtain fields of between 3.5 and 35 cm per side. The movements of the collimator are motorized. The rotary arm bears the radiation head at one end and the beam stopper at the other. The mainframe contains the rotation axis for the arm, the electromechanical system to activate the arm and the pneumatic system to activate the source. The coach has four manual movements and one motorized movement which can be controlled from either of the control panels on either side of the coach. Base is a structure made of steel profile on which the unit is mounted. The mainframe rests on one end of this structure and the treatment couch on the other, the base is embedded in concrete below the level of the finished floor (operating manual INVAP S., Argentina)
The mainframe is a steel structure that supports the treatment assembly – rotary arm/radiation head/beam stopper. It has two doors on each side, which permit maintenance operations to be carried out comfortably.

Computer and Simulation Model

MCNP Monte Carlo N - Particle Computer code package is used to model and simulate the Gamma device unit and its accessories (Briesmeister, et al, 1995, Whalen, et. al, 1996). All geometries, internal components and dimensions of the gamma unit including walls of the room are considered in the model without any geometry approximations as shown in figures 1 & 2. Figure 1 illustrates a horizontal layout of the Gamma unit and its room. The Figure also shows the radiation head and the location number (1 to 7) at which the dose are measured and calculated. The line ABC represents the route at the condition of emergency a person will enter from the external door until reach to the device. Figure 2 illustrates vertical layout of the Gamma device unit. ANSI/ANS photon flux to dose conversion factors are used to convert the calculated Gamma flux at the locations to dose rate (μSv/h)

Method of Measurements

The evolution of radiation doses in certain positions in radiotherapy room is needed to know the contribution of radiation doses in case of normal and abnormal conditions. We have measured the doses for Co-60 source [in cobalt unit for radiotherapy of AEA. These measurements have been made experimentally and theoretically and compared each other to know the accuracy of the measurements. The gamma doses were measured using survey meter AD6-6150 andthermoluminescent (TL) material TLD-100.

AD6-6150 Outomass Survey meter

This Survey meter is qualified to measure doses from gamma rays with measuring range 0.1 μSv/h – 10 mSv/h and Energy range 60 Kev-1.3 Mev .

LiF:Ti,Mg (TLD-100) Dosimeter

The thermoluminescent (TL) material chosen to perform gamma dose measurements in this study is TLD-100 . Measurements were performed usingLithium FluorideLiF:Mg:Ti(TLD-100) chips. Lithium Fluoride having characteristics suitable for dosimetry investigations in nuclear medicine because the density of this kind is nearly to human tissue.This dosimeter is sensitive been used for integrated dose measurements. It used because of their energy independence and low fading. It has high sensitivity, low leak, good resistance against heat, moisture, and other environmental factors, and un-sensitive to light. They has filters for protection to disturbance radiation.

The individual relative sensitive factors and repeatability for all dosimeters used in this work were investigated for gamma radiation, 1 cGy, 137Cs source. The TLD calibration factors have been determined, in air, for different X-ray beam kVp obtained with a SiemensPolymat 50 equipment. Dose evaluations for TLD calibration were carried out with a dosimetric system Radcal, model 9015, with a 6 cc ionisation chamber 90X. The X-rays used were of 63, 66, 70, 73, 77, 81, 85, 90 and

96 kV. The energy dependence curve for the response of the TLDs used was determined using the above-mentioned qualities in terms of effective energy. This procedure allowed the correction of the TLD response with respect to each beam quality considered. This method is quite effective for TLD-100.

The chips were annealed (using TLD Oven, Model PTW-TLDO, Germany). TLDs were calibrated using TLD irradiation facility. The TLDs were annealed at 400°C for 1 h followed by 2 h at 100°C to eliminate all residual signals without the effecting on TLD sensitivity.

As shown in figure 1,sets of TLDs were places at six positions in the room during the source is ON positions. Ambient radiation was monitored and the doses were calculated by averaging the values. These values were used to evaluate the effective dose.The measurements,using AD-6150 and TLD-100,were taken at the same points.

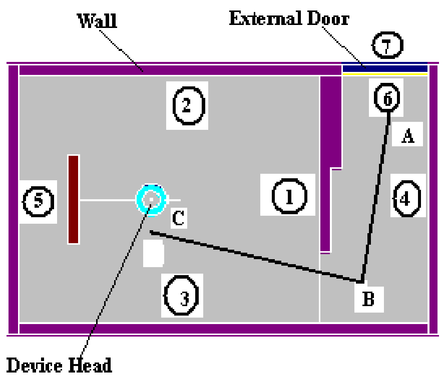

Fig 1. Horizontal Layout of the Gamma unit with different Location Numbers

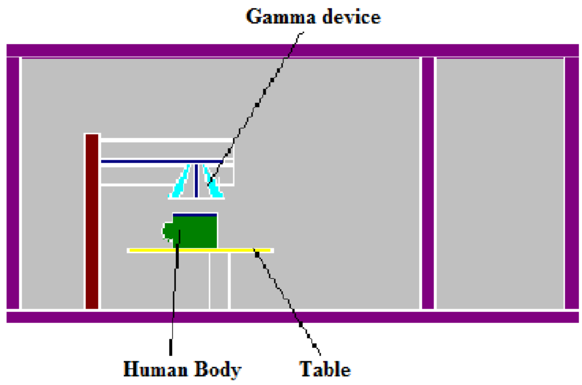

Fig 2. Vertical Layout of gamma Device unit

Results and Discussion

The background radiation level before normal operation was measured using AD6-6150 and TLD card and the mean average value was 0.18 and 0.20µSv/h respectively.

During Normal Operation

The points measured are numbered from 1to 6 and one point (7) out of the door and its chosen at walls med-point and 1 m above the floor as shown in Figure 1. Gamma dose distributions around the gamma device during operation (the source in position ON) are illustrated in table 1. The comparison between the experimental measurements (using AD6-5160 and TLD-100) and the results obtained from MCNP computer model are shown in the same table. From this table it is clear that all the data have the same trend and the dose at the point number 2 is higher than the other points while the lowest dose at point 6. This may be due to point 2 is the nearest one to the device head and there is no shielding in this area while point number 5 is the lower than the dose at points 2,3. This may be due to there are shielding between the head of the device unit and the measured point number 5one (i.e. the measurement doses depending on the distance from the device head). The results indicated good agreement between the measurements and the theoretical computer model [except at point No. 5 and 6, slightly difference].

Table 1. Comparison between measurements and theoretical modeling at different Locations around Gamma unit

Location No.	(TLD) Measurements (normal case) mSv/h	(AD6) Measurements (normal case) mSv/h	MCNP Calculations mSv/h
1	0.666	0.661	0.627 ±0.049
2	2.210	2.010	1.952 ±0.026
3	1.330	1.930	2.023 ±0.029
4	0.019	0.013	0.00238 ±0.000
5	0.313	0.329	1.667 ±0.000
6	0.003	0.005	0.007 ±0.000
7(out the door)	---	----	0.00238 ±0.000

During Emergency Conditions

Figure 3 illustrates the dose rate (µSv/h) versus distance (cm), the distance represents the route ABC at which aemergency person enters the therapy room at emergency conditions during the operation of the Gamma unit. The results indicate that the emergency person moves approximately 10 m from the door to the position of the device. He is exposed to a dose rate which is 2.38 (µSv/h) at the outer area of the door. The dose rate increases to a maximum value of 7000 (µSv/h) at the nearest point to the unit (50 cm from the unit head). This figure is used to evaluate the accumulated gamma dose for a emergency person if he entered the room of the device unit for emergency situations during the operation mode of the unit.

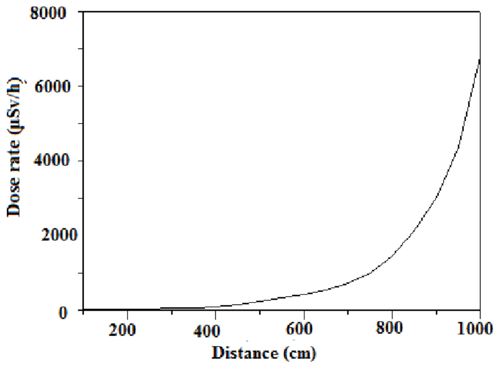

Fig 3. Dose rate (µSv/h) versus distance at emergency entering gamma unit through route ABC

To determine the total dose accumulated (µSv) during emergency conditions through route ABC in Figure 1. The Dose rate (µSv/h) in Figure 3 is fitted in an analytical formula and the resulting formula are integrated over time to determine the total accumulated dose (µSv).

$$D^o = \frac{dD}{dt} = A\exp(x/B) \qquad \textbf{(1)}$$

where
D total dose (µSv)
t time (hours)
x traveling distance through the route ABC (cm)
A, B Constants (A=3.28985, B=131.39148)
(R^2 = 0.99823, Chi^2= 5982.08428). To solve equation (1), the distance x should be expressed as x=vt , where v is the speed (cm/s) where v is constant and t time (s)
Hence;

$$\frac{dD}{dt} = A\exp(vt/B)$$

The exposure dose to the person who fix the problem depending on its speed and the time spending in the unit. This means that the exposure dose is directly proportional to the speed of the person and inversely proportional with the time.

Conclusion

The dose distribution inside the Gamma Cobalt irradiation therapy unit at Egyptian Atomic Energy Authority (EAEA) was determined both Experimentally and theoretically. The dose distribution inside the unit was measured during the unit in operation. MCNP computer code was used to calculate the dose distributions in both normal and abnormal operation of the unit. The results during normal conditions indicated that, good agreement between the measurements and the theoretical computer model (except at point No. 5 and 6). This mean that the angle of reaching the event to the measurements tools may be has difference between experimental and theoretical. The results during emergency conditions indicated that, the person who performs this job will expose to high dose. So he will expose to a maximum dose equal 1.94 µSv/s. Referring to (IAEA Safety Standard),he have totake precautionary urgent protective actions immediately (even under difficult conditions) to keep doses below the generic criteria, i.e. should spend very short time to move and fix the problem.

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