An irradiation system for evaluating individual electronic dosimeters in pulsed x-ray beams

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Abstract. Electronic dosimeters are widely used for individual monitoring, especially for direct dose equivalent assessment associated with a specific task. Most of x-ray beams used in diagnostic radiology have been considered as pulsed one due to their high intensity during a very short time. This work showed that a Rhos Vari X x-ray machine was feasible to be used to evaluate electronic dosimeters in high pulsed air kerma rates to detect deficiencies in their response. In comparison to continuous x-ray beams, it was observed that personal dose equivalent values were severely underestimated by some electronic dosimeters in pulsed radiation fields.

Keywords: pulsed x-ray beams, individual electronic dosimeters, dosimeter calibration

1. Introduction
The knowledge of the metrological characteristics of a dosimeter is the basis for the choice and proper use of a detector in specific radiological conditions. Performance tests allow the characterization of a dosimeter, since they quantitatively determine its response in relation to influence quantities like radiation energy and type, electrical and environmental conditions, radiation incidence geometry and other [1].

Failures the response of solid-state electronic dosimeters were detected in pulsed radiation fields that suggested the need for specific tests. Many individual electronic dosimeters are not designed to measure pulsed x-ray beams, but only in continuous radiation fields in which they were tested [2].

Pulsed beams are found in diagnostic radiology and accelerators mainly if one considers as such all beams with high dose rates during a pulse time lower than 10 s without considering the electrical generator type, as suggested by Ankerhold et al. [2].

The International Electrotechnical Commission, IEC, has set some requirements for testing dosimeters in pulsed beams and the PTB/Germany laboratory has installed a system of pulsed x-rays beams to conduct studies of the response of dosimeters [3, 4]. In Brazil, preliminary studies of the response of some electronic dosimeters were done in standardized x-ray beams produced by a medical diagnostic x-ray machine, but they were not conclusive [5].

The aim of this work was to study the feasibility of using a Rhos Vari X x-ray machine to evaluate the response of individual electronic dosimeters in pulsed beams.
2. Materials and methods

Studies were done in x-ray beams that were produced by three x-ray machines: a constant potential HS 320 kV Isovolt Seifert Pantak, an 800 Pulsar Plus medical VMI and a pulsed beam Rhos Vari X. The x-ray beam code RQR5 with 70 kV, 2.58 mmAl half-value layer and 0.71 homogeneity coefficient was reproduced in all three x-ray machines. Beam dosimetry in terms of air kerma were done by a standard RC6 Radcal ionization chamber traceable to the LNMRI/IRD/Brazil National Laboratory and by an AGMS-D Radcal semiconductor multidetector.

Since the AGMS-D multidetector would be used to monitor the x-ray beam conditions during the irradiation electronic dosimeters, the reliability of its response was studied in RQR5 beams in all three x-ray machines for different air kerma rate values and for different short time exposures. All data were compared to the response of the RC6 ionization chamber.

Figures 1 shows the experimental setups used in each x-ray machine for comparing the response of the AGMS-D multidetector against the RC6 ionization chamber.

![Experimental setups](image)

Figure 1. Experimental setups used for comparing the responses of both the AGMS-D multidetector and the RC6 ionization chamber in the 320 HS Isovolt Seifert Pantak (A), in the Rhos Vari X (B) and in the 800 Pulsar Plus VMI medical (C) x-ray machines.

The EPD-MK2 Electron Corporation and the Rad-60 Mirion Technologies individual electronic dosimeters were used in this study. They were irradiated together with the AGMS-D multidetector on the 30x30x20 cm³ ISO water slab phantom in terms of the personal dose equivalent, \(H_p(10)\), as it is shown in Figure 2.
3. Results

3.1 Reliability of the AGMS-D multidetector in continuos and pulsed x-ray beams

The performance of the AGMS-D multidetector in the RQR5 x-ray beams in all three machines is shown in Table 1. Comparison against the RC6 ionization chamber was done in terms of the air kerma rate measurements.

Table 1. Comparison between the air kerma rates obtained with the AGMS-D multidetector against the RC6 ionzation chamber in the RQR5 x-ray beams produced by three x-ray machines.

| X-ray machine       | Pulse type               | Air kerma rate, $K_{air}$ (µGy s$^{-1}$) | Difference relative to RC6 chamber (%) |
|---------------------|--------------------------|------------------------------------------|---------------------------------------|
|                     |                          | RC6 chamber                              | AGMS-D multidetector                  |                                        |
| Seifert Pantak      | continuous               | 239 (3.6%)*                              | 231 (3.6%)*                           | -3.8                                  |
| VMI                 | short-time and high intensity | 2139 (3.6%)                              | 2026 (3.6%)                           | -5.3                                  |
| Rhos Vari X         | pulsed                   | 22.2 (1.7%)                              | 20.4 (0.5%)                           | -8.6                                  |

* Type A standard uncertainty.

Results from Table 1 show that the difference between the air kerma rate measurements by the AGMS-D multidetector in comparison to the RC6 ionization chamber from 3.8% up to 8.6% may be caused by calibration differences instead of any influence due to the pulse type. Besides both dosimeters showed similar and adequate repeatability of the measurements.

Table 2 show the performance of the AGMS-D multidetector in an 80 kV pulsed x-ray beam in the Rhos Vari X machine for exposure times from 0.1 up to 4.0 s. Comparison were done against the RC6 ionization chamber in terms of the air kerma rate measurements.

Results showed a systematic difference that varied from 6.0% up to 11.3% but there was no trend or influence due to different exposure times. One can conclude that the AGMS-D multidetector is reliable to carry out measurements in both the continuous and pulsed x-ray beams.
Table 2. Comparison between the air kerma rates obtained with the AGMS-D multidetector against the RC6 ionzation chamber in the 80 kV pulsed beam for different exposure times in the Rhos Vari X x-ray machine.

| Exposure time (s) | Air kerma rate, $K_{air}$ (μGy.s$^{-1}$) | AGMS-D multidetector | Difference relative to the RC6 chamber (%) |
|------------------|-----------------------------------------|----------------------|-----------------------------------------|
| 0.1              | 175 (5.4%)*                             | 159 (4.8%)*          | -9.0                                    |
| 0.2              | 618 (1.1%)*                             | 556 (1.0%)*          | -10.0                                   |
| 0.3              | 828 (2.8%)*                             | 736 (2.9%)*          | -11.1                                   |
| 0.5              | 951 (0.7%)*                             | 819 (0.7%)*          | -11.3                                   |
| 0.9              | 922 (0.4%)*                             | 868 (0.5%)*          | -6.0                                    |
| 1.7              | 951 (1.0%)*                             | 878 (1.1%)*          | -7.6                                    |
| 2.8              | 973 (1.2%)*                             | 964 (1.6%)*          | -10.1                                   |
| 4.0              | 994 (2.6%)*                             | 902 (2.8%)*          | -9.3                                    |

* Type A standard uncertainty.

3.2 Response of the individual electronic dosimeters in continuous and pulsed x-ray beams

Table 3 shows the responses of the EPD-MK2 Electron Corporation and the Rad-60 Mirion Tecnologies individual electronic dosimeters in terms of $H_{p}(10)$ in the RQR5 pulsed beam in the Rhos Vari X x-ray machine, for exposure times from 0.5 up to 3.6 s.

The results were analysed through the ratio between $H_{p}(10)$ indicated by each individual dosimeter and the air kerma rate measured by the AGMS-D multidetector because the conversion coefficient from $K_{air}$ to $H_{p}(10)$ is unknown. It is observed that the $H_{p}(10)/K$ values of the MK2 dosimeter are almost constant, which it means there was no influence of different exposure times on the dosimeter response.

For the Rad-60 dosimeter, the $H_{p}(10)$ values were significantly lower than the values indicated by the MK2 dosimeter, which they suggest the influence of its energy dependence. Additionally the $H_{p}(10)/K$ values clearly show there is influence of the exposure time.

Table 3. Influence of the exposure time on the $H_{p}(10)$ response of the EPD-MK2 and the Rad-60 dosimeters in RQR5 low air kerma rate pulsed beam produced in the Rhos Vari X x-ray machine.

| Exposure time (s) | Air kerma rate, $K_{air}$ (μGy.s$^{-1}$) | EPD-MK2 | Rad-60 |
|------------------|-----------------------------------------|---------|--------|
|                  |                                         | $H_{p}(10)$ (μSv.s$^{-1}$) | $H_{p}(10)/K$ (Sv.Gy$^{-1}$) | $H_{p}(10)$ (μSv.s$^{-1}$) | $H_{p}(10)/K$ (Sv.Gy$^{-1}$) |
| 0.5              | 19.9 (4.0%)*                            | 16.9 (5.5%)* | 0.84 | 6.0 (41.1%)* | 0.36 |
| 0.8              | 20.0 (1.7%)*                            | 18.3 (2.5%)* | 0.91 | 3.5 (42.0%)* | 0.17 |
| 1.6              | 19.1 (1.1%)*                            | 18.5 (2.4%)* | 0.92 | 1.9 (23.2%)* | 0.10 |
| 3.6              | 19.1 (1.9%)*                            | 18.5 (1.4%)* | 0.92 | 0.8 (21.2%)* | 0.04 |

* Type A standard uncertainty.

Table 4 shows the responses of the EPD-MK2 Electron Corporation and the Rad-60 Mirion Tecnologies individual electronic dosimeters for 80 kV high air kerma rate pulsed x-ray beam produced in the Rhos Vari X x-ray machine, for exposure times from 0.2 up to 4.0 s.

It is observed that although the air kerma rates are close to the upper dose rate limit given by manufacturers, the MK2 dosimeter showed a high unacceptable underestimation although it did not show any influence of the time exposure. For the Rad-60 dosimeter, its response was too low to be analysed.
Table 4. Influence of the exposure time on the $\dot{H}_p(10)$ response of the EPD-MK2 and the Rad-60 dosimeters in an 80 kV high air kerma rate pulsed beam produced in the Rhos Vari X x-ray machine.

| Exposure time (s) | Air kerma rate, $\dot{K}_{air}$ (µGy⋅s$^{-1}$) | EPD-MK2 | Rad-60 |
|------------------|---------------------------------------------|---------|--------|
|                  |                                             | $\dot{H}_p(10)$ (µSv⋅s$^{-1}$) | $\dot{H}_p(10)/\dot{K}$ (Sv⋅Gy$^{-1}$) | $\dot{H}_p(10)$ (µSv⋅s$^{-1}$) | $\dot{H}_p(10)/\dot{K}$ (Sv⋅Gy$^{-1}$) |
| 0.2              | 485 (47.4%)*                                | 87.5 (21.1%)*                   | 0.18 | 0 | 0 |
| 0.3              | 737 (1.3%)                                  | 112 (2.5%)                      | 0.15 | 0 | 0 |
| 0.5              | 858 (0.2%)                                  | 126 (2.0%)                      | 0.15 | 8.7 (58.2%)* | 0.010 |
| 0.9              | 982 (2.9%)                                  | 140 (7.2%)                      | 0.14 | 7.7 (40.8%) | 0.008 |
| 1.7              | 944 (0.4%)                                  | 138 (0.5%)                      | 0.15 | 8.2 (6.2%) | 0.009 |
| 2.9              | 955 (0.8%)                                  | 141 (0.4%)                      | 0.15 | 7.7 (6.2%) | 0.008 |
| 4.0              | 979 (0.9%)                                  | 143 (1.2%)                      | 0.15 | 8.7 (4.3%) | 0.009 |

* Type A standard uncertainty.

For the sake of comparison, Table 5 shows the $\dot{H}_p(10)$ values that were determined by the AGMS-D multidetector in similar x-ray beams produced by the three x-ray machines. It was considered there is no backscattering influence on the AGMS-D multidetector due to the presence of the slab phantom and the conversion coefficient from $\dot{K}_{air}$ to $\dot{H}_p(10)$ of ($0.88 \pm 0.09$) Sv⋅Gy$^{-1}$ was adopted [6].

The results from Table 5 shows that the response of the EPD-MK2 dosimeter in the $\dot{H}_p(10)$ measurement showed to be acceptable response in all three calibration conditions. On the other side, the Rad-60 dosimeter showed deficiencies in its response due to its limited range of radiation energy and influence of the short-time exposure.

Table 5. Response in terms of $\dot{H}_p(10)$ determined by the AGMS-D multidetector for the EPD-MK2 and the Rad-60 electronic dosimeters in RQR5 continuous and pulsed beams produced by three x-ray machines.

| X-ray machine       | Pulse type                | Air kerma rate, $\dot{K}_{air}$ (µGy⋅s$^{-1}$) | Personal dose equivalent rate, $\dot{H}_p(10)$ (µGy⋅s$^{-1}$) | AGMS-D | EPD-MK2 | Rad-60 |
|---------------------|---------------------------|---------------------------------------------|-------------------------------------------------|--------|---------|--------|
| Seifert Pantak      | continuous                | 91.2                                       | 80.3                                            | 100.3  | 18.2    |
| VMI                 | short-time and high intensity | 1857                                      | 1634                                           | 668    | 334     |
| RhosVari X          | pulsed                    | 20.3                                       | 17.9                                           | 18.5   | 0.81    |

4. Conclusion
The feasibility of the irradiation system using the constant potential HS 320 kV Isovolt Seifert Pantak, the 800 Pulsar Plus medical VMI and the pulsed beam Rhos Vari X machines to produce characterized x-ray beams and the AGMS-D multidetector for carrying out the beam dosimetry and monitoring the beam during the irradiation of individual electronic dosimeter was demonstrated.

This work allowed establishing a metrological framework in the CDTN Dosimeter Calibration Laboratory for calibrating and testing individual electronic dosimeters in continuous and pulsed x-ray beams.
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