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 (^7LiF: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, residue, and re-use results are discussed.

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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. Testing results are based on the ISO 12794:2000(E) standard “Individual Thermoluminescence Dosemeters for Extremities and Eyes.” (1)

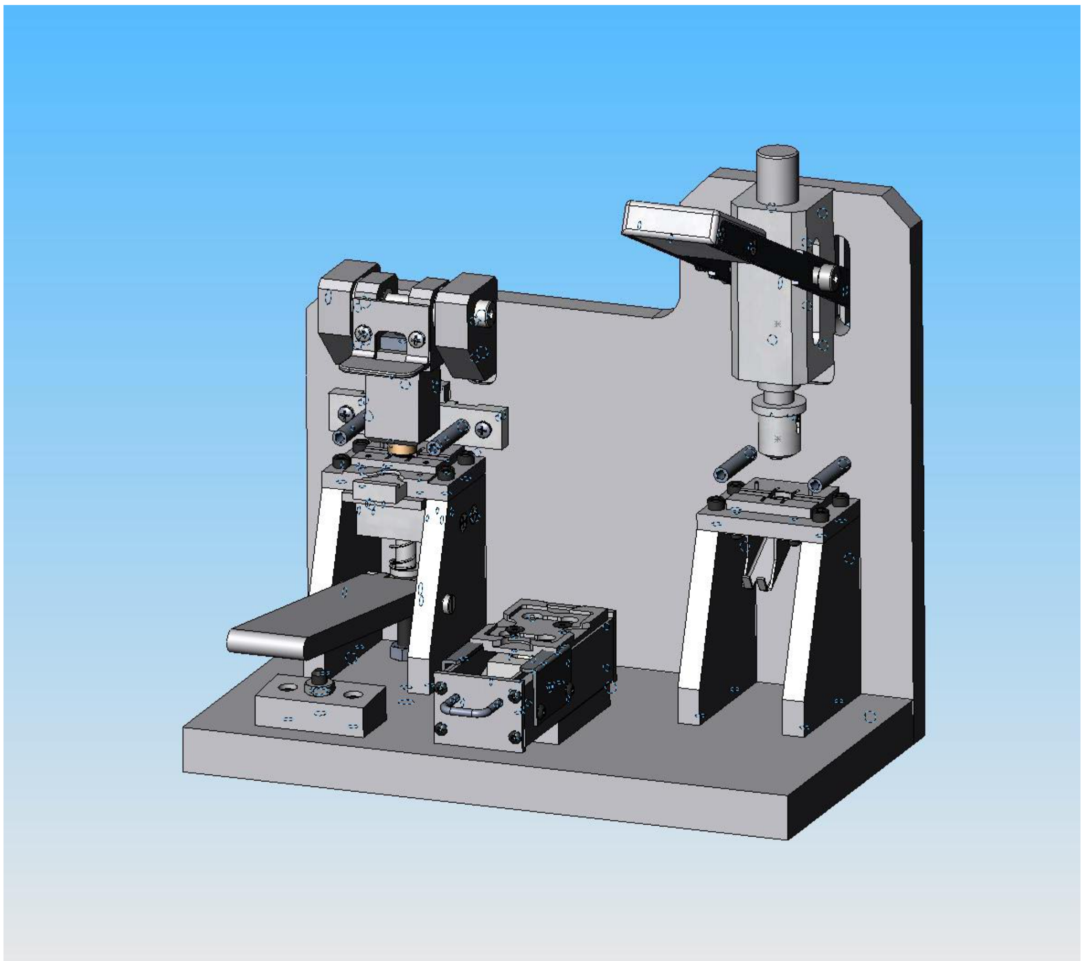
DOSEMETER DESCRIPTION

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 7mg/cm^{2}. The powder is backed by Kapton material and an adhesive. The TLD material diameter was reduced from earlier designs[(2)] to accommodate the angular response requirement.

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(3) was utilized. 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 seconds, Rate = 15°C/Second, Maximum Temperature = 255°C, Anneal = 255°C @ 10 seconds.

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 remover the ringlet from the dosimeter assembly after the wearing period.



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 source built in to the TLD reader. The following tests were performed: Batch Homogeneity, Reproducibility, Detection Threshold, Residual Signal, Photon Energy Response, Beta Energy Response, and Reuse.

Batch Homogeneity: Twenty dosimeters were cleared, irradiated, and read, ten times each. The dosimeter received a dose of 5mSv. The average response $\bar{E}$ is computed for each dosimeter. The standard deviation S_i is computed for each dosimeter. The criteria states that the coefficient of variation must be < 15%. The results show this to be the case with a maximum of 2.1% reported. See Figure 1.

Ring Number	Ē mSv	Si mSv	Si/Ē %
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%**

Figure 1. Batch Homogeneity Results

Reproducibility: Twenty dosemeters were dosed to 5mSv ^{137}Cs equivalent and read. The cycle was repeated a total of ten times. The criteria require that the coefficient of variation of the evaluated value shall not exceed 10% for each dosemeter separately. This is expressed as $(s_{Ej}+Is_j)/\bar{E}_j \leq 10\%$, where s_{Ej} 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 TLD-707H-2 dosemeter. This was under the required limit of 10%. See Figure 2.

Ring Number	1	2	3	4	5	6	7	8	9	10	
Ēj	4.933	4.947	5.018	4.907	4.895	5.026	5.023	5.053	4.997	5.044	mSv
Sj	0.064	0.045	0.051	0.078	0.086	0.059	0.052	0.044	0.037	0.059	mSv
Ij	0.034	0.024	0.027	0.041	0.046	0.031	0.027	0.023	0.020	0.032	mSv
(Sj + Ij) / Ēj	**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**	
Ēj	4.886	5.117	5.034	5.002	5.042	4.887	5.002	5.182	5.009	5.057	mSv
Sj	0.077	0.063	0.042	0.032	0.057	0.090	0.043	0.069	0.072	0.057	mSv
Ij	0.041	0.034	0.022	0.017	0.030	0.048	0.023	0.037	0.038	0.030	mSv
(Sj + Ij) / Ēj	**2.41%**	**1.89%**	**1.28%**	**0.98%**	**1.73%**	**2.81%**	**1.31%**	**2.03%**	**2.19%**	**1.71%**	

Figure 2. Reproducibility Results

Detection Threshold: Twenty undosed dosemeters were read. The criteria require that the detection threshold shall not exceed 1.0 mSv. The detection threshold is defined as E+Ii ≤ 1.0mSv, where E is the evaluated value of each dosimeter and Ii is the half width of the confidence interval. Of the twenty readings, the results show a maximum detection threshold of 0.221 mSv for the TLD-707H-2 dosemeter. This is under the required limit of 1.0 mSv. See Figure 3.

Standard Deviation ($s_{\bar{E}}$)	0.020	mSv
Confidence Interval (I_i)	0.007	mSv
Max. Detection Threshold ($E+I_i$)	**0.221**	mSv

Figure 3. Detection Threshold Results

Residual Signal: A group of twenty were cleared and then dosed to 3mSv. 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 Figure 4.

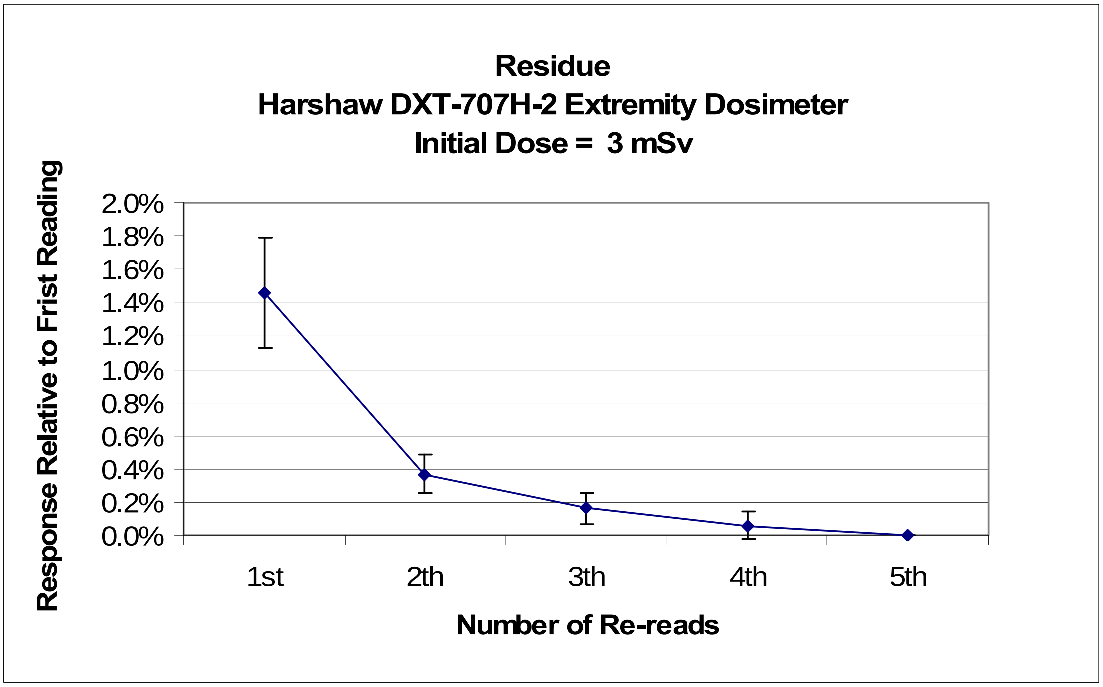


Figure 4. Residue Results

Photon Energy Response: **D**osemeters were irradiated in finger ring holders at Battelle Pacific Northwest Laboratories on a 19mm diameter PMMA finger phantom to obtain a photon energy response. See Figure 2. The radiation techniques used were a 137Cs radioactive source, and N-20, N-60, N120 narrow spectrum X-rays. The DXT-707H-2 showed good flatness over the energy range with a maximum of 30% over-response at 40 to 50 keV. See Figure 5.

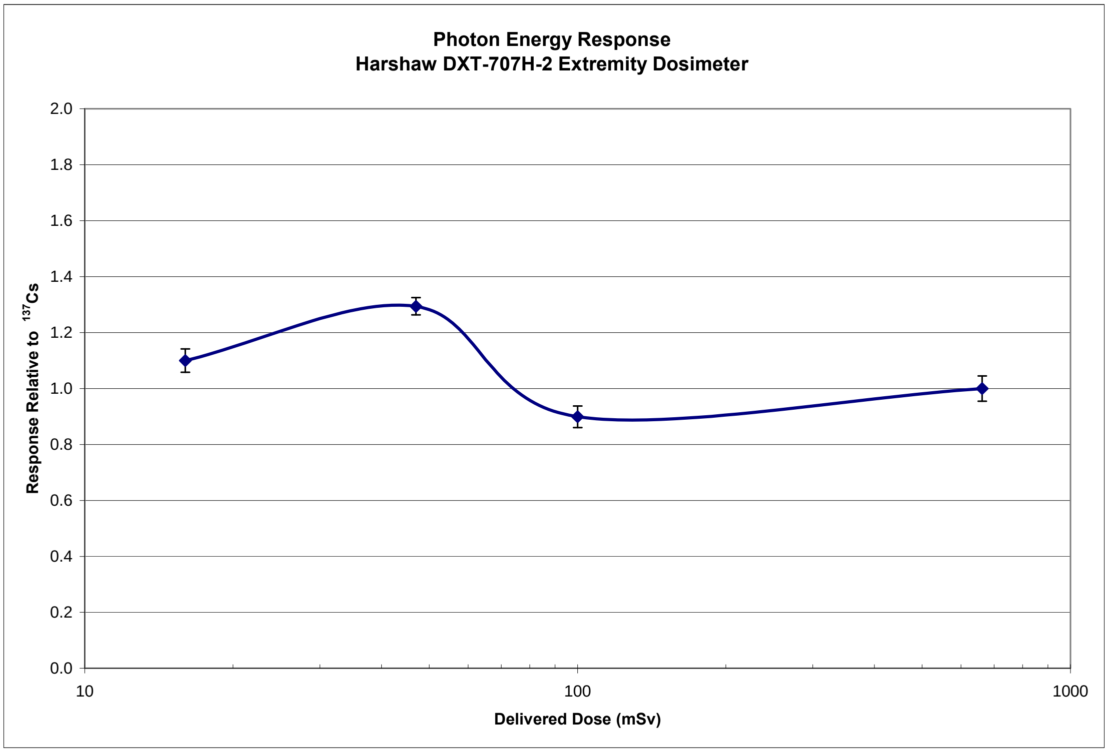


Figure 5. Photon Energy Response Results

Beta Energy Response: Both dosemeter types were irradiated in finger ring assemblies at Battelle Pacific Northwest Laboratories in on a 19mm diameter PMMA finger phantom to obtain a depleted beta energy response. The beta radiation techniques used were ^{147}Pm, ^{204}Tl, ^{60}Kr, and ^{90}Sr/^{90}Y. A ^{137}Cs source was used as a reference. Incident angles of 0 degrees and 60 degrees were used in the testing. The DXT-707H-2 shows good flatness of response throughout the energy range even at extreme angles of incidence. See Figure 6.

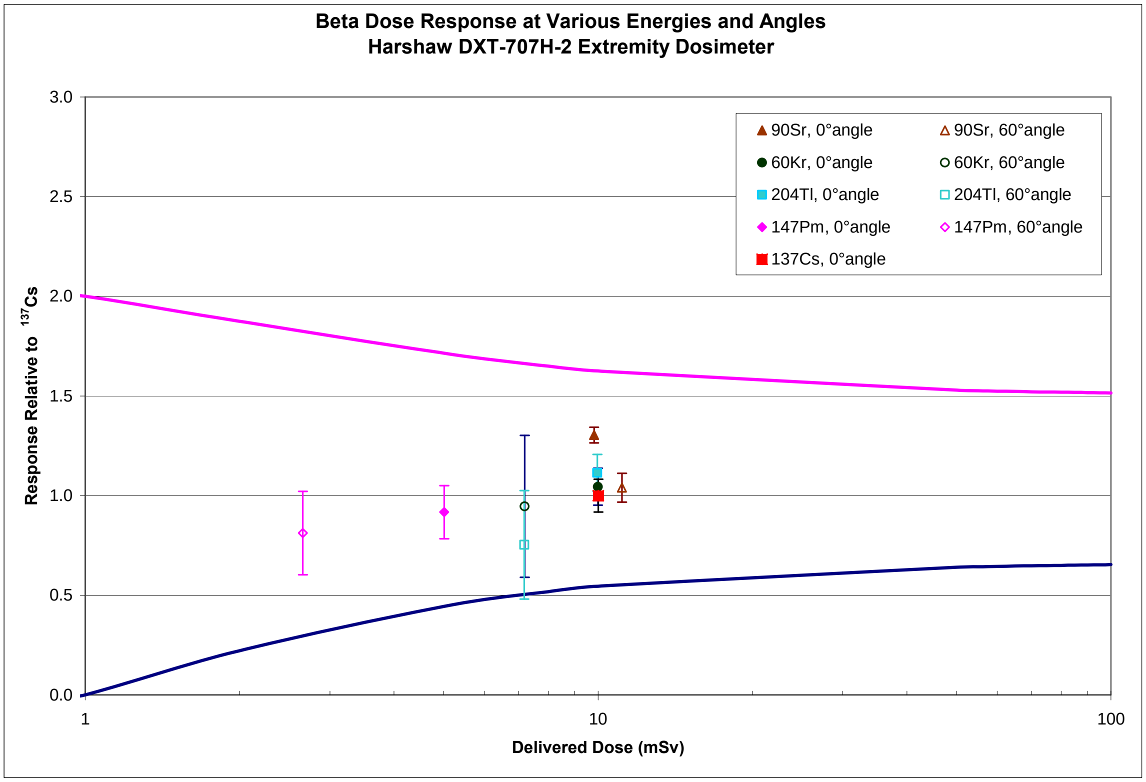


Figure 6. Beta Energy Response Results

Reuse: Eight dosemeters were cleared, dosed to 5mSv, 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 Figure 7.

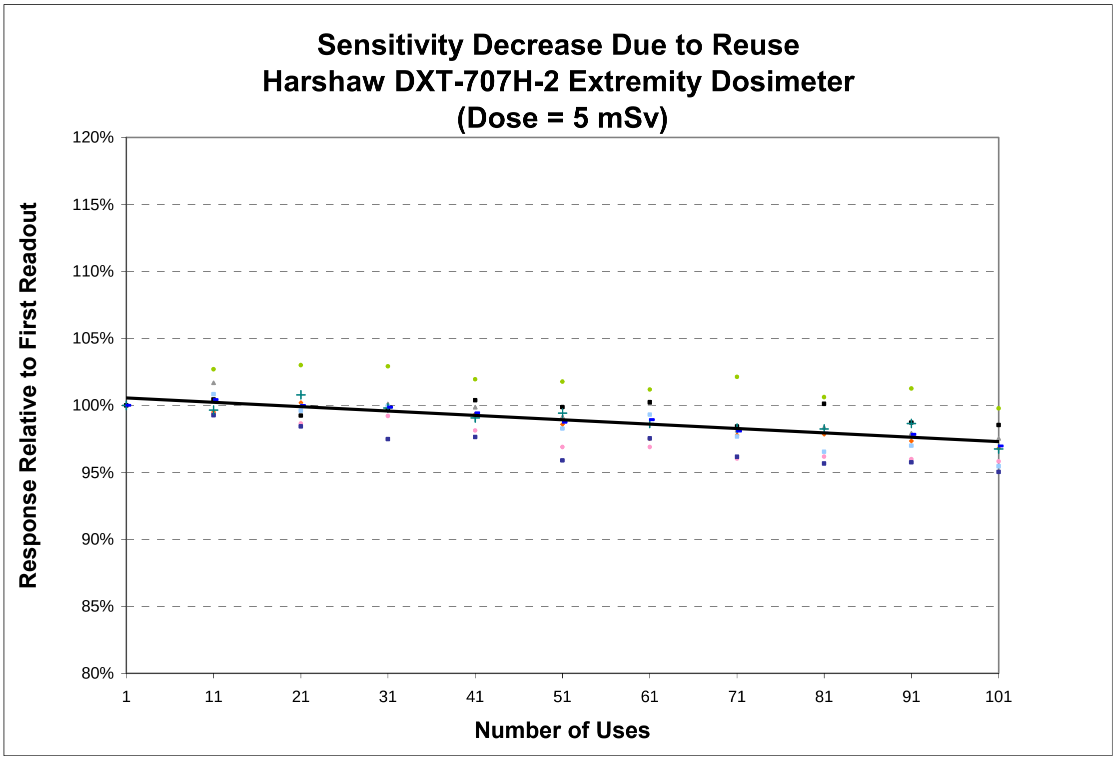


Figure 7. Reuse Results

CONCLUSION

The newly designed TLD-700H-2 extremity dosimeter lends itself to applications that require PTB type testing or where a flat photon and beta energy response a 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.

REFERENCES

1. International Organization for Standardization: *Nuclear Energy – Radiation Protection -Individual Thermoluminescence Dosemeters for Extremities and Eyes,* ISO 12794 : 2000-02-15

2. Luo, L.Z., Velbeck, K.J., Rotunda, J.E., *Evaluating Two Extremity Dosemeters Based on LiF:Mg,Ti or LiF:Mg,Cu,P*, Radiation Protection Dosimetry, Vol. 101, Nos 1-4, pp 211-216 (2002)

3. Moscovitch, M., Szalanczy, A., Bruml, W.W., Velbeck, K.J., and Tawil, R.A., *A TLD System Based On Gas Heating With Linear Time-Temperature Profile*, Radiation Protection Dosimetry Vol. 34, No. 1/4 pp. 361-364 (1990)

Spare Pictures