APPLICATION OF MCP-N DETECTORS FOR ROUTINE RADIATION DOSIMETRY OF RADSOURCE -2400Q IRRADIATOR

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Abstract

Radiation processing involves using ionizing radiation, gamma, X-rays, and electron beams, to alter the biological, physical, or chemical properties of materials. This technology has a wide range of industrial, medical and environmental applications such: medical device sterilization, decontamination in food and agriculture, blood irradiation to prevent transfusion-associated graft-versus-host disease, insect sterilizations, polymer modifications, wastewater treatments, etc. The Institute of Applied Nuclear Physics has used radiation processing for applications in polymer modifications, total microbial load reduction of animal food and in induced plant mutagenesis, since 1984, using the Van de Graf accelerator and the self-shielded gamma irradiator model GU- 3 - Cs-137. A new X-ray biological irradiator has been installed at Institute in 2022 for research applications on insect sterilization, blood irradiation, induced plant mutagenesis etc. The irradiator has a single X-ray tube of Quastar DT-1084 model running at maximum 25 milliampere and 160 kilovolts. It has a mechanical configuration of six cylindrical canisters that are fixed and rotate around the X-ray tube holding material volume of 830 ml each. The irradiator delivers an average dose rate of 16.45 Gy/min in the biological material of larva density of 0.449 gr/cm^3. Irradiation of biological material needs an accurate dose measured by appropriate reference and routine dosimetry system such as ionization chambers, Fricke solution, alanine, radicromic film, thermoluminescence *dosimetry (TLD-s), etc. This work presents the implementation of the European thermoluminescent dosimeters MCP-N (LiF:Mg, Cu, P) as a routine dosimetry system for dose characterization of the biological RS-2400Q for safe and accurate delivery doses to biological material up to 10 Gy.*

Key words*: *Irradiator, thermoluminescent dosemeter, routine dosimetry.

Përmbledhje

Përpunimi me rrezatim përfshin përdorimin e rrezatimit jonizues gama, rrezatimit-X dhe rrezatim elektronik për të ndryshuar vetitë biologjike, fizike ose kimike të materialeve. Kjo teknologji ka një gamë të gjerë aplikimesh industriale, mjekësore dhe mjedisore, të tilla si: sterilizimi i pajisjeve mjekësore, dekontaminimi në ushqim dhe bujqësi, rrezatim gjaku për të parandaluar sëmundjen "graft-versus-host" të lidhur me transfuzionin, sterilizimi i insekteve, modifikimet e polimerëve, trajtimet e ujërave të ndotura, etj. Instituti i Fizikës Bërthamore të Aplikuar ka përdorur përpunimin e rrezatimit për aplikime si modifikime polimerësh, në reduktimin total të ngarkesës mikrobike të ushqimit të kafshëve, në mutaogjenezën e induktuar të bimëve dhe sterilizimin e ushqimit, duke përdorur rrexatim elektronesh nga një përshpejtues Van de Graf dhe rrezatim gama nga rrezatuesi gama të vetë-mbrojtur GU-3 - Cs-137 që prej vitit 1984. Rrezatuesi biologjik i tufave të rrezatimit X Radsource 2400Q për aplikime kërkimore mbi sterilizimin e insekteve, rrezatimin e gjakut, mutagjenezën e induktuar të bimëve është instaluar pranë institutit në vitin 2022. Rrezatuesi ka një tub të vetëm të rrezatimit- X të modelit Quastar DT-1084 që funksionon me maksimum e parametrave 25 miliamper (mA) dhe 160 kilovolt (kV). Ka një konfigurim mekanik prej gjashtë ene cilindrike me një vëllim prej 830 ml të cilat janë të fiksuara dhe rrotullohen rreth tubit te rrezatimit X. Rrezatuesi ka një fuqi dozë mesatare prej 16.45 Gy në minutë në material biologjik me densitet d= 0.449 gr/cm3. Rrezatimi i një materialit biologjik të caktuar kërkon dozë të saktë të matur nga sisteme të përshtatshme të dozimetrisë reference dhe rutinë sic mund të jenë dhome jonizimi, alanine, soulcioni Fricke, film radiokromic, dosimetrat thermolumineshent (TLD-s), etc. Ky punim paraqet implemntimin e dozimetrave termolumineshente evropiane MCP-N (LiF:Mg, Cu,P) si sistem dozimetrie rutinë për karakterizimin e dozës së rrezatuiesit biologjik RS-2400Q për doza të sigurta dhe të sakta të shpërndarjes në materialin biologjik deri në 10 Gy.

Fjalë kyçe: *Rrezatues, dozimetri termolumineshente, dozimetri rutinë.*

Introduction

Self-shielded irradiators expose samples to gamma radiation produced by the isotopes Cs-137 and Co-60 or the low-energy X-ray radiation (bremsstrahlung) produced by an X-ray tube. The gamma radiation source used in the irradiators consists of sealed radionuclides with gamma energies of approximately 1.17 and 1.33 MeV for Co-60 and 0.662 MeV for Cs-137.

Low-energy X-ray emitters use X-ray tubes consisting of an electron source (usually a filament that emits electrons), an electrostatic field to accelerate these electrons, and a target (tungsten material) to generate X-rays. In contrast to monoenergetic gamma radiation, the X-ray energy spectrum extends from low values (about 35 keV) up to the maximum energy of the electron's incident on the X-ray target. Although the gamma and X-ray have similar effects on the irradiated materials they differ in their energy spectra, angular distribution, and dose rates (Mehta IAEA-FAO, 2017; ISO/ASTM 51939, 2017; ISO/ASTM 52628, 2020, A. Dodbiba et al., 2007).

X- ray irradiator RS-2400Q is a self-shielded X-ray cabinet, with a single X-ray tube source of Quastar DT-1084 model, running at maximum 25milliamper (mA) and 160 kilovolts (kV). It has 6 cylindrical canisters holding a material volume of 830 ml each. It conducts an average dose rate of 16.45 Gy/min, a minimum dose rate of 13.96 Gy/min, and dose uniformity of 1.45, measured in a phantom of larva equivalent density (d= 0.449 g/cc) with EBT 3-XD film dosimetry (RadSources. 2400Q operator's manual).

Biological radiation applications of ionizing radiation sources encompass a wide range of absorbed doses for example in blood irradiation and sterile insect the absorbed doses vary from 1 Gy to 600 Gy (Bakri et al., 2021; ISO/ASTM 51940, 2022).

Dosimetry systems used for radiation processing in irradiation of biological materials could be film dosimetry, chemical dosimetry, luminescent dosimetry, gas filled ionization chambers, etc. Generally, a dosimetry mapping phantom fitting the cylindrical canisters volume to simulate a canister filled with the biological material is required to perform commissioning and routine dosimetry for a certain application (ISO/ASTM 51939, 2017; Soares, 2009; ISO/ASTM 51707, 2015; I SO/ASTME 51956, 2013)

The RS- 2400Q has an application mainly in blood irradiation and sterile insect release programs where the absorbed doses vary from 1 Gy to 600 Gy. Dose measurements in terms of dose rate and dose uniformity within volumes of materials (canisters) are important for safe and accurate dose delivering to the biological material e.g., dose for insect sterilization from the irradiator.

This study presents the implementation of lithium fluoride dosimeter dopped with magnesium, copper, and phosphor, MCP-N (LiF:Mg,Cu,P), manufactured by Radcard s.c Poland, as routine dosimetry system for dose characterization of the x-ray irradiator RS-2400Q at doses up to 10 Gy. Dosimeters were provided through the project “Enhancing the Capacities of the Personal Dosimetry Assessment Laboratory”, funded by the National Agency for Scientific Research and Innovation in Albania (NASRI).

Materials and methods

The RS 2400Q is biological cabinet X-ray irradiator with exposure chamber dimensions of 56 cm wide by 32 cm deep by 60 cm high. Inside the exposure chamber is the X-ray tube and carousel system for holding the sample canisters. The carousel system holds 10.2 cm in diameter and 12 cm long canisters and has the option of rotating the canisters around the X-ray source. The parameters of operation at 25 mA and 160 kV.

In this study the MCP-N (01H1H0) was experimented to measure the dose distribution and dose uniformity inside of canister(s) volume irradiated with the Radsource x-ray irradiator. The thermoluminescent detectors consist of two crystals of lithium fluoride doped with magnesium, copper and phosphor, (LiF:Mg,Cu,P), implemented in a typical TLD – card, with disc shape in diameter of 3.6 mm and thickness of 0.38 mm. The MCP-N has a flat photon energy dependence, low fading rate and linear dose response from 10 μGy up to 10 Gy. These passive detectors are compatible with the Harshaw systems used for individual monitoring of occupational exposure implemented at Institute of Applied Nuclear Physics as can show in Figure 1**.** It is worth noting that the device is for the assessment of personal doses of workers and that the radiation device has most of the operating doses above the measurement limit of TLDs. It is also expected that at these doses the error introduced by TLD is somewhat large.

(a) (b) (c)

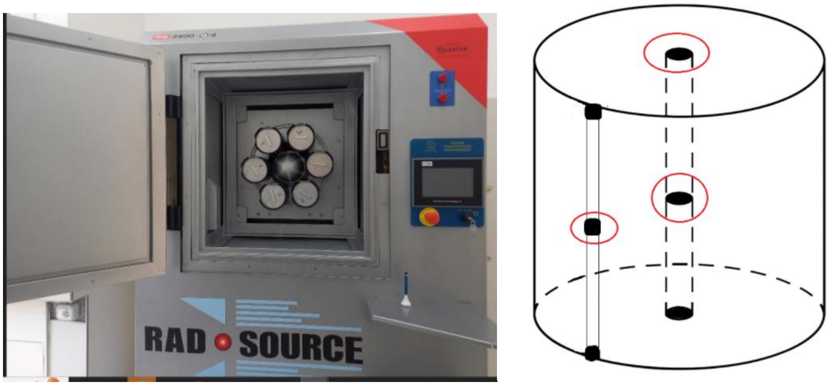
Figure 1. (a) Typical TLD-cards, **(b)** MCP-N in red colour, **(c)** Harshaw 6600 Reader.

Five dosimeters MCP-N (golden cards) from the batch of twenty cards were irradiated in the accredited laboratory at the Jozef Stefan Institute, Slovenia under reference conditions according to standard with ISO 4037-3. Factors of calibrations of reader that converts thermoluminescence lights in dose were processed (Gega et al., 2025; Gega & Bylyku, 2025). The calibration factors for the response of MCPN detectors regarding photon radiations read by Harshaw 6600 were, RCF_{ii} =0.243mC/Gy and RCF_{iii}=0.2393mC/Gy. Subscription (ii) and (iii) correspond to crystals positioned to the second and third window cards as in Figure 1.

Dose measurements

The RS-2400Q X-ray irradiator equipped with X-ray tube model of Quastar DT-1084, is manufactured by Rad Source Technologies Inc, USA. The system comprises six individual Canister containers that rotate around the central X-ray tube (Figure 2) to ensure uniform X-ray exposure. Dosimetry reference show that typically, the maximum dose will be in the middle surface of the Canister, and the minimum dose will be delivered to the central ends of the Canister. The Maximum to Minimum dose ratio gives the dose uniformity and according to manufacture is about 1.45 (RS 2400Q operator's manual).

A central dose of 4 Gy was selected for mapping dose distribution within 830 ml canister volume irradiated by Radsource and measured with MCP-N detector. The purpose of mapping was to get the relative dose at different points to calculate the Dose uniformity (DUR) within canister (s). A set of twelve MCP-N thermoluminescence dosimeter were fixed inside of empty 4-canisters that rotate the x ray source, in positions noted by red circles corresponding to (a) Centre - canister, (b) Centre - Top canister, (c) middle - surface canister. The TLD-s were exposed in air (without any material) for about 17 seconds.



(a) (b)

Figure 2. (a) The RS-2400Q 6-canisters fixed at carrousel around the Xray tube. **(b)** Schematic canister with TLD positions inside

After 24 hours the MCP-N dosimeters were read with the Harshaw 6600 where raw values were measured in millicoulomb and after converted to dose in Gray. The preliminary results of the absorbed doses measured by both crystals MCP-N at the same positions in each canister are presented in the tables below.

Table 1. Dose measured by MCP-N crystal ii

TLD position	**Dose measured in canister number:**				**Average Dose (Gy)**	**Stdev. (Gy)**	**Dose irrad. (Gy)**	**ε (%)**
	1	**2**	**3**	**4**				
Center -Can	4.07	5.27	3.33	3.99	4.17	0.81	4.00	4.17
Middle-Surface	3.95	4.69	4.12	4.36	4.28	0.32	4.00	7.00
Center – Top - Can	5.76	4.16	4.12	6.21	5.06	1.09	4.00	26.54

DUR	1.45	1.27	1.24	1.55	1.21			

Average dose value measured by MCP-N detectors, for the three positioning in canisters, were 4.17 ± 0.81Gy at *centre - canister*, 4.28 ± 0.34Gy in *middle surface of canisters* and 5.06 ± 1.09 Gy at *centre - top* of canisters as in Table 1. Comparing with the dose irradiated of 4 Gy they exhibit a relative error of about 4.17 %, 7.00 % and 26.54 % respectively. Maximum dose delivered was at the *top centre of canister* and the minimum dose delivered was at *centre volume of canister*. Dose uniformity for all canisters was DUR=1.23. Average dose delivered within canister volume in air was 4.50 Gy. Dose reference report measured with film dosimetry sates the lowest dose in the centre can top and the highest values at the middle surface.

Table 2. Dose measured by MCP-N - crystal (iii)

TLD position	**Dose measured in canister number:**				**Average Dose (Gy)**	**stdev**	**Irrad. Dose (Gy)**	**ε (%)**
	1	**2**	**3**	**4**				
Centre – can.	4.14	5.35	3.38	4.05	4.23	0.82	4.00	5.7
Middle-surface	4.01	4.76	4.18	4.43	4.35	0.33	4.00	8.6
Centre- Top-can	5.85	4.22	4.18	6.31	5.14	1.10	4.00	28.5
DUR	1.45	1.26	1.24	1.57	1.21			

Results of dose values measured by the crystal (iii) shown in Table 2 for the same position in all 4 canister volumes show similar pattern. Average dose values were 4.23 ± 0.82 Gy at centre-canister, 4.35 ± 0.33Gy at middle surface canister and 5.14 ± 1.10 *Gy* at centre top canister. Dose differences from dose expected, 4Gy, were from 5.78 % to centre volume of canister to 8.65 % in values at the middle surface of canister and at 28.5 % in centre top of canister.

If we consider one canister the dose distribution inside of a canister volume in the axial plane at the centre of the canister doses varies from 4.14 Gy at the centre of the cylindrical volume to 4.01 Gy at near middle surface canister and 5.81Gy at the top canister. The nonuniformity within the canister volume results DUR=1.45 and an average dose rate 0.27 Gy/s equivalent of 16.20 Gy/min from 16.45 Gy/min as is dosimetry report of Radsource from manufacturer. RS2400Q delivers typically the maximum dose in *the middle surface* of the Canister volume and the minimum dose to the *central ends of the Canister*.

Our measurements show minimum dose values were *at the centre of canister* and that maximum delivered at top-centre with dose uniformity of 1.45 as stated by manufacturer.

Experiment was repeated with the same setup inside of canister volume by adding a fourth TLD positioned at the bottom of canisters as in Figure 3.

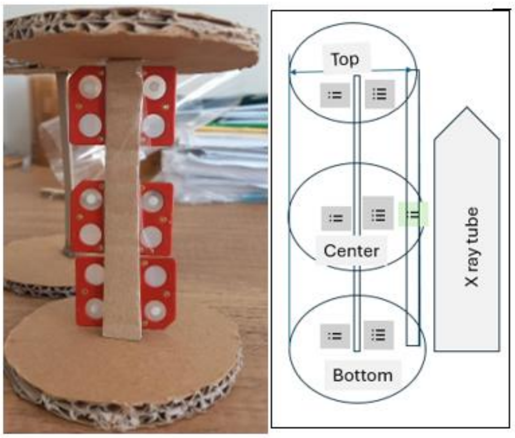


Figure 3. Dosimeters card and position in relation to X-ray tube position.

A preconfigured setup parameters was introduced to the control panel of Radsoruce entering the doze value in Gy and x-ray exposure parameters of 26 mA, 160kV with a time of 17 seconds.

Table 3. Dose measured by MCP-N crystal.

TLD position	Dose measured (Gy) Canister Number:				Aver. (Gy)	Std (Gy)	Irr. (Gy)	ε (%)
	1	2	3	4				
Centre- top (ii)	4.87	5.68	4.42	3.94	4.73	0.74	4.00	18.1
Centre-can (ii)	5.36	3.54	4.00	4.33	4.31	0.77	4.00	7.6
Centre bottom(ii)	4.22	4.83	4.43		4.49	0.31	4.00	12.2
Middle - surface (ii)	4.22	4.83	4.43	5.79	4.82	0.70	4.00	20.4
Centre-top (iii)	3.53	3.82	3.93	3.74	3.75	0.17	4.00	6.1
Centre-can (iii)	3.61	3.97	3.66	3.73	3.74	0.16	4.00	6.4
Centre bottom (iii)	3.61	3.36	4.10		3.85	0.50	4.00	2.1
Middle- surface (iii)	3.61	3.64	4.50	3.81	3.89	0.42	4.00	2.7

From repeated measurements, the TLD-s have shown a better uniformity in the case of crystal three that results in dose values starting from the centre of canister volume, an average dose of 3.74 ± 0.17 Gy, at middle surface 3.89 ± 0.42 Gy, at centre top canister 3.75 ± 0.17 Gy and bottom 3.85 Gy as in Table 3. The maximum dose was measured at middle surface and a minimum at centre volume. DUR value of 1.04. Dose difference from expected dose of 4 Gy vary from 6.5 % to 2.8 % approximately.

Average dose values for the second crystal, ii, were 4.31 ± 0.77 Gy at the centre volume canisters, 4.82 ± 0.7 Gy at middle surface of canister volume 4.73 ± 0.74Gy at the centre top canister volume and 4.49 ± 0.31Gy at the bottom canister. Averaged values at same plane shows that minimal dose 4.00 Gy was conducted in centre of canister and maximum dose of 4.34 Gy in the middle surface of canister.

In the Table 4 are introduced the dose rate reference of RS-2400Q measured with GAF-EBT XD film and average doses calculated for Film and measured by the TLD-s for the same time exposure (i.e., 17s) and the same positions in canister(s) as in experiment.

Table 4. Dose reference of RS-240Q measured by GAF-EBT XD film

Doses measured by GAF- EBT XD film				***Dose measured by TLD-s**	
	Dose rate **(Gy/min)**	Dose rate **(Gy/s)**	Dose calculated for 17 seconds **(Gy)**	(ii) **(Gy)**	(iii)
Centre-top	13.96	0.23	3.96	4.73 ± 0.74	3.75 ± 0.17
Centre-can	17.52	0.29	4.96	4.31 ± 0.77	3.74 ± 0.16
Centre-bottom	14.41	0.24	4.08	4.49 ± 0.31	3.85 ± 0.50
Middle-Surface	20.19	0.34	5.72	4.82 ± 0.70	3.89 ± 0.42
*Dose measured by TLD averaged per crystal positioning at each canister					

If we compare the dose measured by film and TLD-s at the middle surface position of canister, 5.72 Gy versus average dose of 4.82 ± 0.70 Gy, the dose difference in percentage will be 15.7 %.

In overall data measured within canisters at repeated experiment (**Table 3**) point doses measured show a minimum of 3.53 Gy delivered to centre top canister and 5.79 Gy delivered at middle surface canister in accordance with the reference dosimetry equipment.

Results and discussion

Dosimetry requirements for the specific radiation processing applications for installation qualification, operational qualification, performance qualification and routine process requires different dosimetry systems according to ISO/ASTM standards (ISO/ASTM 51939, 2013; ISO/ASTM 51608, 2015; ISO/ASTM 51940, 2022). For each irradiator absorbed-dose rate at a reference position within the irradiated volume in air or a simulated product is measured using reference standard dosimetry which are traceable to appropriate national and international laboratories and have an uncertainty in measurements of 3%, (e.g., ionization chambers, Fricke dosimetry, alanine, etc). Routine dosimetry systems are based on its application including dose mapping and process monitoring with average uncertainty of 6% (e.g., TLD, films etc.). For blood irradiation and induced reproductive insect sterilization the absorbed dose range of interest is from 1 Gy to 600 Gy.

The thermoluminescence-dosimetry system LiF:Mg, Cu, P, could be used for radiation processing as routine dosimetry to measure low doses in the range from 10 μGy to 10 Gy with an uncertainty of the order ± 6% to ± 13% as mentioned by producer of TLDs (ISO/ASTM 51956, 2013; E. Gega et al., 2025). Source of uncertainty in TLD-s is because of the source used for calibration, determination of calibration curve, time between irradiation and redout (fading correction), correction for attenuation in equilibrium material, reproducibility of individual dosimeter response, interspecimen scatter, absorbed dose rate dependence, energy dependence, effect of time between preparation and readout, directional dependence, humidity dependence and effect of size of TLD-s.

Dose measured by MCPN-TLD detectors have shown a dose value difference from nominal dose of 4Gy, in 2% to maximum of 28 %, which is expected as DUR of 1.45 was stated by manufacture.

If all data are analysed statistically dose delivered within canister volumes was an average dose of 4.18 Gy, the minimum dose 3.33 Gy and the maximum dose 6.2 Gy with a standard deviation of 0.71 Gy from 4,0Gy expected. Dose uniformity ratio DUR= 1.48. All data points are presented by graphic in the Figure 4.

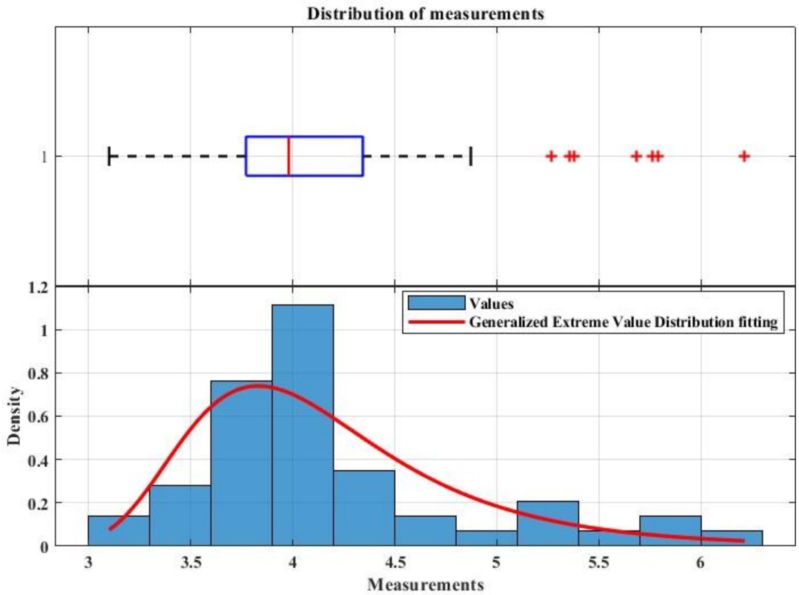


Figure 4. Boxplot, distribution, and fitting with known distributions

Dose values greater than 5.8 Gy that are outlier were measured at the centre top of canister where the lid closes the canister. That might cause a backscatter photon effect which could be added to the detector crystal. Further experiments needed to be performed for optimization of measurements.

From figure 4, the distribution of values is observed, where the measured values are included in all conditions, where it is expected to have some dispersion. The distribution of values has also been studied and has been fitted with a known distribution. Also, bin optimisation is performed using Freedman - Diaconis rule. Normal, lognormal, Inverse Gaussian distributions, etc. have been tested and it resulted that the Generalized extreme value distribution according to loglikelihood is the best fitted. Further, the fit with the Anderson-Darling rule has been tested and the hypothesis raised is accepted.

Conclusions

The RS- 2400Q has an application mainly in blood irradiation, sterile insect release programs and induced mutagenesis with doses that vary in a wide range from 1Gy to 600Gy. The implementation of the European thermoluminescent dosimeters MCP-N (LiF:Mg,Cu,P) as routine dosimetry system for dose characterization of RadSource within volume of the canister (s) makes the administration doses safe in biological material up to 10 Gy.

Point dose distribution within volume of the canister irradiated by RS-2400Q at 4 Gy showed good results in compliance with dosimetry report from manufacturer. The average dose value measured was 4.18 ± 0.71 Gy, the minimum value of 3.33 ± 0.71Gy at centre canister and maximum 6.20 ± 0.71 Gy top canister, and DUR= 1.48. The dose rate calculated was 0.27 Gy/s (16.45 Gy/min). Averaged dose difference per element in the same positions, at four canisters were from 2% to maximum of 28 %, which is expected as DUR=1.45 stated by manufacture.

TLDs doses compared with reference film doses in absolute values gave the same pattern but with large errors (i.e.,15.7 %) which make the TLD-s limited in accurate dose measurements in high doses used for radiation processing. More data are necessary to be performed in further experiments for achieving a better reliable result.

Acknowledgments

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