Energy and dose rate response of radiation protection area survey meters measuring X and γ-radiation

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Abstract

In this paper we present measurement results for the determinations of energy and dose rate response of eight radiation protection area survey meters measuring x and γ-radiation. Experiment was performed at the Secondary Standard Dosimetry Laboratory in Sudan. Instruments were calibrated in terms of ambient dose equivalent H*(10) determined from air kerma measurements and appropriate dose conversion coefficients. Air kerma measurements were made using calibrated reference standard ionization chambers. Parameters tested include the variation of instrument response radiation energy and different dose rates. The mean instrument response s: tracero, RDS and Radiagem type survey meters ranged from 0.4 to 1.04, (0.77-1.3), (0.85-1.4) respectively. Poor response was observed at low energy and dose rates due to the contribution from backscattered radiation, which could be eliminated using monitor chambers and additional beam limiting diaphragms. Survey meters calibrated at 662 keV \textsuperscript{137}Cs photon energy can demonstrate acceptable response when used in energy spectrum typical encountered in radiation protection practice.

Keywords: Radiation protection dosimetry; calibration facilities; ambient dose equivalent; Area survey meters
1. INTRODUCTION

International system of radiation protection requires that occupationally exposed individual should not receive doses that exceed dose limits recommend by the international commission on radiological protections (ICRP) (ICRP, 2007; IAEA, 2018). To insure that radiation limits are not exceeded in the working environment, control strategies involving physical systems (shielding, interlocks, etc), administrative measure (access, occupancy time, etc) and combinations these are applied. Radiation control strategies are solely based on the ambient dose levels at the specified locations. For situation involving x-ray or gamma ray photon fields, ionization chamber type survey instruments calibrated against reference instrument or national standard are employed (IAEA, 2000; 1999).

Radiation protection area survey meters are used for environmental area and workplace monitoring as well as measurements of radiation exposure during nuclear and radiological accidents. Measurements results are used to ensure exposure levels of individual and workplaces are within the norm of acceptable practice. Thus, calibration of these instruments is required to assure that an instrument can measure radiation dose with accuracy needed for its intended purpose including those predefined dose limits for both occupation and public exposures. Calibration of radiation measuring instrument is required generally to achieve standardization of dose measurements and to assure traceability of the measurand to relevant SI unit.

There are overall agreement on the calibration and performance testing methods concerning radiation protection area survey meters (IAEA, 2000; ISO, 1999; ISO, 1996). Generally, one will require to calibrate any survey meter over the full range of its capability. As this is impossible to achieve, there is a tradition of using $^{137}$Cs for calibrations. $^{137}$Cs has an intermediate beam energy (662 keV) which provides acceptable energy response and also relative long have life and thus durable calibration source. The relative low energy compared to other gamma sources such as $^{60}$Co source provide better protection. An even favorable gamma source is used for calibration concern remains how these instrument response in all energy range and if correction factor is needed to account for the instrument response if different energies.
2.- MATERIALS AND METHODS

A study was performed to determine energy and dose rate response to a set of 8 radiation protection area survey meters to photon reference radiations.

2.1.- Calibration facilities

Dosimeter irradiations and measurements were performed at the Secondary Standard Dosimetry Laboratory (SSDL) of the Sudan. Beam conditions and characteristics follow the international standard ISO 4037 for photon reference (ISO,1996). Radiation qualities used were the narrow X-ray series N-60, N-100, N-120 and $^{137}$Cs with effective energy of 48, 80, 100 and 662 keV, respectively. The air kerma rates were between 0.15 µGy/min to 0.21 mGy/min at the reference point of calibration. The X-ray beam was generated by a Pantak HF 60 power supply unit and a Phillips X-ray tube with an equivalent window of 7 mm Be. The $^{137}$Cs γ-ray beam was produced by 740 GBq Bucher OB 85 gamma irradiator. This is a collimated beam with field diameter of 50 cm at a reference calibration distance of 2 m. A set of lead attenuators are placed at the exit window of the irradiator to vary the air kerma rate that is required for the experiment. Air kerma measurements were made using 1000 cc reference standard ionization chamber type Ls-01 that was previously calibrated at the IAEA dosimetry laboratory with its calibration traceable to German Standard Laboratory (PTB).

2.2 Experimental set up

All instruments were calibrated in terms of ambient dose equivalent H*(10). The calibration method and application of the conversion factor are carried out as follows:

- Selection of the dosimeter to be calibrated and calibration condition (e.g. calibration quantity, radiation quantity, direction of incidence).
- Selection of suitable reference radiation field and the calibration point.
- Measurements of the physical quantity air kerma at the calibration point.
- Determination of nominal ambient dose equivalent rate at the calibration point using appropriate air kerma to ambient dose equivalent conversion coefficient.
- Irradiate the dosimeter for calibration following method described in IAEA safety report series No. 16. and determine the calibration coefficient.
- Determination of the instrument response defined as the ratio between the reading of dosimeters and the ambient dose equivalent, H* (10).

2.3 Determination of the ambient dose equivalent H*(10)

Radiation protection monitoring survey meters are calibrated in terms of the operational radiation protection quantity ambient dose equivalent $H^*(10)$ (ICRU, 2000). $H^*(10)$ at a point in a radiation field, is the dose equivalent that would be produced by the corresponding expanded and aligned field, in the ICRU sphere at depth d, on the radius opposing the direction of the aligned field. For penetrating radiation $d = 10$ mm and $H^*(d)$ is written $H^*(10)$ (ICRU, 1993).

In the laboratory, $H^*(10)$ is derived from the air kerma measurements using appropriate conversion coefficients using the following equation (IAEA, 2000):

$$
\dot{H} = h \cdot N^\text{ref}_k \cdot (M_{ch} - M_{Rg}) \cdot k_{TP}
$$

(1)

where $h$ is air kerma to ambient dose equivalent conversion coefficient ($H^*(10)/K_{air}$). $N^\text{ref}_k$ is the air kerma calibration coefficient of the reference ionisation chamber; $M_{ch}$ is the mean ionisation chamber reading; $M_{Rg}$ is the background reading; $k_{TP}$ is the correction factor for air temperature and pressure. Fig. 1 shows the set-up for the measurements of air kerma rate using 1000 cc reference standard ionization chamber type Ls-01.

2.4 Determinations of the calibration factor

Calculation the calibration factor of the dosimeter is defined as the ratio of the conventional true value to the indicated value. The calibration factor of the instrument $N_1$ is determined using equation:

$$
F_c = \frac{H_1(10) \cdot k_{d}}{(M_{I} - M_{Rg}) \cdot k_{TP} \cdot k_{d}}
$$

(2)

Where: $H^*(10)$ is the conventional true value of the dose rate quantity to be measured, $k_{d}$ is the correction factor to account for the decay of the radiation source from the date of $H^*(10)$ measurements#. $M_{I}$ : indicated air kerma rate , $M_{Rg}$ is the background reading; $k_{TP}$ is the correction factor for air temperature and pressure, $k_{d}$ : correction factor to
account for the possible deviation of the actual distance $d$ of the reference source to the measuring instrument from the nominal calibration distance.

![Image of air kerma measurements](image)

Figure 1. Air kerma measurements using reference ionization chamber used from OB-85 gamma calibrator.

### 2.5 Determinations of the response

The response $R$ of a measuring instrument is the quotient of the indication $M$ of the instrument and the conventional true value of the measurand, which is the reciprocal of the calibration (IAEA, 2000).

$$ R = \frac{1}{F_c} $$

In this study the following parameters were determined: Determination of response as a function of energy; dose equivalent response’ (response with respect to dose equivalent).

### 3.- RESULTS

Eight survey meters were studies concerning their performance in photon reference radiation. Table 1 presents survey meter information and data. All survey meters were of Geiger Muleur detectors and were previously calibrated to measure, $H^*(10)$. These survey meters were randomly selected from a pool of dosimeters that were brought to our
laboratory for annual routine calibrations and thus represented the most common types that are used in Sudan.

Table 2. Presents the reference output measurements made using reference standard ionization chamber. Measured output were converted to the dose quantity of interest at the reference point of calibration using air kerma to ambient dose conversion coefficients given in the ICRU report (ICRU,1993). In the results of this study the response of the survey instrument for Cs-137 was within the 30% recommended limit (IAEA,1999).

<table>
<thead>
<tr>
<th>Code</th>
<th>Dosimeter</th>
<th>S/N.</th>
<th>Detector</th>
<th>Dose range</th>
<th>Measuring quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>T202-A-3</td>
<td>070328</td>
<td>GM</td>
<td>0.1-1000 μSv/h</td>
<td>H*(10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hp(10)</td>
</tr>
<tr>
<td>D2</td>
<td>RDS-200</td>
<td>200024</td>
<td>GM</td>
<td>0.01μSv-10 Sv/h</td>
<td>H*(10)</td>
</tr>
<tr>
<td>D3</td>
<td>Radiagem-2000</td>
<td>1302</td>
<td>GM</td>
<td>0.01-100mSv/h</td>
<td>H*(10)</td>
</tr>
<tr>
<td>D4</td>
<td>RDS-120</td>
<td>990371</td>
<td>GM</td>
<td></td>
<td>H*(10)</td>
</tr>
<tr>
<td>D5</td>
<td>Radiagem-2000</td>
<td>1382</td>
<td>GM</td>
<td>0.01μSv - 100mSv</td>
<td>H*(10)</td>
</tr>
<tr>
<td>D6</td>
<td>Radose-2000</td>
<td>260048</td>
<td>GM</td>
<td></td>
<td>H*(10)</td>
</tr>
<tr>
<td>D7</td>
<td>RADOSE-120</td>
<td>990078</td>
<td>GM</td>
<td></td>
<td>H*(10)</td>
</tr>
<tr>
<td>D8</td>
<td>Radiagem Canberra-4000</td>
<td>NA</td>
<td>GM</td>
<td>0.01mrem - 10rem/h</td>
<td>H*(10)</td>
</tr>
</tbody>
</table>

Table 2. Output measurements

<table>
<thead>
<tr>
<th>Energy</th>
<th>48 keV</th>
<th>80 keV</th>
<th>100 keV</th>
<th>662 keV</th>
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<tr>
<td>Distance(m)</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Kair (mGy/h)</td>
<td>11.7</td>
<td>8.0</td>
<td>8.0</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Dosimeter energy response and dose rate dependency were determined at three pulsed X-ray beam qualities with effective energies of 48, 83, 100 keV as well as 662 keV Cs energy. The calibration coefficients of the instruments under study studied ranged from 0.71 to 1.3 providing an energy response that ranged from 1.4 to 0.76 (Fig. 2).
4.- DISCUSSION

As shown in Fig. 2, radiation monitor demonstrated low response around 48 keV and thereafter increased with increasing energy with best response at 662 keV Cs-137 energy. The data presented here demonstrate significant differences and high variability in instrument response conceived at low beam energies. This could be attributed to the contribution of the backscattered radiation. In a typical standard laboratory, contribution of backscattered radiation is eliminated using monitor chambers which was not the case in this case.

The distribution of the dose equivalent response (response with respect to dose equivalent) is presented in Fig. 3. As area survey meters are used in wide dose range, dosimeters need to show acceptable response. Poor dose rate response in also evident at low doses that may be due to increase of scatter radiation in comparison to the primary beam photons.

Fig. 2 Boxplot distribution of dosimeter energy response performance

These results strongly suggest that narrow beam response data are strongly dependent on detector type and model. Assuming that it is feasible to make appropriate corrections (energy, size, direction, etc) to the incident beam, the subsequent application of the
correction factor is essentially integrating the result over the sensitive area of the detector. The results of the instruments were also corrected for background radiation and to reference environmental conditions (temperature and pressure). Where applicable the results are presented as instrument calibration factor and response.

![Boxplot distribution of dosimeter dose rate dependency](image)

Fig. 3. Boxplot distribution of dosimeter dose rate dependency

5.- CONCLUSIONS

Energy and dose rate response of radiation protection area survey meters measuring x and γ-radiation. The instrument demonstrated significant differences and high variability in responses conceived at low beam energies and doses rates that could be attributed to increased levels of scattered radiation. Monitor chambers could be used in addition to the already available beam limiting diaphragms. The results of the experiment showed that survey meters calibrated at 662 keV $^{137}$Cs photon energy can demonstrate acceptable energy and dose rate response when used in overall low and medium energy spectrum typical encountered in radiation protection practice.
Acknowledgments

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REFERENCES


