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Testing results of a new extremity dosimeter designed to meet PTB requirements

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Abstract

This paper describes the design and testing results of a new thin extremity ring dosimeter designed to meet the requirements of the Physikalisch Technische Bundesanstalt (PTB). The ring cap was designed with a thin 3.3 mg cm^{-2} entrance window and a concave ring cap to optimize the dosimeter angular response. A thin 7 mg cm^{-2} monolayer of Harshaw TLD-700H (^{7}LiF:Mg,Cu,P) powder was incorporated in the active element design to accommodate a wide beta energy range. The tissue equivalence of the TL phosphor helps maintain a relatively flat energy response. Energy response for both photons and betas are presented. In addition, lower limit of detection, residual signal, and re-use results are discussed.

Keywords: TLD Harshaw; Extremity dosemeter

1. Introduction

A requirement had arisen to design an extremity dosimeter that meets the Physikalisch Technische Bundesanstalt (PTB) type testing requirement and be compatible with the existing Harshaw TLD reader product line. A previously designed dosimeter could not meet all of the requirements because of stringent requirements on beta energy and angular response. This re-designed dosimeter uses a thin layer of ^{7}LiF:Mg,Cu,P with a smaller surface area and a very thin, but rugged entrance window. The ring cap was re-shaped to accommodate a closer proximity between the TLD material and the entrance window. The re-shaping also allows greater angles of radiation incidence. This new extremity dosimeter was introduced and designated as the DXT-707H-2. The dosemeters, system, and testing are described. The PTB type test requirements are comprehensive. It includes design and construction requirements, metrological requirements, and radiological performance requirements. This work is focused on the radiological performance requirements which in fact bear many similarities with the commonly accepted ISO standard "Individual Thermoluminescence Dosemeters for Extremities and Eyes" (ISO 12794: 2000-02-15). Hence, the testing results are based on this ISO standard except the testing for beta energy and its angular response.

2. Dosimeter description

The extremity dosimeter consists of three components, a ringlet, ring cap, and ring strap. The ringlet is an annular shaped aluminum substrate. The substrate supports a 2.0 mm diameter monolayer of TLD-700H (^{7}LiF:Mg,Cu,P) powder, with a thickness density of 7 mg cm^{-2}. The powder is backed by Kapton material and an adhesive. The TLD material diameter was reduced from earlier designs (Luo et al., 2002), to accommodate the angular response requirement.

3. Equipment and procedures

The new DXTRAD ringlets fit into existing TLD carrier cards designed to accept up to four ringlets. These cards are then compatible with the Harshaw TLD Card Reader product line. For the purposes of development and testing, the Harshaw Model 8800, automatic TLD reader (Moscovitch et al., 1990) was utilized. Unless specified, a ^{90}Sr/^{90}Y beta

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source, built into the TLD reader, is used for all the irradiations. The reader uses heated nitrogen gas as the heating medium and has a thermocouple monitored linear time temperature control system. The TLDs were heated using the following time temperature profile (TTP): preheat = 165 °C @ 10 s, rate = 15 °C s^{-1}, maximum temperature = 255 °C, anneal = 255 °C @ 10 s.

To insert the ringlet into the ring strap and to fit the cap properly, a new loader/un-loader machine was designed. This is a manual machine, using a lever type control, whereby the proper amount of pressure is applied to press the ring cap into the ring strap. This protects the ringlet, containing the active TLD material and will ensure the tightness of the seal, to eliminate infiltration of contaminants from the environment. The mechanism was designed to be independent of the applied pressure by the operator. This machine is used before issuing an extremity dosimeter. Likewise, an un-loading device is included on the same machine to remove the ringlet from the dosimeter assembly after the wearing period.

4. Testing

The tests performed were in accordance with the PTB recommended standards. Irradiations were performed at Battelle Pacific Northwest Laboratories and by using a ^{90}Sr/^{90}Y source built into the TLD reader. The following tests were performed: batch homogeneity, reproducibility, detection threshold, residual signal, photon energy response, beta energy response, and re-use.

Table 1
Batch homogeneity results

Ring number	$\bar{E}$ (mSv)	S_i (mSv)	$S_i/\bar{E}$ (%)
1	5.01	0.04	0.8
2	5.09	0.07	1.5
3	5.04	0.08	1.6
4	5.03	0.09	1.7
5	5.03	0.08	1.6
6	4.99	0.10	2.1
7	4.98	0.08	1.5
8	4.96	0.08	1.6
9	4.96	0.10	2.1
10	4.93	0.10	2.0

Table 3
Detection threshold results

Standard deviation ($s_{\bar{E}}$) (mSv)	0.020
Confidence interval (I_i) (mSv)	0.007
Max. detection threshold ($E + I_i$) (mSv)	0.221

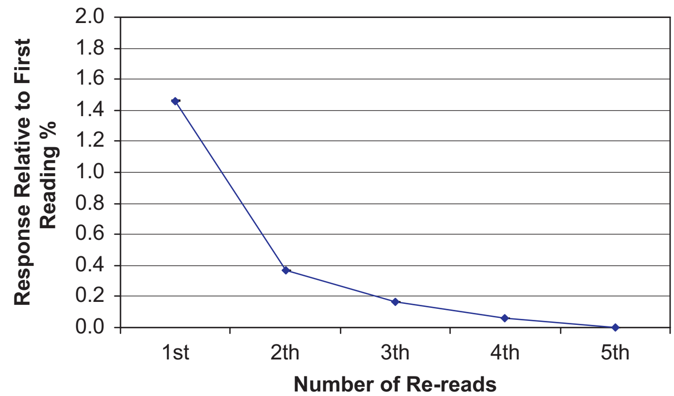

Fig. 1. Residue: Harshaw DXT-707H-2 extremity dosimeter (initial dose = 3 mSv).

Batch homogeneity: Ten dosimeters were cleared, irradiated with the ^{90}Sr/^{90}Y source, and read, 10 times each. The dosimeter received a dose of 5 mSv. The average response $\bar{E}$ is computed for each dosimeter. The standard deviation S_i is computed for each dosimeter. The criteria state that the coefficient of variation must be $< 15\%$. The results show this to be the case with a maximum of 2.1% reported (see Table 1).

Reproducibility: Twenty dosimeters were irradiated to 5 mSv ^{137}Cs equivalent, with the ^{90}Sr/^{90}Y source, and read. The cycle was repeated a total of 10 times. The criteria require that the coefficient of variation of the evaluated value shall not exceed 10% for each dosimeter separately. This is expressed as $(s_{E_j} + Is_j)/\bar{E}_j \leqslant 10\%$, where s_{E_j} is the standard deviation, $\bar{E}_j$ is the mean of the evaluated value, and Is_j is the half width of the confidence interval. The maximum coefficient of variation at the 95% confidence interval was 3% for the DXT-707H-2 dosimeter. This was under the required limit of 10% (see Table 2).

Detection threshold: Twenty unexposed dosimeters were read. The criteria require that the detection threshold shall

Table 2
Reproducibility results

Ring number	1	2	3	4	5	6	7	8	9	10
$\bar{E}_j$ (mSv)	4.933	4.947	5.018	4.907	4.895	5.026	5.023	5.053	4.997	5.044
S_j (mSv)	0.064	0.045	0.051	0.078	0.086	0.059	0.052	0.044	0.037	0.059
I_j (mSv)	0.034	0.024	0.027	0.041	0.046	0.031	0.027	0.023	0.020	0.032
$(S_j + I_j)/\bar{E}_j$ (%)	1.98	1.39	1.56	2.42	2.71	1.79	1.57	1.32	1.12	1.80
Ring number	11	12	13	14	15	16	17	18	19	20
$\bar{E}_j$ (mSv)	4.886	5.117	5.034	5.002	5.042	4.887	5.002	5.182	5.009	5.057
S_j (mSv)	0.077	0.063	0.042	0.032	0.057	0.090	0.043	0.069	0.072	0.057
I_j (mSv)	0.041	0.034	0.022	0.017	0.030	0.048	0.023	0.037	0.038	0.030
$(S_j + I_j)/\bar{E}_j$ (%)	2.41	1.89	1.28	0.98	1.73	2.81	1.31	2.03	2.19	1.71

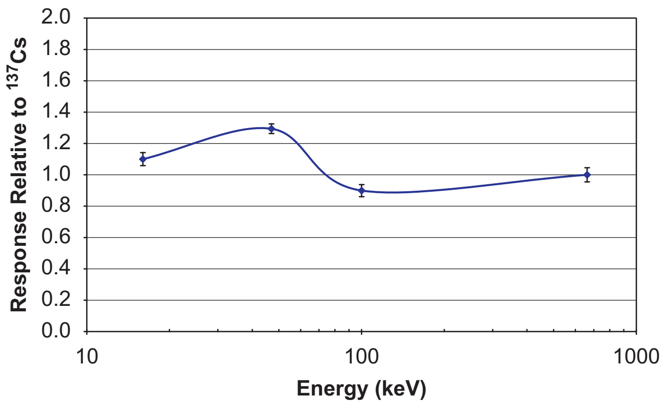

Fig. 2. Photon energy response: Harshaw DXT-707H-2 extremity dosimeter.

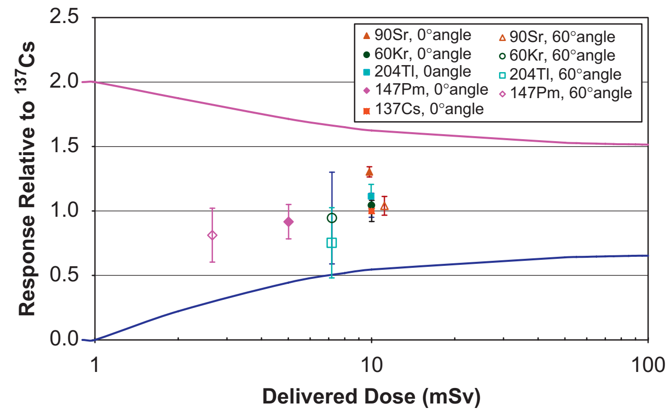

Fig. 3. Beta dose response at various energies and angles. Harshaw DXT-707H-2 extremity dosimeter.

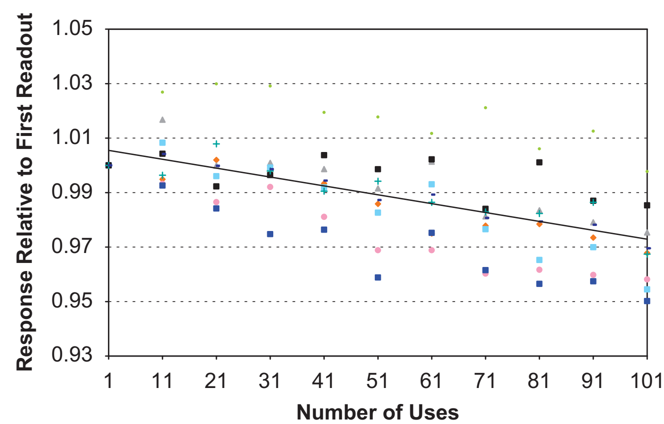

Fig. 4. Sensitivity decrease due to re-use. Harshaw DXT-707H-2 extremity dosimeter (dose = 5 mSv).

not exceed 1.0 mSv. The detection threshold is defined as $E + I_i \leqslant 1.0$ mSv, where E is the evaluated value of each dosimeter and I_i is the half width of the confidence interval. Of the 20 readings, the results show a maximum detection threshold of 0.221 mSv for the DXT-707H-2 dosemeter. This is under the required limit of 1.0 mSv (see Table 3).

Residual signal: An alternative test was performed. A group of 20 dosimeters were cleared and then irradiated to 3 mSv ^{137}Cs equivalent, with the ^{90}Sr/^{90}Y source. Each dosimeter was then read 5 times more. The residual signal for each successive reading was then plotted. The residual signal is defined as the response of each reading divided by the initial dosed reading. The residual of the first re-read is 1.5% (see Fig. 1).

Photon energy response: Three dosimeters, for each point, were irradiated in finger ring assemblies, at Battelle Pacific Northwest Laboratories, on a 19 mm diameter PMMA finger phantom to obtain a photon energy response (see Table 2). The radiation techniques used were a ^{137}Cs radioactive source, and N-20, N-60, N-120 narrow spectrum X-rays. They conform to ISO 4037-1. The DXT-707H-2 showed good flatness over the energy range with a maximum of 30% over-response at 40–50 keV. It meets the requirements (see Fig. 2).

Beta energy response: Three dosimeters, for each point, were irradiated in finger ring assemblies at Battelle Pacific Northwest Laboratories on a 19 mm diameter PMMA finger phantom to obtain a beta energy response. The beta radiation techniques used were ^{147}Pm, ^{204}Tl, ^{85}Kr, and ^{90}Sr/^{90}Y. A ^{137}Cs source was used as a reference. Incident angles of 0° and 60° were used in the testing. The DXT-707H-2 shows good flatness of response throughout the energy range even at extreme angles of incidence. This meets the stringent PTB beta requirements (see Fig. 3).

Re-use: Though it is not a required test in the standard, it is a useful dosemeter stress test. Eight dosimeters were cleared, dosed to 5 mSv, and read. This cycle was repeated again and again after eight further reads. Every 10th reading that occurred after an irradiation was plotted. The dosimeters are guaranteed by the manufacturer for 50 uses. At 50 uses, the dosimeter lost only 1% of its sensitivity. The test was extended to about 100 uses. At 100 uses, the dosimeter lost 3% of its sensitivity (see Fig. 4).

Other tests: Note that linearity, fading, self-irradiation, isotropy for photons, and the effect of light were not tested for this new dosimeter design. They were, however, tested on the previous dosimeter design, in other work (Luo et al., 2002). It was determined the results would not be different for this new design.

5. Conclusion

The newly designed DXT-707H-2 extremity dosimeter lends itself to applications that require PTB type testing or where a flat photon and beta energy response is required. This new DXTRAD extends its extremity monitoring ability to wider energy ranges for photons and betas and accommodates wider angles of radiation incidence. It meets the requirements of the PTB and ISO 12794: 2000 as tested.

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