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The new *EYE-D*™ dosemeter for measurements of $H_P(3)$ for medical staff

P. Bilski [a,*], J-M. Bordy [d], J. Daures [d], M Denoziere [d], E. Fantuzzi [c], P. Ferrari [c], G. Gualdrini [c], M. Kopeć [e], F. Mariotti [c], F. Monteventi [c], S. Wach [b]

[a] Institute of Nuclear Physics, Polish Academy of Sciences, Radzikowskiego, 152, 31-342 Kraków, Poland
[b] RADCARD, Lubelska 14-18, 30-003 Kraków, Poland
[c] ENEA IRP Radiation Protection Institute, Via dei Colli 16, 40136 Bologna (BO), Italy
[d] CEA, LIST, Laboratoire National Henri Becquerel (LNE LNHB), F91191 Gif sur Yvette, France
[e] AGH University, Al. Mickiewicza 30, Kraków, Poland

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A B S T R A C T

In recent years an increased interest in assessment of eye lens doses in interventional radiology has been observed, due to the fact that it seems that cataracts may be induced by radiation doses at levels lower than so far expected. One of the tasks of the EU FP7 ORAMED project was to develop the first dosemeter specially dedicated to measurements of $H_P(3)$. This goal was achieved by designing and testing of the *EYE-D*™ dosemeter. This dosemeter, comprising an MCP-N (LiF:Mg,Cu,P) thermoluminescent detector and an optimized polyamide capsule, was developed by the RADCARD company. The dosemeter is designed for an indefinite use and enables cold sterilization. The test measurements and Monte Carlo calculations of the photon energy response and angular response produced very satisfactory results: all obtained values are within about 20% around unity (with respect to Cs-137). The dosemeter fulfills all requirements for its application in dosimetry in interventional radiology.

1. Introduction

In recent years an increased occurrence of radiation related eye lens opacities for interventional radiologists have been reported (Chodick et al., 2008; Haskal and Worgul, 2004; Worgul et al., 2007; Vano et al., 2010). It seems that cataracts may be induced by radiation doses at levels lower than so far expected. This implies the need for reliable determination of radiation doses to eye lens for medical staff in interventional radiology rather than extrapolation through $H_P(0.07)$ measurements. However, the eye doses are seldom measured in routine applications or even if measured, the correctness of these measurements may be questionable. The main reason is that at the present time there is no dedicated dosemeter for eye lens dosimetry available due to the a lack of procedures to measure eye lens doses. $H_P(3)$ is indicated as the operational quantity to control the dose limits, but the existing calibration procedure is not sufficient (no 'eye lens' phantom and appropriate conversion coefficients existed).Both these shortcomings were addressed within the Work Package 2 of the EU funded FP7 ORAMED (Optimization of Radiation protection for MEDical staff) project. The objectives of this work package were: to develop via the theoretical study of the operational quantity $H_P(3)$ a formalism to measure eye lens doses and its practical implementation (a phantom design) and to design and develop a new practical thermoluminescent (TL) based dosemeters suitable to respond in terms of $H_P(3)$. The development of the eye lens dosemeter was realized mainly by the RADCARD company and results of this work are described in the present paper. The development of the $H_p(3)$ calibration formalism in the framework of ORAMED project is described in the other articles (Gualdrini et al., 2011; Bordy et al., 2011).

2. Designing of the dosemeter

From the beginning of the development process it was decided that the dosemeter would be designed in a modular form, consisting of two separate parts: the measuring element, i.e. a capsule with a thermoluminescent detector (TLD), and a holder, which fixes position of a capsule close to an eye.

The process of designing consisted of optimization of two main characteristics: photon energy response and angular response. The energy range of interest is 20–100 keV. The optimization could be achieved by variation of four factors: TLD type, TLD dimensions, capsule material and capsule dimensions.

* Corresponding author.
E-mail address: pawel.bilski@ifj.edu.pl (P. Bilski).

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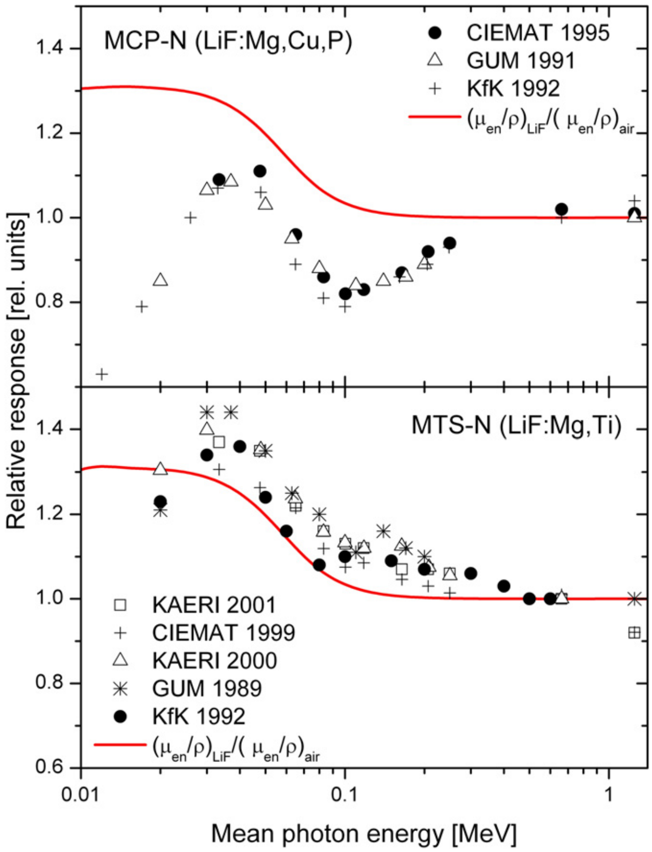

Fig. 1. Photon energy response of LiF:Mg,Cu, P (MCP-N) and LiF:Mg,Ti (MTS-N) as measured in several experiments. Solid lines indicate dependence of the mass energy absorption coefficient (after Olko, 2002).

It was decided to limit studied TLD types to those based on lithium fluoride (LiF). LiF detectors show very good dosimetric properties: sensitivity (detection threshold below 1 μSv), dose response (linear up to 1 Sv), flat energy response, stability at various conditions. Two types of TLDs based on lithium fluoride are available: the standard LiF:Mg,Ti and the high-sensitive LiF:Mg,-Cu,P, and their photon energy response is significantly different (Fig. 1). It can be seen that the measured response of LiF:Mg,Ti is up to about 10% higher compared to what can be predicated from the mass energy absorption coefficients. The measured photon energy response of LiF:Mg,Cu,P is lower than predicted on the basis of mass energy absorption coefficients, with a characteristic minimum at

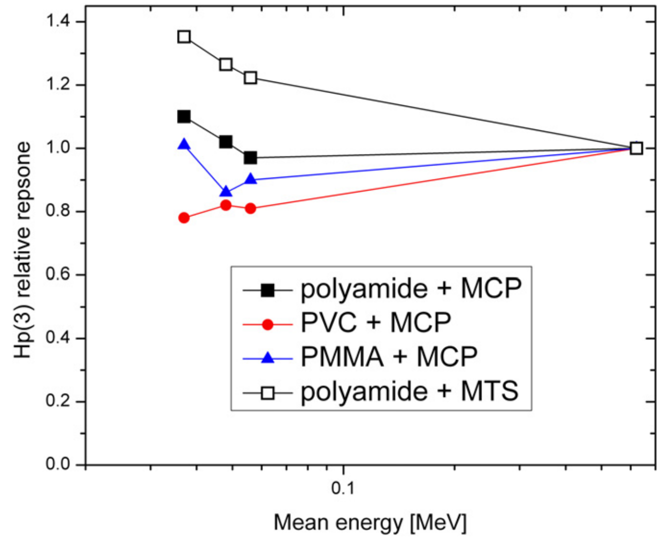

Fig. 2. The measured photon energy response of the tested dosemeter configurations.

100 keV. The observed differences are a result of the dependence of intrinsic thermoluminescence efficiency on ionization density and can be explained with microdosimetric models (Olko et al., 1994; Olko, 2002). Both LiF:Mg,Ti (MTS-N) and LiF:Mg,Cu,P (MCP-N) types of TLDs were considered for application in the eye dosemeter,

The main tool in the process of dosemeter designing was computer modeling. Firstly, radiation transport calculations were performed, using the MCNP-X code (Pelowitz, 2005). $H_P(3)$ values were calculated according to the formalism described by Gualdrini et al. (2011). The response of dosemeter models mounted on a 20 cm diameter 20 cm height cylinder with 0.5 cm PMMA walls, filled with water, were studied through the Monte Carlo simulations. Several polymer materials for manufacturing of measuring capsules were studied, as well as both types of TLDs of different thickness.The response of TL detectors for the given radiation modality X was calculated by folding the dose deposited $D(E_e)$ in the detector by secondary electrons of energy E_e with calculated relative efficiency of LiF:Mg,Cu,P for monoeneregtic electrons $\eta(E_e)$.

$$R_X = \int D_X(E_e)\eta_X(E_e)\mathrm{d}E_e \tag{1}$$

This was realized exploiting the microdosimetric model of TL efficiency (Olko, 2002). Finally, the relative response R of the dosemeter normalized to Cs-137 γ-rays, was calculated as

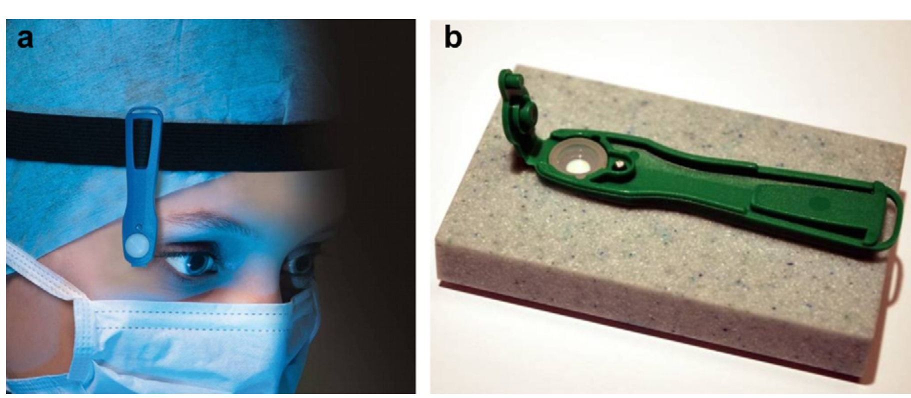

Fig. 3. Illustration of the the *EYE-D*™ as worn on head and placed on the opening tool.

$$R = \frac{R_X/H_P(3)_X}{R_{Cs137}/H_P(3)} \quad (2)$$

The results of first calculations indicated that the optimum configuration of the dosemeter is a polyamide capsule and LiF:Mg,Cu,P detector. It was also found that there is no need to decrease TLD thickness below the standard 0.9 mm. The choice of polyamide was also good from the technological point of view, as polyamide is a good material for the injection molding, which was the preferred production technology. The correctness of this decision was verified through measurements with different X-ray spectra realized using the above described phantom. The irradiation tests were done at CEA LIST LNHB French primary laboratory using Cs-137 gamma rays and RQR spectra (IEC 2005) (RQR spectra are much wider than N spectra ISO series, but better resemble the real spectra at workplaces). For testing, the capsule models were manufactured with the machine cutting technology from polyamide and also, for comparison, from PMMA and PVC. Similarly, for comparison LiF:Mg,Ti detectors were also used.

The results of measurements presented in Fig. 2 confirm conclusions drawn from the calculations. The LiF:Mg,Ti detectors exhibited a significant over response, as expected. The photon energy response of LiF:Mg,Cu,P detectors in a polyamide capsule was the most flat. Therefore, it was decided to use the 3 mm thick polyamide capsule having shape of a hollow hemisphere which assures the best energy and angular response. The polyamide has density 1.13 g/cm^3, what is higher than tissue, but the increased photon absorption of the polyamide for low energy photons was compensated by the slight over-response of LiF:Mg,Cu,P in these energy regions.

The capsule will be prepared to accommodate MCP-N LiF:Mg,Cu,P TL detectors in form of pellets Ø4.5 mm × 0.9 mm. The capsules will be inserted into a holder, which should be attached to a headband (Fig. 3a). The new dosemeter was named *EYE-D*™. The construction of the capsule ensures that it is watertight, enabling cold sterilization or disinfection. Opening of the dosimeter is easy with a special tool (Fig. 3b). The holder and the capsule are designed for an indefinite use.

3. Characterization of the final prototype

After manufacturing of the prototype batch of dosemeters, a new series of calculations and measurements aiming on determination of photon energy and angular characteristics was realized. Irradiations were performed again at the CEA primary laboratory. This time not only RQR but also ISO narrow series spectra were applied (ISO, 1997).

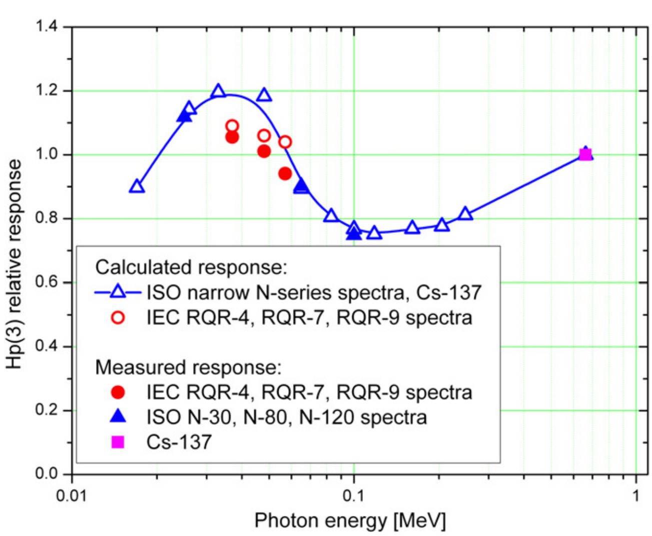

Fig. 4. Calculated (open symbols) and measured (full symbols) H_P (3) response of the new *EYE-D*™ dosemeters for RQR and ISO N X-ray spectra.

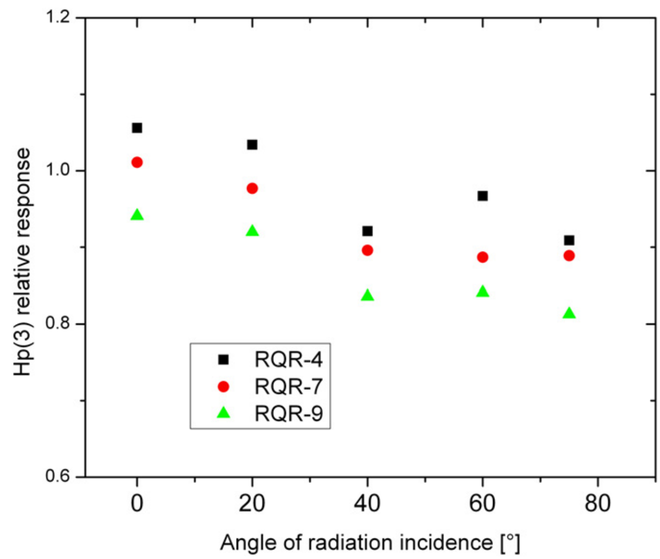

Fig. 5. Angular H_P (3) response of the new *EYE-D*™ dosemeter for RQR spectra (normalized to response to Cs-137 gamma rays, normal incidence).

The results are presented in Figs. 4 and 5. Calculations were done using the complete N series of ISO, while measurements with a few chosen qualities allow validating these calculations over the all energy range of interest. Both calculations and measurements results indicate that the response of the dosemeter is within about 20% for narrow spectra and within 10% for RQR spectra, what should be considered as a very encouraging result. The minimum of the response at 100 keV, typical for LiF:Mg,Cu,P, is present. The angular response is presented with respect to the response for Cs-137 gamma rays at 0° radiation incidence, what represents the standard conditions of calibration. The obtained values are between 1.05 (RQR-4, 0°) and 0.81 (RQR-9, 75°). While these results are quite satisfactory, they might be still improved by correcting a small (5–20%) under response observed at larger angles. This can be achieved by applying a 5–10% correction factor to the Cs-137 calibration and consequently shifting all results up. In this way the relative response of the *EYE-D*™ for RQR wide spectra should be within about +/−12% around unity for all angles.

Simulation of the dosemeter response for beta-rays fields was not performed and is planned to be realized in the next future. However, the construction and energy response of the dosemeter tend to suggest that it can be applied without any modifications for typical beta-rays radiation fields in nuclear medicine.

4. Conclusions

Within the work package 2 of the EU ORAMED project a new eye lens dosemeter responding in terms of $H_P(3)$ was designed, optimized and tested. The dosemeter consists of an MCP-N (LiF:Mg,Cu,P) TL detector inside a polyamide capsule. The dosemeter holder enables comfortable wearing it on a head, at position fixed close to an eye. The dosemeter is designed for an indefinite use and enables cold sterilization. The test measurements and Monte Carlo calculations of the photon energy response and angular response produced very satisfactory results: all obtained values are within about 20% around unity (with respect to Cs-137). The dosemeter fulfills all requirements for its application in dosimetry in interventional radiology.

The dosemeter was named *EYE-D*™ and is commercially available from the RADCARD company.

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