STUDY ON THE COEFFICIENT OF VARIATION IN INDIAN PERSONNEL MONITORING SYSTEM

by

Sneha CHANDRASEKHAR* *, Suresh M. PRADHAN, Madhumita BHATTACHARYA, Ratna PRADEEP, and Debabrata DATTA

TLD-Personnel Monitoring and Services Section, Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, CT&CRS, Anushaktinagar, Mumbai, India

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The primary parameters for testing an individual monitoring system are standard deviation and the coefficient of variation. The International Electrotechnical Commission (IEC) standard 62387-1 recommends testing the coefficient of variation of dosemeters for various doses because the acceptable coefficient of variation changes with the dose level. However, for dose quantity $H_p(10)$, *i. e.* doses greater than 1.1 mSv, the acceptable limit is 5 % and remains unchanged up to the highest dose in the measurable range. This study was carried out to confirm whether the same is followed in the Indian personnel monitoring system when measuring $H_p(10)$ and also in order to study the variation in the coefficient of variation with a given dose. It was observed that even if the coefficient of variation at doses between 0.1 mSv and 1.1 mSv is lower than the IEC requirement, at higher doses, the same may not be true. In routine monitoring, since the anticipated doses are less than 1 mSv, a monitoring system which performs better than the IEC requirement at these levels of doses is an advantage. However, good performance at said dose levels does not naturally indicate good performance at higher doses.

Key words: coefficient of variation, personnel monitoring, India

INTRODUCTION

In India, a single thermoluminescence (TL) based dosemeter developed by the Bhabha Atomic Research Centre (BARC) is approved for personnel monitoring of all radiation workers working with X, beta, and gamma radiations. The performance characteristics of this dosemeter in terms of $H_p(10)$ are well established [1, 2]. There are several accredited service providers who offer personnel monitoring using the said device. The quality of the service is guaranteed by the Central Accreditation Agency which certifies that the service provider meets the prescribed procedures and requirements. Quality is further confirmed by a regular and comprehensive quality assurance (QA) programme. Internally, every laboratory is expected to carry out periodic checks on the quality of its dosemeters.

The primary parameters for testing an individual monitoring system are standard deviation (*SD*) and the coefficient of variation (*CoV*). The validation procedure of new dosemeters involves individual testing of the dosemeters by exposure to 3 mGy air kerma of ^{137}Cs photon radiation in open-air geometry and subsequent readings in the calibrated reader. Dosemeters are acquired in batches of thousands. After the reading, exposed dosemeters are grouped per response while ensuring that the *CoV* of a single batch is less than 5 %. Typically, this may be around 3-4 %. Therefore, from the very beginning, it can be expected that all dosemeters in a monitoring laboratory have a *CoV* of less than 5 %. However, since individual calibration factors are not applied and only batch calibration is used it is likely that, with wear and tear, the *CoV* will surpass its original value. Service providers are expected to discontinue the use of dosemeter batches whose *CoV* degrades to above 5 %. However, conditions such as a delay in identifying the deterioration in quality may occur, with the provider continuing to offer its service with devices with a *CoV* greater than 5 %. Therefore, periodic testing of *CoV* within the laboratories of the service provider is considered essential.

When testing for *CoV*, guidance is taken from the recommendations of the International Electrotechnical Commission (IEC 62387-1) [3] which include the exposure of fixed numbers of dosemeters to various doses. The dosimetry system is considered to have passed the test if the *CoV* does not exceed a given limit for each dose level. These limits vary, with higher values being permissible for lower doses, probably due to the increased random errors at lower ones. The acceptance limit for *CoV*

* Corresponding author; e-mail: snehac@barc.gov.in

according to IEC 62387-1 is 15 % for $H_p(10)$ less than 0.1 mSv, $[16 - (H_p(10))/(0.1\ \text{mSv})]$ % for $H_p(10)$ from 0.1 mSv to 1.1 mSv and 5 % for $H_p(10)$ greater than 1.1 mSv. To determine whether the same is followed in the Indian Personnel Monitoring System, this study was carried out.

In the second part of our research the dose-related behavior of *SD* was analyzed.

MATERIALS AND METHODS

The dosemeter used in the present study is the same as used in the countrywide personnel monitoring programme for monitoring personal doses due to *X*, beta, and gamma radiations. Our study, however, considers only the dosemeter's response due to photon radiation. The dosemeter is comprised of three identical $CaSO_4$: Dy teflon discs, each placed under a different filter [1].The readings are carried out in a nitrogen gas heating-based semiautomatic TLD badge reader [4].

This dosimeter is used for estimation of $H_p(10)$ (whole body) dose. Though the readings of all three discs are required, the reading under dosemeter disc D1 (with an effective filtration of 1060 mg/cm^2) is considered primary and serves for the calibration of the reader to ^{137}Cs gamma and estimation of the dose due to photons of energy greater than 200 keV. Therefore, in our study, the readings of disc D1 are employed for *SD* estimation.

Dosemeters for personnel monitoring services are acquired in bulk. They are individually checked for response to radiation by annealing, exposed to 3 mGy of ^{137}Cs radiation and read on a calibrated reader. Since a large number of these devices are to be annealed, exposed and read in a short span of time, irradiations are carried out in free-air panoramic setup. Though this method is not valid for calibration and estimation of doses in terms of $H_p(10)$, it is considered adequate for the selection of dosemeters. The calibration of readers is necessary so as to ensure consistency in their performance and is therefore carried out on a daily basis, using dosemeters already in service. In a single batch, at least 200 dosemeters are tested for each of the 3 elements. If the *CoV* of the entire batch exceeds 5 %, the batch is rejected. Otherwise the batch is accepted. In accepted batches, dosemeters showing individual readings greater than 1.15 or less than 0.85 times the mean readings are rejected. Variations due to other factors such as reader stability and background radiation are kept to an acceptable minimum.

In this study, dosemeters from 2 procurement batches were used – "Batch 1" of 1500 dosimeters with a *CoV* of 3.5 % and "Batch 2" of 1000 dosemeters with a *CoV* of 8.3 %. For each level of dose, a random sample of 10 dosemeters was taken from each batch.

Irradiations for *CoV* testing were carried out on a phantom, as per ISO-4037 [5], at a distance of 1.5 m from the source. After ensuring that the d_F values were not exceeded, 5 dosemeters were irradiated simultaneously, at 6 dose levels, w_i (i =1, 2, …, 6). For each level of dose, 2 such irradiations were carried out so that 10 dosemeters were irradiated for each dose level. Irradiations were carried out at normal incidence and for a single energy, ^{137}Cs gamma.The conventional true value of $H_p(10)$ (C) was obtained by multiplication of delivered air kerma (measured in open-air) with 1.21 (h_{pk} value for R-Cs) [5]. After irradiation, the mean indicated value of $H_p(10)$($\overline{G}$) along with SD was calculated for each of the 3 individual dose elements.

In the second part of the investigation we have analyzed variation of *SD* with the signal (dose).

Three types of variation of *SD* are considered common in metrology [6, 7]:

(a) variance (V_T) proportionate to response (Poisson)

$$V_T \quad a \quad kS \tag{1}$$

(b) *SD* (σ_T) increasing linearly with dose

$$\sigma_T \quad a \quad kS \tag{2}$$

and

(c) the quadratic model

$$V_T \quad a \quad kS^2 \tag{3}$$

Here, V_T is the total variance, σ_T – the total *SD*, a represents σ_B (*SD* of background) in eq. (2) and σ_B^2 in eqs. (1) and (3), k represents the slope of *SD* variation with signal S (asymptotic relative *SD*) in eqs. (1) and (2); in eq. (3) k represents the square of asymptotic relative *SD*.

Measurement results were fitted to the curves (1) – (3) and conclusions of *SD* behavior regarding doses drawn.

Since the *SD* of a sample can have varying values, 90 % confidence limits of the true (population) *SD* have been estimated. Variances of random samples (s^2) from a normal population have a skewed distribution depending on N, the sample size and population *SD* (σ). Therefore, chi-square distribution is used for estimating the range of *SD* within a confidence interval based on a single measurement of a sample *SD*

$$\chi^2 \quad \frac{(N \quad 1)s^2}{\sigma^2} \tag{4}$$

RESULTS AND DISCUSSION

The values C, $\overline{G}$, and *SD* are given in tab. 1 for dosemeter disc D1. Discs D2 and D3 showed similar values.

When a small sample is used, *SD* can have some significant variation. Also, the most probable value of *SD* is less than the conventional true value (σ) [8]. To account for this, IEC 62387-1 [3] gives additional factors to ensure a probability of 80 % of passing a test if the *SD* being tested is 0.9 times the acceptable limit. These factors are given for samples of size 5 and testing at 12 dose levels. In a similar way, c_1, c_2 [8] values

Table 1. Mean indicated value, measured *SD* and *CoV* at different dose levels

No. of dose levels w	Conventional true value, C [μSv]	Mean indicated value $\overline{G}$ [μSv]		Measured *SD* s [μSv]		Coefficient of variation, *CoV* [%]		*CoV* [%] (IEC)	CoV_{max} [%] with corrections for	
		Batch 1	Batch 2	Batch 1	Batch 2	Batch 1	Batch 2		c_1	c_2
1	351	350	312	11.6	23.1	3.31	7.4	12.5	13.1	17.3
2	531	547	491	16.8	31.2	3.08	6.3	10.7	11.2	14.8
3	849	877	823	27.2	52.6	3.10	6.4	7.5	7.9	10.4
4	1168	1229	1144	34.3	53.0	2.79	4.6	5.0	5.2	6.9
5	2113	2158	2000	33.1	137.6	1.53	6.9	5.0	5.2	6.9
6	3184	3184	3183	126.7	326.0	3.98	10.2	5.0	5.2	6.9
7	0	0	0	13	32	–	–		–	–

for various sample sizes/dose levels are available for confirming whether the performance of a dosimetric system is adequate for the *CoV*. This method gives a probability of 50 % for passing the test if the *SD* being tested is equal to the acceptable limit. If w is the number of dose levels for which the testing is carried out, adequate performance will be ensured if for w-2 or more dose levels, the measured *CoV* is less than c1 times the acceptance limit. Further, for the maximum two, not adjacent dose levels, the measured *CoV* should be less than c_2 times the acceptance limit (c_2 is greater than c_1).

The method used in this paper includes irradiation of a sample of 10 at 6 dose levels. Usage of parameters c_1 and c_2 is flexible and can be applied for any sample size and any number of dose levels greater than 5. Table 1 also shows maximum acceptable limits of CoV(CoV_{max}) for each of the dose levels after application of these factors, c_1 =1.046 and c_2 = 1.389 [8].

From the results in tab. 1, it can be seen that Batch 1 passed the *CoV* test for all doses, but Batch 2 failed to pass the test for dose levels w = 5, 6. This was expected as Batch 2 had a higher *CoV* at the procurement test.

Further, a plot of the experimental *SD* values for Batch 1 is given in fig. 1 along with the variations as predicted by eqs. (1)-(3) (using σ_B = 13 μSv and k = = 0.0398).

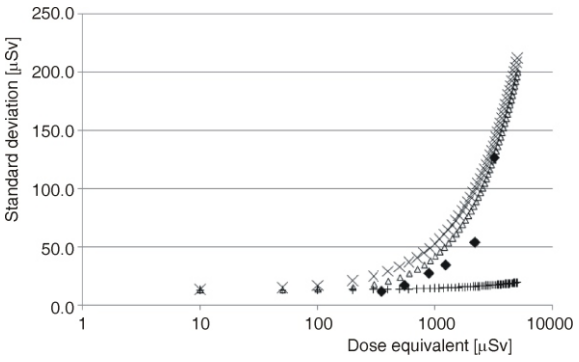

Figure 1. Plot of variation of standard deviation with mean indicated value ($\overline{G}$). Plus sign, cross and open triangle are theoretical values based on eqs. (1), (2) and (3) for dosemeters from Batch 1. Filled squares are experimental values of Batch 1

It can be seen that eq. (1) (Poisson) and (2) (linear) do not correspond with experimental observations. The best fit is (3).

In the specific case of personnel monitoring, based on empirical data, the behavior of *SD* has been reported to follow eq. [9]

$$\sigma_T^2 \quad \sigma_B^2 \quad \sigma_\mu^2 K_T^2 \tag{5}$$

This is identical to the quadratic model, eq. (3), where σ_T – the total *SD*, σ_B – the *SD* in background dosemeters, σ_μ – the relative *SD* at high doses, and K_T – the value of the dose. The relative *SD* is an asymptotic value, and it is assumed that the relative *SD* at 3 mSv is acceptable as an approximation for the relative *SD* at high doses. Therefore, the behavior of our dosimetry system can be approximated by the quadratic equation.

IEC standard 62387-1 requires 5 dosemeters for the determination of *CoV*. However, the *SD* measured from small samples can have significant variations. A useful approximation defined in literature for estimation of uncertainty in s/σ is $1/[2(N \quad 1)]^{1/2}$ [10], where s is the sample *SD*, σ is the true *SD* and N is the size of the sample. Therefore, with an increase of N, the uncertainty in estimation of s would be reduced. The present study has been carried out for samples of 10 dosemeters. With the approximation stated above, the inherent error in estimation of σ for samples of 10 dosemeters would be 23.6 %. The 90 % confidence limits of σ for the experimental values obtained using (4) are given in tab. 2. The expected *SD* as per (3) is also given in the table. This data validates our assumption

Table 2. 90 % confidence limits of population standard deviation based on experimental standard deviation

Mean indicated value $\overline{G}$ [μSv]	Measured *SD* s [μSv]	Expected *SD* [μSv]	90 % confidence limit of σ	
			Upper limit [μSv]	Lower limit [μSv]
350	11.6	17.9	19.1	8.5
547	16.8	23.1	27.6	12.2
877	27.2	33.3	44.8	19.8
1229	34.3	44.9	56.4	25.0
2158	53.8	76.6	88.5	39.2
3184	126.7	112.2	208.4	92.4

that the quadratic equation is a good representative of the behavior of our personnel monitoring system.

These observations imply that if a batch of dosemeters is tested for *CoV*, then it is preferable to carry out the testing at multiple values of dose. Very often, the testing is carried out at a single dose level. In such cases, care should be taken that the dose is sufficiently high to ensure that the measured value of *CoV* is a true representation.

CONCLUSION

An important parameter for testing an individual monitoring system is the coefficient of variation. In routine monitoring of radiation workers, the doses encountered are most often less than 1 mSv. Therefore, it is sometimes considered that a monitoring system which performs better than the IEC requirement at these values of doses should be a better system. However, good performance at these dose levels does not naturally indicate good performance at higher levels of doses. In the monitoring system studied it is observed that dosemeters which show poor performance in terms of standard deviation or coefficient of variation at higher doses may actually show acceptable behavior at lower doses. Internationally, higher values of coefficient of variation are accepted at lower doses since random errors may be higher. However, exact dose estimation is of greater importance at higher doses than at lower doses since predicted health effects from radiation exposure are determined at this dose. Therefore, it is required that the values of coefficient of variation at all the dose values indicated by IEC are calculated for a monitoring system and periodically checked.

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AUTHORS' CONTRIBUTIONS

The experimental work was carried out by C. Sneha and M. Bhattacharya. All authors analyzed and discussed the results. The manuscript was written by C. Sneha along with S. M. Pradhan and R. Pradeep.

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**Снеха ЧАНДРАСЕКХАР, Суреш М. ПРАДХАН,
Мадхумита БАТАЧАРЈА, Ратна ПРАДИП, Дебабрата ДАТА**

ПРОВЕРА КОЕФИЦИЈЕНТА ВАРИЈАЦИЈЕ У ИНДИЈСКОМ СИСТЕМУ ЛИЧНОГ МОНИТОРИНГА

Стандардна девијација и коефицијент варијације су примарни параметри провере система личног мониторинга. Стандард 62387-1 Међународне електротехничке комисије препоручује проверу коефицијента варијације дозиметара за разне вредности доза, јер се прихватљива вредност коефицијента варијације мења са нивоом дозе. Ипак, за величину $H_p(10)$, при дозама већим од 1.1 mSv, прихватљива граница је 5 %, која остаје непроменљива чак и при дозама блиским граничним вредностима мерног опсега. Ова студија је спроведена како би се потврдило да се исти поступак спроводи и у систему личног мониторинга у Индији при мерењу $H_p(10)$, као и да се изучи промена коефицијента варијације са дозом. Уочено је да иако је коефицијент варијације за дозе у опсегу од 0.1 mSv до 1.1 mSv нижи од захтева стандарда, то није случај и при вишим дозама. Током рутинског мониторинга, пошто су очекиване вредности доза мање од 1 mSv, систем личног мониторинга који има ниже вредности захтеваних параметара од стандарда, у предности је у овом опсегу доза. Међутим, добре перформансе у датом опсегу доза нису индикатор добрих перформанси при вишим дозама.

Кључне речи: коефицијент варијације, лични мониторинг, Индија