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Uncertainty estimation in Individual Monitoring – Part II

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Abstract

For an individual monitoring service is really important to provide accurate reports of the dose and to what extent the reported value is a good estimate of the true one. The process of determined the uncertainty which produces the best estimate of the quantity to be measured and may differ from the same quantity given by the instrument is an important one. This process can improve the result of the measurement by using different information beyond the indication of the instrument. The work reported here is focused to estimate the absolute standard uncertainty arises for the non-linearity, radiation energy and direction of radiation incidence and for measured value in order to achieve a good estimation of the overall uncertainty for better determination of the equivalent dose for occupational exposure workers from the whole body dosimeter. In this study the thermoluminescence dosimeters are used and measured with Harshaw4500 Reader at Personal Dosimetry Laboratory in the Institute of Applied Nuclear Physics and irradiated in Secondary Standard Dosimetry Laboratory (SSDL) in the Dosimetry Department of Greek Atomic Energy Commission. The method used in this study is based on Guide to the Expression of Uncertainty in Measurement and ISO TR 62461 standard. The absolute standard uncertainty estimation from the non-linearity is found to be 0.069, from the radiation energy and direction of radiation incidence is 0.0838 and from the measured value is 2.5473nC.

Keywords: Absolute standard uncertainty, non-linearity, radiation energy, radiation incidence, thermoluminescence dosimeters

Introduction

In individual monitoring for the estimation of uncertainty we take into account those that comes from laboratory measurements not those which might come from the users (e.g. if they wear them or hold them properly). The external dosimetry can give dose values that are not exactly precise and accurate for several reasons. Uncertainty of measurement is mainly caused by the lack of knowledge about the environment in which a dosimeter will be used, the response of a dosimeter may vary based on calibration of the instrument compared with field measured. Other sources of uncertainty in external dosimetry are related to: the lack of precision in the response of the dosimeter partly due to differences in the material composition of the detector, incorrect calibration of the dosimeter, orientation of the workers in relation to the radiation field being measured, etc. The personal dosimeters, most of them, used in the photon radiation fields provide measurements within the limits set by international and national standards organizations [PWGSC 2011, 8.4, pg. 22]. For an individual monitoring service is really important to provide accurate reports of the dose and to what extent the reported value is a good estimate of the true one. The process of determined the uncertainty which produces the best estimate of the quantity to be measured and may differ from the same quantity given by the instrument is an important one. The objective of this study is to estimate the other three parameters which influence to the overall uncertainty associated to the measurement, the absolute standard uncertainties arise for the non-linearity, radiation energy and direction of radiation incidence and for measured value for better determination of the equivalent dose for occupational exposure workers from the whole body dosimeter.

Materials and methods

The personal dosimetry laboratory in the Institute of Applied Nuclear Physics is involved in providing personal dosimetry services at national level concerning the assessment of occupational exposure of all workers who works with ionizing radiation. The Tld-100 cards kept in a holder are issued by bimonthly (2 months) basis to the occupational exposed workers and then returned to the dosimetry laboratory for measurement. All workers wear the badge in proper places during their work. It can be assumed that Hp(10) measured by a personal dosimeter worn on the chest approximates the effective dose sufficiently accurately, at least for anterior–posterior, rotational and isotropic geometry. In addition, for an amount of different uses of radiation (e.g. intervetional medical procedures) the Hp(10) dose values measured by a dosimeter worn on the upper left side of the chest could be used for thyroid and eye lens doses estimation and a conservative estimation of the effective dose. In this study the thermoluminescence dosimeters (LiF:Mg,Ti) are used and irradiated in Secondary Standard Dosimetry Laboratory (SSDL) in the Dosimetry Department of Greek Atomic Energy Commission. The doses of the received Tlds are measured in the Harshaw4500 Reader by using hot nitrogen gas flow. The gas heating system uses a stream of hot nitrogen at precisely controlled, linearly ramped temperatures to a maximum of 300°C. The Tld cards are read and the records are processed by the WinREMS software. The evaluated value of dose is obtain from the readout value given in nC from the Harshaw4500 Reader by applying the detector sensitivity coefficient, calibration coefficient, zero dose (blank indication) of the dosimeter. So the determination of the dose for whole body dosimeters is determined using the formula:

$$Hp(10)_i = \frac{(D_i - D_{av.0})}{(ECC_i * RCF)}$$

Where, Di is the measured value of the detector i in nC given by the Reader, Dav,0is the average zero dose reading in nC, ECCi individual relative sensitivity of detector i (Element Correction Coefficient), RCF reader calibration factor in nC/μSv.

Uncertainty estimation for non – linearity

For uncertainty estimation we need a mathematical model function which states the relation of the input quantities X_i and the output quantity M [IEC 62461, (5.1.1)]. The dose in μSv is determined by using the model function:

$$M_{corr.} = \frac{(D_{dose} - D_{av.\ zero})}{N_{RCF} \times k_{ECC}} \times k_{lin.} \times k_{E,\alpha}$$

The correction for non-linearity is the $k_{lin.}$ quotient given as a ratio of the TL response R_n under conditions where only the equivalent dose value varies, and the reference response R_0. The $k_{lin.}$ is equal to unity for a linear dosimetry system [IEC 62387:2020 (3.5)].

(1) $$k_{lin} = \frac{R_n}{R_0}$$

For determined the correction factor for linearity we irradiated 12Tlds in different reference doses with Cs-137 and Co-60 sources in SSDL laboratory in the Dosimetry Department of Greek Atomic Energy Commission.

The data for radiation quality, true values reported by the irradiating laboratory, reported values by the Harshaw4500 Reader and the response or correction factor for linearity are shown in the Table 1.

Table 1: Non -Linearity test

Rad. Quality	True Value by SSDL, Hp(10)mSv	Reported mean Values, Hp(10)mSv	k_{lin}, (reported/true)	Best estimation	Abs(k_{lin}-1)
S-Cs-S/0°	0.9	0.60	0.67	1	0.12
S-Cs-L/0°	4.8	3.73	0.78	1	0.02
S-Co-L/0°	4.8	3.71	0.77	1	0.02
S-Co-M/0°	48	40.76	0.85	1	0.12
S-Co-H/0°	350	254.02	0.73	1	0.04

In order to estimate uncertainty of the correction factor for linearity, we took into consideration the worst case, with the assumption that the best estimate is the average value of the reported mean values. As mentioned in to the Table 1 the highest relative deviation from the best estimation is 12%. We assume the distribution as a rectangular one and found the uncertainty using the formula below:

$$u_{s_{k_{lin.}}} = \frac{s_{k_{lin.}}}{\sqrt{3}} = 0.069$$

Uncertainty estimation for radiation energy and direction of radiation incidence

For determination of the relative response due to mean photon radiation energy and angle of incidence we have used the following radiation qualities specified in the ISO 4037 series such as N-60, N-150, S-Cs (137Cs), S-Co (60Co). Irradiations have been performed for the energies and angles of incidence 0° and 60° at the SSDL laboratory. We have irradiated 12 Tlds and for each energy and angle we used two Tlds cards, Table 2.

Table 2: Response to different radiation qualities and angles

Rad. Quality	$D_{ref.}$ Hp(10)	$D_{rep.}$ Hp(10)	Response R (Reported/True)
N-60/0°	1.51	1.97	1.30
		1.55	1.03
N-60/60°	1.28	1.91	1.49
		1.62	1.27
N-150/60°	1.51	1.58	1.05
		1.7	1.13
Cs-137/0°	4.8	3.68	0.77
		4.16	0.87
Co-60/0°	48	39.94	0.83
		41.57	0.87
Co-60/0°	350	242.65	0.69
		265.39	0.76

The mean value was found to be $k_{E,\alpha}$=1.004 and standard deviation $s_{kE,\alpha}$=0.2513. For determination of the absolute standard uncertainty of the correction factor for radiation energy and direction of radiation incidence, we used the formula below:

$$u_{s_{E,\alpha}} = \frac{s_{E,\alpha}}{3} = 0.0838$$

Uncertainty estimation of the measured value

The dosimeter will give the gross dose after subtraction of the zero dose (blank indication), and after the application of correction and calibration factors, which is also known as the measured value. The gross dose in general will include a contribution from natural background radiation in addition to any dose from the worker's occupational exposure [IAEA DS453, pg. 131]. To determine the absolute standard uncertainty of the measured dose we irradiated 7 Tlds with 2mSv in Cs-137 source at 0° angle at SSDL laboratory and measured in Harshaw4500 Reader. The mean value was found to be D_{dose}=59.57nC and standard deviation s_{Ddose}=7.642nC. The absolute standard uncertainty of measured dose if we assume the data distribution as a normal distribution is:

$$u_{s_{D_{dose}}} = \frac{s_{D_{dose}}}{3} = 2.5473nC$$

Conclusions

The definition of the measurement model as the key element for the uncertainty estimation and the identification of input quantities is very essential.
The contribution of different quantities on uncertainty of measurement has been calculated.
The absolute standard uncertainty estimation from the non-linearity is found to be 0.069, from the radiation energy and direction of radiation incidence is 0.0838 and from the measured value is 2.5473nC.
This study will be expand to complete uncertainty analysis for a measurement, called the uncertainty budget of the measurement which include all sources of the uncertainty.

References

1. IAEA, "Assessment of Occupational Exposure Due to External Sources of Radiation", IAEA and and ILO, Safety Guide, No. RS-G-1.3, IAEA, Vienna (1999).
2. IAEA, "International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources", Safety Series No. 115, IAEA, Vienna (1996).
3. ICRP, "General Principles for the Radiation Protection of Workers", ICRP Publication No. 75, Annals of the ICRP 27, Pergamon Press, Oxford and New York (1997).
4. ICRP, "Compendium of Dose Coefficients" based on ICRP Publication 60, ICRP Publication 119, October 2012, ISSN 0146-6453, Elsevier.
5. IEC TR 62461:2015, "Radiation protection instrumentation – determination of uncertainty in measurements", Technical Report, IEC 2015, (2015).
6. IEC 62387:2012, Radiation protection instrumentation - Passive integrating dosimetry systems for environmental and personal monitoring - Part 1: General characteristics and performance requirements.
7. IEC 62387:2020, Radiation protection instrumentation - Dosimetry systems with integrating passive detectors for individual, workplace and environmental monitoring of photon and beta radiation.
8. PWGSC, "Introduction to dosimetry", Minister of Public Works and Government Services Canada (PWGSC) 2011, pg. 22, ISBN 978-1-100-19735-7. Published by the Canadian Nuclear Safety Commission (CNSC).