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Influence quantities of optical density for Agfa personal monitoring film used in personal dosimetry

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In this paper the main influence quantities of optical density of Agfa Personal Monitoring film which have a significant component of uncertainty of dose measurement are treated and discussed. The energy and angle dependence for photographic dosemeter were studied for different energies and angles. The aim of this paper is to present and compare the impact on the uncertainty of dose measurement of these influence quantities, in order to review the accuracy of photographic dosemeter for fulfilling the newest EU Technical Recommendations.

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1. Introduction

The use of the ionizing radiation in a large area of applications involves the need of adequate radiation protection of workers. The assessment of doses to workers routinely or potentially exposed to external sources of radiation doses due to external irradiation is assessed by the individual monitoring of exposed workers [1].

An essential aspect in individual monitoring is assessing the quality of the measurement results. A required quality can be expressed as a combined standard uncertainty or as an expanded uncertainty with a coverage factor of 2, or by a coverage interval, with in general a 95% coverage probability [2].

Assessment of the uncertainty is quantified by determining all input/influence quantities that may contribute to the uncertainty (film density, radiation energy, angle of incidence, calibration sources, temperature, humidity) and assigning a probability density function to each of the of the input/influence quantities [3, 4].

The aim of this paper is to present the main parameters that influence the optical density of Agfa Personal Monitoring film and compare their impact on the uncertainty of dose measurement is analyzed in order to review the accuracy of photographic dosemeter for fulfilling the newest EU Technical Recommendations [6].

2. Experimental part

Photographic film dosimeters are used for assessment of doses in 0.1 mSv - 1 Sv interval, for external exposure due to X and gamma radiation and contains a dosimetric film in a PTW badge. The PTW badge contains a set of metallic filters of different thicknesses and an open window which allows the radiation to pass the film without attenuation. Agfa Personal Monitoring film consists of a very sensitive film - D10 (that can not cover complete dose range: saturation at 5 – 6 OD) and a low speed film - D2 (for high doses).

Initial density (fog density) of film is 0.20 – 0.30 for D10 film and 0.14–0.16 for D2 film according to Agfa Gevaert manufacturer. The optical density of the films is measured with densitometer having the measurement range 0.00–6.5 O.D.; uncertainty between 0.02 and 0.07 over the 3.00–6.5 measurement range.

The determination of the response characteristics for photographic dosimeter was done in reference radiation fields, on ISO water slab phantom [7], in terms of the operational quantities, Hp(d).

The calibration curves at reference energy of S-Cs and at ISO photon reference radiations energy are presented in Fig. 1.

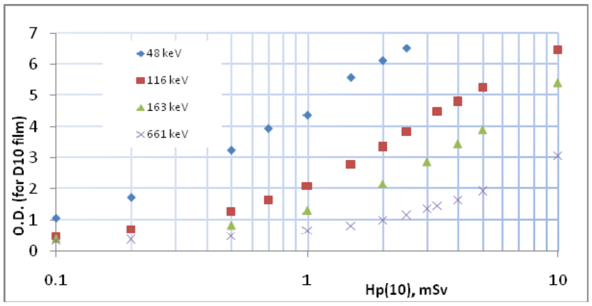

Fig. 1. Calibration curves at ISO photon reference radiations energy (for narrow energy distributions and mono-energetic radiation fields).

2.1 The energy and angle dependence of dosimeter response

The energy and angle dependence of the optical density for D10 film were studied by irradiating the photographic dosemeters at the same dose, Hp(10) = 1 mSv, for different radiation quality, at different incidence angle. Dosimeters were irradiated on ISO water slab phantom to emulate backscatter and attenuation by the person's body.

In Table 1 are presented the average values of the optical density in open window for D10 film and D2 film at different radiation quality and ±45°.

Table 1. The energy and angle dependence of optical density for D10 and D2. Hp(10)=1 mSv.*

Radiation Quality	Mean energy keV	Optical density, open window Normal incidence		Optical density, open window Irradiation at ±45° **	
		D10 film	D2 film	D10 film	D2 film
N-60	48	4.78	0.26	4.86	0.27
N-150	116	2.20	0.19	2.06	0.18
N-200	163	1.42	0.17	1.28	0.16
^{137}Cs	661	0.76	0.16	0.64	0.16

* dose conventional true value with an uncertainty < 5.1 %

** half dose at +45° and half dose at –45°

It can be seen that D10 film has a high sensibility at low energies that decrease with the increasing of irradiation energy.

The angular response varies with radiation energy, due to the increase of the attenuation in the material with incidence angle (incident radiation at an angle will pass through more material to reach a given depth than radiation incident normally to the surface) [2].

The measurement model for evaluating dose equivalent from optical density of the film is [3]:

$$Hp(10) = f(X_1,\ X_2,\ \ldots,\ X_N) \tag{1}$$

where the array $X = X_1,\ X_2,\ \ldots,\ X_N$ are the input and influence quantities.

For energy and angle as main influence quantities:

$$Hp(10) = f(O.D.,\ E,\ \alpha) \tag{2}$$

where the O.D is the optical density of the film (the input quantity), E is radiation energy and α is the incidence angle (the influence quantities).

2.2 Assessment of uncertainties

For uncertainty evaluation two methods are available:

- The GUM framework (GUMF) based on the law of propagation of uncertainties (LPU) and the central limit theorem [3, 4].
- Monte Carlo method [5].

The GUM framework given by the GUM [ISO GUM; JCGM 100] is currently the mainstream choice for uncertainty evaluation [3]. The main focus in the GUM is on calculation methods that depend on the law of propagation of uncertainties, LPU and the central limit theorem which is the method used by the majority of laboratories. Using GUMF, the overall uncertainty of a dosimetric system is determined from the combined effects of the two types of uncertainty (Type A and Type B).

The standard uncertainty of Type A, U_A is identified with the standard deviation $\sigma(\bar{X})$ of a series of measurements with observed values x_i. Type A uncertainties can be reduced by increasing the number of measurements.

The type B uncertainty is evaluated from each individual influence quantity:

$$U_B = \sqrt{\textstyle\sum_i U_{B_i}^2} \tag{3}$$

The probability density function for the energy and incidence angle can be assigned to be rectangular distribution [5]. For these influence quantities it must be estimated the upper limit and the lower limit for the dosimetric response so the probability that the response lies within the interval to is equal to one and is zero outside this interval.

The standard uncertainty is:

$$U_B = \frac{a_+ - a_-}{\sqrt{12}} \tag{4}$$

For energy and angle as main influence quantities of optical density of dosimetric film:

$$U_B = \sqrt{U_{B_E}^2 + U_{B_\alpha}^2} \tag{5}$$

And the combined uncertainty U_C:

$$U_C = \sqrt{U_A^2 + U_B^2} \tag{6}$$

2.3 Requirements for accuracy of dose assessment

The requirements for photographic dosemeters are standardized in ISO 1757:1996 [8] and presented in Table 2.

Table 2. Requirements given by ISO 1757:1996 for photon dosemeters.

Influence quantity	ISO 1757 (1996), film, whole body
Radiation energy	0.65 ≤ response ≤ 1.35
Incidence angle	at two energies: 0.65 ≤ response ≤ 1.35
Linearity	0.2 mSv to 1Sv check only at limits*
Coefficient of variation	Optical density: 2% to 5% Homogeneity of filters: 2%
Environmental conditions and others	Temperature up to +50^{0}C 0.8 ≤ response ≤ 1.2 Humidity up to 90% 0.9 ≤ response ≤ 1.1

*requirements only for optical density, not for dose value

Performance criteria for the energy and angular response of a personal dosimeter are specified for each parameter separately, for the energy response at normal radiation incidence and for the angular response at specific energies. However, the effects of these two parameters on the uncertainty are interrelated and criteria should also be specified for their combined effect [2].

The allowable accuracy interval can be smoothed as a function of dose level (so-called "the trumpet curves") [9], which provide acceptable upper and lower limits for the ratio measured dose/conventional true dose; any changes in the value of the recording level influence the shape of the trumpet curve in the low dose region.

Also it can be used a single value of the overall uncertainty of a dosimetry system for demonstrating compliance with the ICRP's recommendation on overall accuracy (i.e. an uncertainty interval of –33% to +50% for doses near the dose limit) [2].

An allowable uncertainty of –33% to +50% of the dose being measured can be met at the 95% confidence level (corresponding to a coverage factor of 1.96) if:

$$U_c = \sqrt{U_A^2 + U_B^2} \leq 0.21 \tag{7}$$

The combined standard uncertainty is multiplied by 2, to yield an expanded uncertainty ("overall uncertainty"). A coverage factor of 2 will correspond to confidence limits of approximately 95%.

3. Results and discussion

In order to provide good results, all input/influence quantities that may contribute to the uncertainty (film density, radiation energy, angle of incidence, calibration sources, temperature, humidity) must be determined and quantified. In practice, the uncertainties caused by the energy and angular dependence of the response of the dosimeter receive more attention than any other source of error, because the effects from all other uncertainty components are assumed to be much smaller [2].

To each of the input/influence quantities must be assigning a probability density function for uncertainty evaluation using a mathematical model of the dosimetry system.

However, it is well-known that some differences between the accuracy of a measurement with a dosemeter under laboratory condition in a reference radiation field and a measurement in the real radiation fields can be expected.

For improving the performance of dosimetry system, periodic intercomparison exercises within the EU would be a necessary step to investigate and improve the characteristics of dosimetric systems, in order to obtain dose data internationally recognized.

4. Conclusions

The performance of the photographic dosemeter must be analyzed in order to fulfil actual requirements for accuracy of dose assessment. To improve the quality of the measurement results dose algorithms must be used and the influence quantities that have significant effects on accuracy and uncertainty must be evaluated.

Despite the rapid development of other promising dosemeters systems, the photographic dosemeter remain a reliable, well-priced, multi-analyzable technique, who can offer also quality information about the exposure (such mean energy and beam direction), suitable for most applications in the whole body dosimetry of X and gamma radiation. For some application, like the one involving pulsed radiation fields [10, 11], the photographic dosemeter can be consider as a first choice for personal dosimetry.

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