TLD measurements in liquid water of dosimetry characteristics of a new ^{125}I seed

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ABSTRACT

To enable measurements of brachytherapy seed characteristics in liquid water, plastic jigs and mini capsules for TLD powder have been designed. Each plastic jig is a frame of 3 sheets of plastic (1mm thick Lexan), separated by thin acrylic rods, standing 11cm high. All 3 sheets have identical circular or spiral patterns of holes at precisely known distances from the centers of the respective sheets. The jig holds and positions the mini capsules at known distances around the active seed in liquid water. The active seed, mounted on the tip of a thin polystyrene post (diameter ~ 1mm) sits at the center of the hole patterns. The mini capsule, consisting of a glass capillary (1.2mm inner diameter, 0.3mm wall) holds ~11mg TLD powder (7mm length). The TLD powder for measurements was "TLD-100" from Harshaw. This system was used to measure dosimetry characteristics of a new source model from Imagyn Medical Technology Inc. The preliminary measurements yielded a dose-rate constant of 0.96 $\pm$ 0.03 cGy h-1 U-1. The TLD results for anisotropy factor and radial dose function show good agreement with Monte Carlo calculations performed at the Radiological Physics Center (RPC). The same mini capsules have been also used for TLD measurements in a Solid Water^{TM} (RMI model 457) phantom to compare with measurements in liquid water. The results indicate approximately 15% difference in dose rate constant.

INTRODUCTION

Dosimetry measurements of brachytherapy seed sources using TLD in water equivalent plastic materials have been reported in several publications in the past, but never in liquid water. Measurements with TLD in liquid water pose several challenges.

This work presents such measurements for a new ^{125}I seed from Imagyn Medical Technologies, Inc. The seed is a new thick-walled design that was constructed with the purpose of improving the anisotropy characteristics of the "Isostar" model IS-12501 source.

Challenges associated with measurements in water include:

(i) TLD requires waterproofing.

(ii) The waterproofing holder for TLD should meet the requirements of minimal wall thickness and proper material to minimize the impact of its being non-water equivalent on the dosimetry results.

(iii) The source holder to hold the radioactive seed in place also should be constructed from the least amount of material for the same reasoning.

iv) An irradiation jig of solid material is required to position the source and the TLDs in predetermined precise positions. Again the jig should involve the smallest possible amount of material and its material should be kept as far as possible from the source and TLDs.

(v) some kind of check device is required to confirm centering of the seed source when placed into the irradiation jig.

The design of the system described in the following sections is based on all these constraints and requirements.

Materials and Methods

To achieve the requirements stated in the preceding section, the following system was developed:

TLD: Lithium Fluoride in powder form was preferred to achieve the best precision, as indicated by the RPC's long-term experience.

Capsules: Glass capillaries with inner diameter 1.3 mm, wall thickness 0.25 mm, and length 12.7 cm were employed. A 7 mm long piece of polystyrene rod of matching diameter was inserted into the bottom end of capillary and sealed with epoxy. A specially designed dispenser was used to pour ~12 mg powder to fill a 6 mm length above the polystyrene plug. Subsequently, the upper blank space of capillary was filled by sliding a long (~8 cm) polystyrene rod. We refer to these TLD holders as "mini-capsules".

Seed Holder: The seed is glued to the tip of a thin polystyrene rod (diameter 1mm). A specially designed jig holds the seed and the rod in the desired alignment for gluing the two. A tiny amount of super glue is then applied under an illuminated magnifier. The rod is then slipped into a hole along the axis of a plastic disc. When it is time to begin irradiation, the disc carrying the rod and the seed is inserted into the circular hole at the bottom of the irradiation jig. The seed thus gets positioned at the center of the array of TLD mini-capsules. For measurements of dose-rate constant and radial dose function, one end of the seed is glued to the rod coaxially so that the seed is held vertically during irradiation. For measurement of anisotropy, the seed is glued at its middle, transverse to the rod, so that the seed is horizontal during irradiation.

Irradiation Jig: A frame was constructed of three sheets of plastic (1 mm thick Lexan), each separated by 11 cm high thin acrylic rods. All three sheets of the jig have identical circular or spiral patterns of holes at precisely known distances from the center of the pattern. The holes in the jig support and position the mini-capsules at known distances and angles around the active seed in liquid water.

Hole Patterns: The irradiation jigs were designed with two kinds of whole patterns.

(i) A spiral pattern for measuring radial dose function. The spiral pattern prevented TLD capsules from being shadowed by any other TLD capsule.

(ii) A circular pattern for measuring dose-rate constant and anisotropy function. The irradiation jig held 24 TLD capsules 15º apart around the active seed on circles of radii 1.0, 2.0, 3.0, 4.0 and 5.0 cm. The capsules and the seed were supported vertically in the water phantom.

TLD Irradiation: TLD capsules loaded with unirradiated TLD power were placed in the irradiation jig holes. The holder carrying the active seed was then inserted into the irradiation jig. The loaded jig was submerged quickly in water. The TLD capsules were generally removed after they received 100 - 300 cGy of dose and replaced by fresh (unirradiated) TLD capsules for repeat measurements.

TLD Signal and Dose Determination: The irradiation jig for dose-rate constant held 24 TLD capsules, spaced 15º apart around the seed source, on a circle of radius 1.00 cm. The TLD signal was converted to dose using a published formulism.

Measurements in Solid Water™: Gammex/RMI model-457 Solid Water™ was machined to hold 24 TLD capsules, 15º apart around the active seed in a circle of radius 1.00 cm. This geometry was identical to that provided by the corresponding irradiation-jig for measurements in liquid water. The purpose was to compare dosimetric parameters determined in Solid Water^{TM} to those in liquid water through actual measurements.

Results

Figure 3A,B shows representative TLD measurements of dose-rate constant in liquid water and solid water^{TM} respectively, presented in both polar and Cartesian forms. The polar presentation most clearly demonstrates the reproducibility of the data and the error in source positioning. The pattern for liquid water, is circular but is displaced slightly relative to the origin. This displacement corresponds to 0.4 mm error in centering of the active seed during irradiation. However, this systematic error in source positioning gets almost cancelled in averaging of all 24 TLD signals. The displacement contributes to the error of the final result for dose-rate constant through the statistical variation in TLD readings.

- 9 sets of repeat measurements yielded a dose-rate constant Λ of 0.97 $\pm$ 0.03 cGy hr^{-1} U^{-1}. An energy correction factor 0.80 was used to adjust the dose calibration of the TLDs from ^{60}Co to ^{125}I energy. This correction was determined by J. Esteban et. al.**

- A comparison of averaged TLD signals from irradiations in Solid Water^{TM} and liquid water at 1 cm distance from the source, using identical geometry, yielded a correction factor of 1.15 + 0.03 as liquid water to Solid Water^{TM} ratio. However, the ratio reported in the literature[1] is 1.031 based on Monte Carlo calculations.

- Figure 4 shows both polar and Cartesian presentations of TLD signals for measurements of anisotropy. Our TLD results and the published[2,3,4] values are presented in Table 1, and shown plotted in figure 5. Our data are currently being reviewed for the significant discrepancies with the published data.

- Our TLD results and the published[2,3,4] values for radial dose function g (r) are presented in Table 2, and shown plotted in figure 6. The data show good agreement with the Monte-Carlo calculations[5].

Uncertainty

The determination of dose rate constant involves uncertainties in (i) TLD signal, (ii) positioning error of the source and TLD, (iii) ^{60}Co calibration of TLD, (iv) ^{60}Co to ^{125}I energy correction factor, and (v) ADCL calibration of the brachytherapy seed. One standard deviation (σ) for these have been estimated to be 1.5, 2.0, 0.4, 2.3, and 1.2, respectively. Therefore, the compounded effective uncertainty is 3.6% at the one σ level.

Conclusions

The measured dose rate constant for the ^{125}I new seed model in liquid and Solid Water^{TM} is 0.97 + 0.04 and 0.84 + 0.04 cGy/h^{-1} U^{-1}, respectively. The correction factor to convert from solid water to liquid water is therefore 1.15 + 0.03. The limited data measured for the radial dose function g (r) show good agreement with the data reported in the literature. However, our data for anisotropy function F(r,θ) are currently being reviewed for the significant discrepancies with the values in literature.

References

1. Meigooni et al., "The Best double wall 103-Pd brachytherapy source", Med. Phys. 28, P 2572 (2001).
2. D. M. Gearheart, A. Drogin, K. Sowards, A. S. Meigooni, and G. S. Ibbott, "Dosimetric characteristics of a new ^{125}I brachytherapy source," Med. Phys. **27**, 2278-2285 (2000).
3. R. Nath and N. Yue, "Dose distribution along the transverse axis of a new ^{125}I source for interstitial brachytherapy," Med. Phys. **27**, 2536-2540 (2000).
4. S.C. Chang et al., Monte-Carlo results from MCNP (DLC-146), Private communication

Acknowledgement

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Tabl1-1: Anisotropy Data Table

Angle (deg)	Radius = 1.0 cm TLD in water	Radius = 1.0 cm Gearhart TLD	Radius = 1.0 cm MCNP	Radius = 2. 0 cm TLD in water	Radius = 2. 0 cm Gearhart TLD	Radius = 2. 0 cm MCNP	Radius = 3. 0 cm TLD in water	Radius = 3. 0 cm Gearhart TLD	Radius = 3. 0 cm MCNP
0	0.280	0.241	0.289	0.328	0.337	0.364	0.388	0.362	0.412
10	-	0.327	0.325	-	0.399	0.411	-	0.440	0.439
15	0.383	-	-	0.430	-	-	0.465	-	-
20	-	0.479	0.463	-	0.532	0.526	-	0.563	0.547
30	0.532	0.634	0.625	0.598	0.663	0.655	0.627	0.681	0.671
40	-	0.768	0.766	-	0.775	0.790	-	0.786	0.801
45	0.688	-	-	0.762	-	-	0.757	-	-
50	-	0.867	0.885	-	0.870	0.880	-	0.878	0.887
60	0.821	0.946	0.953	0.875	0.944	0.970	0.880	0.944	0.953
70	-	0.986	0.979	-	0.985	0.997	-	0.987	0.988
75	0.913	-	-	0.943	-	-	0.966	-	-
80	-	0.998	0.988	-	0.994	0.992	-	1.004	1.005
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table-2: Radial Dose Function for Report

Distance (cm)	MCNP calculations	TLD in water	Gearheart MC (original model)	Gearheart TLD (thick wall)	Nath TLD (original model)
0.5	1.045	1.018	1.080	0.997	1.040
0.7	-	1.043	-	-	-
1.0	1.000	1.000	1.000	1.000	1.000
1.2	-	0.988	-	-	-
1.5	0.929	0.966	0.907	0.960	0.940
2.0	0.846	0.841	0.808	0.800	0.800
2.5	0.763	0.737	0.715	-	-
3.0	0.681	0.658	0.618	0.580	0.610
3.5	0.603	-	0.533	-	-
4.0	0.531	0.496	0.463	0.465	0.430
4.5	0.466	-	0.404	-	-
5.0	0.407	0.375	0.348	0.333	0.330
6.0	0.308	0.279	0.253	0.246	0.230
7.0	0.231	0.215	0.193	0.173	-
8.0	0.171	-	0.149	0.125	-
9.0	0.127	-	0.100	-	-
10.0	0.094	-	0.075	-	-

Figure-1:

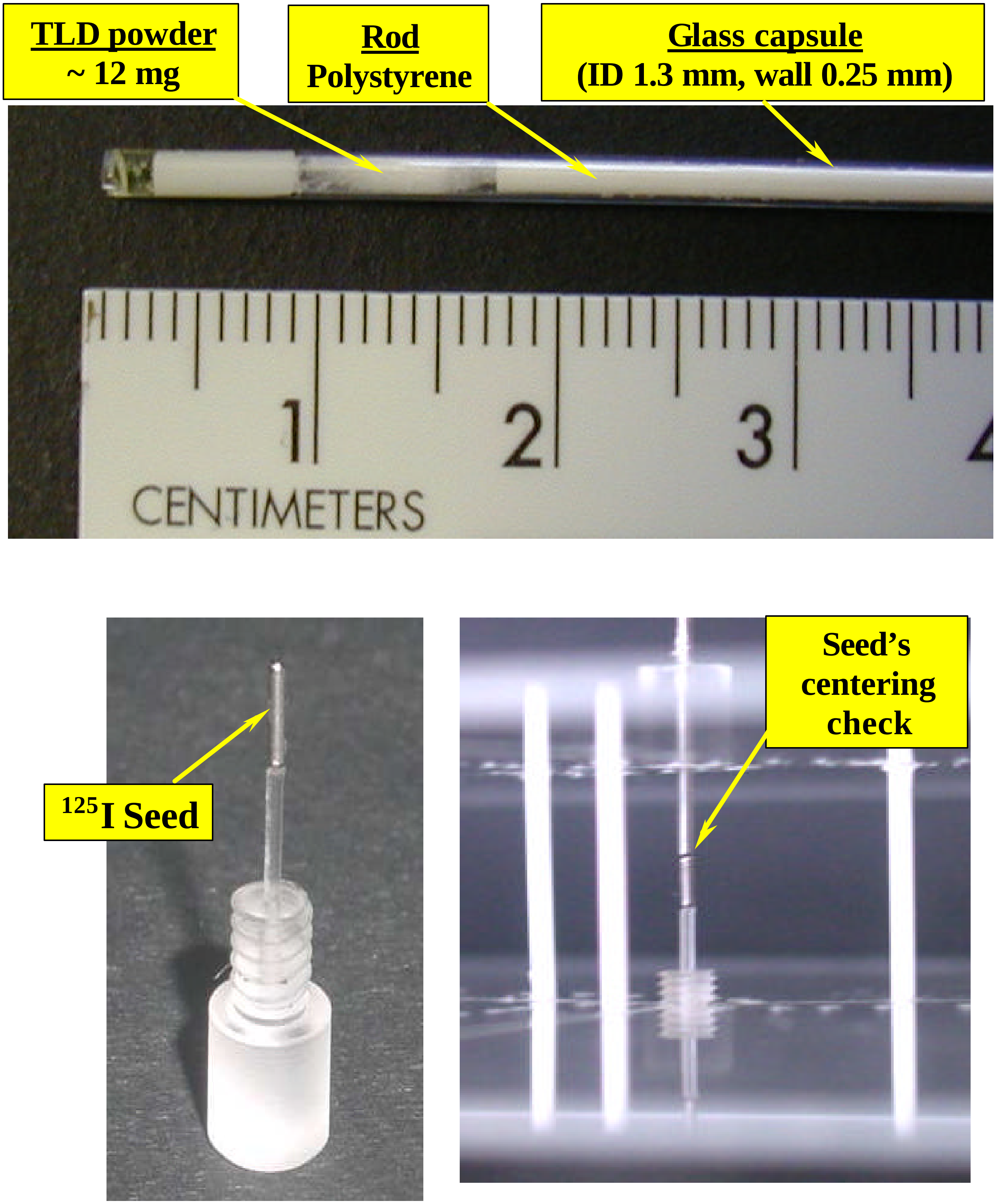

TLD powder
~ 12 mg
Rod
Polystyrene
Glass capsule
(ID 1.3 mm, wall 0.25 mm)
1
2
3
CENTIMETERS
^{125}I Seed
Seed's
centering
check

Figure -2A: Irradiation-jig for Radial dependence

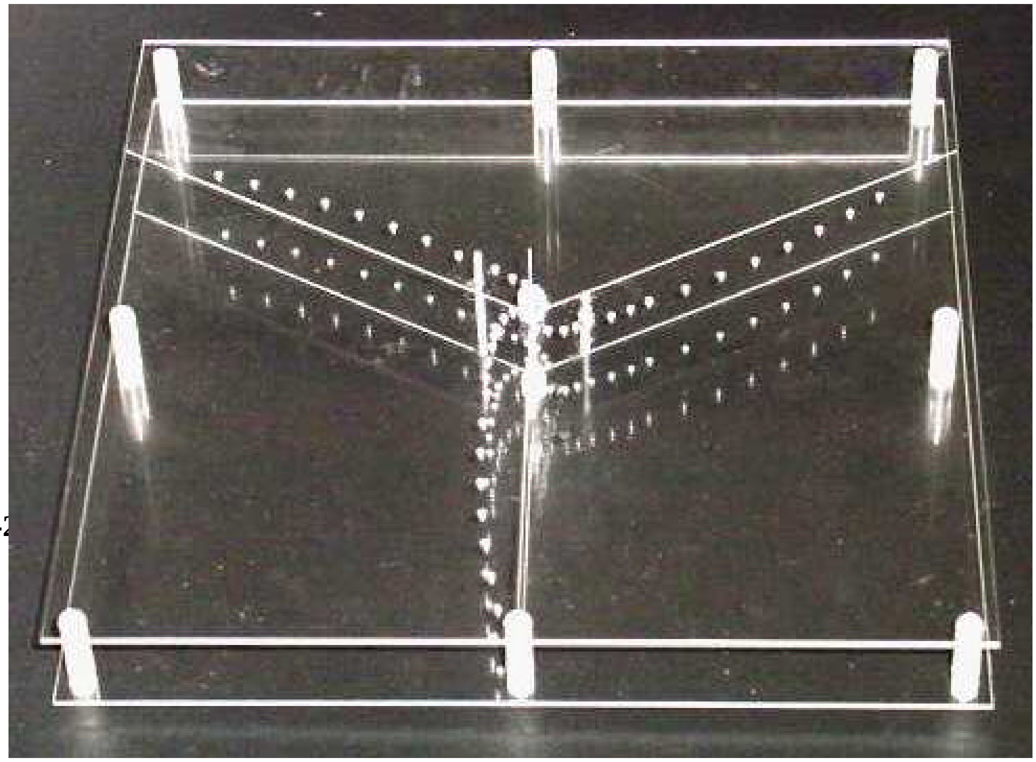


Figure -2

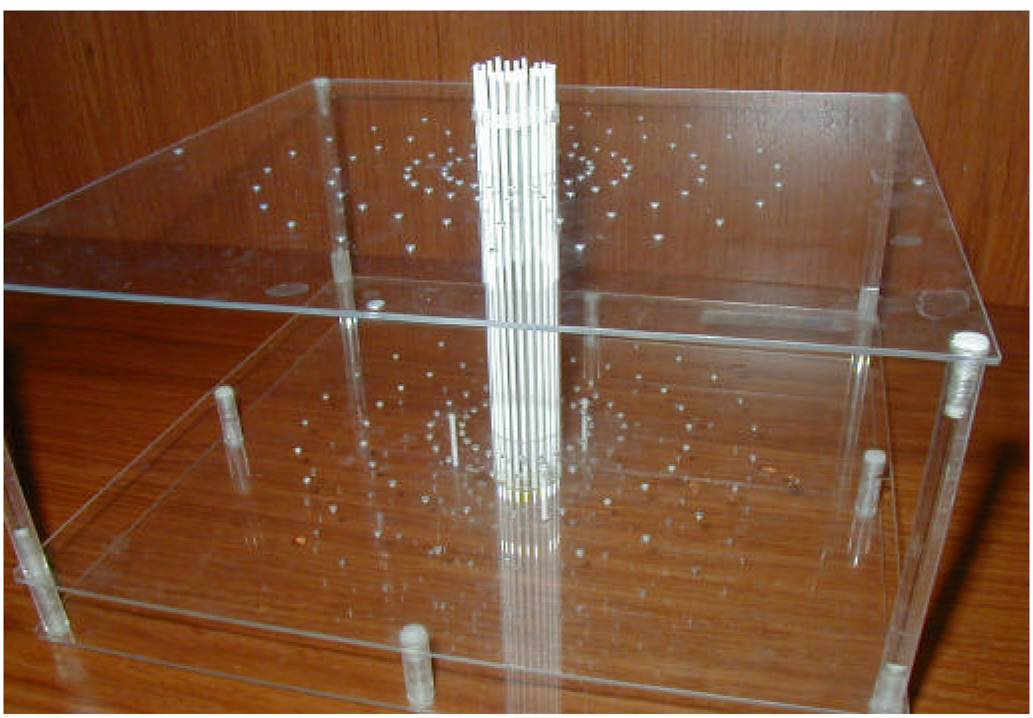


Figure -3A: **TLD signals for dose-rate constant in liquid water**

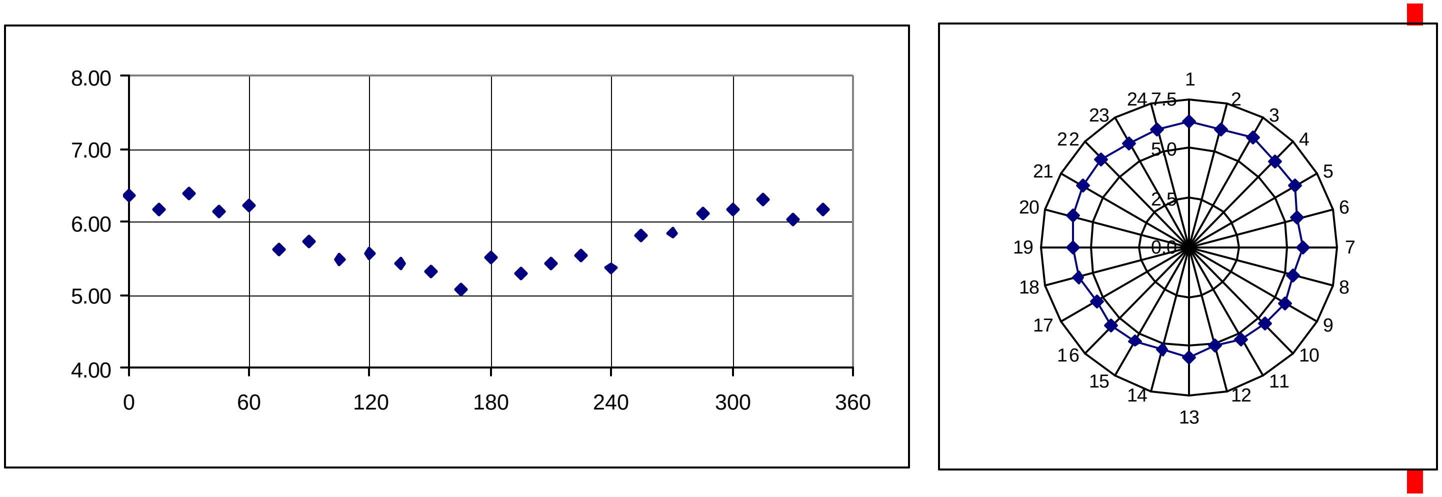


Figure -3B: **TLD signals for do se-rate constant in soli water™**

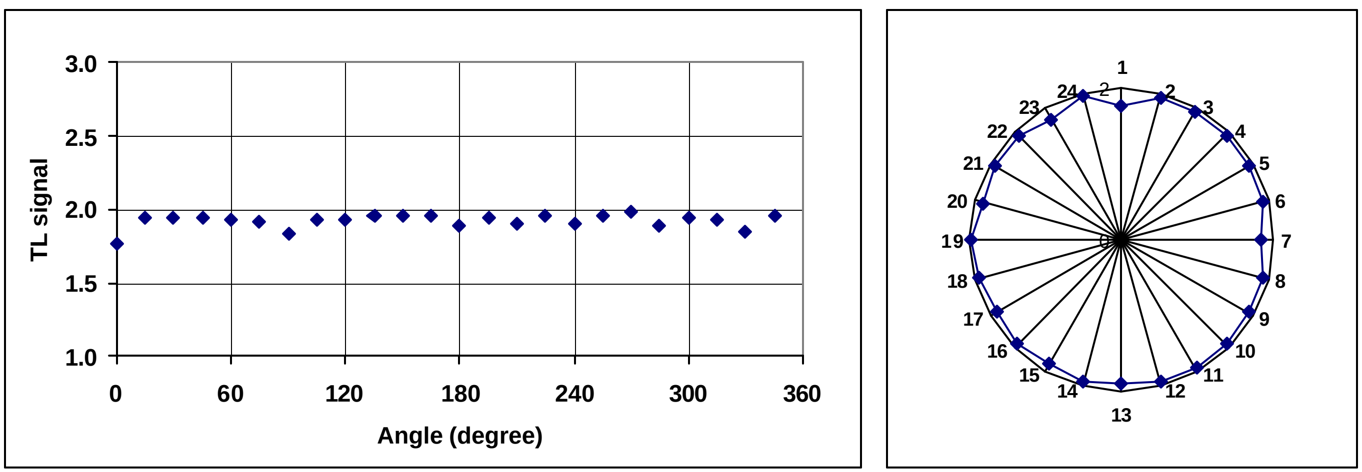
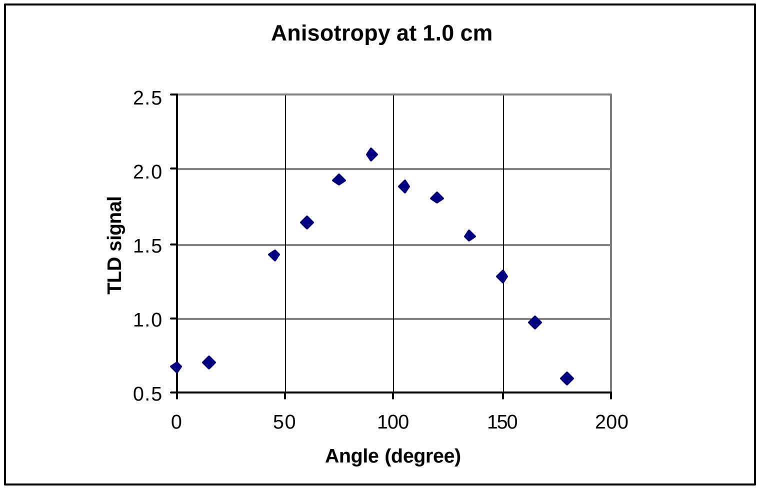
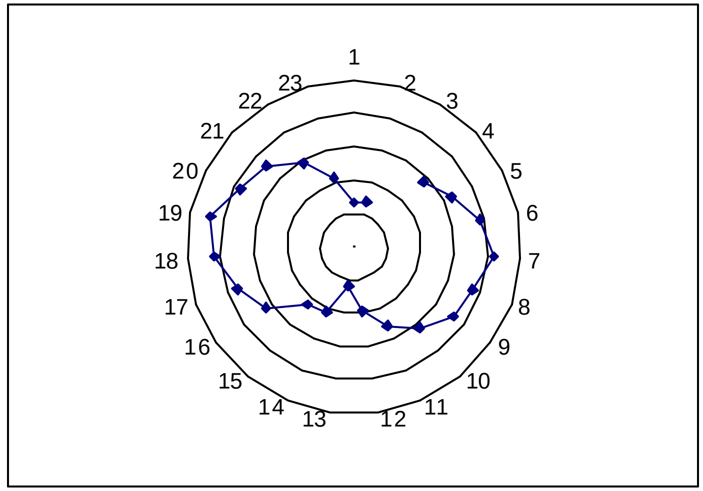
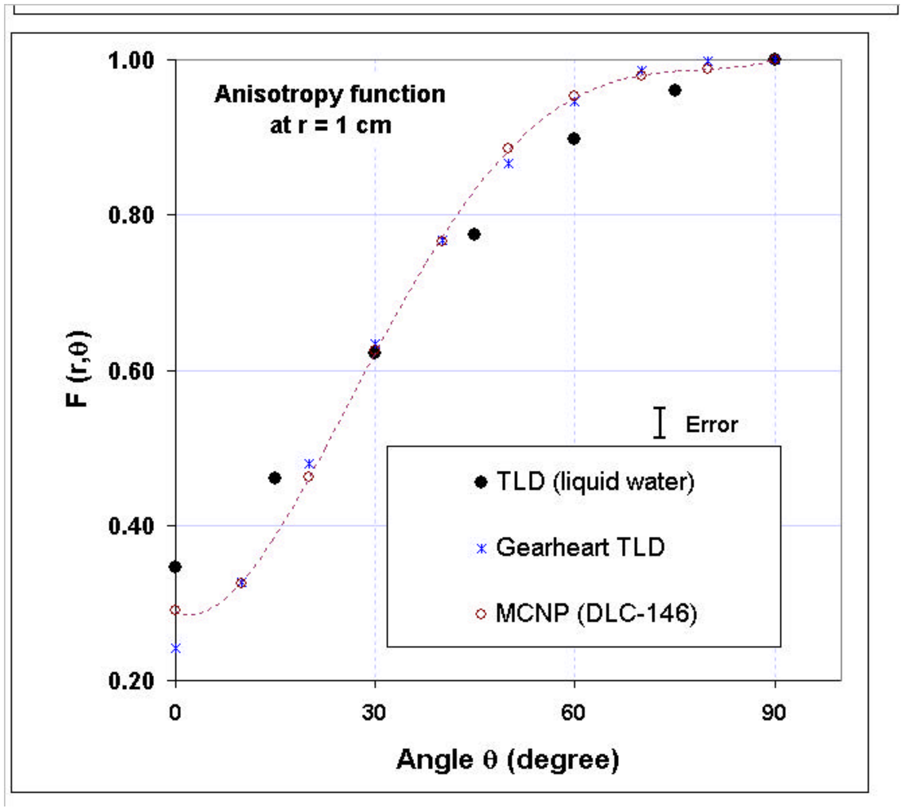


Figure -4: TLD signals for anisotropy in liquid water





<u>Figure</u> -5A: **Anisotropy function, F(r,q) at 1 cm from source**



<u>Figure</u> -5B: **Anisotropy function, F(r,q) at 2 cm from source**

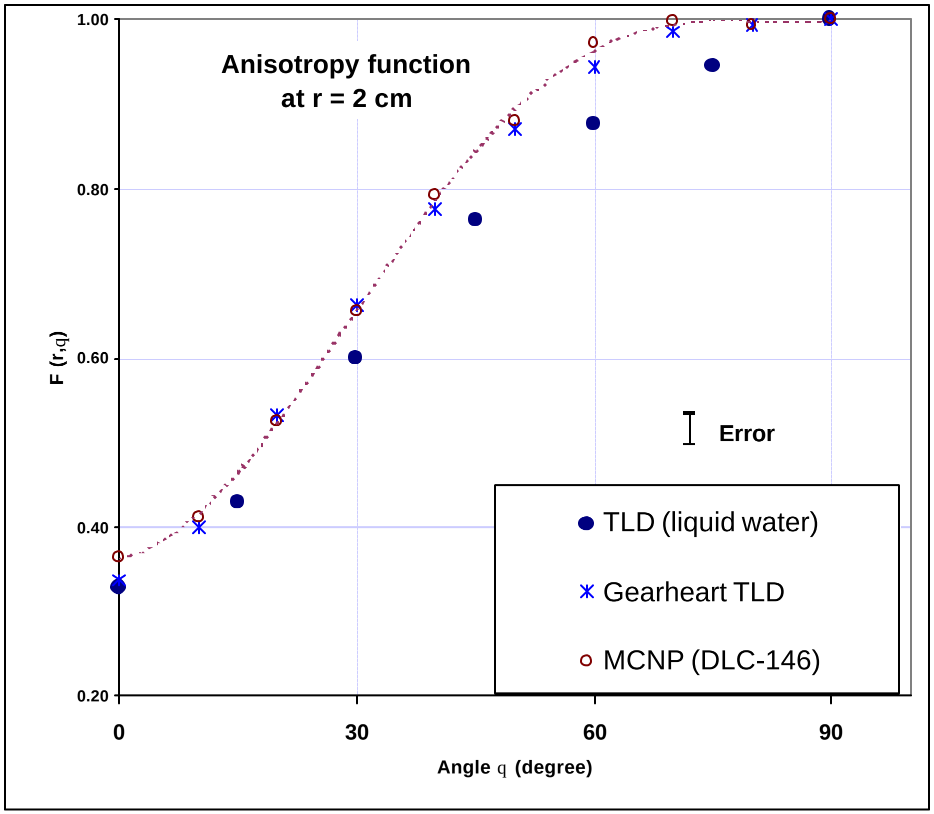


Figure -5C: Anisotropy function, F(r,q) at 3 cm from source

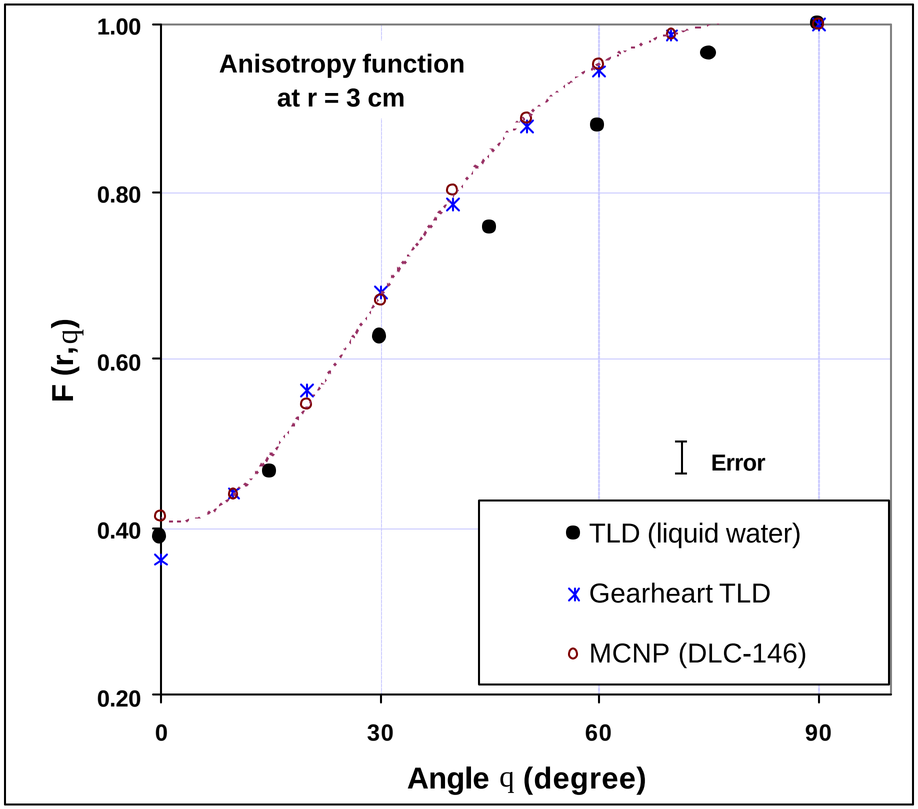


Figure -6: Radial-dose function, g(r)