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Simulation of Photon and Electron dose distributions by MCNP5 code for the treatment area using the linear electron accelerator (LINAC) in Dongnai General Hospital, Vietnam

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ABSTRACT:

Nowadays, radiotherapy by linear electron accelerator (LINAC) has become popular and given high effects for cancer treatment in hospitals of Vietnam. The paper presents simulation for distribution of radiation dose rate by MCNP5 code for electron and photon radiations inside and outside a treatment room in Dongnai General Hospital. From that, a comparison between the results of calculation and those of experimental measurements at Dongnai General Hospital could be carried out.

The calculation results described the distributions of radiation dose rate fields at some positions inside and outside the treatment room. This is one of the important bases for calculating radiation safety in radiotherapy as well as construction and setup of the treament room.

Keywords: *Radiotherapy, Linear electron accelerator* **(***LINAC), Radiation safety, Dose field, MCNP5 code*

I. INTRODUCTION

The LINAC can emit one of two types of radiation which are photons, electrons with high dose rate, so the dose rate distribution in the treatment area is relatively complex. From receiving the dose distribution results fully and accurately, some comments about radiation safety for healthcare facilities using the LINAC should be recommened. MCNP5 code is used to calculate and simulate distributions of photon and electron dose rate inside and outside the treatment room. Subjective of simulations in this report is Primus machines of Cancer Center, Dongnai General Hospital, Vietnam.

II. EXPERIMENTAL

Radiation therapy room in Dongnai General Hospital is setup according to the general regulations of the manufacturer [1] with machine room dimensions shown in Figure 1.

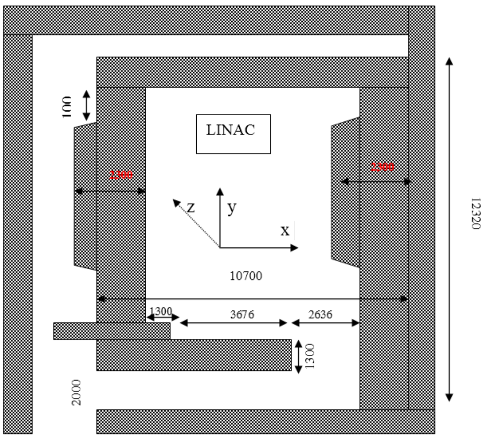

Figure 1. Radiation room model at Dongnai General Hospital

The internal and external walls were made by concrete with density of 2.5 g/cm^3. Radiation therapy room door was made by lead together on/off semi-automatic control system.

Configuration and parameters of LINAC:

Configuration and specifications of the LINAC [2] are as follows:

- Brand: Primus;
- Manufacturer: Siemens (Germany);
- Radiation types:

  + Single-energy electrons with energies of 5, 7, 8, 10, 12, 14 MeV;

  + Photons with energies of 6 and 15 MV are contributed in Table 1 and 2.

Table 1. Distribution of photon beam with energy of 6 MV

Energy (MV)	Relative probabilities (%)	Energy (MV)	Relative probabilities (%)	Energy (MV)	Relative probabilities (%)	Energy (MV)	Relative probabilities (%)
0.10	0.05	0.40	0.80	1.00	11.80	3.00	9.60
0.15	0.10	0.50	1.60	1.25	14.40	4.00	8.10
0.20	0.20	0.60	3.20	1.50	15.80	5.00	6.40
0.30	0.60	0.80	9.00	2.00	16.40	6.00	0.80

Table 2. Distribution of photon beam with energy of 15 MV

Energy (MV)	Relative probabilities (%)	Energy (MV)	Relative probabilities (%)	Energy (MV)	Relative probabilities (%)	Energy (MV)	Relative probabilities (%)
0.10	0,06	0.50	2.28	1.50	4.86	6.00	7.17
0.15	0.73	0.60	2.35	2.00	10.18	8.00	6.72
0.20	0.89	0.80	4.69	3.00	16.98	10.00	4.19
0.30	1.98	1.00	4.65	4.00	13.48	15.00	1.00
0.40	2.19	1.25	5.42	5.00	9.08	20.00	0.00

Notice: These values obtained as performing QA at Dongnai General Hospital.

Setup the input file:

Input files are a description of all the parameters of the problem, including materials, resources, components of LINAC [3].

The geometry of the problem consists of two components: fixed part and the other is routating part with many different angles around the axis of the machine.

- Radiotherapy room consists of 4 walls around the room, primary radiation shielding walls, hallways, a patient bed and a lead door.

- Accelerator consists of the machine body, a locomotive, cones, a waveguide, a Tungsten target, two ionization chambers, the collimator and jaws with an aperture of 1.83×1.83 cm^2 (according to the field size 40×40 cm^2).

Source with disc-shape, isotropic toward the patient bed with a distance of 224 cm from ground. Photon and electron energy levels listed above.

The objective of the work is to calculate dose rate in air and concrete blocks shaped 1.5 cm diameter, 5 cm width at the following locations:

+ Direction -$\vec{y}$: the cell with coordinates of (0,-5,120), (0,-10,120)... (0,-400,120), respectively.

+ Direction -$\vec{x}$: the cell with coordinates of (-5,0,120), (-10,0,120) ... (-590,0,120), respectively; original co-ordinate is from ground, and the central axis of the source.

III. RESULTS AND DISCUSSION

After using the software simulation mode and calculated by the Visual Editor executable (command form), the results are as follows:

Simulation of radiation therapy room structure by MCNP5 visual version

The treatment room at *Dongnai General Hospital is decribed in 3 dimension space by MCNP5 in Figure 2.*

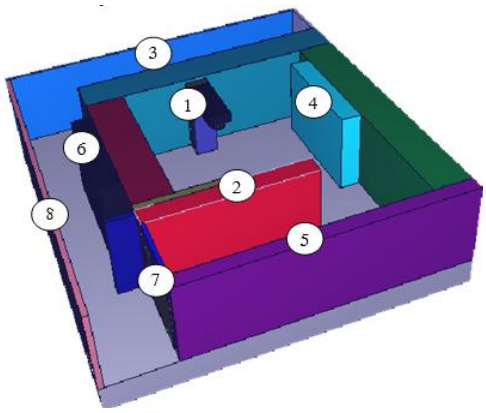

Figure 2. The treatment room at Dongnai General Hospital
(1: LINAC; 2: inside walls; 3, 4, 5, 6: concrete walls; 7: lead door; 8: corridor)

Scattering of photons and electrons* inside *the room

Implementation of particle display function of this software for simulation of scattering processes of photons and electrons in the treatment room is presented in Figures 3, 4 and 5.

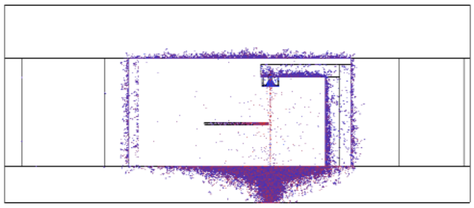

Figure 3. Scattering of 15 MV energy photons (plane y, z)

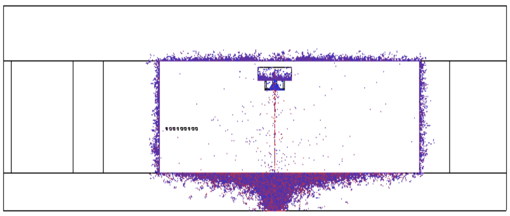

Figure 4. Scattering of 15 MV energy photons (plane x, z)

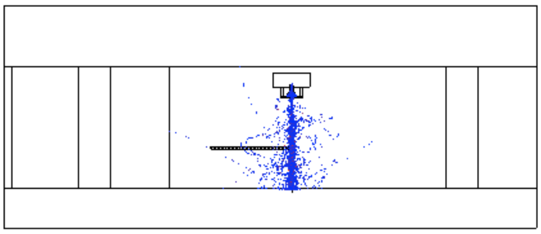

Figure 5. Scattering of 10 MeV energy electrons (plane x, z)

From the scattering images, It is obviously shown that: range of scattering photon is very large and complex distribution in the case of large particles carrying out with range spreading over the room, consisting of locomotives. In the case of gantry at 0^o angle, primarily scattering direction is toward the patient bed. For the case of gantry at 90^o angle, the scattering direction is directed toward the operators with a relatively high intensity, and the scattering range of electron has tendency for concentrating in the direction from the source to the patient bed.

Results of calculating dose rate

From calculating the dose rate for each position, the dose distribution with distances from the source is obtained. Besides, these results had been compared with experimental results measured by the portable photon dose-rate meter of Inspector (made in USA).

Table 3. The dose distribution of 15 MeV energy photon in the direction of $-\vec{y}$

Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error (*)	Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error	Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error
0	119238	0.002	100	1389	0.019	200	223	0.035
5	114602	0.004	105	1210	0.02	205	213	0.036
10	98721	0.005	110	1062	0.02	210	192	0.037
15	32470	0.006	115	919	0.022	215	186	0.034
20	23848	0.007	120	811	0.023	220	159	0.035
25	18610	0.008	125	738	0.024	225	150	0.035
30	14647	0.009	130	682	0.024	230	143	0.036
35	11907	0.009	135	606	0.025	235	137	0.036
40	9637	0.010	140	550	0.026	240	124	0.036
45	8042	0.011	145	487	0.027	245	115	0.036
50	6622	0.011	150	446	0.028	250	111	0.036
55	5601	0.012	155	423	0.028	255	103	0.036
60	4743	0.013	160	391	0.029	260	98	0.036
65	3902	0.013	165	341	0.03	265	81	0.037
70	3378	0.014	170	321	0.032	270	72	0.037
75	2896	0.015	175	314	0.031	275	63	0.037
80	2552	0.015	180	305	0.032	280	51	0.037
85	2116	0.016	185	274	0.033	285	42	0.037
90	1815	0.017	190	246	0.034	290	38	0.037
95	1562	0.018	195	226	0.035	295	21	0.038

* Relactive error $*R = S_{\bar{x}}/\bar{x}$ and represents the estimated relative error at the 1σ level. These interpretations of R assume that all portions of the problem phase space are being sampled well by the Monte Carlo process Calculation and simulation results showed consistent ones with experimental values. The measured experimentally values are negligible higher due to environmental background [3].

Table 4. The dose distribution of 15 MV energy photon in the direction of $-\vec{x}$

Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error	Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error	Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error
0	119338	0.0020	100	1375	0.0189	200	234	0.0354
5	114613	0.0037	105	1215	0.0200	205	219	0.0366
10	98634	0.0052	110	1059	0.0203	210	179	0.0340
15	31970	0.0063	115	961	0.0216	215	168	0.0340
20	23830	0.0071	120	849	0.0224	220	158	0.0370
25	18590	0.0078	125	745	0.0234	225	148	0.0380
30	15049	0.0085	130	661	0.0242	230	128	0.0390
35	12090	0.0091	135	585	0.0251	235	119	0.0410
40	9596	0.0099	140	564	0.0256	240	107	0.041

Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error	Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error	Distance from source (cm)	Dose rate calculated by MCNP (mSv/h)	Relative error
45	7948	0.0106	145	500	0.0269	245	106	0.042
50	6614	0.0112	150	465	0.0274	250	90	0.042
55	5627	0.0118	155	436	0.0275	255	87	0.043
60	4716	0.0125	160	410	0.0283	260	65	0.044
65	4029	0.0132	165	353	0.0297	265	51	0.045
70	3462	0.0139	170	328	0.0307	270	47	0.046
75	2863	0.0148	175	322	0.0310	275	42	0.046
80	2444	0.0155	180	287	0.0330	280	35	0.046
85	2177	0.0161	185	262	0.0335	285	29	0.047
90	1878	0.0170	190	259	0.0334	290	25	0.047
95	1608	0.0181	195	243	0.0343	295	19	0.047

Table 5. A comparison between the calculated results and experimental measurements

Number	Location	Field Size (cm)	calculated (µSv/h)	experimental (µSv/h)	difference (%)
1	200,420,120	20	903	1000	9.7
2	200,440,120	20	892	1000	10.8
3	200,460,120	20	861	980	12.1
4	200,480,120	20	835	978	14.6
5	200,500,120	20	829	945	12.3
6	200,420,120	40	925	1000	7.5
7	200,440,120	40	910	1000	9.0
8	200,460,120	40	916	1000	8.4
9	200,480,120	40	870	1000	13.0
10	200,500,120	40	810	980	17.3

Because the threshold of the dose rate meter is 1000 µSv/h, therefore just only measuring at a few of locations far from the center axis. As simulation process is just only care of photon (mode p), however, measured dose rate included secondary radiation particles. Hence, measured results are always higher than simulated ones.

Table 5. The dose distribution of 15 MV energy photon in the direction of -$\vec{x}$ (in primary leftside concrete wall)

Distances from the source (cm)	Dose rate calculations MCNP (µSv/h)	Distances from the source (cm)	Dose rate calculations MCNP (µSv/h)
305	3798.47	360	585.43
310	3204.63	370	416.69
320	2280.96	380	296.59
330	1623.52	390	211.10
340	1155.57	400	150.26
350	822.50	410	106.95

Notice: In this case, there is no any measurement (because of these cells inside the concrete wall).

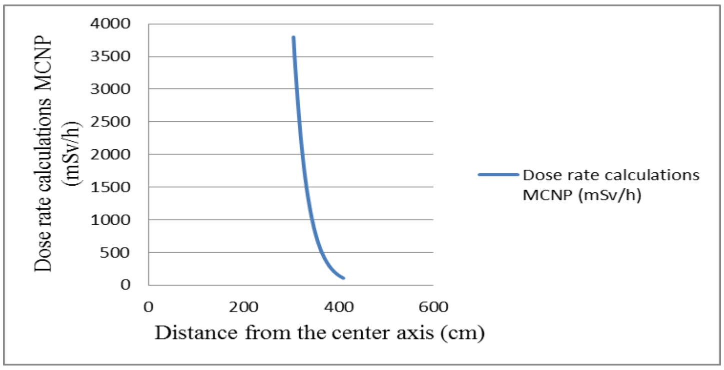

Figure 6. A decrement of dose rate inside leftside concrete wall (refer to Table 5)

Radiation is decreased rapidly in the concrete wall, so the concrete shielding is suitable. The simulation of radiation and dose rate measurements can help for getting optimal shielding.

Table 6. The dose distribution of 10 MeV energy electron in the direction of $-\vec{x}$

Distance from source (cm)	Dose rate calculated by MCNP (µSv/h)	Relative error	Distance from source (cm)	Dose rate calculated by MCNP (µSv/h)	Relative error	Distance from source (cm)	Dose rate calculated by MCNP (µSv/h)	Relative error
0	119942	0.002	65	100	0.015	130	19	0.028
5	113691	0.003	70	85	0.016	135	18	0.029
10	68987	0.004	75	75	0.017	140	16	0.033
15	1224	0.005	80	60	0.018	145	15	0.034
20	814	0.006	85	48	0.019	150	13	0.035
25	549	0.007	90	44	0.02	155	12	0.036
30	404	0.008	95	43	0.024	160	11	0.038
35	329	0.009	100	36	0.026	165	7.1	0.038
40	265	0.010	105	31	0.026	170	6.7	0.038
45	208	0.011	110	31	0.026	175	4.0	0.038
50	175	0.012	115	29	0.027	180	3.9	0.038
55	152	0.015	120	26	0.027	185	3.5	0.039
60	132	0.015	125	20	0.027	190	3.4	0.039

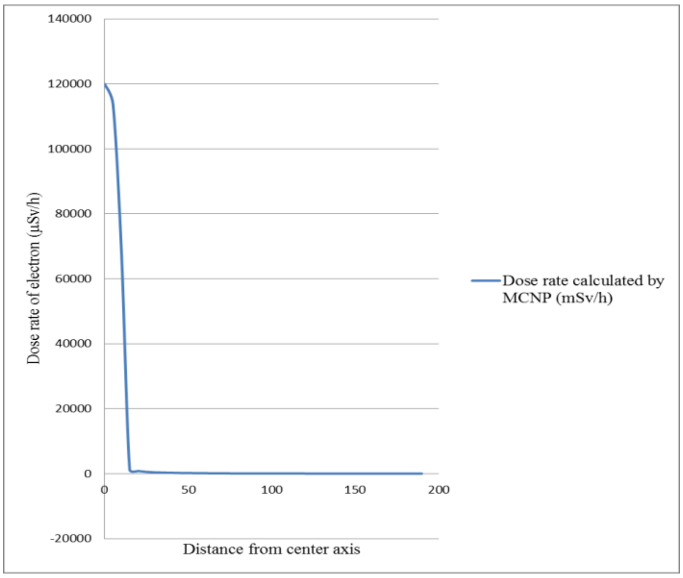

Figure 7. Dose rate distribution from the center axis to outside site

Refer to Figure 7, it is shown that electron dose rates decreased rapidly with distance, because their concentration is higher than that of photons.

IV. CONCLUSION

From independently simulation by the MCNP5 software, the obtained results are relatively consistent with experimental measurements. This allows the user to confirm that the simulation method and calculation of dose rate distribution for all radiation in different energy levels at all positions inside and outside the radiation room are suitable. From that, a 3-dimension map on dose rate field distribution inside and outside the treatment room could be established.

One of the important goals of our research is directed toward safety shielding calculations for radiation treatment room for the sake of being sure of radiation safety and gathering in the high efficiency of economics by changing thicknesses of the concrete as well as the size and structure of the treatment room.

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