USING MONTE CARLO SIMULATION TO CALCULATE THE DOSE REDUCTION AT THE MAZE ENTRANCE OF A RADIOTHERAPY ROOM

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Abstract:

The aim of this study was to introduce a method to reduce the dose of the backscattered photons from a linear accelerator at the maze entrance of a radiotherapy room (RR). For this purpose a typical RR was designed and simulated using FLUKA Monte Carlo Code (version 2011.2b.1). The maze of a RR was the main focus for the study. Its walls including, floor and ceiling were lined with thin sheets of lead and stainless steel of 2 mm and 4 mm thicknesses respectively to find the most effective material and thickness for dose reducing.

It was found that 2 mm lead sheet was able to reduce the dose at the maze entrance by more than 60 % and 4 mm 70 %. Whereas, 2 mm of stainless steel was able to reduce about 30% of the dose and 4 mm was able to reduce about 35%.

Keywords: Scattered photons, radiotherapy room, calculation of the dose at the maze, radiation protection, FLUKA Monte Carlo Code.

1- Introduction:

Radiotherapy is one of the main treatment modality for cancer disease and external beam radiation treatment is the most common form of radiotherapy. Cancerous cells are destroyed through damage caused by X-rays ionising radiation. Energy is transferred to tissue by the photon beam through particle interactions within the tissue (Marcu et al, 2012). Unfortunately, as we all should know, radiation is a double-edged sword. Radiation that can treat tumors and save lives can also cause cancer, cataracts, etc. and is potentially lethal (Hall, 2005). Therefore, patients receiving radiotherapy as well as staff working near linear accelerator need to be shielded from high-energy radiation doses. These two groups are protected in quiet different ways: normally patients are protected by direct shielding on the linear accelerator; whilst staff and passerby are protected by mazes and thick concrete walls.

The primary objective of designing a radiotherapy room (RR) and its access maze together called “bunker” is to ensure that dose rate limits for staff and the public are not exceeded and are kept as low as reasonably practicable. This is accomplished by constructing the walls of bunkers thick enough from medium and high density materials such as concrete, lead and steel to provide adequate shielding. The degree to which photon beam is attenuated depends upon the photon energy, the atomic number and density of the elements in the shielding material, the thickness of the shielding (Amin, 2014).

The maze length and shape must be such that there are satisfactory dose rates at the interface with the outside RR. At this point there are two factors contributing to the dose rate. The first factor is the x-rays (photons) that are generated from the interactions of primary beam within patients, collimators, surface of walls of RR and air in the room. It is found that the energy spectra of those photons were not to exceed 400 keV with an average of about 100 keV (Biggs, 1991; Al-Affan et al, 1998; Al-Affan, 2000). The second factor is the leakage radiation from the treatment head. Leakage radiation penetrates machine head and travels through the wall adjacent to the maze entrance (Ionisation Regulation Radiation, 1991).

Previously several actions were taken to reduce the dose at the maze entrance such as extending the maze length long enough or add a turn with a small length in the maze (called legs) in a different direction (Carinou et al, 1999). However, extending the maze length whether in one direction or adding another leg in a different direction would certainly add to the cost of RRs, occupy more space which can be a problem if the situation was to upgrade an existing RR within an area of a very limited space. A long maze would also mean more time being taking patients in and out of RRs; accordingly, it is significant to determine another method to reduce the dose.

Both lead and steel are widely used for radiation protection purposes, because of their high absorption of radiation. Lead has a very high density and is a very good X- and gamma ray shielding material, however, it is toxic and more expensive than concrete (Xu, 2008). Steel is also expensive compared to concrete, but is not toxic (James, 2005). It is more efficient than concrete as an X- and gamma rays shielding material, but less efficient than lead. However, it should be noted that steel has the advantage of lower photoneutron production (Biggs, 2010).The aim of this research was to focus on the scattered photons which may contribute more than 50% of the dose at the maze entrance (Al-Affan and Smith, 1996; Al-Affan, 2000) and how they can be reduced. This can be achieved by lining the surface of the maze walls by different metals (lead and stainless steel) with various thicknesses by using a computational method termed Monte Carlo simulation. Leakage radiation could be treated in the future study. The treatment head of a linear accelerator can be modeled to produce leakage radiation and see the level of leakage radiation at the maze entrance and how it can be reduced either through increasing the thickness of the wall adjacent to the maze entrance or line the wall surface with extra high density material such as lead.

2- Method of Calculations:

This research presents a method using Monte Carlo simulation to predict energy spectrum based upon the ratio of photon backscattered from the walls of the RR, particularly the maze walls. The simulation was divided into three different parts; in the first simulation, RR with its access maze was modeled without any change; in the second simulation, the walls of the maze including its roof and floor were lined with 2 and 4 mm lead sheet of density 11.25 g.cm^{-3} respectively; and in the third simulation, walls of the maze including its roof and floor were lined with 2 and 4 mm stainless sheet of density 8.0 g.cm^{-3} respectively. The geometry of the RR with its access maze is shown in Figure 1.

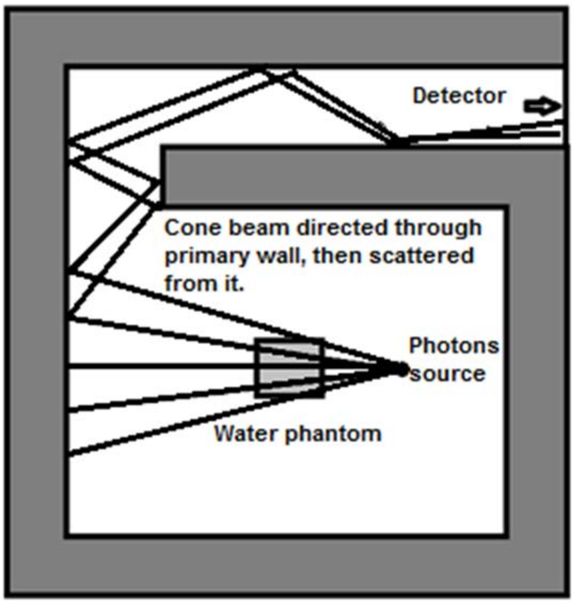

Figure 1: Diagram of a typical radiotherapy room used to calculate the dose for multi-scattered photons at the maze entrance.

The room walls, roof and floor are made of concrete of density 2.35 $g.cm^{-3}$. Also, in this simulation, it was assumed and suggested by National Council on Radiation Protection & Measurements (NCRP, 2005) that the concrete had an elemental composition of (in percentage by weight composition) 0.92% hydrogen, 49.83% oxygen, 1.71% sodium, 4.56% aluminum, 31.58% silicon, 1.92% potassium, 8.26% calcium and 1.22% iron. The typical RR including the maze was 1200.0 cm in length, 800.0 cm in width, and 300.0 cm height. All walls had 100 cm thickness, and both floor and roof thicknesses were 30 cm (that assumption was used to speed up the computation without compromising the results). The photon source was fixed at 100 cm away from the surface of the rectangular parallelepiped water phantom that had a symmetric size of 50 cm × 50 cm × 50 cm a long beam axis. Moreover, in this simulation the worst case of the beam was selected (i.e. the highest expected dose at the maze entrance). Although photons source from the linear accelerator is divided into primary photons and leakage photons, in the present work, beam was assumed to have only primary photons and leakage photons was ignored because less amount of the dose at the maze entrance comes from leakage photons in compare to scattered photons. The photon beam had a radius of 5.65 cm (at 100 cm from the phantom surface) at the surface of water phantom giving an equivalent area (field size) of 10 x 10 cm^2.

In order to calculate doses of backscattered photons and increase the efficiency of the detector, a large rectangular parallelepiped water detector was positioned at the entrance of the maze and covered the maze as a door. This detector approximately was 200.0 cm in length, 1 cm in depth, and 300 cm in height. This size was restricted by the width and height of the maze.

The whole geometry was surrounded by a large sphere of Void of 1000 cm in radius and of air medium, and this was surrounded by a larger sphere of Black Hole of 100000 cm in radius. The irradiations were carried out for a range of photon energies (0.5, 1, 2, 3, 5, and 6 MeV) to study several components of the X-ray spectrum which are usually present in the primary beam (of energies up to 10 MV). These energies were taken because if the photon energy is greater than (6-7 MeV or 10 MV) neutrons are generated by photonuclear reaction in the treatment head of the linear accelerator (Ongaro et al, 1999). Therefore different actions need to be taken for the purpose of dose reduction due to scattered neutrons. For each energy value FLUKA MC was run for 3 cycles to reduce statistical fluctuation in the results; moreover, 1x 10^7 photon histories were followed for each simulation to get the required statistical uncertainty of better than 10%. Therefore, calculations of the doses were taken for a long time, which was about 100 hours per 3 cycles for all statuses.

3- Results and Discussion:

Table 1 shows that the calculations made by the detector that was placed at the entrance of the maze. It can be seen that the ratio of the dose at the maze entrance as shown in Fig. 1 when 2 mm lead was used to that with no lead (only concrete wall) varies from 26% to about 39% depending on the energy of the primary beam generated by the linear accelerator.

Table 1: Dose with 2 mm lead **(D_L)** and with concrete **(D_C)** and their ratios at the entrance of the maze

Energy (MeV)	D_L (MeV/cm^3) per particle (×10^{-7})	D_C (MeV/cm^3) per particle (×10^{-7})	Ratio=(D_L / D_C)x100 %	Percentage of statistical uncertainty
0.5	0.82	3.16	26.0	8
1	1.1	3.93	28.0	9
2	1.85	5.56	33.26	5
3	1.96	5.43	36.12	7
4	1.95	5.67	34.41	8
5	2.08	5.59	37.27	6
6	2.25	5.77	38.90	9

However, in the Table 2 it can be seen that the ratio of the dose at the maze entrance when 4 mm lead was used to that with no lead (only concrete wall) varies from 23% to about 28% depending on the energy of the primary beam generated by the linear accelerator. Therefore it would be useful to know the spectrum of the primary beam to be able to simulate the dose calculations at the maze entrance. This would be interesting to show that 2 mm lead lining the maze would reduce the dose scattered through the maze by more than 60% and 4 mm lead lining the maze would reduce more than 70% of the scattered dose.

Table 2: Dose with 4 mm lead **(D_L)** and with concrete **(D_C)** and their ratios at the entrance of the maze

Energy (MeV)	D_L (MeV/cm^3) per particle (×10^{-7})	D_C (MeV/cm^3) per particle (×10^{-7})	Ratio=(D_L / D_C)x100 %	Percentage of statistical uncertainty
0.5	0.74	3.16	23.0	8
1	1.2	3.93	26.0	9
2	1.66	5.56	30.00	5
3	1.40	5.43	26.00	7
4	1.49	5.67	26.27	8
5	1.86	5.59	33.24	5
6	1.60	5.77	28.00	7

Table 3 shows calculations made by same detector and under same conditions, only lining metal was changed from lead to stainless steel. It can be noted that the ratio of the dose at the maze entrance varies from 49% to 77% when 2 mm of stainless steel was used to that with no stainless steel .So, this means that 2mm of stainless steel can reduce lesser amount of the scattered dose than 2 mm of lead. This due to fact that stainless steel has lesser density than lead.

Table 3: Dose with 2 mm stainless steel **(Ds)** and with concrete **(Dc)** and their ratios at the entrance of the maze

Energy (MeV)	D_S (MeV/cm^3) per particle ($\times10^{-7}$)	D_C (MeV/cm^3) per particle ($\times10^{-7}$)	Ratio=(D_S / D_C)x100 %	Percentage of statistical uncertainty
0.5	1.57	3.16	49.84	8
1	2.82	3.93	71.95	6
2	4.43	5.56	79.67	7
3	3.97	5.43	73.16	7
4	3.64	5.67	64.23	8
5	3.92	5.59	70.03	6
6	4.49	5.77	77.80	4

However, in the Table 4 it can be seen that the ratio of the dose at the maze entrance when 4 mm stainless steel was used to that with no stainless steel varies from about 50% to about 80% depending on the energy of the primary beam generated by the linear accelerator. By comparing the calculations of the Table 3 and Table 4, it can be noted that there was not much difference between the ratios of the dose with 2 mm and 4 mm stainless steel sheets.

Table 4: Dose with 4 mm stainless **(Ds)** and with concrete **(Dc)** and their ratios at the entrance of the maze

Energy (MeV)	D_S (MeV/cm^3) per particle ($\times10^{-7}$)	D_C (MeV/cm^3) per particle ($\times10^{-7}$)	Ratio=(D_S / D_C)x100 %	Percentage of statistical uncertainty
0.5	1.57	3.16	49.84	8
1	2.55	3.93	65.04	7
2	3.93	5.56	70.68	10
3	3.54	5.43	65.24	9
4	3.28	5.67	57.84	6
5	3.62	5.59	64.79	8
6	4.63	5.77	80.24	9

In this study, it is clear that from the calculations shown in Tables (1, 2, 3 and 4), 2 mm and 4 mm lead sheets could reduce more scattered dose than stainless steel, and therefore, it is better than stainless steel for the purpose of the maze lining. In addition, 2 mm lead should be the thickness of choice for the purpose of maze lining and dose reduction at the maze entrance, due to some Physical phenomenon such as Photoelectric effect, Compton scattering and Pair production which occurs at photon energy more than 1 MeV and may contribute with the scattered photons and after that increase the dose.

Practical measurement of the dose from the scattered photons at the maze entrance would be harder than theoretically (computing) due to contributions of the leakage radiation which may effects the actual calculations. Leakage radiation arises from the treatment of the linear accelerator. Therefore, the treatment head must be shielded to reduce it as low as practically applicable. Otherwise there will be disagreement between practical and computed calculations.

4- Conclusion:

The aim of the present research was to use and compare two different shielding materials for the purpose of dose reduction at the maze entrance of radiotherapy rooms. After simulation and design of RR with its maze, irradiation was carried out for rang energies up to 6 MeV, it was found that 2 mm lead sheet could reduce up to about 60 % and 4 mm 70 % of the dose. Whereas 2 mm of stainless could reduce about 30 % and 4 mm 35 %, of the dose of backscattered photons at the maze entrance when linear accelerator runs at the worst case (highest expected dose at the maze entrance).

In this research, it was determined that lead is the material of choice for the maze lining to reduce the dose, because of its high photons absorption compare to the stainless steel. In addition, photons energy more than 10 MeV or higher energies will lead to photoneutron production and so another method needs to be used to solve the problem. Therefore energies lower than 10 MeV were selected.

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كورتی:

مەرەم ژ ڤێ ڤەكولینێ ئەوە كو رێكەكێ دیاركەین بو كێمكرنا دوزا فوتونێت دشكێن و پاشڤە دزڤرن ژ ئامیرێ تاودانەوا راستەوانەی ل بەردەمێ رێكا جونا ژورا چارەسەركرنا تیشكی (RR). ژبەر ڤێ مەرەمێ ژورەكا جوری یا (RR) هاتە دیزاینكرن ب رێكا پروگرامێ مونتی كارلو كود (دەرچوون b.1٢٠١١.٢). رێكا بەردەمێ (RR) مەرەما سەرەكی یا ڤێ ڤەكولینێ بو. هەمی دیوارێت وێ دكەل ئەرد و بانێت وێ هاتنە داپووشین ب قاتێت تەنك یێت قوروقوشمی و ستیلی یێ ٢ ملم و ٤ ملم ستیر ل دویف ئێك ژبو دیاركرنا كاریگەرترین مادده و ستیراتی ژبو كێمكرنا دوزێ.

دڤێ ڤەكولینێ دا هاتە دیاركرن كو ٢ ملم یێت قورقوشمی دشێن دوزێ كێم كەن ل بەردەمێ ژورا چارەسەركرنا تیشكی پتر ژ ٦٠٪ و ٤ ملم ٧٠٪. بەلێ یا ٢ ملم ستیلی دشێن نێزیكی ٣٠٪ یا دوزێ و ٤ ملم دشێن ٣٠٪ كێم كەن.

الخلاصة:

كان الهدف من هذه الدراسة هو تقديم طريقة لتقليل جرعة من الفوتونات المرتدة من معجل خطي عند مدخل متاهة من غرفة العلاج الإشعاعي (RR). لهذا الغرض تم تصميم (RR) نموذجي باستخدام FLUKA مونت كارلو كود (الإصدار b.1٢٠١١.٢). وكانت المتاهة من (RR) التركيز الرئيسي للدراسة. لذلك صطف جدرانه بما في ذلك والأرضيات والسقف مع صفائح رقيقة من الرصاص والفولاذ المقاوم للصدأ ٢ مم و ٤ مم سمك على التوالي للعثور على المواد وسمك الأكثر فعالية للمتصاص جرعة.

وقد تبين أن ٢ مم ورقة الرائدة تمكنت من تقليل الجرعة عند مدخل المتاهة بأكثر من ٦٠٪ و ٤ مم ٧٠٪. في حين كانت ٢ ملم من الفولاذ المقاوم للصدأ قادرة على الحد من حوالي ٣٠٪ من الجرعة وكان ٤ مم قادرة على تخفيض حوالي ٣٥٪.