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COMPUTATION OF P1 PROBLEM USING THE MONTE CARLO CODE GATE

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ABSTRACT :

GATE (Geant4 Application for Tomographic Emission) is a new generic Monte Carlo simulation platform based on GEANT 4, providing new functionalities for nuclear imaging applications, among which movement and time management. Currently, this code is validated for brachytherapy-radiotherapy applications. The anisotropy functions are presented in the form of away-along curves and tables for 1 and 5 cm ¹⁹²Ir wires. The relative depth dose is calculated in liquid water at 1 cm from the source.

Introduction:

The QUADOS source description has been compared with the microSelectron-HDR source [1] and the GammaMed HDR Plus source [2] models. The Monte Carlo photon transport (MCPT) code is used to model the first source and the anisotropy functions and the Monte Carlo code GEANT3 is used to model the second one.

GATE has been used to calculate the anisotropy functions at distances $r=1, 2, 3, 4, 5$ cm from the source and for different cuts in energy concerning the primary photons emission. The results obtained have been compared to the results of the MCPT and GEANT3 codes. The data are presented as both tables and curves.

1 ¹⁹²Ir energy spectrum

33 gamma-ray were simulated according to the spectral information provided in table 1:

Table 1: Energy spectrum for ¹⁹²Ir

Energy / keV	Intensity	Normalised Intensity
61.49	1.60000E-02	7.13192E-03
63.00	2.03000E-02	9.04863E-03
71.30	6.62900E-03	2.95484E-03
73.40	1.73200E-03	7.72031E-04
110.09	1.26900E-04	5.65651E-05
136.34	1.83600E-03	8.18388E-04
176.98	4.28800E-05	1.91136E-05
201.31	4.71900E-03	2.10347E-03
205.80	3.30300E-02	1.47230E-02
280.04	2.32600E-04	1.03680E-04
283.27	2.62700E-03	1.17097E-03
295.96	2.86700E-01	1.27795E-01
308.47	3.26900E-01	1.45714E-01
316.51	8.28600E-01	3.69344E-01
329.31	1.85600E-04	8.27303E-05
374.49	7.20800E-03	3.21293E-03
416.47	6.64400E-03	2.96153E-03
420.53	7.33800E-04	3.27088E-04
468.07	4.78300E-01	2.13200E-01
484.58	3.18700E-02	1.42059E-02
485.30	2.20000E-05	9.80639E-06
489.04	4.43300E-03	1.97599E-03
588.59	4.51500E-02	2.01254E-02
593.37	4.25200E-04	1.89531E-04
599.40	3.87800E-05	1.72860E-05
604.42	8.23200E-02	3.66937E-02
612.47	5.30900E-02	2.36646E-02
703.98	5.34400E-05	2.38206E-05
766.00	1.49200E-05	6.65052E-06
884.54	2.91900E-03	1.30113E-03
1061.48	5.28000E-04	2.35353E-04
1089.70	1.07300E-05	4.78285E-06
1378.30	1.24200E-05	5.53616E-06
Total	2.24343427	1

2. Angular anisotropy

2.1 Measurements

Figure 1 shows the system used to measure the anisotropy function at 19 polar angles, θ , at distances of $r = 1.0, 2.0, 3.0, 4.0$ and 5.0 cm. The ^{192}Ir source is positioned at the centre of a 30cm diameter liquid water sphere. The dose was calculated in a cylinder as shown in Figure 2. The cylinder dimensions vary according to the value of r . For $r = 1.0$ and 2.0 cm, $R' = 2$ mm and $H/2 = 1$ mm, for $r = 3.0$ and 4.0 cm, $R' = 4$ mm and $H/2 = 2$ mm and for $r = 5.0$ cm, $R' = 4$ mm and $H/2 = 4$ mm.

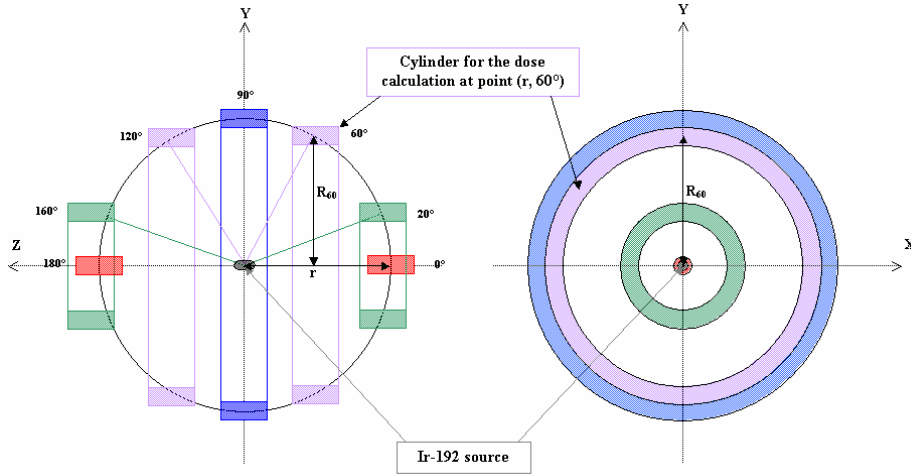


Figure 1: Angular anisotropy measure system

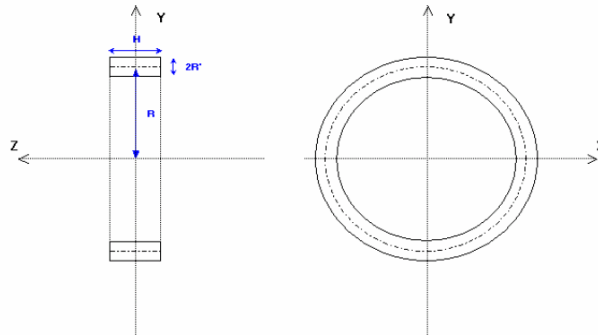


Figure 2: Cylinder for the dose measurement

2.2 Results for energy cuts

The angular anisotropy was calculated for different gamma energy cuts and for a 1 mm electron range cut. 1×10^7 starting particles were simulated. We made a comparison of the anisotropy function of the HDR source presented in this article to other Monte Carlo simulations of HDR sources (microSelectron-HDR source [1] and GammaMed HDR Plus source [2]). Figures 3 to 7 show the anisotropy function calculated by the Monte Carlo code GATE [3] at different energy cuts (1keV, 10keV, 100keV) and the anisotropy function for the microSelectron-HDR source and the GammaMed HDR Plus source, for the 19 polar angles and the distances $r = 1.0, 2.0, 3.0, 4.0$ and 5.0 cm.

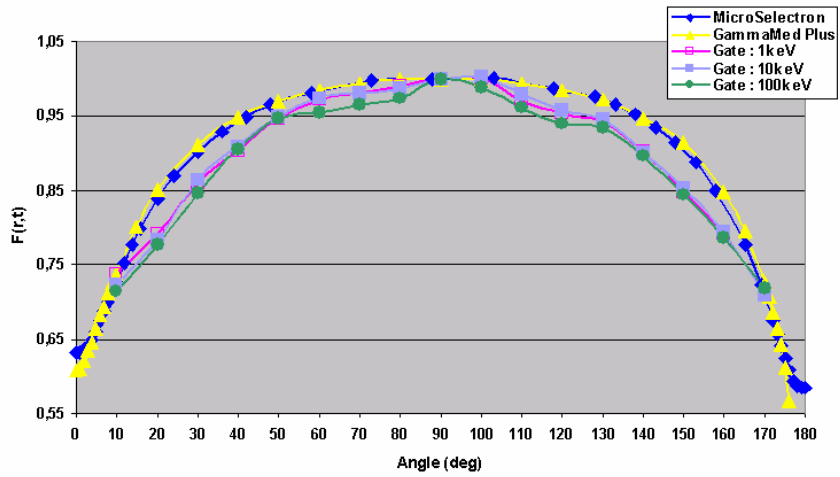


Figure 3: Anisotropy function for $r=1.0\text{cm}$

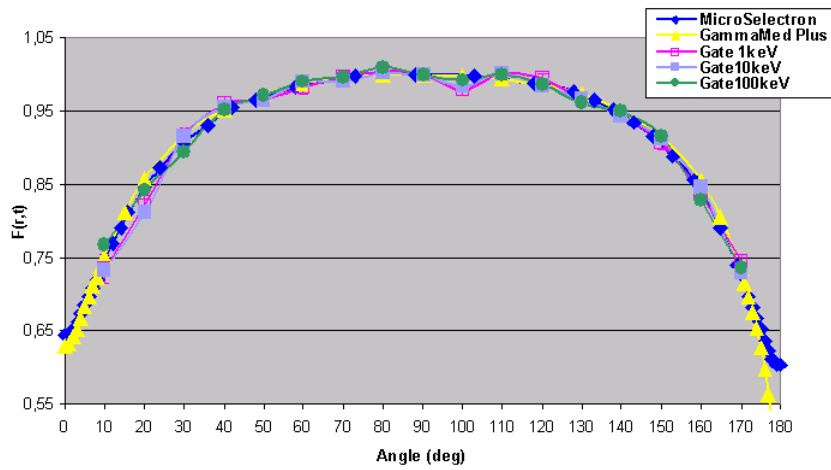


Figure 4: Anisotropy function for $r=2.0\text{cm}$

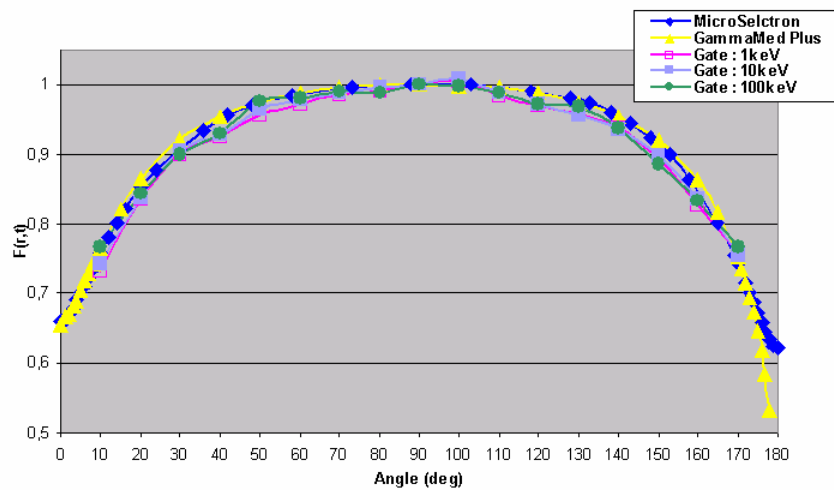


Figure 5: Anisotropy function for $r=3.0\text{cm}$

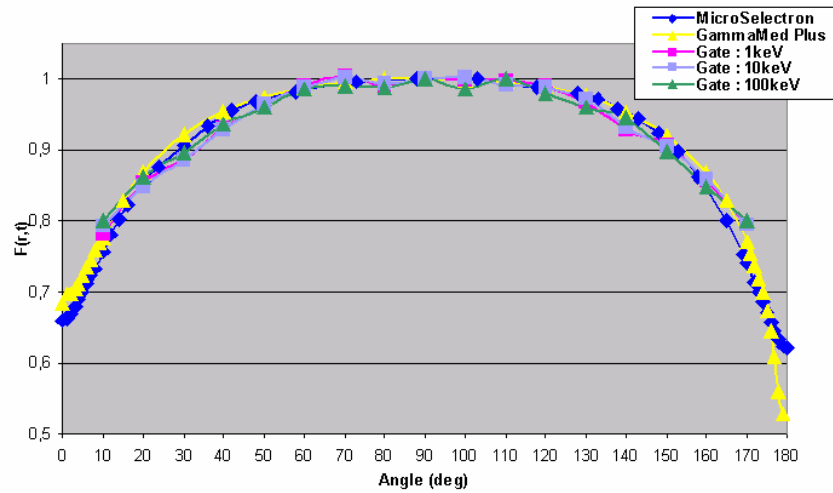


Figure 6: Anisotropy function for $r=4.0\text{cm}$

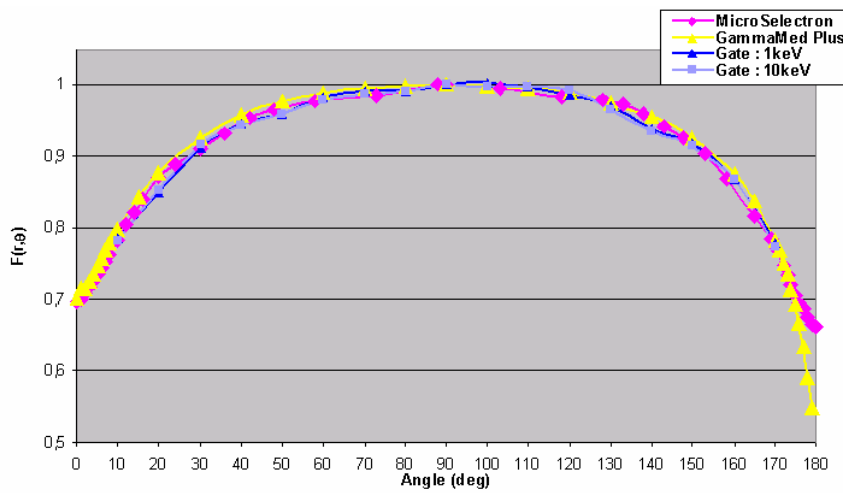


Figure 7: Anisotropy function for $r=5.0\text{cm}$

2.3 Results for 1keV energy cut

As we assume that the energy cuts at 1 keV give more reliable results than for higher cuts, the results obtained by the Monte Carlo code GATE for this energy cut have been summarized in Table 2 and Figure 8. The electron range cut is set to 1mm.

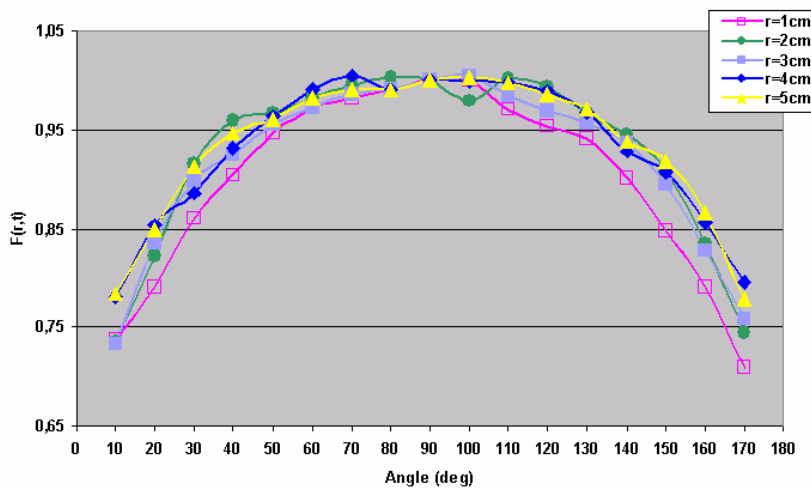


Figure 8: Anisotropy Function calculated by GATE (energy cut = 1keV)

Table 2: Anisotropy Function calculated by GATE (energy cut = 1keV)

θ (deg)	r = 1cm	r = 2cm	r = 3cm	r = 4cm	r = 5cm
0					
10	0.73729	0.73458	0.73380	0.78101	0.7848
20	0.79154	0.82179	0.83465	0.85375	0.8495
30	0.86109	0.91610	0.89857	0.88604	0.9133
40	0.90421	0.95987	0.92613	0.93076	0.9464
50	0.94671	0.96633	0.95597	0.96427	0.9606
60	0.97165	0.98250	0.97206	0.98997	0.9829
70	0.98221	0.99557	0.98583	1.00505	0.9910
80	0.99062	1.00319	0.99031	0.99038	0.9913
90	1.00000	1.00000	1.00000	1.00000	1.00000
100	1.00046	0.97875	1.00454	0.99915	1.0028
110	0.97065	1.00137	0.98432	0.99744	0.9975
120	0.95347	0.99391	0.96964	0.98967	0.9860
130	0.94166	0.96669	0.95714	0.96846	0.9712
140	0.90217	0.94517	0.93692	0.92839	0.9383
150	0.84789	0.90798	0.89423	0.90711	0.9183
160	0.79172	0.83564	0.82795	0.85644	0.8664
170	0.70976	0.74413	0.75927	0.79538	0.7786
180					

2.4 Discussion

The results obtained with GATE at r = 2 cm have been compared to GEANT3 and MCPT calculations. The standard deviation between both GATE with GEANT3 and MCPT results do not exceed 13.942 %, the majority of the standard deviation calculated are below 1%.

(The microSelectron MCPT results have not been listed in [1] for $\theta = 80, 110, 130, 140, 150, 160^\circ$)

θ (deg)	GATE	Gammamed (GEANT3)	microSelectron (MCPT)	Std deviation GATE/GEANT3 (%)	Std deviation GATE/MCPT (%)
0		0,629	0,645		
10	0,73458	0,752	0,745	2,344	1,419
20	0,82179	0,858	0,846	4,443	2,946
30	0,91610	0,918	0,907	0,174	0,994
40	0,95987	0,951	0,955	0,924	0,508
50	0,96633	0,973	0,965	0,691	0,137
60	0,98250	0,988	0,982	0,529	0,051
70	0,99557	0,996	0,998	0,083	0,244
80	1,00319	1,000		0,288	
90	1,00000	1,000	1,000	0,000	0,000
100	0,97875	0,998	0,999	1,926	2,069
110	1,00137	0,994		0,716	
120	0,99391	0,987	0,989	0,705	0,494
130	0,96669	0,973		0,643	
140	0,94517	0,950		0,532	
150	0,90798	0,916		0,894	
160	0,83564	0,856		2,436	
170	0,74413	0,734	0,727	1,335	2,302
180			0,603		

Table 4: Calculation of standard deviation between GATE and MCPT and GEANT3 anisotropy functions results at r = 2cm from the source.

This comparison confirms the reliability of using GATE for ^{192}Ir brachytherapy application.

We can note that the results obtained with GATE at $r = 1$ cm are much more uncorrelated to GEANT3 and MCPT calculations.

Table 5 shows the discrepancy between GATE and GEANT3 results at $r = 1$ cm. We can note that the standard deviation keeps always lower than 8%. Moreover, we can remark that the discrepancy involve as the polar angle go away from 90° .

θ (deg)	GammaMed (GEANT3)	GATE	Std deviation (%)
0	0,608		
10	0,738	0,737	0,069
20	0,852	0,792	7,128
30	0,912	0,861	5,562
40	0,948	0,904	4,629
50	0,971	0,947	2,522
60	0,985	0,972	1,336
70	0,995	0,982	1,265
80	0,999	0,991	0,829
90	1,000	1,000	0,000
100	0,999	1,000	0,146
110	0,995	0,971	2,418
120	0,985	0,953	3,181
130	0,972	0,942	3,092
140	0,948	0,902	4,834
150	0,914	0,848	7,253
160	0,847	0,792	6,538
170	0,725	0,710	2,062
180			

Table 5: Calculation of standard deviation between GATE and GammaMed (GEANT3) anisotropy functions results at $r = 1$ cm from the source.

3 Dose distribution in water

3.1 Measurements

The dose distribution was calculated at 49 points along a line parallel to the X -axis at a distance of 1 cm from the source. The x -coordinate of the points ranged from distances from -4.8 to $+4.8$ cm; each point being separated by 0.2 cm. The relative dose distribution is normalised to the dose at P, centered on the X -axis and situated 1 cm from the Y -axis. Figure 9 shows the system used to measure the dose distribution. The dose was calculated in a cylinder as shown on Figure 9. Each cylinder has the same dimensions: height = 2 mm, internal radius $R1 = 9$ mm and external radius $R2 = 11$ mm.

Table 3: Dwell positions (relative time)

Source position	1	2	3	4	5	6	7	8	9	10
Particles	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000
Time (s)	1	1	1.33333	2.66667	3.33333	3.33333	2.66667	1.33333	1	1

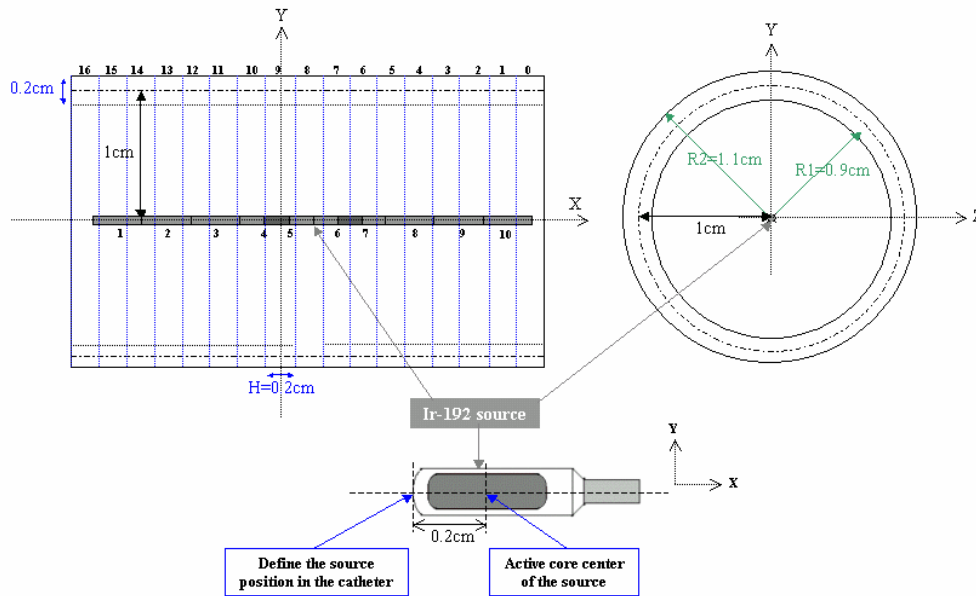


Figure 9 : Dose distribution measure system

3.2 Results

The dose distribution was calculated for two different gamma energy cuts (1keV, 10keV) and for a 1mm electrons range cut. 18,666,666 photons were simulated. Figures 10 shows the dose distribution of the HDR source calculated by the Monte Carlo code GATE.

The curve is shifted 2mm from the centre because of the 2mm shift between the point that defines the source position in the catheter and the active core of the ^{192}Ir source.

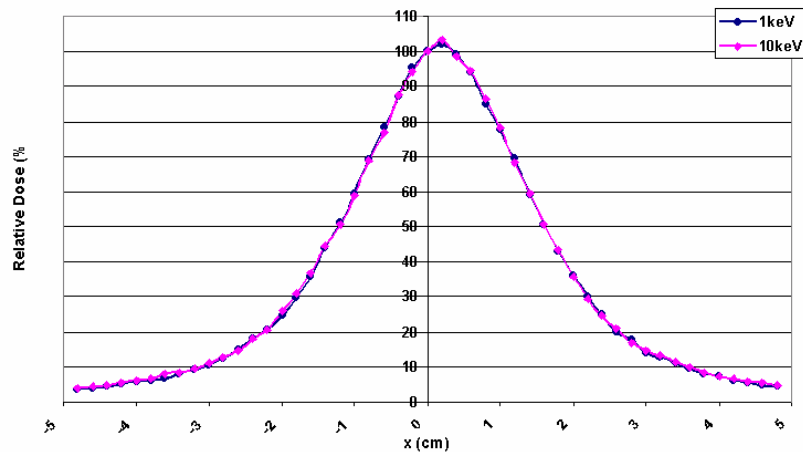


Figure 10 : Dose distribution for a hypothetical treatment scenario

References

- [1] G.M. Daskalov, E. Loffler, J.F. Williamson, "Monte Carlo-aided dosimetry of a new high dose-rate brachytherapy source" Med. Phys. 25 (11), (1998).
- [2] F. Ballester, V. Puchades, J. L. Lluch, M. A. Serrano-Andrés, Y. Limami, J. Pérez-Calatayud, E. Casal, "Technical note : Monte Carlo dosimetry of the HDR 12i and Plus ^{192}Ir source" Med. Phys. 28 (12), (2001).
- [3] <http://opengate.in2p3.fr>