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Dependence of Response of Active Personal Dosimeters on Different Calibration Methods

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Active personal dosimeters (APDs) are used by occupationally exposed workers to measure the dose equivalent of radiation that they were exposed to. These dosimeters need to be calibrated to ensure that the dosimeters are accurate. There are two methods for which the APD can be calibrated: the accumulative method and the staggered method. However, there is no recommendation on which of the two calibration methods is most suitable for use. This study aimed to investigate the dependence of the response of APD with various detectors on the two calibration methods. In this work, APDs were irradiated to different dose values of 0.5, 0.1, and 1.5 mSv using accumulative method and staggered method at the Secondary Standard Dosimetry Laboratory – Radiation Protection Services Section (SSDL-RPSS) of the Department of Science and Technology – Philippine Nuclear Research Institute (DOST-PNRI). The results showed that APDs have better response in the staggered method compared to accumulative method and best reflects the practical conditions in the use of the APDs in the field. The results of the study could, therefore, be a basis in developing a more standardized protocol and procedure for the calibration of APDs.

Keywords: active personal dosimeter, calibration, detector, response

INTRODUCTION

Nuclear technology has many beneficial applications in the Philippines such as in the medical, industrial, agricultural, and research fields. These applications provided jobs to multitudes of employees. However, nuclear technologies involve the use of ionizing radiation, which can be a serious health hazard. It is thus important to keep the exposure to ionizing radiation to within the safe limits.

Personal dosimeters are devices worn by personnel while working with ionizing radiation. It is used to measure the amount of radiation a worker is exposed to. There are two types of personal dosimeters: passive and active dosimeters. Passive personal dosimeters are dosimeters that must undergo a certain process before obtaining the dose result. APDs, on the other hand, instantaneously display the dose received by the worker while using the dosimeter.

As these instruments help workers monitor the dose they received in a particular activity, it is very essential that the output measurements of the instruments are accurate and reliable. Calibration is done for this purpose to ensure that instruments are accurate, acceptable, and traceable to international standards. The calibration of radiation monitoring instruments is performed regularly, the frequency depends on the requirement of the regulations and the practical application. There are two methods that can be used to calibrate an APD: 1) staggered method and 2) accumulative method. In the staggered method, dosimeters

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are reset to zero each time prior to irradiation to different dose values. In the accumulative method, dosimeters are continuously irradiated – in increments – up to a maximum dose value without resetting.

The Radiation Protection Services Section of the Department of Science and Technology – Philippine Nuclear Research Institute (PNRI-RPSS) calibrates radiation monitoring instruments, including the personal dosimeters, through its SSDL. It utilizes Cesium-137 (Cs-137) as the standard source for calibration. Although there are safety reports and ISO documents that describe calibration procedure of a radiation monitoring instrument, there is currently no recommendation on which of the two calibration methods is most suitable for use.

This study aims to investigate the dependence of the response of APD with various detectors on the two calibration methods. It also aims to determine which of the two methods best reflects the practical conditions in the use of the APDs in the field and will give more accurate measurements. The results of the study could thus be a basis in developing a more standardized calibration protocol and procedure for personal dosimeters.

MATERIALS AND METHODS

For the experiment, a collimated Cs-137 irradiator (JL Shepherd and Associates) with an activity of 41.79 TBq as of 30 May 2018 was used as illustrated in Figure 1. It was conducted at the SSDL, which operates several radioactive sources and maintains the national standards for ionizing radiation. The laboratory offers routine calibration of radiation monitoring instruments including survey meters, APDs, contamination meters, rate meters, and other nuclear equipment. The available sources in the facility are traceable to primary standards (IAEA 2007).

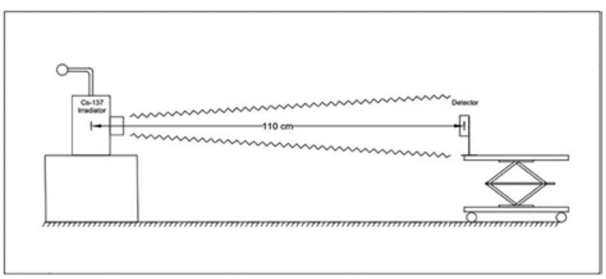

Figure 1. Schematic diagram of irradiation set-up.

The irradiation parameters used in the experiment were listed in Table 1. The delivered equivalent dose of the Cs-137 irradiator is traceable to the SSDL of the International Atomic Energy Agency. The method used is in accordance with Safety Report Series No. 16 "Calibration of Radiation Protection Monitoring Instruments" (IAEA 2000).

Five kinds of APD with two different types of detectors, which are typically utilized in the field, were used in the experiment (Bolognese-Milsztajn *et al.* 2004). In particular, Arrow-Tech / W 138, Dosimeter / 862, Aloka / MyDose, MGP / DMC 2000, and Isotrak / DoseGuard were the APDs used, Table 2 lists the detectors by each type of APD, which were either an ionization chamber or a silicon diode. An ionization chamber is a gas-filled detector that relies on the ionization of the gas inside the detector to cause an electric current to flow due to the pairing of electrons. A silicon diode, on the other hand, is a solid-state detector that uses crystalline substances that exhibit measurable effects when exposed to radiation (Meier and Kappadath 2015).

The APDs were attached to an aluminum stand and placed on a bench, as shown in Figures 2 and 3. The source-to-detector distance was 110 cm. The APDs were then irradiated in air with equivalent dose values of 0.5, 1.0, and 1.5 mSv, based on the calibration procedure (Almares and Caseria 1995). Readings were taken after every irradiation.

The dosimeters were irradiated using the accumulative method and staggered method. In the accumulative method, the dosimeters were irradiated with dose values of 0.5 up to a maximum value of 1.5 mSv without resetting. In the staggered method, the dosimeters were irradiated to 0.5, 1.0, and 1.5 mSv but were reset to zero prior to irradiation to each dose value.

The response of the APDs was then determined using Equation 1. The response R is the quotient of the indication of the instrument M divided by the conventional true value or delivered dose H (IAEA 2000).

$$R = \frac{M}{H} \qquad (1)$$

Table 1. Irradiation parameter.

Source activity as of reference date	Irradiation condition	Beam quality	Collimator	Source to detector distance (cm)	Delivered equivalent dose (mSv)	Irradiation time (min)
41.79 TBq as of 30 May 2018	In air	Cs-137	2	110	0.5	12

The irradiation beam is narrowed to almost 30.4 cm at 200 cm from the source by means of collimator 2; at 110 cm, the beam size is about 16.8 cm (ISO 1996, 1999). Routine calibrations of personal dosimeters are being done simply in free air or ambient dose equivalent (IAEA 2005).

Table 2. List of irradiated dosimeters with different type of detectors.

Brand	Model	Type of detector
Analog		
Dosimeter	862	Ionization chamber
Arrow-Tech	W 138	Ionization chamber
Electronic		
Aloka	MyDose	Silicon diode
Isotrak	DoseGuard	Silicon diode
MGP	DMC 2000	Silicon diode

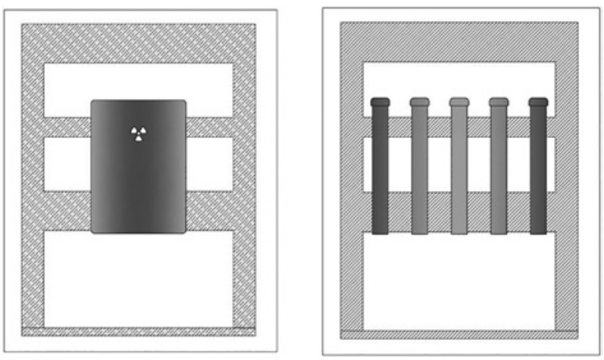

Figure 2. Dosimeters attached to an aluminum stand. On the left was set-up for electronic APD and on the right was the set-up for analog APD.

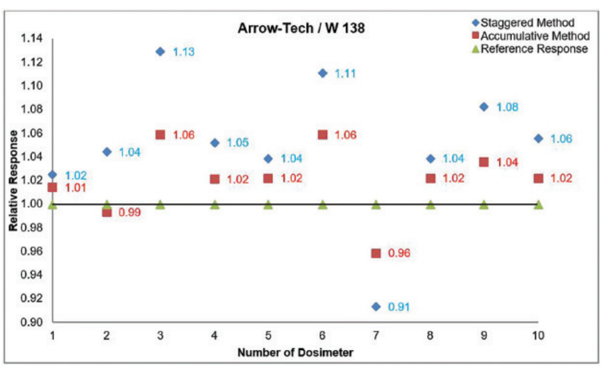

Figure 3. Response of the Arrow-Tech / W138 APDs. The relative expanded uncertainty in the measurement is 12.11% at k = 2 and 95% confidence level.

Several units of each type of APD were irradiated, and the average of the response was determined using Equation 2.

$$R_{average} = \frac{\Sigma R_{response\ of\ detector}}{R_{total\ number\ of\ dosimeter}} \quad (2)$$

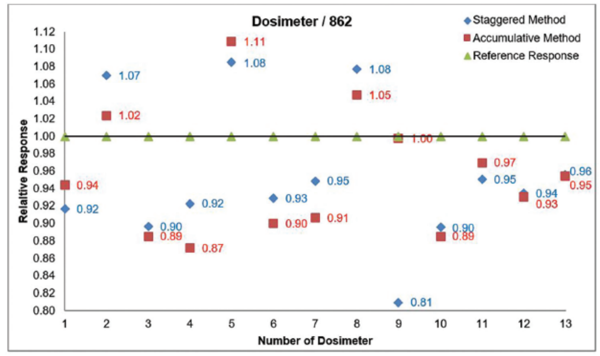

Figure 4. Response of the Dosimeter / 862 APDs. The relative expanded uncertainty in the measurement is 12.61% at k = 2 and 95% confidence level.

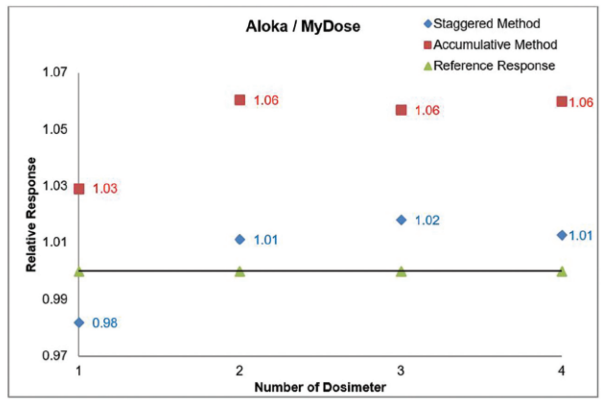

Figure 5. Response of the Aloka / MyDose APDs. The relative expanded uncertainty in the measurement is 3.17% at k = 2 and 95% confidence level.

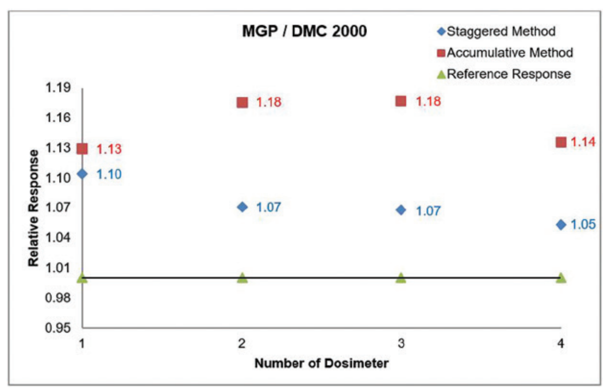

Figure 6. Response of the MGP / DMC 2000 APDs. The relative expanded uncertainty in the measurement is 3.17% at k = 2 and 95% confidence level.

RESULTS

The response for each dosimeter is shown in Figures 3–7 and the average response per type of detector was presented in Table 3. The relative uncertainty in the measurements per dosimeter corresponds to a coverage factor (k = 2) and at 95% confidence level (Soeres 2006).

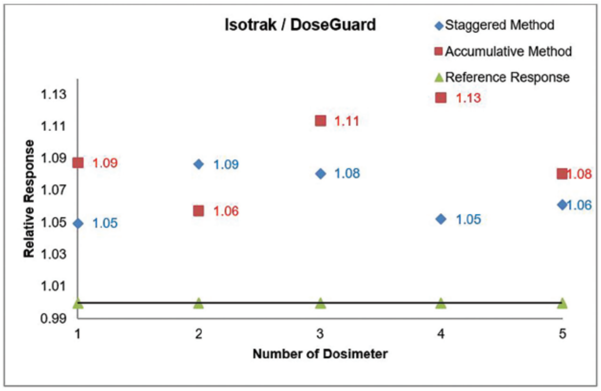

Figure 7. Response of the Isotrak / DoseGuard APDs. The relative expanded uncertainty in the measurement is 3.17% at k = 2 and 95% confidence level.

Table 3. Response of detector.

Method	Type of detector	
	Ionization chamber	Silicon diode
Staggered	1.00*	1.05*
Accumulative	0.99	1.10

Asterisk (*) shows which method the detector has the response closest to 1.0.

The average response of Arrow-Tech / W 138 (Figure 3) in the accumulative method was 1.02 ± 12.11% whereas the average response in staggered method was 1.05 ± 12.11%. Dosimeter / 862 (Figure 4) average response to accumulative method was 0.96 ± 12.61% and 0.95 ± 12.61% in staggered method. The response of Aloka / MyDose, MGP / DMC 2000 and Isotrak / DoseGuard are shown in Figures 5, 6, and 7, respectively. The response of Aloka / MyDose in accumulative method was about 1.05 ± 3.17% while 1.01 ± 3.17% in staggered method. The MGP / DMC 2000 response was 1.15 ± 3.17% and 1.07 ± 3.17% in accumulative and staggered methods, respectively. The response of Isotrak / DoseGuard in accumulative method was 1.09 ± 3.17% and staggered method was 1.07 ± 3.17%. In these three types of dosimeters, response is better in staggered method.

Table 3 summarizes the result of the tested APDs with different types of detectors. It can be seen that both the ionization chamber and silicon diode detectors have better responses (closer to 1.0) in staggered method (1.00 and 1.05) than in the accumulative method (0.99 and 1.10).

DISCUSSION

The response of the APD is affected by the type of calibration methods. The results of the experiment showed that the response of the APDs is better in the staggered method *i.e.*, measurement of the dose is more accurate. It is thus recommended that calibration is performed using the staggered method. However, as the removal of the dosimeter from the aluminum stand for getting measurement, resetting, and reattaching it may increase the uncertainties in this calibration method, special attention is needed to ensure the accuracy of the alignment during irradiation to each dose value.

In practical situations, on the other hand, radiation workers seldom reset their APDs to zero *i.e.*, they let the readings accumulate over time and just subtract the initial from the final value to determine their total dose received during a certain activity. It is, therefore, recommended to reset the APD before each use. This is to help ensure a more accurate measurement of the radiation exposure received by the worker during the activity.

CONCLUSION

The results of the study show that the response of an APD is affected by the type of calibration method used. The APD response is shown to be better in the staggered method. Thus, it is recommended that – in practical situations – the APD should be reset to zero before using it for radiation safety purposes. Users are advised to have their APD calibrated according to schedule to ensure the accuracy of its measurement. Also, the result of the study could be used by the RPSS in developing a protocol on calibrating APDs.

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