Technical note: Dosimetric study of a new Co-60 source used in brachytherapy

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The purpose of this study is to obtain the dosimetric parameters of a new Co-60 source used in high dose rate brachytherapy and manufactured by BEBIG (Eckert & Ziegler BEBIG GmbH, Germany). The Monte Carlo method has been used to obtain the dose rate distribution in the updated TG-43U1 formalism of the American Association of Physicists in Medicine. In addition, to aid the quality control process on treatment planning systems (TPS), a two-dimensional rectangular dose rate table, coherent with the TG-43U1 dose calculation formalism, is given. These dosimetric data sets can be used as input data of the TPS calculations and to validate them. © 2007 American Association of Physicists in Medicine. [DOI: [10.1118/1.2759602](https://doi.org/10.1118/1.2759602)]

Key words: brachytherapy, Co-60, Monte Carlo, HDR

I. INTRODUCTION

Although not as widespread as Ir-192, Co-60 is also available on afterloading equipment dedicated to high dose rate (HDR) brachytherapy, mainly addressed to the treatment of gynecological lesions.¹⁻³

This study is aimed at obtaining the dose rate distribution in the TG-43 U1 formalism of the American Association of Physicists in Medicine (AAPM),^{4,5} and the 2D dose rate table in Cartesian coordinates of the new BEBIG (Eckert & Ziegler BEBIG GmbH, Germany) ⁶⁰Co HDR source (model Co0.A86) using the Monte Carlo (MC) code GEANT4.⁶ This new Co-60 source is a modified version of the old Co-60 source (model GK60M21) from BEBIG.⁷ The dosimetric data sets given in this study can be used as input and to validate the TPS calculations.

II. MATERIAL AND METHODS

The geometric design and materials of the new BEBIG Co-60 source (model Co0.A86) were obtained from the manufacturer and are shown schematically in Fig. 1. The new BEBIG ⁶⁰Co brachytherapy source is very similar to the old BEBIG source (model GK60M21), both in design and materials. The new source differs from the old one in that it has a smaller active core (0.5 mm in diameter for the new source vs 0.6 mm in diameter for the old one) and a more rounded capsule tip.⁷ The new source is composed of a central cylindrical active core made of metallic ⁶⁰Co, 3.5 mm in length and with a diameter of 0.5 mm. The active core is covered by a cylindrical stainless-steel capsule 0.15 mm thick with an external diameter of 1 mm.

In order to obtain the dose rate distribution of the new ⁶⁰Co source the Monte Carlo code GEANT4 (Ref. 6) (version 7.1) has been used. This code has been widely used by our

group in other dosimetric studies of brachytherapy sources.⁷⁻⁹ The Monte Carlo code GEANT4 used in this study fulfills all the recommendations of the report, "Dosimetric prerequisites for routine clinical use of photon emitting brachytherapy sources with average energy higher than 50 keV," of the AAPM-ESTRO associations.¹⁰

The physics "low energy" models of GEANT4 have been used. These physics models use the EPDL97 cross-sections library¹¹ for photons and the EEDL library¹¹ for electrons. In order to speed up the simulations only the gamma part of the ⁶⁰Co spectrum was used. It has been verified that the contribution of the β spectrum and electron spectra to the dose is negligible due to the presence of the stainless-steel cover around the metallic ⁶⁰Co where the electrons are stopped.⁷ The gamma spectrum used in the simulations was obtained from the NuDat database.¹² A cutoff energy of 10 keV was used for both photons and electrons. The methodology used for this Monte Carlo study follows the recommendations of the TG-43 U1 report.⁵

In order to obtain the dose rate distribution in water, the source has been located in the center of a spherical phantom of 50 cm in radius that acts as an unbounded phantom for a ⁶⁰Co source up to a distance of 20 cm from the source.^{3,7} The density used for the liquid water has been 0.998 g cm⁻³ at 22 °C as recommended in the TG-43 U1.⁵ To obtain the along and away dose rate table, a grid system composed of 400 × 800 cylindrical rings 0.05 cm thick and 0.05 cm high, concentric to the longitudinal source axis, was used, and to obtain the dose rate distribution in the form given by the TG43 report a system of 400 × 180 concentric spherical sections 0.05 cm thick with an angular width of 1° in the polar angle θ was used. The coordinate axes used are shown in Fig. 1.

FIG. 1. Schematic view of the ^{60}Co source (model Co0.A86). The coordinate axes used in this study are also shown with their origin situated in the geometric center of the active volume. Dimensions are in millimeters.

As electronic equilibrium conditions are not fulfilled in the near region of the source, both kerma and dose have been scored using the grid systems defined above. At points where electronic disequilibrium exists⁷ (those located at distances of less than 1 cm from the source) the values obtained as scoring dose are used to give the dose rate distribution, and at the points where electronic equilibrium exists the scored kerma values have been used to approximate dose because in this case kerma and dose match each other and the kerma is obtained with lower uncertainty. In an effort to speed up

calculations and to reduce statistical uncertainties, kerma has been obtained using the linear track-length kerma estimator.¹³

To estimate the air-kerma strength the BEBIG ^{60}Co source was located in the center of a $4 \times 4 \times 4 \text{ m}^3$ air cube and kerma was scored using cylindrical ring cells, 1 cm thick and 1 cm high, located along the transverse source axis. The procedure used to extract the air-kerma strength is the same as that used in previous studies by our group.⁷

The number of photon histories simulated was 10^9 to obtain kerma and 6×10^9 to obtain dose; 10^8 photon histories have been simulated to obtain the air-kerma strength.

III. RESULTS AND DISCUSSION

The raw data obtained from the Monte Carlo simulations were analyzed with the ROOT data analysis framework¹⁴ in order to obtain the along-away 2D Cartesian lookup data $\dot{D}(y, z)$ and the TG-43 dosimetric parameters.

TABLE I. Dose rate in an unbounded liquid water phantom per unit air-kerma strength ($\text{cGy h}^{-1} \text{U}^{-1}$) around the new BEBIG ^{60}Co source (model Co0.A86). The coordinate axes are defined in Fig. 1.

Distance along z (cm)	Distance away y (cm)														
	0	0.25	0.5	0.75	1	1.5	2	2.5	3	4	5	6	8	10	14
-14	0.00399	0.00409	0.00404	0.00405	0.00407	0.00408	0.00406	0.00403	0.00398	0.00386	0.00370	0.00350	0.00308	0.00263	0.00185
-10	0.00853	0.00866	0.00867	0.00867	0.00870	0.00870	0.00861	0.00847	0.00828	0.00778	0.00718	0.00655	0.00531	0.00423	0.00264
-8	0.01400	0.01401	0.01409	0.01414	0.01418	0.01406	0.01380	0.01342	0.01294	0.01177	0.01052	0.00927	0.00705	0.00533	0.00310
-6	0.0258	0.0259	0.0260	0.0261	0.0260	0.0255	0.0246	0.0233	0.0219	0.01882	0.01589	0.01330	0.00931	0.00660	0.00355
-5	0.0380	0.0380	0.0382	0.0382	0.0379	0.0366	0.0346	0.0321	0.0295	0.0243	0.01970	0.01595	0.01059	0.00726	0.00377
-4	0.0602	0.0602	0.0608	0.0604	0.0596	0.0560	0.0513	0.0460	0.0408	0.0316	0.0244	0.01894	0.01190	0.00789	0.00396
-3	0.1077	0.1092	0.1096	0.1078	0.1040	0.0930	0.0804	0.0684	0.0577	0.0410	0.0297	0.0221	0.01315	0.00847	0.00412
-2.5	0.1562	0.1591	0.1585	0.1535	0.1453	0.1245	0.1030	0.0840	0.0685	0.0463	0.0325	0.0236	0.01371	0.00871	0.00418
-2	0.247	0.252	0.247	0.233	0.214	0.1708	0.1329	0.1032	0.0808	0.0518	0.0352	0.0251	0.01420	0.0089	0.0042
-1.5	0.447	0.453	0.430	0.384	0.333	0.239	0.1713	0.1251	0.0938	0.0570	0.0375	0.0263	0.01461	0.00909	0.00428
-1	1.035	1.026	0.882	0.703	0.546	0.333	0.215	0.1472	0.1059	0.0613	0.0394	0.0272	0.01493	0.00921	0.00431
-0.75	...	1.806	1.384	0.985	0.701	0.386	0.236	0.1569	0.1109	0.0630	0.0401	0.0276	0.01503	0.00926	0.00432
-0.5	...	3.82	2.27	1.365	0.874	0.434	0.254	0.1645	0.1147	0.0642	0.0406	0.0278	0.01511	0.00929	0.00433
-0.25	...	9.47	3.57	1.763	1.025	0.469	0.265	0.1695	0.1172	0.0650	0.0410	0.0280	0.01514	0.00931	0.00433
0	...	15.15	4.32	1.929	1.087	0.482	0.269	0.1712	0.1179	0.0652	0.0410	0.0280	0.01516	0.00931	0.00434
0.25	...	9.48	3.58	1.758	1.025	0.469	0.265	0.1694	0.1171	0.0650	0.0410	0.0280	0.01516	0.00932	0.00434
0.5	4.83	3.86	2.26	1.368	0.874	0.434	0.253	0.1645	0.1147	0.0642	0.0406	0.0278	0.01511	0.00930	0.00433
0.75	2.02	1.829	1.389	0.986	0.700	0.385	0.236	0.1568	0.1109	0.0630	0.0401	0.0276	0.01503	0.00926	0.00432
1	1.079	1.037	0.884	0.703	0.546	0.333	0.215	0.1472	0.1058	0.0613	0.0394	0.0272	0.01493	0.00922	0.00431
1.5	0.466	0.463	0.432	0.385	0.333	0.239	0.1713	0.1251	0.0938	0.0570	0.0375	0.0263	0.01461	0.00909	0.00428
2	0.258	0.259	0.250	0.234	0.214	0.1710	0.1329	0.1032	0.0808	0.0517	0.0352	0.0250	0.01420	0.00892	0.00424
2.5	0.1631	0.1647	0.1610	0.1546	0.1459	0.1245	0.1030	0.0840	0.0685	0.0463	0.0325	0.0237	0.01371	0.00871	0.00418
3	0.1123	0.1132	0.1118	0.1088	0.1044	0.0932	0.0806	0.0685	0.0577	0.0410	0.0297	0.0221	0.01315	0.00847	0.00412
4	0.0618	0.0626	0.0623	0.0615	0.0601	0.0563	0.0514	0.0461	0.0409	0.0316	0.0244	0.01893	0.01190	0.00790	0.00395
5	0.0390	0.0393	0.0393	0.0390	0.0385	0.0369	0.0347	0.0322	0.0296	0.0243	0.01972	0.01594	0.01058	0.00726	0.00377
6	0.0266	0.0268	0.0269	0.0268	0.0265	0.0258	0.0247	0.0234	0.0219	0.01887	0.01592	0.01331	0.00930	0.00660	0.00356
8	0.01454	0.01460	0.01455	0.01456	0.01449	0.01428	0.01394	0.01348	0.01298	0.01181	0.01052	0.00927	0.00705	0.00533	0.00310
10	0.00884	0.00899	0.00895	0.00896	0.00893	0.00885	0.00871	0.00856	0.00833	0.00780	0.00720	0.00656	0.00531	0.00423	0.00265
14	0.00414	0.00418	0.00418	0.00419	0.00419	0.00416	0.00412	0.00409	0.00403	0.00389	0.00372	0.00352	0.00308	0.00263	0.00185

TABLE II. Anisotropy function $F(r, \theta)$ for the new BEBIG ^{60}Co source (model Co0.A86). The coordinate axes are defined in Fig. 1.

θ (degrees)	r (cm)															
	0.25	0.5	0.75	1	1.5	2	3	4	5	6	7	8	10	12	15	20
0	...	0.939	0.966	0.945	0.945	0.947	0.945	0.944	0.945	0.945	0.947	0.947	0.952	0.955	0.958	0.959
1	...	0.941	0.969	0.948	0.947	0.947	0.946	0.946	0.948	0.949	0.951	0.952	0.955	0.957	0.961	0.962
2	...	0.938	0.968	0.952	0.952	0.952	0.952	0.953	0.955	0.956	0.957	0.959	0.959	0.962	0.964	0.966
3	...	0.939	0.969	0.956	0.956	0.957	0.958	0.958	0.959	0.960	0.961	0.962	0.964	0.965	0.967	0.970
4	...	0.941	0.972	0.959	0.959	0.960	0.961	0.962	0.962	0.964	0.965	0.966	0.968	0.968	0.970	0.975
5	...	0.944	0.975	0.962	0.962	0.962	0.963	0.965	0.965	0.966	0.967	0.968	0.970	0.970	0.971	0.976
6	...	0.947	0.979	0.964	0.964	0.964	0.964	0.965	0.965	0.966	0.967	0.968	0.970	0.970	0.972	0.975
8	...	0.954	0.980	0.968	0.967	0.967	0.967	0.968	0.968	0.969	0.970	0.971	0.972	0.973	0.975	0.975
10	...	0.957	0.980	0.971	0.971	0.971	0.971	0.972	0.972	0.973	0.973	0.974	0.975	0.975	0.977	0.979
15	...	0.961	0.981	0.978	0.979	0.979	0.979	0.979	0.979	0.980	0.980	0.980	0.981	0.981	0.982	0.983
20	...	0.972	0.990	0.985	0.985	0.985	0.985	0.985	0.985	0.985	0.986	0.986	0.986	0.986	0.986	0.987
25	...	0.987	0.989	0.988	0.989	0.989	0.989	0.989	0.989	0.990	0.990	0.990	0.990	0.990	0.990	0.991
30	...	0.991	0.996	0.993	0.993	0.993	0.993	0.993	0.992	0.993	0.993	0.993	0.992	0.993	0.992	0.993
40	...	0.998	0.998	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.997
50	...	1.000	1.000	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.998	0.998	0.998
60	0.957	0.999	1.002	0.999	0.999	0.999	0.999	0.999	0.998	0.998	0.999	0.999	0.999	0.999	0.998	0.999
70	0.974	0.998	1.001	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	1.000	1.000	0.999	0.999	1.000
80	0.990	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000
90	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
100	0.990	0.994	1.000	1.001	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000
110	0.975	0.997	1.002	1.000	1.000	1.000	1.000	1.000	0.999	0.999	1.000	0.999	1.000	0.999	0.999	1.000
120	0.956	0.999	1.000	0.999	0.999	0.999	0.999	0.999	0.998	0.998	0.998	0.999	0.998	0.998	0.998	0.999
130	...	1.000	1.001	0.997	0.999	0.999	0.998	0.998	0.998	0.997	0.998	0.998	0.998	0.998	0.997	0.997
140	...	0.994	0.996	0.995	0.996	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995
150	...	0.983	0.996	0.991	0.991	0.991	0.990	0.990	0.990	0.990	0.991	0.991	0.991	0.991	0.991	0.991
155	...	...	0.985	0.987	0.987	0.986	0.986	0.987	0.986	0.986	0.987	0.987	0.987	0.987	0.988	0.988
160	...	...	0.976	0.980	0.980	0.981	0.981	0.981	0.981	0.981	0.982	0.982	0.982	0.982	0.983	0.984
165	...	...	...	0.970	0.969	0.969	0.969	0.970	0.970	0.970	0.971	0.972	0.973	0.973	0.974	0.976
170	...	...	...	0.953	0.954	0.954	0.955	0.956	0.957	0.958	0.960	0.961	0.962	0.963	0.965	0.968
172	...	...	...	0.944	0.944	0.944	0.946	0.947	0.949	0.950	0.951	0.952	0.954	0.955	0.959	0.961
174	...	...	...	0.934	0.934	0.934	0.936	0.937	0.939	0.941	0.942	0.944	0.947	0.948	0.951	0.956
175	...	...	...	0.926	0.927	0.928	0.930	0.932	0.934	0.936	0.938	0.939	0.942	0.945	0.948	0.953
176	...	...	...	0.921	0.922	0.923	0.925	0.928	0.929	0.931	0.934	0.936	0.939	0.943	0.947	0.952
177	...	...	...	0.919	0.919	0.919	0.921	0.924	0.926	0.928	0.930	0.932	0.936	0.940	0.943	0.947
178	...	...	...	0.913	0.913	0.914	0.918	0.920	0.922	0.924	0.925	0.929	0.933	0.936	0.939	0.944
179	...	...	...	0.910	0.908	0.908	0.911	0.913	0.915	0.918	0.918	0.921	0.926	0.930	0.934	0.938

The along-away 2D Cartesian lookup data $\dot{D}(y, z)$ are shown in Table I. To obtain the TG-43U1 dosimetric parameters from $\dot{D}(r, \theta)$ we have used the geometric factor $G_L(r, \theta)$ with a length of $L=3.5$ mm. The dose rate constant obtained has been $\Lambda=1.087\pm0.011$ cGy h⁻¹ U⁻¹, where the air-kerma strength is expressed in units 1 U=1 $\mu\text{Gy h}^{-1} \text{ m}^2$. The anisotropy function, $F(r, \theta)$, is presented in Table II and the radial dose function, $g_L(r)$, in Table III.

The uncertainties in the final dose rate distributions for ^{60}Co sources can be reduced to only the statistical uncertainties;⁷ thus, in this study the final uncertainty (standard deviation of the mean with $k=1$) is less than 0.7% for all the points, except at the points located near the longitudinal axis, where it is about 1.1%.

The dose rate distribution obtained for the new BEBIG source has been compared with that obtained for the old BEBIG HDR source⁷ in Fig. 2. This comparison shows that

both dose rate distributions are nearly identical in front of the source, the differences between both sources less being than 0.5%. In the zone near the longitudinal source axis, they are less than 4% for $z>0$ and less than 10% for $z<0$. In the latter case the differences are due to the fact that, in the study of the old BEBIG HDR source, the source cable length was 20 mm, and in this study it was 5 mm, which reproduces the clinical setup better on highly curved catheters.

IV. CONCLUSIONS

In this study, a complete dosimetric data set for the new BEBIG ^{60}Co source (model Co0.A86) was obtained for an unbounded liquid water phantom using the Monte Carlo GEANT4 code. Functions and parameters following TG-43U1 formalism are presented: the dose rate constant, the radial dose function, and the anisotropy function. In addition, in order to aid quality control on TPS, a 2D rectangular dose

TABLE III. Radial dose function for the BEBIG ^{60}Co source (model Co0.A86). The radial dose function has been fitted to a third-order polynomial with coefficients $a_0=1.0159$, $a_1=-1.577 \times 10^{-2}$, $a_2=-1.020 \times 10^{-4}$, $a_3=-2.404 \times 10^{-7}$ between 0.25 and 20 cm. Note that the fit is the same that used in for the old BEBIG Co-60 source (Ref. 7).

Distance r (cm)	$g_L(r)$
0.25	1.007
0.5	1.036
0.75	1.015
1	1
1.5	0.992
2	0.984
3	0.968
4	0.952
5	0.936
6	0.919
7	0.902
8	0.884
10	0.849
12	0.813
15	0.756
20	0.665

rate table consistent with the TG43 dose calculation formalism is given.

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FIG. 2. Isodose curves in $\text{cGy h}^{-1} \text{U}^{-1}$ for the old BEBIG source and the new BEBIG HDR source. The background of the figure is the ratio between the kerma rate distribution obtained for the new and the old sources.

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