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An Improved Harshaw TLD Extremity Dosimeter DXT-RAD Beta Ring

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An improved Harshaw TLD™ passive extremity dosimeter system that is rugged in design and easy to wear is presented. This dosimeter is improved for personnel beta monitoring while still having exceptional full range photon performance. The dosimeter style, referred to as Thermo Scientific™ DXT-RAD™, is small in size and has identification by means of a circular barcode. It consists of a detector composed of a thin 7mg•cm^{-2} monolayer of Harshaw TLD-700H (LiF:Mg,Cu,P) powder and a ring cap with a 3.3 mg•cm^{-2} entrance window. The use of the TLD-700H TLD material provides excellent beta energy response as well as flat energy response from low energy x-rays to high energy gammas. A new assembly tool that aids in making the dosimeter geometry consistent and rugged for warm and cold sterilization is also developed. With the optimized design, this dosimeter is capable of accommodating a wide beta energy range and angular response, as well as a wide photon energy range and angular response, which meets the stringent requirements. A type test and additional operational tests to pass ISO-12794, such as residue, reuse, warm and cold sterilization, and environmental leakage are performed and presented.

Introduction

Extremity includes the hand, elbow, forearms; the foot, knee, and lower leg. The extremity monitoring is measuring the skin dose for these parts of the human body. An extremity ring for hand monitoring is presented.

Owing to their strong penetrating ability, most thermoluminescence (TL) dosimeters respond well to photons. However, the response of these dosimeters to beta radiation greatly depends on the beta energy. This makes it difficult to estimate the dose where the radiation field is unknown. Therefore, many products and designs of extremity dosimeters are aimed to overcome this difficulty.

An ideal extremity dosimeter is independent of the radiation type and energy, has a mass thickness of 5-10 mg•cm^{-2}, measuring skin dose at 0.07 mm deep in the tissue. In practice a dosimeter consists of two functional parts: A. a dosimeter which encompasses a detector element, an entrance window or shielding and an identification method; B. an attachment, such as a strap or ring, for wearing.

Extremity Dosimeter Design

The LLD, defined as above, depends on the deviation, sample As a product, a dosimeter must meet the dosimetric requirements for national or international standards. In addition, it offers user-friendly features and is cost effective. The followings are some of the design considerations:
• sensitivity to photons and betas
• energy, angular and dose independent
• thin detector and window (5-10mg•cm^{2})
• tissue equivalent, small or no correction factor
• no fade
• insensitive to light
• protected from the environment
• readable id
• easy to handle, process and rugged
• comfortable to wear
• repeatable and reusable
• meet standards (ANSI N13.32, ISO-12794, PTB, etc)

Harshaw TLD™ introduced its first extremity dosimeter in the early 1990s. Prior to the use of copper doped TLD materials (LiF:Mg,Cu,P), LiF:Mg,Ti chip detectors were used in EXT-RAD dosimeters, figure 1. They were reusable, comfortable to wear, insensitive to light and easy to handle. In that design, the window is thin (7 mg•cm^{-2}), but in order to have a good signal-to-noise ratio the detectors thickness ranges 24 to 100 mg•cm^{-2}. This thicker detector and entrance window makes this design unsuitable for the dose measurement of ^{147}Pm. In addition, the detector is glued on to flexible Kapton film, which makes the thinner detector more fragile.

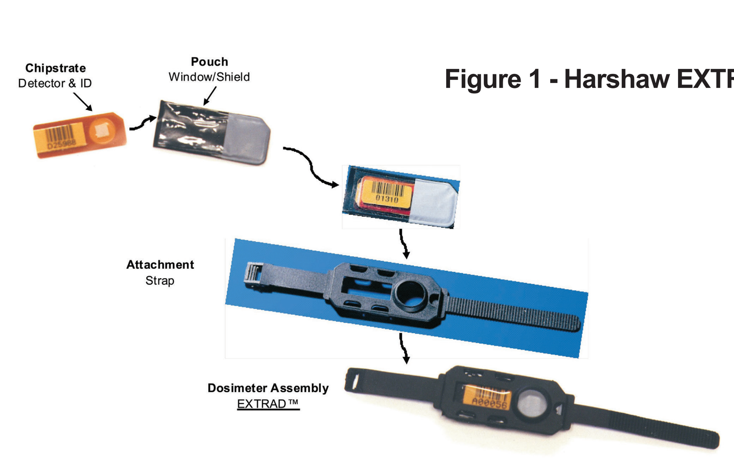


Figure 1 - Harshaw EXTRAD

Efforts of improving the products and developing newer generation products have been a continued goal. After high sensitivity LiF:Mg,Cu,P material was introduced, it was possible to make a thin layer detector without compromising the signal-to-noise ratio. Later, DXT-RAD dosimeters were developed, figure 2. This new type of dosimeter is made of three components, a ringlet, ring cap, and ring band. The ringlet is an annular shaped aluminum substrate. A TLD chip or powder is deposited on Kapton film. A 5 mg"cm cap is assembled, using an assembly device, on to the ring strap to shield it from the environment. This DXT-RAD dosimeter has an excellent photon and beta energy response. It is also rugged and comfortable to wear. But, it is not perfect. There was still a challenge to make this dosimeter sensitive to the medium and low energy betas at angles up to 60 without a correction factor.

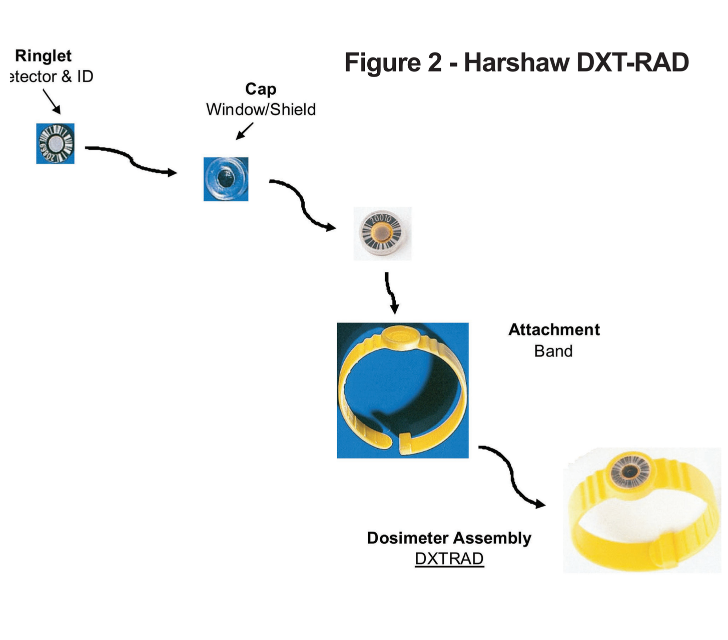
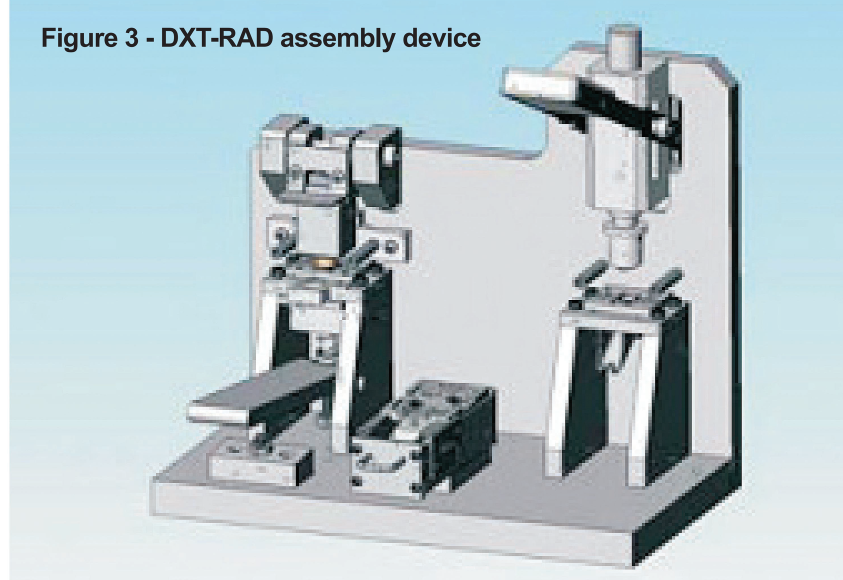


Figure 2 - Harshaw DXT-RAD

To improve the angular response, the effective TL material exposed to the radiation should not be dependent on the incident beta ray. This can be achieved if a relatively large window covers the detector. However, that is restricted by size constraints of the intended design. Hence, an improved DXT-RAD dosimeter was developed which reduces the detector size from 3 to 2 mm in diameter and moves the detector closer to the window, which is also reduced to 3.3mg•cm^{-2} in mass thickness. In addition, the assembly device is improved as well to ensure that the detector-to-window distance is reproducible, figure 3, and that the ringlet to cap seal are maintained. These improvements make this version of DXT-RAD one of the best beta extremity dosimeters in the industry.

Figure 3 - DXT-RAD assembly device



Test Results

A series of test are carried out on this DXT-RAD dosimeter. These test are designed according to ISO-12794 and IEC 61066 standards. Additional tests are also performed to meet PTB requirements. In this test, a Harshaw Model 8800 TLD reader is utilized. Unless specified, a ^{90}Sr/^{90}Y beta source, built into the TLD reader, is used for all the irradiations.

Uniformity
150 ringlets are exposed to 3.7 mSv and then read. The coefficient of variation is 1.5%. It meets the 15% requirement by a large margin.

Reproducibility
10 ringlets are exposed to 3.7 mSv and read, the expose-read cycle is then repeated 10 times. The average of ten reads for each ringlet and the average of ten readings for each cycle is determined. The maximum deviation of the result is 3.4%. This is less than 10% requirement.

Detection
20 ringlets are cleared (to zero dose). The average response plus its uncertainty should be less than 1 mSv. The test result is 0.2 mSv.

Self Irradiation
10 DXT-RADs are cleared and stored in a normal laboratory conditions for 70 days. The average response plus its uncertainty, less the background, is 0.24 mSv. This is less than the 2 mSv required limit from the standards.

Residue
After being dosed to 1 Sv, both the zero point and the dose response should remain within the limit. Six DXT-RADs are used. They are read ten times after 1 Sv irradiation to clear the dose. A dose of 3.7 mSv irradiation is then followed to determine any dose response shifting. The results show that the detection limit is 0.34 mSv (<1 mSv limit) and the response is within 1.03-1.05 (inside the limits 0.9-1.1). Figure 4 shows a decreasing residue signal curve vs. the number of re-reads.

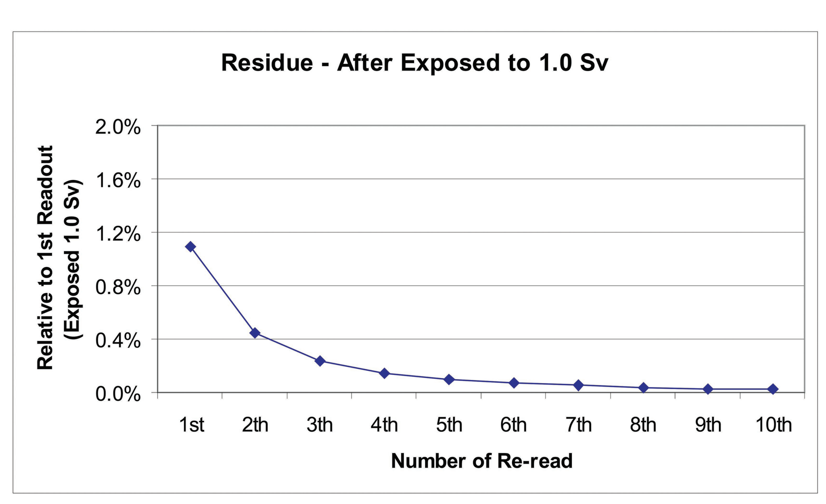


Figure 4 - Residue

Light Effect
Light effect includes two parts: zero point and response drifting. 10 DXT-RADs are used as controls, stored in the normal laboratory condition under a subdue lighting, and 10 DXT-RADs are test samples. Dosimeters are cleared first for zero point test. For the response test, they are irradiated to 12.4 mSv. The zero point drifting in 24 h is observed as 0.13 mSv (<1 mSv limit) and the relative response drifting in 1 week is within 0.94-0.97 (inside the limits 0.9-1.1). The light source used is two fluorescent lamps which gives a measured light of 50,000 lux.

Reuse
20 ringlets are read 100 times and are irradiated to 3.7 mSv after every 10th reading. The readings after irradiation are plotted. The sensitivity decrease over the reuses is shown in the figure 5.

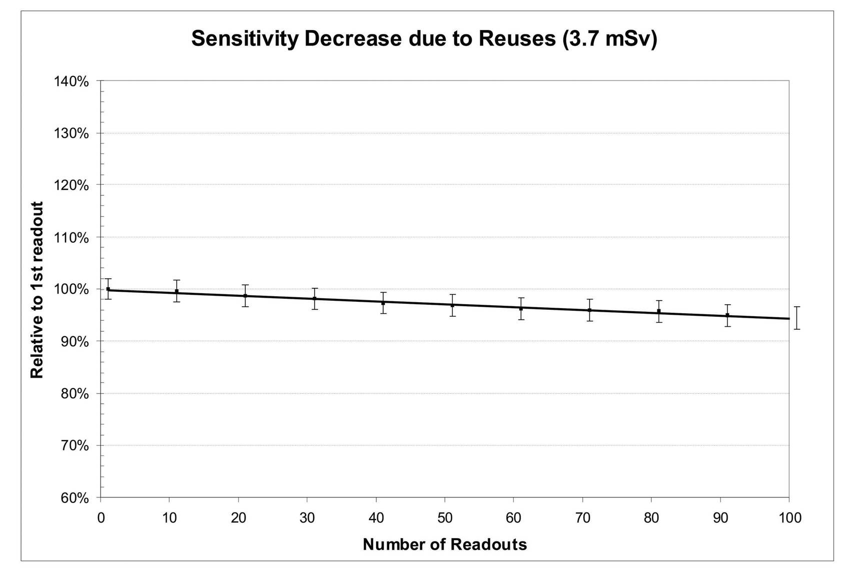


Figure 5 - Sensitivity decrease over the reuses

Radiological Performance
Radiological tests include dose response, energy response and angular response.

Linearity
Three DXT-RADs per irradiation are irradiated, at PNNL Battelle, to ^{137}Cs and N-80 x-ray from 1 mSv to 10 Sv. The response-to-true value is plotted in figure 6. It is required that the response-to-true value is within 0.9 to 1.1. For N-80 x-ray, it is linear within ±3% though it is overresponse at this energy. The result of relative responses for ^{137}Cs is within ±2%, except at the 1 mSv level, where it is over-responding by 13%. This might be caused by a high transit background accumulation.

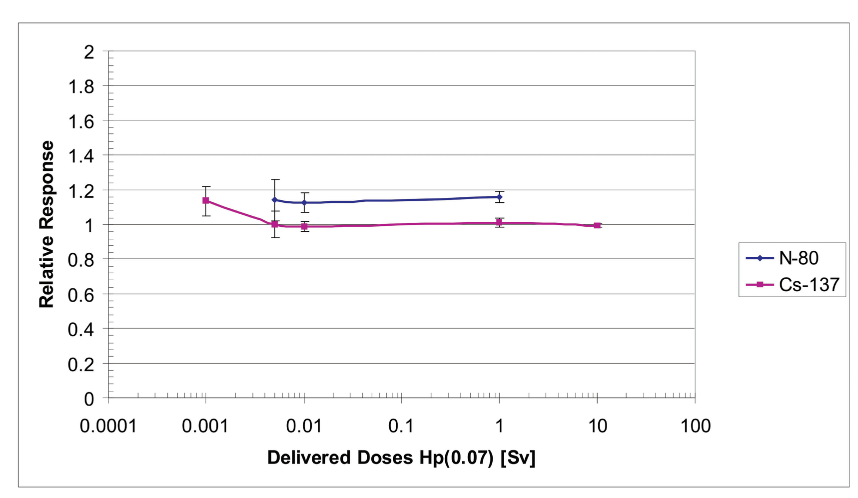


Figure 6 - Linearity Test

Energy and Angular Responses
Three DXT-RADs per irradiation are irradiated to various energies of photons and betas (^{90}Sr/Y, ^{85}Kr and ^{147}Pm) at angles 0˚, 30˚ and 60˚. The responses are shown in figures 7-9.

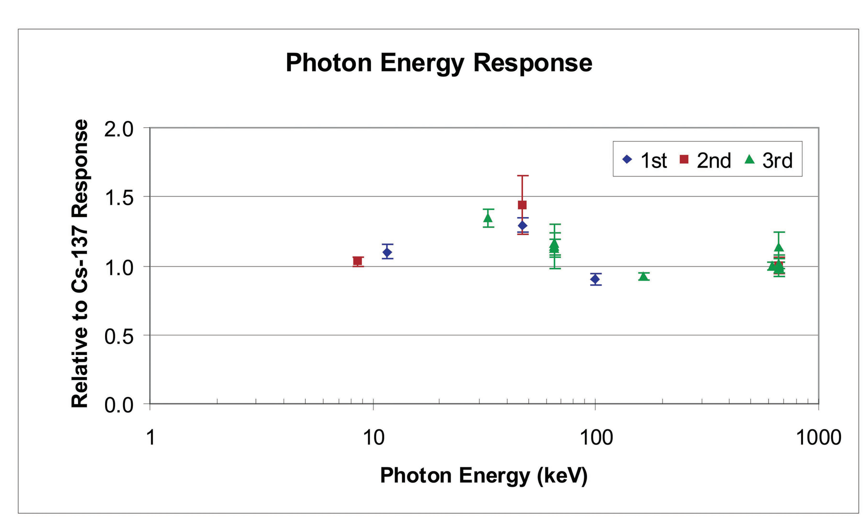


Figure 7 - Photon Energy Response

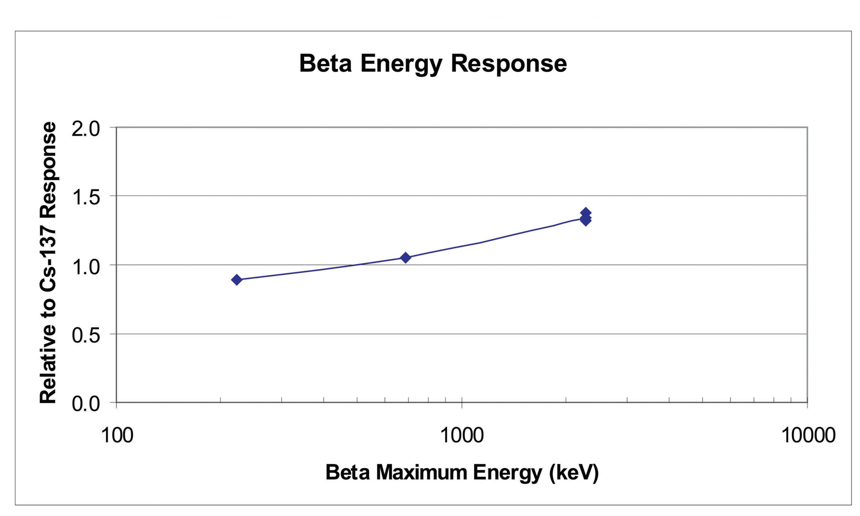


Figure 8 - Beta Energy Response

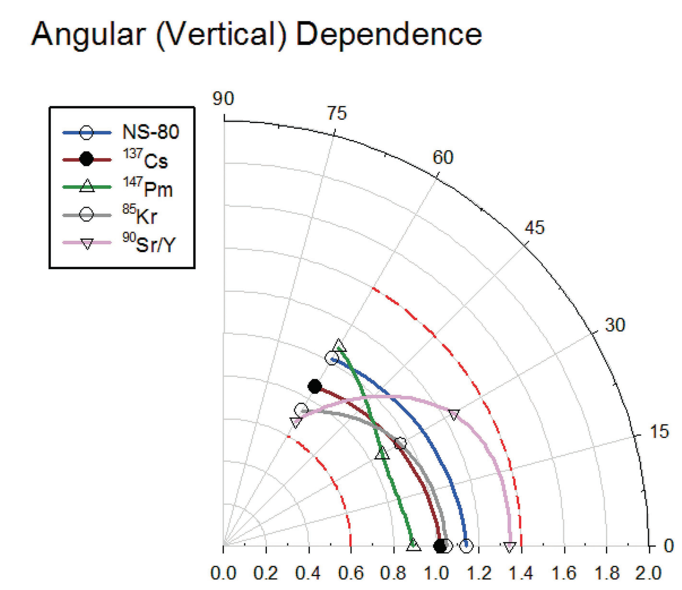


Figure 9 - Angular Response

Performance
The overall radiological performance can be reiterated as, Figure 10, commonly presented for tests in PTB,HSE etc.

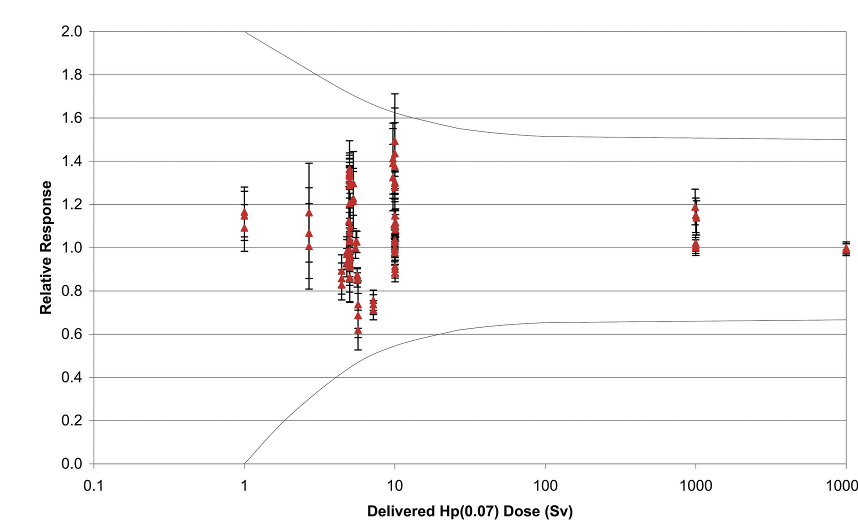


Figure 10 - Overall performance

Operational Test
A good dosimeter not only performs well dosimetrically, but also demonstrates a high quality in operational practice. The next three stress tests are designed to test its sealable quality.

Salt Water
Warm salt water (non-iodized salt 0.0028 kg/m^{3}, 37˚C) is used to emulate human sweat. 24 DXT-RADs are irradiated to 10 mSv and then 12 are put inside the warm salt water for 8 hours and 12 are used as controls. The relative response is 1.016 with an uncertainty of 0.022.

Sterilizations
Dosimeters are also under went sterilization tests. One is steam test and another is chemical test. The steam test condition is 120˚C at steam flush pressure between 15 to 45 psia for 30 minutes. For the chemical test, ethylene oxide sterilization is used. For the both tests, 24 DXT-RADs are irradiated to 3.7 mSv. Among them 12 are controls and 12 are test samples. The relative response for steam test is 1.04 ± 0.02 and for chemical test it is 1.015 ± 0.023.

Summary

The improved Harshaw TLD DXT-RAD extremity dosimeter system is rugged in design and easy to operate. This dosimeter is improved for personnel beta monitoring especially in angular response. A new assembly device that aids in making the dosimeter geometry consistent and rugged for warm and cold sterilization is also developed. With the optimized design, this dosimeter is capable of meeting the stringent requirements. The test results are summarized inTable 1.

Category	Sub-category	Requirement	Result
Dosimetry Properties	Uniformity	15%	1.5%
	Reproducibility	10%	3.4%
	Detection	1 mSv	0.2 mSv
	Self Irradiation	2 mSv	0.24 mSv
	Residue	Detection, 1 mSv Response, 0.9 – 1.1	0.34 mSv 1.03 – 1.05
	Light Effect	Detection, 1 mSv Response, 0.9 – 1.1	0.13 mSv 0.94 – 0.97
	Reuse	Not specified	Fig. 5
Radiological Performance	Linearity	0.9 – 1.1	Fig. 6
	Energy and Angular Responses	Varies	Figs. 7-9
	Performance	Trumpet Curves	Fig. 10
Operational Test	Salt Water	Not specified	1.016 ± 0.022
	Sterilization - Steam	Not specified	1.04 ± 0.02
	Sterilization - Chemical	Not specified	1.015 ± 0.023

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