ORAMED: Optimization of the use of active personal dosemeters in interventional radiology (Work Package 3)

Deliverable 3.2 : Practical guidelines proposed to improve the response of APDs in interventional radiology

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GUIDELINES FOR THE USE OF ACTIVE PERSONAL DOSEMETERS IN INTERVENTIONAL RADIOLOGY/CARDIOLOGY

These guidelines were established in the framework of the ORAMED project (2008-2011), a Collaborative Project supported by the European Commission within its 7th Framework Program.

General problematic

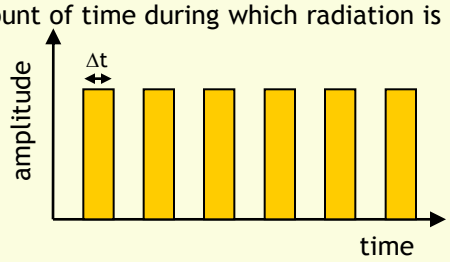
Active personal dosemeters (APD) are used in the context of operational radiation protection taking advantage of an immediate dose reading and an alarm at a pre-set dose and/or dose rate level [1-2]. In interventional radiology and cardiology (IR/IC), the possibility to assess the dose in real time is particularly interesting since operators can receive relatively high doses while standing close to the primary radiation field. In addition, the possibility to have an alarm when the personnel is accidentally exposed to the primary beam is very attractive.

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]. These guidelines propose recommendations when selecting and using an APD in IR/IC based on the work performed in the framework of the European project ORAMED (2008-2011) [6].

Terms and definitions

BEAM CHARACTERISTICS IN PULSED MODE

In pulsed fluoroscopy, X-rays are delivered in pulses that follow in rapid succession. This reduces the amount of time during which radiation is released.



Pulse frequency: number of pulses per second = pps
Pulse width: Δt
Direct beam: beam directly delivered by the X-ray tube
Scattered beam: beam backscattered by the patient

TYPICAL FIELDS IN INTERVENTIONAL RADIOLOGY AND CARDIOLOGY

Table 1. Typical radiation field characteristics in interventional radiology and cardiology
(data gathered through questionnaires sent to hospitals, literature and quality control outputs, calculations of dose rate at specific points of interest and typical scattered spectra were performed using Monte Carlo codes)

Parameter	Range
High voltage	60-120 kVp
Intensity	5-1000 mA
Inherent filtration	3 – 6 mm Al_{eq} (typically 4.5 mmAl_{eq})
Additional filtration	0.2 – 0.9 mmCu
Pulse duration	1 - 20 ms (typically 10-20 ms)
Pulse frequency	1 – 30 pps (typically 15 pps)
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 $Sv.h^{-1}$
Energy range of scattered spectra	20 keV – 100 keV

Recommendations when selecting an APD in IR/IC

- The APD has to fulfil the requirements of the IEC 61526 standard (2010 – 07) [7] in particular for the following points:
  - energy response: correct* response within the energy range 20 keV – 150 keV
  - angular response: correct* angular response from 0° to 60° from reference direction within the energy range 20 keV – 150 keV
  - dose equivalent rate range: the maximum dose equivalent rate value required by the IEC standard is 1 $Sv.h^{-1}$ but, since dose equivalent rates can be high very close or inside the direct beam, if the APD can stand higher dose equivalent rates it is an interesting feature that has to be taken into account. In any case, the APD should be able to give at least an alarm for dose equivalent rates higher than 1 $Sv.h^{-1}$.

- As pulsed radiation fields are not taken into account in existing standards, some information on the APD characteristics in pulsed field are needed (i.e. effect of pulse frequency and width on the dose equivalent response). Different sources of information can be used:
  - results of tests performed within the ORAMED project (see annex of these guidelines and reference [6])
  - results of tests eventually performed by the manufacturer
  - perform tests using the following configuration:
    - ✓ place one ISO slab phantom on the table to simulate the backscatter created by the patient
    - ✓ place one ISO slab phantom at a representative position of the operator
    - ✓ place the APD and a passive dosemeter side by side on the operator phantom without lead apron
    - ✓ use a usual configuration for your facility in terms of kV, mAs, etc. and integrate at least 300 µSv
    - ✓ results: a factor of 2 between the doses given by the two types of dosemeters can be considered as acceptable.

**correct response: limit of variation of instrument parameter in the range -29% to +67%, as required in IEC 61526 standard (2010 - 07) [7]*

Recommendations when using an APD in IR/IC

- The APD has to be periodically (according to local regulation) calibrated or verified in terms of $H_p(10)$ with X-ray beams in a calibration laboratory traceable to a primary standard, the conditions of calibration have to be as close as possible as those of use.
- The APD is considered, for this application in IR/IC, as a tool to optimize and reduce the exposure, we then recommend to wear it the over the lead apron.
- It is not recommended to use APD for the legal dose record in case of IR/IC, the reference $H_p(10)$ is still given by the passive dosemeter
- The alarm should be switched ON (only visual alarm) in order to warn the operator when he/she is too close to the direct beam.

References

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SEVENTH FRAMEWORK PROGRAMME

ANNEX - Main results of tests performed in the ORAMED project

The work performed in the ORAMED project consisted in:
- making a selection of APDs deemed suitable for application in interventional radiology/cardiology
- defining, by measurements under laboratory conditions, the dose, the dose rate, the energy and the angular response of selected commercial APDs, with continuous X-ray beams.
- studying, by measurements under laboratory conditions and with tests in different hospitals, the effect of dose equivalent rate, pulse frequency and pulse width on the APD response, with pulsed X-ray beams.

Figure 1. APDs selected for tests (pre-requisite: the APD should respond to low photon energies starting from 20 keV)

TESTS DONE WITH CONTINUOUS X-RAY BEAMS IN CALIBRATION LABORATORY CONDITIONS

Dose equivalent response : S-Co, N-150 for DoseAware
Dose equivalent rate response from 0 to 10 Gy.h^{-1}: S-Co for all APDs, H-100 for EDD30 and N-150 for DoseAware
Energy response: N-15, N-20, N-25, N-30, N-40, N-60, N-80, N-100,N-120, S-Cs, S-Co for all APDs, from N-30 to N-300 for DoseAware
Angular response at +/- 60°: N-25, N-30, N-40 and N-60

All APDs have a linear response with the dose equivalent and most of them have a satisfactory response at low energies from N-30.
Most APDs can stand high dose equivalent rates up to 10 Sv.h^{-1}, except:
- PM1621A for which the response is diverging rapidly from 1 Sv.h^{-1}
- EDD30 which saturates for dose rates above 2 Sv.h^{-1}.
- DoseAware which saturates for dose equivalent rates above 4 Sv.h^{-1}

All APDs have a satisfactory angular response from the energy of N-30 (except AT3509C: satisfactory angular response only from N-80)

TESTS DONE WITH PULSED X-RAY BEAMS IN CALIBRATION LABORATORY CONDITIONS

① **Dose rate** (in multi-pulsed mode):
- pulse duration: 20 ms,
- pulse frequency: 10 pulses per second (pps)
- **dose equivalent rate variation from 100 mSv.h^{-1} to 50 Sv.h^{-1} (up to 1,8 Sv.h^{-1} for DoseAware)**

For most APDs the response decreases when the dose equivalent rate increases. For dose equivalent rates < 2 Sv.h^{-1} the responses are, in general, close to 1 and fall down for higher dose equivalent rates, except for DIS-100 that stands relatively high dose equivalent rates.

Table 2. Threshold in terms of dose rate (Sv.h^{-1}) for which the maximum APD response is divided by a factor 2.

APD	DMC 2000XB	EPD MK2.3	EDM III	PM1621A	DIS-100	EDD 30	AT3509C	DoseAware
Dose rate (Sv.h^{-1}) for APD response divided by 2	5	7	20	NO SIGNAL	Response within +/- 30% for all dose equivalent rates up to 55 Sv.h^{-1}	10	3.5	0.8

② **Pulse frequency** (in multi-pulsed mode) for all APDs:
- dose equivalent rate: 1.8 Sv.h^{-1} and 6.8 Sv.h^{-1} (908 mSv.h-1 and 1,8 Sv.h-1 for DoseAware)
- pulse duration: 20 ms,
- **pulse frequency variation: 1 pps, 10 pps and 20 pps (1 pps and 10 pps for DoseAware)**

The response of APDs decreases from 10% to 40% when the pulse frequency increases from 1 to 20 pps.

Table 3. Percentage of variation on the APD response from 1 to 20 pps.

APD	DMC 2000XB	EPD MK2.3	EDM III	PM1621A	DIS-100	EDD 30	AT3509C	DoseAware
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 pps; No signal at 1 pps	<10 (between 1 and 10 pps)

③ **Pulse width** (in single pulsed mode):
- **pulse width variation: 20, 50, 100 and 1000 ms at 1.8 Sv.h^{-1} (DoseAware not tested in this configuration)**

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

TESTS DONE WITH PULSED X-RAY BEAMS IN HOSPITALS

A series of tests was made in different European hospitals in routine practice. The interventional radiologists and cardiologists were asked to wear, side by side, an APD and an additional passive dosemeter above their lead apron during daily practice.
The main objective of these tests was to have an overview of differences between active and passive dosimetry in routine practice, where all kinds of procedures and parameter settings are used and without an accurate knowledge of the field characteristics. Four dosemeters were tested in these conditions: DMC 2000XB, EPD Mk2.3, EDMIII and DIS-100.

All tested APDs present a slight under-response with respect to passive dosemeters.

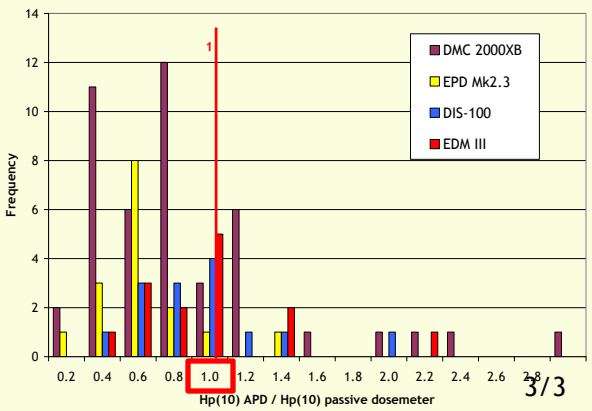

Figure 2. Distribution of APD response compared with passive dosemeter response in realistic conditions