Dosimetry Characterization of a Brachytherapy Seed by Thermoluminescence Dosimetry in Liquid Water

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Purpose:

A primary goal of this project was to resolve discrepancies in the reported values of the dose rate constant for ^{131}Cs (model Cs-1), and to use liquid water as a phantom to measure a complete set of dosimetric parameters. This method avoids the uncertainties introduced by use of water-equivalent plastics.

Introduction:

The updated AAPM Task Group 43 Report (TG-43U1)[1] for brachytherapy dosimetry recommends the use of dosimetric parameters measured in, or related to, water. Measurements of dosimetric parameters are often made using thermoluminescence dosimetry (TLD). However, TLD measurements in water are quite challenging to perform for a number of reasons. As such, brachytherapy sources are generally characterized in water-equivalent plastics such as Solid Water™ (SW). The dose measured in SW must then be converted to dose in liquid water using a correction factor based on Monte Carlo (MC) calculations. Errors can be introduced by this procedure if the chemical composition of the SW material used for measurement is not identical to that used for MC simulation.[2]

To avoid the additional sources of uncertainty associated with measurements in water-equivalent materials, a set of plastic jigs was designed to support TLD capsules around a brachytherapy source in liquid water.[3] The jigs were used to characterize a new model of brachytherapy source, the ^{131}Cs source (model Cs-1 Rev. 2) produced and marketed by IsoRay Medical, Inc. (Richland, Washington).

^{131}Cs produces a mean photon energy of ~ 30.4 keV[4], and is of interest because it exhibits desirably shorter $T_{1/2}$ of 9.7 days[4] compared to 60 days for ^{125}I and 17 days for ^{103}Pd.[5] A radiobiological model suggests advantages of short $T_{1/2}$ in permanent brachytherapy implants.[6]

Several reports of the dosimetric characteristics of ^{131}Cs have been published.[7-10] There are significant differences among the values for dose rate constant reported previously.[7-10] Our results measured in liquid water are compared against those from previous publications.[7,10]

Methods & Materials:

^{131}Cs source: Fig.1 shows a cut away view of the seed (model Cs-1 Rev.2) through its longitudinal axis. The source has been designed with outer dimensions similar to those of existing ^{125}I and ^{103}Pd seeds. The radioactive core is made of a gold wire surrounded by an inorganic substrate to which ^{131}Cs is chemically bound.

A total of 13 seeds(^{131}Cs) were used in this study. Air-kerma strength of each source was determined by the M.D. Anderson ADCL. The sources used in this study had initial strengths of 11-15 U.

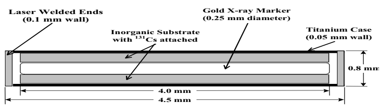


Fig. 1: Schematic of the cross-section through the axis of ^{131}Cs model CS-1.

TLD capsules: Measurements were performed using TLD capsules. A capsule (Fig.2) consists of a glass capillary tube containing ~13 mg of llithium fluoride powder (TLD-100). The powder volume corresponds to 7.0 mm in length and 1.4 mm in diameter.

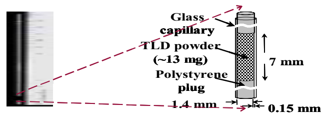


Fig. 2: Picture and schematic of TLD capsule.

TLD reading: A manual TLD reader (Harshaw model 3500) and standard procedures[11,12] developed by the Radiological Physics Center (RPC) were employed to read irradiated TLD. The TLD signal (TLD reading/mass) was converted to dose following the RPC convention.[11,12] Dose response of TLD was calibrated in a ^{60}Co beam, whose output was measured using the TG51 protocol.[13] Relative energy response of TLD for 28-30 keV versus ^{60}Co photons was previously determined to be 0.707 $\pm$ 2.5%.[14] Other corrections due to the capsule's glass wall, and TLD volume's finite size were also incorporated.[15]

Dose-rate constant: Measurements were made employing a specially designed jig.[3] This jig holds 24 TLD capsules equally spaced in a circle of 1.00 cm radius around the seed. During irradiation, the seed mounted coaxially on tip of a graphite rod was vertical (parallel to all TLD) and at the exact center of TLD array. For irradiation, the jig supporting the source and TLD capsules was submerged in water so that the source and capsules were surrounded by at least 10 cm of water in all directions.[14] After irradiation, the TLD were read, and the TLD signal was converted to dose. A correction for decay during the irradiation was applied. The dose rate constant was determined from an average of the 24 TLD signals in each irradiation run (total 8 runs for water and SW). The results are shown in Table-1.

Anisotropy Function: The same jig, as used for measurement of Λ, was employed. However, the seed was glued perpendicularly to the tip of the graphite support rod. The jig has 24 equally spaced TLD positioning holes along each of the 5 concentric circles (radii 1-7 cm). A set of 24 TLD was positioned along one circle at a time to prevent TLD's mutual shadowing.

Measurements were repeated with 4 different seeds. In each irradiation run, symmetry of TLD in 4 quadrants provided 4 data points per angle (θ). The active length (L) of 4.0 mm, provided by the manufacturer, was employed in determination of the geometry factor $G(r,\theta)$.

Radial Dose Function: Another jig[3], designed for this measurement, holds TLD capsules in 3-armed spiral pattern to avoid TLD's mutual shadowing. The jig holds the seed (^{131}Cs) to be irradiated, parallel to the TLD capsules. Each spiral arm holds 15 TLD capsules positioned at distances 0.5-10 cm from the source axis. Following irradiation, each TLD measurement was converted to dose as explained previously.

Results & Conclusions:

Dose rate Constant: Our results from 8 irradiation runs (2 per seed) are presented in Table-1, demonstrating an average dose rate constant of 1.078 $\pm$ 3.3%. Comparison with the values reported by other investigators is also provided.

Measured

Seed ID	Λ	Mean Λ
FS0637-005-001	1.074	
FS0637-005-002	1.069	1.078
FS0637-005-002	1.082	± 0.05
CL0650-003	1.087	

Reported by other investigators

Investigator	Λ (cGy h^{-1} U^{-1})	Comment
Murphy, et al [7]	0.915	Used an earlier design of this source.
Chen, et al [8]	1.066	Determined by gamma-ray spectrometry
Chen, et al [8]	1.058	TLD dosimetry in Solid Water™
Wittman & Fisher [9]	1.040	MC calculations
Rivard [10]	1.046	MC calculations

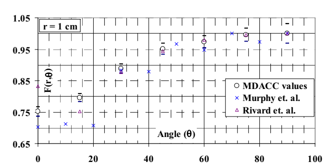
Table-1: Values of dose rate constant.

Anisotropy Function: Table-2 summarizes the measured values of $F(r,\theta)$ and compares them with the values reported by Rivard.[10] The 1D anisotropy function was determined by simple numerical integration from the 2D dose-rte measurements.

Angle	1 cm			2 cm			3 cm			5 cm			7 cm		
θ (deg)	MDACC	Rivard	Ratio	MDACC	Rivard	Ratio	MDACC	Rivard	Ratio	MDACC	Rivard	Ratio	MDACC	Rivard	Ratio
0	0.752	0.833	0.903	0.788	0.839	0.939	0.824	0.842	0.979	0.853	0.848	1.006	0.851	0.852	0.999
15	0.796	0.753	1.057	0.798	0.791	1.009	0.835	0.811	1.030	0.864	0.831	1.039	0.865	0.841	1.028
30	0.888	0.878	1.011	0.886	0.894	0.991	0.912	0.902	1.011	0.907	0.909	0.998	0.935	0.912	1.025
45	0.950	0.944	1.006	0.949	0.950	0.999	0.972	0.953	1.020	0.961	0.956	1.005	0.965	0.956	1.009
60	0.973	0.980	0.993	0.968	0.981	0.987	1.010	0.982	1.029	0.985	0.982	1.003	0.986	0.982	1.004
75	0.996	0.995	1.001	0.984	0.996	0.988	1.004	0.996	1.008	1.005	0.996	1.009	1.006	0.996	1.010
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	1.000
$\phi_{an}(r)$	0.971	0.966	1.005	0.954	0.960	0.994	0.977	0.961	1.017	0.971	0.963	1.008	0.975	0.964	1.011

Table-2: Values of $F(r,\theta)$ measured in liquid water.

Our measured values of $F(r,\theta)$ are graphically presented below in Fig.3 along with the values reported by Murphy et. al.[7] and Rivard.[10] Our values agree better with Rivard's than for Murphy's values.



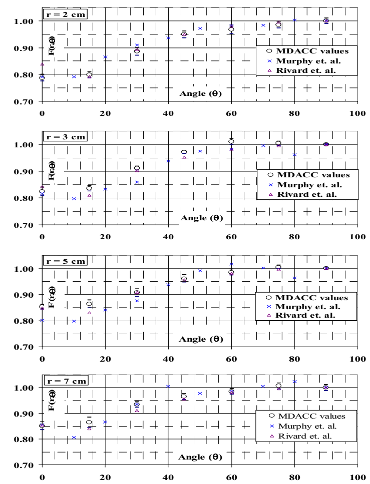


Fig. 3: Values of $F(r,\theta)$ measured in liquid water.

Radial Function: Our measured values of $g_L(r)$ based on line-source approximation, along with the values reported by Murphy et. al.[7] and Rivard[10] for comparison, are shown in Figure 4. Generally good agreement is seen over the range in which measured data were reported by Murphy.[7] Better agreement is seen with the MC calculations reported by Rivard.[10]

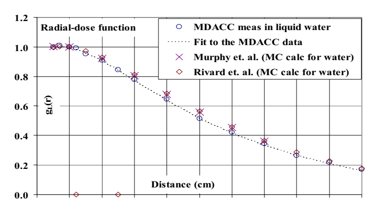


Fig. 4: Radial dose function measured in water.

Table-3 presents our measured values of $g_L(r)$. Comparison with the values reported by Murphy et. al.[7] and Rivard[10] is also shown.

r (cm)	MDACC Meas. in liquid water	Rivard MC in liquid water	Murphy Meas. in VW	Murphy MC in liquid water
0.050		1.051		
0.075		0.965		
0.100		0.960		
0.250		0.989		
0.500	0.998	1.006	1.023	1.003
0.750	1.009	1.009		
1.000	1.000	1.000	1.000	1.000
1.200	0.992			
1.500	0.952	0.962		
2.000	0.909	0.908	0.864	0.923
2.500	0.845			
3.000	0.780	0.777	0.736	0.806
4.000	0.645	0.642	0.586	0.679
5.000	0.515	0.518	0.462	0.558
6.000	0.420	0.411	0.361	0.454
7.000	0.344	0.323	0.274	0.361
8.000	0.266	0.251		0.286
9.000	0.217	0.193		0.225
10.000	0.171	0.147		
15.000				

Table-3: Radial dose function measured in water.

The results reported by Murphy et. Al.[7] (especially Λ) disagree significantly with those of ours and others. The difference is at least partly due to a change in the source design subsequent to Murphy's measurements. Some differences between our results and those of others might be explained by the use of SW (water-equivalent plastic) phantom for measurements by others .

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