**Study on the use of the number of attachments and neutral dissociations as a measure of damage in a gamma radiotherapy linac**

**Introduction**

The idea of the study is to check if the number of attachments and neutral dissociations caused by a gamma radiotherapy linac beam is not proportional to the dose in all areas.

**Material and methods**

We have calculated in different areas of a water phantom the dose and compared it to the number of attachments and neutral dissociations. The points selected are marked in figure 1.

**P1**

**P2**

**P3**

**P4**

**P5**

**P6**

**P7**

**P8**

**P9**

Fig. 1. Calculation points

The dimensions of the voxel to calculate the dose are 2x2x2 mm. 1.E9 events take about 130 hours of CPU and the dose has an error that is quite big for the points at the edges (see Table 1). Reducing the voxel for example to 1x1x1 mm would mean that we would need 64 times more CPU for the same error, what seems prohibitive. In any case the conclusions of this work are not expected to change by a further reduction of the voxel dimensions.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  | | --- | --- | --- | --- | |  | Dose +- (REL error) | | | | P1 | 2.98E-14 | +- | 0.0107815 | | P2 | 2.02E-14 | +- | 0.0131094 | | P3 | 1.15E-14 | +- | 0.0174004 | | P4 | 6.66E-15 | +- | 0.0234022 | | P5 | 1.91E-14 | +- | 0.013494 | | P6 | 1.91E-15 | +- | 0.0399702 | | P7 | 1.18E-15 | +- | 0.0576965 | | P8 | 6.29E-16 | +- | 0.104196 | | P9 | 2.78E-16 | +- | 0.131382 | |

Table 1. Dose at points in water cube calculated with Livermore physics

We have divided the calculations in three.

1. Calculate the phase space of particles after traversing the linac geometry, using EGSnrc and the real linac geometry with a field 10x10 cm
2. Send the particles in the phase space on a phantom of water of dimensions 35x35x35cm placed starting at Z=100 cm, using Livermore GEANT4 phyiscs. The dose in the phantom is calculated in the cubes placed at the nine indicated positions. We write a phase space of the electrons and positrons created by an interaction (photoelectric, Compton or pair conversion) of a beam gamma that may reach one of the cubes. This electron will later be tracked with LEPTS, so to avoid having to track all electrons, we have only saved those that have a change to reach the voxel:
   1. Are created in the voxel (voxel)
   2. Or are created in a cube 20x20x20 mm around the voxel (voxelBig)
   3. Or have an energy > 1 MeV (outVoxel)
3. We chose one of the nine voxels and track with LEPTS all the electrons that may reach the voxel. To understand it better we have separated in different jobs the electrons from the three cases above. For case a) we track all, but for cases b) and c) we do not track those whose energy would not allow them to reach the voxel: we have studied that the probability that an electron or its secondaries reach a distance from its origin bigger than D (cm) = 1.1 E (MeV) is very small, so we use the condition that the distance of the origin of an electron to the voxel walls have to be D (cm) < 2\*E (MeV) to start its tracking.

**Results**

For each of the nine voxels we calculated in the voxel the dose, the number of attachments, the number of neutral dissociations and the ratio:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | N ATTACH | N NEUT DISS | DOSE | DOSE ERROR (REL) | DOSE/NATT | DOSE/NNEUD | %DOSE |
| P1 | voxel | 5606,2 | 22116,7 | 1,44E-14 |  | 2,57E-18 | 6,50E-19 | 16,8% |
|  | voxelBig | 22247,0 | 80879,3 | 5,71E-14 |  | 2,57E-18 | 7,06E-19 | 66,8% |
|  | outVoxel | 5694,2 | 21344,3 | 1,39E-14 |  | 2,45E-18 | 6,53E-19 | 16,3% |
|  | TOTAL | 33547,4 | 124340,3 | 8,54E-14 | 0,16 | 2,55E-18 | 6,87E-19 |  |
|  |  |  |  |  |  |  |  |  |
| P2 | voxel | 4178,2 | 16209,4 | 1,07E-14 |  | 2,57E-18 | 6,61E-19 | 15,0% |
|  | voxelBig | 15747,9 | 60543,1 | 4,08E-14 |  | 2,59E-18 | 6,74E-19 | 56,9% |
|  | outVoxel | 8149,9 | 31122,3 | 2,01E-14 |  | 2,47E-18 | 6,47E-19 | 28,1% |
|  | TOTAL | 28076,1 | 107874,7 | 7,17E-14 | 0,11 | 2,55E-18 | 6,65E-19 |  |
|  |  |  |  |  |  |  |  |  |
| P3 | voxel | 2082,3 | 8087,8 | 5,29E-15 |  | 2,54E-18 | 6,54E-19 | 14,4% |
|  | voxelBig | 8806,6 | 33055,2 | 2,23E-14 |  | 2,53E-18 | 6,74E-19 | 60,6% |
|  | outVoxel | 3697,4 | 14038,9 | 9,19E-15 |  | 2,49E-18 | 6,55E-19 | 25,0% |
|  | TOTAL | 14586,3 | 55181,9 | 3,68E-14 | 0,13 | 2,52E-18 | 6,67E-19 |  |
|  |  |  |  |  |  |  |  |  |
| P4 | voxel | 1141,1 | 4514,7 | 2,90E-15 |  | 2,54E-18 | 6,43E-19 | 12,6% |
|  | voxelBig | 5681,1 | 20939,4 | 1,26E-14 |  | 2,21E-18 | 5,99E-19 | 54,4% |
|  | outVoxel | 3061,0 | 11515,4 | 7,64E-15 |  | 2,49E-18 | 6,63E-19 | 33,1% |
|  | TOTAL | 9883,2 | 36969,5 | 2,31E-14 | 0,06 | 2,34E-18 | 6,25E-19 |  |
|  |  |  |  |  |  |  |  |  |
| P5 | voxel |  |  |  |  |  |  |  |
|  | voxelBig |  |  |  |  |  |  |  |
|  | outVoxel |  |  |  |  |  |  |  |
|  | TOTAL |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| P6 | voxel | 937,3 | 3841,7 | 2,42E-15 |  | 2,58E-18 | 6,30E-19 | 27,2% |
|  | voxelBig | 1331,5 | 5155,9 | 3,35E-15 |  | 2,52E-18 | 6,50E-19 | 37,6% |
|  | outVoxel | 1252,6 | 4840,4 | 3,14E-15 |  | 2,51E-18 | 6,48E-19 | 35,2% |
|  | TOTAL | 3521,3 | 13838,0 | 8,91E-15 | 0,10 | 2,53E-18 | 6,44E-19 |  |
|  |  |  |  |  |  |  |  |  |
| P7 | voxel | 697,2 | 2869,0 | 1,80E-15 |  | 2,58E-18 | 6,27E-19 | 49,7% |
|  | voxelBig | 655,1 | 2541,7 | 1,65E-15 |  | 2,52E-18 | 6,48E-19 | 45,5% |
|  | outVoxel | 58,3 | 270,9 | 1,72E-16 |  | 2,95E-18 | 6,35E-19 | 4,8% |
|  | TOTAL | 1410,6 | 5681,6 | 3,62E-15 | 0,06 | 2,57E-18 | 6,37E-19 |  |
|  |  |  |  |  |  |  |  |  |
| P8 | voxel | 450,3 | 1868,6 | 1,17E-15 |  | 2,59E-18 | 6,25E-19 | 57,2% |
|  | voxelBig | 273,9 | 1087,8 | 7,00E-16 |  | 2,56E-18 | 6,44E-19 | 34,3% |
|  | outVoxel | 64,3 | 262,9 | 1,74E-16 |  | 2,70E-18 | 6,61E-19 | 8,5% |
|  | TOTAL | 788,5 | 3219,3 | 2,04E-15 | 0,07 | 2,59E-18 | 6,35E-19 |  |
|  |  |  |  |  |  |  |  |  |
| P9 | voxel | 198,9 | 832,2 | 5,18E-16 |  | 2,61E-18 | 6,23E-19 | 53,3% |
|  | voxelBig | 137,5 | 553,8 | 3,56E-16 |  | 2,59E-18 | 6,43E-19 | 36,6% |
|  | outVoxel | 39,0 | 150,6 | 9,86E-17 |  | 2,53E-18 | 6,55E-19 | 10,1% |
|  | TOTAL | 375,4 | 1536,6 | 9,73E-16 | 0,27 | 2,59E-18 | 6,33E-19 |  |

**Conclusion**

The ratio between the number of attachments and the dose or the number of neutral dissociations and the dose is very similar at all points.

Appendix A: Comparison between the dose in the voxels with LEPTS and with Livermore

|  |  |  |  |
| --- | --- | --- | --- |
| Voxel | DOSE LEPTS | DOSE Livermore | RATIO |
| P1 | 2,56E-14 | 2,98E-14 | 1,16 |
| P2 | 2,15E-14 | 2,02E-14 | 0,94 |
| P3 | 1,10E-14 | 1,15E-14 | 1,04 |
| P4 | 6,93E-15 | 6,66E-15 | 0,96 |
| P5 |  | 1,91E-14 |  |
| P6 | 2,67E-15 | 1,91E-15 | 0,71 |
| P7 | 1,09E-15 | 1,18E-15 | 1,09 |
| P8 | 6,13E-16 | 6,29E-16 | 1,03 |
| P9 | 2,92E-16 | 2,78E-16 | 0,95 |

Appendix B: maximum reach of an electron or its secondaries vs. the initial electron energy

|  |  |
| --- | --- |
| Energy(MeV) | Max Range(cm) |
| 0.01 | 0,00045 |
| 0.05 | 0,008 |
| 0.1 | 0,028 |
| 0.2 | 0,084 |
| 0.5 | 0,45 |
| 1 | 0,95 |
| 2 | 2 |
| 3.99 | 4,4 |