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Evaluation of the performance of newly developed ^{6}LiF and ^{7}LiF TLDs based on Mg, Cu and Si doped material in the mixed fields of neutrons and gamma rays

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1. Introduction

Neutron dosimetry is by far a regulatory requirement in the mixed fields of neutrons and gamma rays for the estimation of doses to occupational workers in nuclear facilities, namely nuclear reactors, fuel processing and fabrication facilities and also high energy particle accelerators. While the dosimetry of X and gamma rays is simple and straight forward with unity radiation weighting factor, the neutron dosimetry is much more complicated due to the variability of the energy of neutrons and the associated radiation weighting factors. Most widely used technique for personal dosimetry has been the albedo technique using a pair of ^{6}LiF (high sensitivity to thermal neutrons) and ^{7}LiF (insensitive to neutrons) TLDs, viz TLD-600 and TLD-700 (Mg and Ti doped LiF TLDs) from Harshaw Chemical Co, USA. The major problem has been the low sensitivity of LiF:Mg,Ti. Although, the availability of ^{6}LiF and ^{7}LiF TLDs doped with Mg, Cu, & P have enabled to overcome the problem of the required sensitivity to some extent, but they suffer from the draw backs of change / reduction in the sensitivity on reuse, limitation of heating not beyond 240 ˚C and higher residual TL. LiF:Mg,Cu,Si TLD appears to have over come the deficiencies of LiF:Mg,Cu,P and therefore ^{7}LiF:Mg,Cu,Si and ^{6}LiF:Mg,Cu,Si were prepared and evaluated to provide a pragmatic solution for mixed fields of neutrons and gamma ray dosimetry.

2. Material and Methods

High purity ^{6}LiF and ^{7}LiF powders were procured and analysed to have 90.5±0.2 % of ^{6}Li and 99.97±0.01 % of ^{7}Li, respectively, by using inductive coupled plasma mass spectroscopy (ICPMS). Optimized methods with appropriate dopant concentrations of $MgSO_4.7H_2O$, CuSO4.5H2O and SiO2 were arrived at to offer the best results. TLD discs of diameter 4.5 mm and thickness 0.8 mm of differently enriched LiF:Mg,Cu,Si were made using a method similar to that reported earlier [1]. Their performances were tested by loading the TLD discs in to the standard neutron badge of Harshaw Chemical Co. USA and by using the calibrated ^{137}Cs gamma ray sources and neutron fields of ^{252}Cf sources. The badge had a provision to hold each pair of ^{6}LiF and ^{7}LiF TLD discs under two different filter regions, namely ABS plastic + Cd filter with the mass thickness of 465 mg/cm^2 and under ABS plastic only with the mass thickness of 300 mg/cm^2.

3. Results and Discussions

The responses of indigenously prepared TLDs were compared with the commercially available TLDs (Table-1). It may be noted that the intrinsic gamma ray sensitivity of LiF:Mg,Cu,Si is very high.

Table.1 Relative gamma ray sensitivity (TL/mGy) of different LiF TLDs (Harshaw LiF:Mg,Ti TLD100 ribbons=1).

Make & Dopants	LiF	^{6}LiF	^{7}LiF
Harshaw, Mg,Ti	1.00_{TLD100}	1.02_{TLD600}	1.12_{TLD700}
Korea, Mg,Cu,Si	55	27.4	32.0
China, Mg,Cu,P	53	44.6	43.0
Poland, Mg,Cu,P	36	25.4	32.9

Table 2 shows the relative responses of different LiF TLDs in mixed field of neutrons (45 mSv) and γ rays (5.58 mSv) of D_2O moderated ^{252}Cf (Cd covered) sources (in terms of TL equivalent to ^{137}Cs gamma rays). By assuming the response of Harshaw TLD700 to be negligible to neutrons and using it for the estimation of gamma rays doses in the mixed fields, the relative neutron sensitivities (ratios of TL/mSv to neutrons and gamma rays) of ^{6}LiF:Mg,Ti (TLD600; 95.62% of ^{6}Li), ^{6}LiF:Mg,Cu,Si, GR206 (^{6}LiF:Mg,Cu,P) of China and MCP6 (^{6}LiF:Mg,Cu,P) of Poland were estimated to be 2.96, 1.22, 1.23 and 1.15, respectively for the D_2O moderated ^{252}Cf neutrons.

Table.2 Relative responses (TLD700=1) of different LiF in mixed field of neutrons (45 mSv) and γ rays (5.58 mSv) of moderated ^{252}Cf neutron sources (in terms of TL equivalent to ^{137}Cs gamma rays)

Make & Dopants	^{7}LiF	^{6}LiF	LiF
Harshaw,Mg,Ti	1.00_{TLD700}	25.0_{TLD600}	8.24_{TLD100}
Korea,Mg,Cu,Si	1.04	10.9	3.44
China,Mg,Cu,P	1.55_{GR207}	10.9_{GR207}	3.42_{GR200}
Poland,Mg,Cu,P	1.08_{MCP7}	10.2_{MCP6}	2.58_{MCPN}

The relative neutron sensitivities of ^{6}LiF TLDs doped with Mg,Cu,P and Mg,Cu,Si (Table-2) were much smaller than that of TLD-600. This was attributed to the LET dependence [2] indicating that the LET dependence of LiF:Mg,Cu,Si is similar to that of LiF:Mg,Cu,P.

Table-3 shows the relative net TL per mSv of neutron dose for ^{6}LiF:Mg,Cu,Si/^{7}LiF:Mg,Cu,Si (Korean TLD pair) and TLD600/TLD700 (Harshaw TLD pair) pairs held in the Harshaw TLD badge for the estimation of neutron doses in different types of mixed fields of neutron and gamma rays from ^{252}Cf sources. Although the TLD-600/TLD-700 pair exhibited higher neutron-gamma discrimination (Table-2), but the high intrinsic TL sensitivity of ^{7}LiF:Mg,Cu,Si and ^{6}LiF:Mg,Cu,Si outweighs this aspect (Table-3).

Table.3 Relative net TL per mSv of neutron dose for ^{6}LiF:Mg,Cu,Si/^{7}LiF:Mg,Cu,Si pair (Korean TLD pair) and TLD600/TLD700 pair (Harshaw TLD pair) for the estimation of neutron doses in different types of mixed fields of neutron and gamma rays from ^{252}Cf sources.

Type of ^{252}Cf Neutron Field & Av. Energy	Harshaw TLD pair	Korean TLD TLD pair
D_2O Moderated (0.43 MeV)	1.00	12.2
D_2O Moderated & Cd Covered (0.52 MeV)	0.74	10.1
Bare (1.84 MeV)	0.10	1.56

Table-4 shows that the responses of neutron insensitive ^{7}LiF TLDs for the estimation gamma ray doses. The responses of ^{7}LiF:Mg,Ti TLD700 (99.993% of ^{7}Li) and ^{7}LiF:Mg,Cu,Si (99.97±0.01 of ^{7}Li) are about the same. The lack of enrichment of ^{7}Li in ^{7}LiF:Mg,Cu,Si appears to have been compensated by the enhanced LET dependence of ^{7}LiF:Mg,Cu,Si [2]. However, ^{7}LiF:Mg,Cu,Si could measure gamma ray doses as low as 1 μSv as against about 40 μSv by using TLD700.

The ^{6}LiF:Mg,Cu,Si/^{7}LiF:Mg,Cu,Si pair held in Harshaw neutron badge holders were tested for the estimation of unknown doses. For this, the badges were exposed to different combinations of doses of ^{137}Cs gamma rays (in the range from 2 to 8 mSv) and neutrons from ^{252}Cf sources held in D_2O moderated and Cd assembly (in the range from 0.9 to 11 mSv) and were given to the authors for the evaluation of doses. The types of radiation were disclosed but the given doses and the proportion of neutron and gamma ray doses were not disclosed until reported by the evaluating author. An algorithm similar to that of Harshaw system was used for the estimation of the doses. The measured and given doses were found to be within 10%, thus well within the ANSI limits set for the audit of quality assurance. This test demonstrated that the ^{6}LiF:Mg,Cu,Si and ^{7}LiF:Mg,Cu,Si pair can directly replace the TLD600 and TLD700 pair in the Harshaw badge for the estimation of personal doses encountered by the occupational workers in the nuclear facilities .

Table.4 Gamma ray content (percent of given neutron dose) measured by different neutron insensitive LiF TLDs in different types of mixed fields of neutron and gamma rays from 252Cf sources.

Type of Neutron Insensitive TLD	Measured Gamma Ray Content in different ^{252}Cf Neutron Fields		
	D_2O Mod &Cd Cov.	D_2O Mod	Bare
^{7}LiF:Mg,Ti$_{(TLD-700)}$	12.23	10.88	4.27
^{7}LiF:Mg,Cu,Si$_{(Korea)}$	12.22	11.36	4.18

4. Conclusions

Development of Korean TLDs based on Mg, Cu and Si doped ^{6}LiF and ^{7}LiF offer a much sensitive dosimeter system for personal dosimetry in the mixed fields of neutrons and gamma rays. The performance of the dosimeters was found to be highly encouraging for the estimation of doses in mixed fields of neutrons and gamma rays. However, there is still a need to standardise the method of preparation of ^{6}LiF:Mg,Cu,Si and ^{7}LiF:Mg,Cu,Si TLDs so as to have differently (^{6}Li and ^{7}Li) enriched TLDs with about the same intrinsic sensitivity to gamma rays to make the algorithm simpler and pragmatic. Although the pair of TLD-600 and TLD-700 exhibited higher neutron-gamma discrimination, but the high intrinsic TL sensitivity of ^{7}LiF:Mg,Cu,Si and ^{6}LiF:Mg,Cu,Si outweighs this aspect.

REFERENCES

[1] J.I. Lee, J.S. Yang, J.L.Kim, A.S Pradhan, J.D. Lee, K.S. Chung and H.S. Choe. Dosimetric characteristics of LiF:Mg,Cu,Si thermoluminescent materials, Appl. Phys. Lett. 89, 094110, 2006.

[2] A.S.Pradhan and R.C. Bhatt, Radiat. Thermal neutron response and photon energy dependence on LiF:Mg,Cu,P. Prot. Dosim. 27, 185-188, 1989