Active personal dosemeters in interventional radiology: Tests in laboratory conditions and in hospitals

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ACTIVE PERSONAL DOSEMETERS IN INTERVENTIONAL RADIOLOGY: TESTS IN LABORATORY CONDITIONS AND IN HOSPITALS

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The work package 3 of the ORAMED project, Collaborative Project (2008-2011) supported by the European Commission within its 7th Framework Programme, is focussed on the optimization of the use of active personal dosemeters (APDs) in interventional radiology and cardiology (IR/IC). Indeed, a lack of appropriate APD devices is identified for these specific fields. Few devices can detect low energy X-rays (20-100 keV), and none of them are specifically designed for working in pulsed radiation fields. The work presented in this paper consists in studying the behaviour of some selected APDs deemed suitable for application in IR/IC. For this purpose, measurements under laboratory conditions, both with continuous and pulsed X-rays beams, and tests in real conditions on site in different European hospitals were performed. This study highlights the limitations of APDs for this application and the need of improving the APDs technology as to fulfil all needs in the IR/IC field.

INTRODUCTION

The optimization of the use of active personal dosemeters (APDs) in interventional radiology and cardiology (IR/IC) is performed by one of the work packages of the ORAMED project, a Collaborative Project(1) (2008-2011) supported by the European Commission within its 7th Framework Program.

APDs are used for monitoring of occupational exposure in many applications involving ionising radiation, especially the nuclear industry. In hospital environments, they are much less used(2). In IR/IC, the possibility to assess the dose and/or dose rate in real time is particularly interesting since operators can receive relatively high doses while standing close to the primary radiation field. In addition, an attractive feature of the APD is the possibility to have an alarm when a particular dose rate or dose value is exceeded. Due to the specificity of the X-ray fields used in IR/IC (low energies and pulsed fields), the current technology of APDs can be inadequate. This problem was highlighted during two previous international intercomparisons(3-5).

The work presented in this paper consisted in:

- studying the real radiation field characteristics encountered in IR/IC in terms of energy, angular distribution, dose rate and pulse characteristics,
- making a selection of commercial APDs deemed suitable for application in IR/IC according to several criteria, in particular the capacity to respond to photon energies down to 20 keV,
- testing, under laboratory reference conditions, the dose, dose rate, energy and angular response of the selected APDs,
- studying, under laboratory reference conditions, the effect of the dose rate, pulse frequency and pulse width on the APD response,
- performing tests in several European hospitals in workplace conditions.

MATERIAL AND METHODS

Typical fields in IR/IC

The typical fields and parameters encountered in IR/IC were gathered through questionnaires sent to hospitals, a literature search and quality control outputs. Calculations of dose equivalent rate at specific points of interest and typical scattered spectra were performed using the Monte Carlo codes MCNPX and PENELOPE(6,7).

Selection of APDs

The selection of commercial APD models was based on the results from international intercomparisons[3-5], and on their availability in different European countries. A pre-requisite for consideration was that each device should respond to photon energies down to 20 keV. Following those criteria, seven commercial APDs were selected (Figure 1): DMC 2000XB (MGPi), EPD Mk2.3 (Thermo), EDM III (Dosilab), PM1621A (Polimaster), DIS-100 (Rados), EDD30 (Unfors) and AT3509C (Atomtex).

Figure 1. Active personal dosemeters tested in this study

Tests of APDs under laboratory conditions

The tests with continuous X-ray fields were made in two calibration laboratories (IRSN in France and SCK•CEN in Belgium). These tests were performed to determine the dose, energy, dose rate and angle responses of the above mentioned APDs. Two devices of each type were always used. The following reference fields were used (N-15, N-20, N-25, N-30, N-40, N-60, N-80, N-100, N-120, S-Cs and S-Co) as defined in the ISO 4037-1[8] standard.

The tests[9] in pulsed mode were made at the French standard laboratory for ionizing radiation (Laboratoire National Henri Becquerel - LNHB, CEA LIST in France). The influence of several parameters on the response of the APD in pulsed mode was studied (70 kVp, HVL 5.17 mm Al):

- the effect of the dose equivalent rate (i.e. the mean dose equivalent rate during one pulse) from 1 to 55 $Sv.h^{-1}$ for a pulse duration = 20 ms and a pulse frequency = 10 s^{-1} – tests performed in multi-pulsed mode,
- the effect of the pulse frequency from 1 to 20 s^{-1} for a dose equivalent rate = 1.8 $Sv.h^{-1}$ and a pulse duration = 20 ms – tests performed in multi-pulsed mode,
- the effect of the pulse width from 20 ms to 1000 ms for a dose equivalent rate = 1.8 $Sv.h^{-1}$ – tests performed in single pulsed mode; for technical reasons, tests under 20 ms were not possible.

Tests of APDs under realistic conditions in hospitals

A series of tests were made in ten European hospitals during routine practice. The interventional radiologists and cardiologists were asked to wear, side by side and above their lead apron, an APD and an additional passive dosemeter during daily practice. The dosemeters were worn during several interventions to integrate doses of at least 300 µSv for several types of IR/IC procedures. The main objective of these tests was to compare the measurements performed by the active and passive dosemeters worn in routine practice in hospitals, where all kinds of procedures and parameter settings are used and without an accurate knowledge of the field parameters.

For practical reasons, only four dosemeters were tested in these realistic conditions: DMC 2000XB, EPD Mk2.3, EDM III and DIS-100.

RESULTS

Typical fields in IR/IC

The compilation of data presented in Table 1 gives an overview of typical fields encountered in IR/IC independently of the procedure considered.

The instantaneous dose equivalent rate obtained by quality control measurements using DAP-meters in the direct field at the level of the table ranges from 2 to 360 $Sv.h^{-1}$. The dose equivalent rate in the scattered beam, at the level of the operator for tube position of 0° and 90°, was found to range from 5.10^{-3} to around 10 $Sv.h^{-1}$. In addition, Monte Carlo calculations showed that the influence of the filtration on the scattered spectra is very small. The energy of the scattered spectra ranges from 20 to 100 keV.

Table 1 Typical field characteristics encountered in interventional radiology/cardiology

Parameter	Range
High peak voltage	50-120 kV
Intensity	5-1000 mA
Inherent Al equivalent filtration	4.5 mm
Additional Cu filtration	0.1 – 0.9 mm
Pulse duration	1 - 20 ms
Pulse frequency	1 – 30 s^{-1}
Dose equivalent rate in the direct beam (table)	2 to 360 $Sv.h^{-1}$
Dose equivalent rate in the scattered beam (operator – above the lead apron)	5.10^{-3} to 10 $Sv.h^{-1}$

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Response of APDs in continuous mode

In continuous mode, all APDs have a linear response with dose. The energy response (Figure 2) is within the interval [0.71 – 1.67] as required in the IEC 61526 standard[10] from ^{60}Co energy down to N-30 for all APDs except EDD30. For EDD30, these results are consistent with the fact that this APD is designed to work specifically at low energy.

Figure 3 illustrates the response of the selected APDs as a function of dose equivalent rate. Most tested APDs provide a response for dose equivalent rates up to 10 Sv.h^{-1}, except PM1621A for which the response is diverging rapidly from 1 Sv.h^{-1} and EDD30 which saturates for dose equivalent rates above 2 Sv.h^{-1}. The dose equivalent rate range requirement specified in IEC 61526[10] is 1 Sv.h^{-1} thus, all the dosemeters fulfil the IEC standard.

All devices showed under and over-responses for low energy photons and high angles, but these stayed within the limits of the IEC standard[10] except AT3509C (Figure 4) for which the angle response is inside this interval at 60° only from N-80.

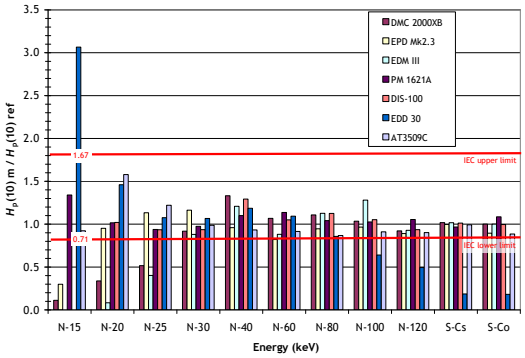

Figure 2. Energy response of APDs in continuous mode (for dose equivalent rate $H_p(10)$ around 10 mSv.h^{-1}, and integrated dose equivalent around 0.5 mSv)

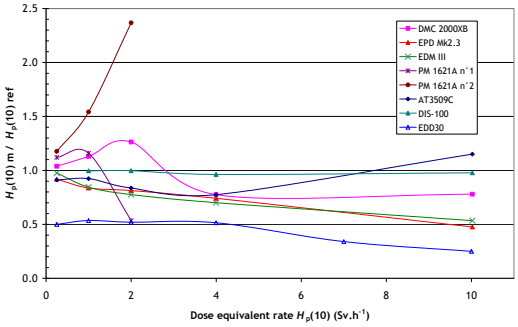

Figure 3. Dose equivalent rate response of APDs in continuous mode (except for PM1621A, whose response diverged, the mean value of the 2 units of each APD type is represented)

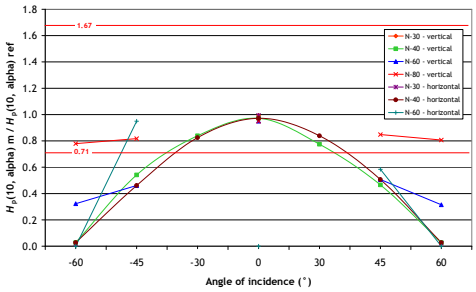

Figure 4. Response of AT3509C at different photon radiation energies and angles of incidence in continuous mode.

Response of APDs in pulsed mode

Effect of dose equivalent rate

For most APDs, the response decreases when the dose equivalent rate increases (Figure 5). For dose equivalent rates lower than 2 Sv.h^{-1}, the responses are, in general, close to 1 and fall down more or less rapidly for higher dose rates, except DIS-100 that gives correct response up to 55 Sv.h^{-1}.

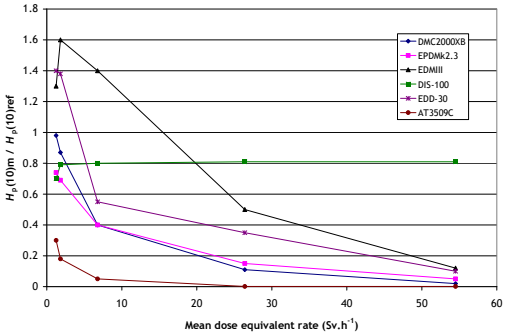

Figure 5. Dose equivalent rate response of APDs in pulsed mode for a pulse frequency equal to 10 s^{-1}.

Effect of pulse frequency

Table 2 sums up the effect of pulse frequency as a percentage of variation in the APD response between 1 and 20 s^{-1}. This variation is roughly equal to 30% for all devices, except PM1621A (no signal) and EDD30 for which a saturation was observed from 2 Sv.h^{-1}.

Effect of pulse width

When the pulse width is larger than 1 s, the responses in pulsed and continuous radiation field are quite similar. No significant effect of pulse width was observed.

All results from the pulsed field tests show that the more continuous the field tends to, that is to say the longer the pulses and the higher the frequency, the more satisfactory the behaviour of the devices.

These results show that it is important to add tests in pulsed mode when type-testing APDs, and thus the IEC 61526[10] standard should be revised.

Table 2. Effect of the pulse frequency (1 to 20 s^{-1}): percentage of variation on the APD response for a dose equivalent rate = 1.8 $Sv.h^{-1}$ and a pulse duration = 20 ms

APD	DMC 2000XB	EPD MK2.3	EDM III	PM1621A	DIS-100	EDD30	AT3509C
Variation on the APD response (%)	25-30	30-40	<10	NO SIGNAL	30	10 (1.8 $Sv.h^{-1}$) saturation from 2 $Sv.h^{-1}$	30 (10- 20 s^{-1}) No signal at 1 s^{-1}

Response of APDs in hospitals

The results of tests performed in hospitals are presented in Figure 6 as the distribution of APD reading normalized to the passive dosemeter reading.
With respect to passive dosemeters, DMC 2000XB (median 0.65), EPD Mk2.3 (median 0.69), DIS-100 (median 0.78) and EDM III (median 0.81) on average, present an under-response. The behaviour of APDs is globally more satisfactory in hospitals than in laboratories because devices are mainly exposed to scattered fields.

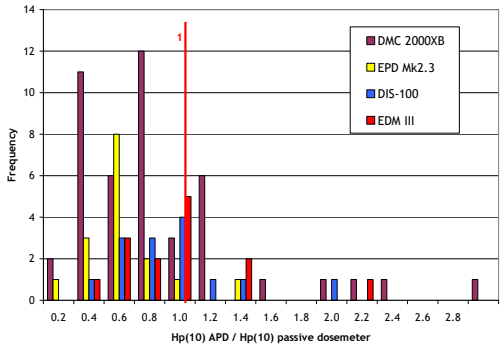

Figure 6. Distribution of APD response compared with passive dosemeter response in realistic conditions

CONCLUSION

The tests performed with continuous X-ray beams showed that all APDs have a satisfactory response at lower energies typical of IR/IC. Most APDs provide a correct response for dose equivalent rates up to 10 $Sv.h^{-1}$, except PM1621A for which the response is diverging rapidly from 1 $Sv.h^{-1}$ and EDD30 which saturates above 2 $Sv.h^{-1}$. However, the dose equivalent rates in the direct beam can be much higher than those tested here. So these tests cannot guarantee that the APDs will correctly measure the high dose equivalent rates in the direct beam.

The study in pulsed mode showed that, except PM1621A, whose display does not give any indication, all APDs provide a reading. The tests performed in laboratory conditions with pulsed X-ray fields determined the effect of the dose rate, pulse frequency and pulse width on the APD response. First, for most APDs, the response is generally equal to 1 for dose equivalent rates lower than 2 $Sv.h^{-1}$, and decreases for higher dose rates, except DIS-100 that gives correct reading for high dose rates. Second, for a pulse frequency ranging from 1 to 20 s^{-1}, a variation of 30% in average is observed for all APDs. Finally, no significant effect of pulse width was observed.
The measurements in hospitals confirmed an under-response of APDs (median ranging from 0.65 to 0.81) with respect to passive dosemeters.
Since all selected APDs, except PM1621A, provide a reading in pulsed mode, this means they could be used in routine monitoring at hospitals, provided correction factors are introduced[11]. Some preliminary guidelines with recommendations about how to use APDs in practice were presented at IRPA2010[12].

Acknowledgement

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