Original article

Revision of the dosimetric parameters of the CSM11 LDR Cs-137 source

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Abstract

Purpose: The clinical use of brachytherapy sources requires the existence of dosimetric data with enough of quality for the proper application of treatments in clinical practice. It has been found that the published data for the low dose rate CSM11 Cs-137 source lacks of smoothness in some regions because the data are too noisy. The purpose of this study was to calculate the dosimetric data for this source in order to provide quality dosimetric improvement of the existing dosimetric data of Ballester *et al*. [1]

Material and methods: In order to obtain the dose rate distributions Monte Carlo simulations were done using the GEANT4 code. A spherical phantom 40 cm in radius with the Cs-137 source located at the centre of the phantom was used.

Results: The results from Monte Carlo simulations were applied to derive AAPM Task Group 43 dosimetric parameters: anisotropy function, radial dose function, air kerma strength and dose rate constant. The dose rate constant obtained was 1.094 ± 0.002 cGy h^{-1} U^{-1}. The new calculated data agrees within experimental uncertainties with the existing data of Ballester *et al*. but without the statistical noise of that study.

Conclusions: The obtained data presently fulfills all the requirements of the TG-43U1 update and thus it can be used in clinical practice.

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Key words: Monte Carlo, brachytherapy, Cs-137, dosimetry, GEANT4, TG43.

Purpose

Although the use of low dose rate (LDR) sources in brachytherapy has declined in recent years in favor of the high dose rate sources (HDR), the use of LDR ^{137}Cs sources is still prevalent in some centers. The reason for this is the necessity of the existence of updated dosimetric data tables that allows proper treatment planning. One of these LDR sources is the CSM11 source (BEBIG GmbH, Germany). The earlier study of this source by Ballester *et al.* [1] was performed using the Monte Carlo code GEANT3 [2]. Ballester *et al*. obtained dosimetric data for this source with statistical uncertainty too elevated (see figures 2 to 5 of the publication) for the recommendations given in the TG-43U1 protocol [3]. Therefore, it is necessary to update the data to reduce the noise. The purpose of this study was to obtain the dosimetric data for the CSM11 source without noise using the Monte Carlo code GEANT4 [4] in order to improve the existing data.

Material and methods

The dimensions and materials of the LDR ^{137}Cs CSM11 source model (BEBIG GmbH, Germany) were obtained from the study by Ballester *et al.* (Fig. 1). The active part was a seed of pollucite (Cs_2O, Al_2O_3, $4SiO_2$, $\rho = 2.9$ g/cm^3) encapsulated in a stainless steel (Z3 CDN 18/12). It is important to note that in this study the origin of coordinates was situated at the middle of the source active part, not in the center of the source as for other ^{137}Cs LDR sources. In Ballester *et al*. study, the origin was located in the geometric center of the source.

The Monte Carlo code GEANT4 (version 9.2) was used to obtain the dose rate distributions around the CSM11 source. The ^{137}Cs photon spectrum applied in the Monte Carlo simulation was obtained from the Nudat database [5]. Physical models used for Compton scattering, photoelectric effect and Rayleigh scattering processes were acquired from the low-energy package of GEANT4 which uses the cross sections from the EPDL97 library [6] as recommended in TG-43U1. In the simulations the kerma track-length estimator [7] was used to optimize the simulation time and to reduce the statistical noise of the data. Kerma was calculated assuming electronic equilibrium in the region of interest [8] and thus in that region kerma coincides approximately with dose. The cutoff energy for photons and electrons was 10 keV.

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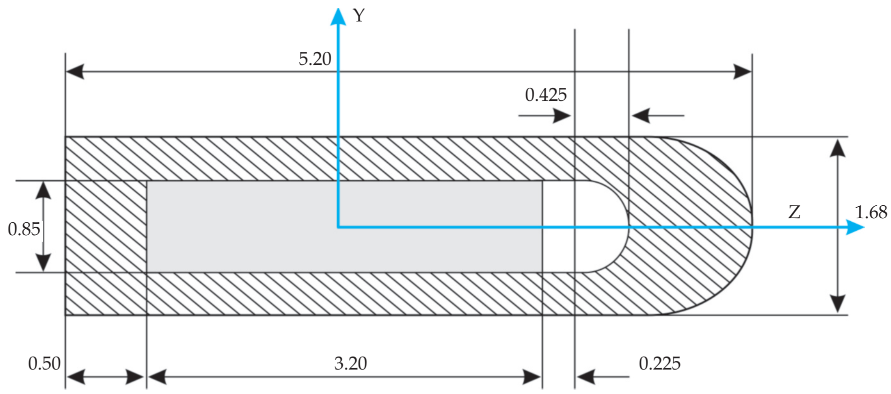

Bebig LDR ^{137}Cs model CSM11 source

Fig. 1. Schematic view of the CSM11 source. All the dimensions in millimeters

Table 1. Dose rate in cGy/hU in water per unit air-kerma strength around the BEBIG CSM11 type stainless-steel encapsulated source. Origin is taken at the center of the active part

	Distance away y (cm)													
Distance along z (cm)	0	0.25	0.5	0.75	1	1.5	2	2.5	3	4	5	6	8	10
–10	0.00944	0.00945	0.00945	0.00944	0.00938	0.00922	0.00903	0.00882	0.00859	0.00803	0.00740	0.00675	0.00546	0.00433
–8	0.01524	0.01539	0.01535	0.01526	0.01512	0.01477	0.01436	0.01388	0.01335	0.01212	0.01083	0.00954	0.00727	0.00548
–6	0.0279	0.0283	0.0281	0.0278	0.0274	0.0264	0.0252	0.0239	0.0224	0.01933	0.01636	0.01372	0.00960	0.00681
–5	0.0410	0.0413	0.0409	0.0403	0.0395	0.0376	0.0354	0.0329	0.0302	0.0249	0.0203	0.01642	0.01093	0.00750
–4	0.0650	0.0652	0.0644	0.0628	0.0611	0.0570	0.0521	0.0469	0.0417	0.0324	0.0250	0.01949	0.01229	0.00816
–3	0.1171	0.1172	0.1140	0.1100	0.1052	0.0939	0.0814	0.0694	0.0587	0.0419	0.0305	0.0227	0.01358	0.00875
–2.5	0.1694	0.1690	0.1634	0.1555	0.1463	0.1254	0.1040	0.0852	0.0696	0.0473	0.0333	0.0243	0.01417	0.00901
–2	0.2660	0.264	0.251	0.234	0.214	0.1718	0.1342	0.1045	0.0821	0.0529	0.0360	0.0258	0.01467	0.00922
–1.5	0.4786	0.467	0.430	0.384	0.333	0.240	0.1728	0.1267	0.0954	0.0582	0.0385	0.0270	0.01509	0.00941
–1	1.095	1.031	0.874	0.700	0.546	0.335	0.217	0.1491	0.1076	0.0626	0.0404	0.0280	0.01542	0.00953
–0.75	1.986	1.783	1.363	0.978	0.701	0.388	0.238	0.1589	0.1126	0.0643	0.0411	0.0284	0.01552	0.00957
–0.5	4.82	3.69	2.23	1.356	0.877	0.437	0.256	0.1666	0.1165	0.0656	0.0417	0.0286	0.01560	0.00961
–0.25	–	9.47	3.53	1.753	1.030	0.472	0.268	0.1717	0.1189	0.0664	0.0420	0.0287	0.01566	0.00963
0	–	16.22	4.32	1.941	1.094	0.486	0.272	0.1734	0.1198	0.0666	0.0421	0.0288	0.01567	0.00964
0.25	–	9.48	3.53	1.753	1.030	0.472	0.268	0.1717	0.1189	0.0664	0.0420	0.0288	0.01566	0.00963
0.5	4.80	3.69	2.23	1.357	0.878	0.437	0.256	0.1667	0.1165	0.0656	0.0417	0.0286	0.01561	0.00961
0.75	1.982	1.768	1.363	0.979	0.703	0.388	0.238	0.1588	0.1127	0.0643	0.0412	0.0283	0.01553	0.00958
1	1.090	1.016	0.874	0.701	0.547	0.335	0.217	0.1491	0.1076	0.0626	0.0404	0.0280	0.01541	0.00953
1.5	0.472	0.459	0.427	0.383	0.333	0.241	0.1731	0.1268	0.0954	0.0582	0.0385	0.0270	0.01510	0.00940
2	0.263	0.260	0.248	0.232	0.214	0.1719	0.1343	0.1047	0.0822	0.0529	0.0361	0.0258	0.01468	0.00922
2.5	0.1668	0.1663	0.1607	0.1539	0.1455	0.1252	0.1041	0.0852	0.0697	0.0474	0.0333	0.0243	0.01417	0.00901
3	0.1147	0.1151	0.1124	0.1086	0.1044	0.0937	0.0814	0.0694	0.0587	0.0420	0.0305	0.0227	0.01359	0.00875
4	0.0635	0.0643	0.0634	0.0619	0.0604	0.0567	0.0520	0.0468	0.0417	0.0324	0.0251	0.01951	0.01229	0.00816
5	0.0402	0.0407	0.0403	0.0396	0.0390	0.0373	0.0352	0.0328	0.0301	0.0249	0.0203	0.01643	0.01093	0.00750
6	0.0275	0.0279	0.0277	0.0274	0.0270	0.0261	0.0251	0.0238	0.0224	0.01932	0.01637	0.01373	0.00961	0.00681
8	0.01495	0.01524	0.01514	0.01504	0.01492	0.01458	0.01422	0.01379	0.01327	0.01210	0.01082	0.00955	0.00727	0.00548
10	0.00922	0.00936	0.00935	0.00931	0.00925	0.00911	0.00895	0.00874	0.00852	0.00799	0.00738	0.00674	0.00546	0.00433

The CSM11 source was placed at the center of a spherical liquid water phantom 40 cm in radius which was acting as an unbounded phantom up to 20 cm from the source center [9,10] in order to obtain the dose rate distribution around the CSM11 source. A grid system composed of 400 × 180 concentric spheres sections of 0.05 cm thick with an angular size of 1 was used to score kerma. To acquire s_K the source was surrounded by vacuum except for a small cylindrical air cell of 0.1 cm in diameter and air kerma was scored in the air cell. The composition by weight and density of water and air used for the simulations was that recommended in the TG-43U1 update.

Results

The results obtained by the Monte Carlo code were analyzed with the ROOT data analysis framework [11] enable to attain the along-away Cartesian 2D lookup data and the TG-43 dosimetric parameters. The along-away 2D Cartesian lookup data $\dot{D}(y,z)$ is presented in Table 1. The TG-43 parameters were obtained through the data $\dot{D}(r,\theta)$ using the geometric factor $G_L(r,\theta)$ with the line-source approximation. The active length of the source was L = 0.32 cm. We found a value for the dose rate constant of Λ = 1.09 ± 0.002 cGy h^{-1} U^{-1}. The anisotropy function obtained, $F(r,\theta)$, is presented in Table 2. The radial dose function $g_L(r)$, is

Table 2. Calculated anisotropy function $F(r,\theta)$ for the BEBIG CSM11 source. Origin is at the center of the active part. The 0° points towards the source tip

	r (cm)													
θ (deg)	0.25	0.5	0.75	1	1.5	2	2.5	3	4	6	8	10	12	15
0	–	0.964	0.960	0.963	0.957	0.957	0.956	0.954	0.952	0.954	0.953	0.956	0.955	0.955
1	–	0.969	0.969	0.969	0.966	0.965	0.965	0.963	0.963	0.965	0.966	0.966	0.969	0.969
2	–	0.974	0.972	0.971	0.970	0.969	0.969	0.968	0.968	0.970	0.972	0.972	0.976	0.975
5	–	0.973	0.969	0.967	0.965	0.964	0.964	0.964	0.965	0.967	0.969	0.971	0.972	0.975
8	–	0.968	0.963	0.962	0.961	0.961	0.961	0.962	0.963	0.964	0.967	0.969	0.971	0.973
10	–	0.963	0.960	0.959	0.959	0.959	0.959	0.960	0.961	0.964	0.965	0.968	0.970	0.972
15	–	0.958	0.959	0.959	0.960	0.960	0.961	0.962	0.964	0.966	0.968	0.970	0.973	0.975
20	–	0.964	0.966	0.966	0.967	0.968	0.969	0.970	0.971	0.973	0.974	0.976	0.977	0.979
25	–	0.973	0.973	0.974	0.975	0.975	0.976	0.977	0.977	0.979	0.981	0.981	0.983	0.984
30	–	0.979	0.980	0.981	0.982	0.982	0.983	0.983	0.983	0.984	0.985	0.986	0.986	0.988
40	–	0.988	0.988	0.989	0.990	0.990	0.990	0.990	0.990	0.991	0.992	0.992	0.993	0.993
50	–	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.995	0.995	0.996	0.996	0.996	0.996
60	–	0.997	0.997	0.997	0.997	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998
70	0.999	0.998	0.998	0.999	0.999	1.000	0.999	1.000	0.999	0.999	0.999	0.999	1.000	1.000
80	1.000	1.000	0.999	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.001
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	0.999	0.999	1.000	0.999	0.999	1.000	0.999	1.000	0.999	1.000	1.000	1.001
110	1.000	0.999	0.998	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	1.000
120	–	0.997	0.996	0.997	0.996	0.996	0.997	0.997	0.997	0.997	0.997	0.997	0.998	0.998
130	–	0.992	0.992	0.993	0.993	0.994	0.994	0.994	0.994	0.995	0.995	0.995	0.996	0.996
140	–	0.987	0.987	0.988	0.989	0.989	0.989	0.990	0.990	0.991	0.991	0.991	0.992	0.993
150	–	0.978	0.980	0.980	0.982	0.983	0.983	0.984	0.984	0.986	0.986	0.987	0.988	0.989
155	–	0.974	0.976	0.976	0.978	0.979	0.979	0.979	0.981	0.982	0.983	0.984	0.985	0.986
160	–	0.970	0.971	0.972	0.974	0.975	0.976	0.976	0.977	0.979	0.980	0.981	0.982	0.984
165	–	0.971	0.972	0.972	0.972	0.972	0.973	0.973	0.974	0.976	0.977	0.978	0.980	0.981
170	–	0.979	0.978	0.977	0.975	0.975	0.974	0.974	0.975	0.976	0.978	0.979	0.980	0.981
172	–	0.982	0.981	0.979	0.978	0.977	0.977	0.977	0.978	0.979	0.980	0.980	0.982	0.984
175	–	0.983	0.983	0.983	0.982	0.982	0.981	0.981	0.980	0.982	0.983	0.985	0.985	0.985
178	–	0.982	0.984	0.982	0.982	0.982	0.980	0.980	0.981	0.982	0.983	0.982	0.984	0.984
179	–	0.978	0.976	0.977	0.977	0.977	0.976	0.977	0.977	0.977	0.979	0.980	0.981	0.981
180	–	0.968	0.962	0.967	0.971	0.969	0.972	0.974	0.973	0.967	0.972	0.978	0.975	0.976

shown in Table 3 compared with that of Ballester *et al.* As could be observed in Table 3 both datasets are coincident within statistical uncertainties.

Discussion

Following the recommendations of the TG-43U1 report, dose rate uncertainties were evaluated considering the type A or statistical uncertainty contributions inherent to the Monte Carlo technique and the type B contributions arising from uncertainties in the cross section databases in the geometry of the source in the photon spectra and in other possible systematic uncertainties. In case of type A uncertainties, we distinguished between two intervals. In case where $\theta > 10$ and $\theta < 170°$, the obtained values for the uncertainty below 0.2% and close to the longitudinal source axis for $\theta < 10°$ and $\theta > 170°$, where the statistical uncertainty was less than 1%. The statistical uncertainty in the case of the simulation of air-kerma strength was less than 0.1% (type A uncertainty). The combination of both statistical uncertainties gives type A uncertainties of 0.2% for the first interval and 1% for the points located near the longitudinal source axis. The uncertainties due to the source construction processes were not evaluated in this study. The uncertainty contribution associated to the cross section libraries and other systematic uncertainties associated with the MC calculation were not evaluated, however a conservative value of 1% seems appropriate [12]. The final dose rate values, combining both types A and B uncertainties, for points near the longitudinal source axis were less than 1.4% and less than 1% for the other points.

Conclusions

In this study the dosimetric parameters of the CSM11 source were acquired in order to obtain the TG-43 parameters of the source. The results were coincident within the statistical uncertainties with that obtained for the same source by Ballester *et al*. This study presents insignificant statistical noise in contrast with the study of Ballester *et al*., thus the new dosimetric data for the CSM11 source fulfils the requirements of the TG-43U1 report to be used in clinical practice as a reference data and improves the existing dosimetric data for this source.

Table 3. Radial dose function, $g_L(r)$, for the CSM11 source and comparison with the data of Ballester *et al*. As could be observed, the data are nearly coincident. The radial dose function was fitted to a fifth order polynomial between r = 0.2 cm and r = 15 cm with coefficients: $a_0 = 1.00126$, $a_1 = -1.422 \times 10^{-2}$ cm^{-1}, $a_2 = 1.996 \times 10^{-3}$ cm^{-2}, $a_3 = -4.055 \times 10^{-4}$ cm^{-3}, $a_4 = 2.780 \times 10^{-5}$ cm^{-4} and $a_5 = -6.791 \times 10^{-7}$ cm^{-5}

r (cm)	$g_L(r)$ (Ballester *et al.*)	$g_L(r)$ (this study)
0.25	1.003	1.010
0.5		1.005
0.75		1.003
1	1.000	1.000
1.5	0.992	0.995
2	0.989	0.990
2.5	0.986	0.985
3	0.975	0.980
4	0.962	0.969
6	0.942	0.942
8	0.911	0.911
10	0.874	0.875
12	0.834	0.836
15	0.769	0.771

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