Uncertainty budget for Ambient Dose Equivalent Rate Measurements with Energy – compensated GM Counters

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***Abstract*— Dosimetric measurements are readily used to assess the exposure of public and working force to ionizing radiation via monitoring various spaces and goods that are imported or in transit through the country. This is done by measuring the ambient dose equivalent rate on the surface of the goods, in the transportation vehicle, or inside of the object of interest. The instruments that are often used in this monitoring type of measurement are compensated Geiger-Muller tube counters. The indication of these instruments is often count per second (cps) and therefore it has to be multiplied by calibration coefficient to obtain result in Sv/h. Due to this and due to the nature of the measurement itself, the greatest challenge is to define the uncertainty budget and calculate the measurement uncertainty accordingly. In this paper we will present the analysis of the uncertainty budget for 4 types of dosimeters used in Radiation and Environmental Protection Department, their calculated measurement uncertainty and the comparison conducted between our instruments and other calibrated instruments that are in the quality management system.**

***Index Terms*— dosimetry; uncertainty budget; measurement uncertainty**

I. Introduction

Dosimetric measurements are in wide use in radiation protection, aimed both at continuous control of medical instruments that are using the ionizing radiation sources and exposure of patients and staff operating those instruments [1]. Also, dosimetric measurements are readily used to assess the exposure of public and working force to ionizing radiation via screening of various spaces and goods that are imported or in transit through the country [2, 3]. This is done by measuring the ambient dose rate equivalent, $H^*(10)$, on the surface of the goods, in the transportation vehicle, or inside of the object of interest – ambient monitoring.

Dosimeters used for ambient monitoring are often based on compensated Geiger-Muller tubes, and most of these instruments used in Radiation and Environmental Protection Department in the Institute for Nuclear Sciences Vinča, are made inhouse. Ambient dose equivalent rate is the quantity that is used for ambient monitoring and it is expressed in unit sievert per hour (Sv/h). Many ambient monitors have indication directly in Sv/h, but other instruments have indication in counts per second (cps) and the values in terms of ambient dose equivalent need to be calculated based on the calibration coefficient [4]. Due to this and due to the nature of the measurement itself, the greatest challenge is to define the uncertainty budget and calculate the measurement uncertainty accordingly.

The uncertainty budget has to include all the contributions to the uncertainty that may arise from the fact that, unlike during the calibration in reference fields, radiation energy, angle of incidence and dose rate are unknown. Therefore, the position of the instrument with respect to the source, the distance from the source and the discrepancy of measured radiation fields in comparison to those used for calibration of the instrument, can greatly influence the result.

In this paper we will present the analysis of the uncertainty budget for 4 types of dosimeters used in Radiation and Environmental Protection Department, their calculated measurement uncertainty and the comparison conducted between our instruments and other calibrated instruments that are in the quality management system.

II. Main Results and Discussion

In the Radiation and Environmental Protection Department of the Institute for Nuclear Sciences Vinča, the instruments used for dosimetry are produced inhouse. The following types of instruments will be analyzed: MOKO-100, KOMO-100 RMK 10 and RMK-10P (total of 10 instruments). These instruments have an indication in cps and therefore the indication has to be multiplied by a calibration coefficient to produce results in Sv/h. However, the position of the instrument in relation to the examined

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objects, the energy emitted from the present radionuclides, as well as overall conditions of the measurement can widely differ from the conditions in which the calibration was performed. That is why the uncertainty budget has to contain not only the contribution from the calibration factor itself, but contributions from other parameters that are influencing the measurement result. The task of defining the contributions and measuring the value of each contribution to the measurement uncertainty is by definition an uncertainty budget.

A. Uncertainty budget

The first contribution to the uncertainty budget is the calibration factor. The calibration is performed in the Secondary Standards Calibration Laboratory in the Radiation and Environmental Protection Department by using the sources with the defined radiation quality, angle of incidence and dose rate. Calibration coefficient is then defined as the ratio of the refrence value and the indication of the instrument. The calibration coefficient with the appropriate measurement uncertainty is stated in a Calibration certificate. Exact functional dependence of calibration factor on radiation energy, dose rate and angle is not known and is different for each type of the dosimeter (depending on the tube, casing, additional energy compensation filters, software corrections, e.g. for dead time, etc). Furthermore, even if this was known, analytical treatment of uncertainty would be hard or impossible, especially in case of energy dependence, because the radiation is not monoenergetic, but is instead covering a wide spectrum, with unknown distribution. Because of this, it is assumed that energy, dose rate and angle can be anywhere in the defined ranges (ranges are appropriate for the planned use of the dosimeters). In this case, worst case scenario is used – maximum variation of calibration factor with energy, angle and dose rate and rectangular distribution, which is wider than normal or triangular.

After the calibration coefficient is determined, the linearity of the instrument response has to be evaluated. It is done by exposing the instrument to the different dose equivalent rates produced by the same or different reference source. The range of instrument calibration coefficients for different dose rates represents the range of linearity. Since it is assumed that the distribution of the results follows rectangular distribution, the range should be divided by 2 (to obtain the half range needed for the usual way of setting the uncertainty i.e. result ± half of the range) and then by 1.73 in order to obtain the standard measurement uncertainty with coverage factor 1.

Also, the repeatability of the measurement should be checked. For this purpose, we measured an enclosed point source containing ^{60}Co, product number 9031-OL-591/09 with activity of 732.9 kBq on 01.08.2011, produced by Czech Metrology Institute. Measurement was repeated 20 times and the standard deviation of the obtained values was calculated. This source and setup were chosen because the dose rate corresponds to the conditions occurring in routine dosimetry measurements.

Finally, the dependence of instrument response to different energies (qualities of the beam) and angles of incidence was estimated. Special attention was given to the range of energies. This should be as close as possible to the range of energies that are expected to be encountered in the real measurement situation. For this purpose, the sources containing ^{60}Co and ^{137}Cs were used, as well as radiation qualities from narrow series produced by an X-ray unit according to ISO 4037-1 [1]. Angular dependence was evaluated together with energy dependence, as is recommended by relevant IEC standards [5]. The range of responses for both different angles and different energies was recorded. Since the rectangular distribution was assumed, the range was divided by 2 and then by 1.73 for the rectangular distribution, in order to obtain the standard measurement uncertainty with coverage factor 1 [6].

Exact functional dependence of calibration factor on radiation energy, dose rate and angle is not known and is different for each type of the dosimeter (depending on the tube, casing, additional energy compensation filters, software corrections, e.g. for dead time, etc). Furthermore, even if this was known, analytical treatment of uncertainty would be hard or impossible, especially in case of energy dependence, because the radiation is not monoenergetic, but is instead covering a wide spectrum, with unknown distribution. Because of this, it is assumed that energy, dose rate and angle can be anywhere in the defined ranges (ranges are appropriate for the planned use of the dosimeters). In this case, worst case scenario is used – maximum variation of calibration factor with energy, angle and dose rate and rectangular distribution, which is wider than normal or triangular.

After all the contributions to the measurement uncertainty were identified and assessed, the expanded combined measurement uncertainty can be calculated using the following Equation [6]:

$$U = 2 \cdot \sqrt{\sum_i u_i^2} \cdot \qquad (1)$$

where U represents the expanded combined measurement uncertainty with coverage factor k=2 and u_i are individual contributions, as described in this section. It is assumed that all the contributions to the uncertainty have the same influence on the result, and that they are mutualy independent, all weighing factors are set to 1. Coverage factor 2 means that that the true value lies with approximately 95% confidence level within the range of the measured value ± given uncertainty (normal distribution is assumed for the combined uncertainty) .

B. Results and Discussion

The uncertainty budget contributions with the range of values obtained for each contribution is presented in Table I.

The values of the contributions to the uncertainty were obtained for each of 10 investigated instruments, using procedures described in previous section of the manuscript.

TABLE I
CONTRIBUTIONS TO THE MEASUREMENT UNCERTAINTY

Contribution	Standard uncertainty range [%]
Calibration factor	4.1 – 13.6
Linearity	1.0 – 5.8
Energy and angle	18.3 – 22.3
Repeatability	1.7-3.2
Expanded combined measurement uncertainty, coverage factor 2	40-51%

As it can be seen from the Table I, the range of different contributions is wide, but it is noticeable that the energy and angular dependence carries the largest part. It is to be expected, due to the construction of the counting tube itself. The repeatability test showed satisfying results, since the indication of the instruments did not vary significantly. Therefore, the contribution of the repeatability to the measurement uncertainty is only 2-3%.

Linearity proved to be quite stable for all instruments, contributing with 1.0-5.8% to the overall measurement uncertainty. This contribution is of the order of magnitude of the repeatability of measurements at a single dose rate, and as such, can be attributed to the stochastic nature of the interaction between the instrument and the radiation from the source.

The measurement uncertainty of the calibration factor is dependent on the process of the calibration and therefore can not be influenced directly. It contains within itself, all the contributions to the uncertainty that arises from the procedure of calibration.

When all the contributions are combined according to the Equation (1), the expanded combined measurement uncertainty ranges from 39.8% to 51.2%, for coverage factor 2. This quite large uncertainty is not unexpected in this kind of measurement as it can be seen from [5]. It is important to note that all the investigated properties of the 4 dosimeter types are within the limits defined by relevant international standard [1].

Additional check-up of the performance of some of the investigated instruments was conducted by comparison with other calibrated instruments that are in the quality management system (i.e. commercially available instruments used in other accredited laboratory, in this case Ionization chamber Cardinal, AD6 probe and Scintilation dosimeter ADb). The reported results, in form of mean value of 10 measurements with appropriate measurement uncertainty and also standard deviation of 10 measurements, are presented in Table II. The results of the comparison showed satisfactory agreement between the instruments, since all the reported results did not differ within the limits of the measurement uncertainty. Furthermore, the limits of acceptability of the results were set on 2 standard deviations of all reported results, calculated to be 0.27 μSvh-1 and all instruments produced acceptable results. This proved the accuracy of the measurements conducted using instruments for ambient monitoring.

TABLE II
CONTRIBUTIONS TO THE MEASUREMENT UNCERTAINTY

Instrument	Measured dose [μSvh-1] 10 measurements per instrument	
	Reported result	Measurement uncertainty
KOMO TL s/No. 001	2.23	1.07
Ionization chamber Cardinal 451P, s/No. 635	1.36	0.33
AD6 s/No. 109737	2.12	1.22
Scintilation dosimeter ADb, 109281	2.06	0.95
ATOMTEX AT6130	2.13	0.58
MOKO 100 s/No. 1802	2.14	0.92
RMK 10P s/No. 0412	2.12	1.10

III. CONCLUSION

In this paper we presented the analysis of the uncertainty budget for 4 types of dosimeters used in Radiation and Environmental Protection Department and their calculated measurement uncertainty. The scenario for which the uncertainty was estimated is measurement of dose rate in the field of unknown radiation source from unknown direction. The combined expanded uncertainty is between 40 and 51 percent, depending on the dosimeter type. The dosimeter properties giving rise to the measurement uncertainty are within the limits of tolerance given in IEC 60846-1 [5]. Although there are some contributions to the uncertainty that can not be influenced (such as the calibration factor and repeatability), there are some improvements that can be defined in the measurement in order to diminish, to a degree, some other contributions.

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