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Use of active personal dosimeters in hospitals: EURADOS survey

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Abstract

Considering that occupational exposure in medicine is a matter of growing concern, active personal dosimeters (APDs) are also increasingly being used in different fields of application of ionising radiation in medicine. An extensive survey to collect relevant information regarding the use of APDs in medical imaging applications of ionising radiation was organised by the EURADOS (European Radiation Dosimetry Group) Working Group 12. The objective was to collect data about the use of APDs and to identify the basic problems in the use of APDs in hospitals. APDs are most frequently used in interventional radiology and cardiology departments (54%), in nuclear medicine (29%), and in radiotherapy (12%). Most types of APDs use silicon diodes as the detector; however, in many cases their calibration is not given proper attention, as radiation beam qualities in which they are calibrated differ significantly from those in which they are actually used. The survey revealed problems related to the use of APDs, including their reliability in pulsed x-ray fields that are widely used in hospitals. Guidance from regulatory authorities and professional organisations on the testing and calibration of APDs used in hospital would likely improve the situation.

Keywords: occupational exposure, medicine, dose monitoring, radiation dose, active personal dosimeters

Introduction

In most European countries, passive dosimetry systems are used to evaluate the magnitude of occupational exposure to ionising radiation and to verify compliance with the respective dose limits.

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Contrary to passive dosemeters that are measured after due time following the exposure, active personal dosimeters (APDs, also called electronic personal dosimeters, EPDs) are small portable personal devices which have powered electronic circuitry, usually a battery, with associated software and/or firmware, and normally with visible or audible indication of an integrated dose and/or dose rate (European Commission 2009). APDs are frequently used as secondary or supporting dosimeters, mainly in industrial applications of ionising radiation, but also in hospitals. They are mainly used as alarm dosimeters in potential high dose workplaces and help in the application of the optimisation principle. In some countries, APDs are also accepted as official dosimeters and no passive dosimeters are used, but this practice is still very limited. Considering that occupational exposure in medicine is a matter of growing concern, APDs are also increasingly used in various fields of application of ionising radiation in medicine (radiotherapy, nuclear medicine, interventional cardiology, and interventional radiology-IC/IR) (Clairand *et al* 2011, Struelens *et al* 2011, Chiriotti *et al* 2011). Regarding occupational exposure in medical applications, they can be very useful 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 (Ginjaume *et al* 2007).

In 2001, a EURADOS (European Radiation Dosimetry Group) Working Group on the harmonisation of individual monitoring investigated new developments in individual monitoring with an emphasis on the possibilities and performance of active dosimeters for both photon/beta and neutron dosimetry. The first step was the distribution of a questionnaire to the users of APDs in industry and hospitals. Secondly, an intercomparison of APDs for the individual monitoring of external exposure from photon and beta radiation was organized as a joint venture project of EURADOS and the International Atomic Energy Agency (IAEA) to assess the technical capabilities of different types of APDs (IAEA 2007). It was concluded that the general dosimetric properties of the tested APDs are comparable to the performance of standard passive dosimetric systems. The accuracy in reference photon radiation beam qualities and the reproducibility and repeatability of the measurements were even better for APDs than for most of the passive dosemeters (IAEA 2013). A decade later, within the ORAMED (Optimisation of Radiation Protection for Medical Staff) project, various existing APDs were tested under both laboratory conditions and conditions that are met in clinical practice (e.g. pulsed fields, energy of the scattered spectra from 20–100 keV). A series of guidelines for the use of these APDs in IC/IR have been developed (Clairand *et al* 2011, Struelens *et al* 2011, Vanhavere *et al* 2011). Most APDs had a satisfactory energy and angular response. However, in pulsed radiation fields the response of most APDs decreases when the instantaneous personal dose equivalent rate increases, probably due to the time response of their electronic system (Vanhavere *et al* 2011).

In the years following the ORAMED project, a number of new facts related to the performance of APDs have become available, including new types of dosimeters, standardisation of tests for pulsed radiation fields, and the evident increase in use of APDs in hospitals. Therefore, it was decided to perform a new study on dosimeters within the framework of the activities of EURADOS Working Group 12.

The WG12 activities are focused on dosimetry harmonisation, evaluation and development of dosimetry methods, intercomparisons, and measurement campaigns to assess occupational and patient doses (Carinou *et al* 2014, Carinou *et al* 2015, Clairand *et al* 2016). Following its main objectives, WG12 has organised an extensive survey to identify all relevant issues for the use of APDs in medical imaging applications of ionising radiation. The specific objectives of this work were:

- To collect data about the use of APDs, e.g. where and how APDs are used in hospitals;
- To identify the basic problems in APDs that the end users have to deal with; and
- To draft some basic conclusions related to the use of APDs in hospitals.

Survey design

A questionnaire was developed and sent to WG12 members, medical physicists, and radiation protection officers in hospitals across Europe. The questionnaire was designed to be clear, unambiguous, and in a way that answering is not time consuming. It included questions related to the use of the APDs, their calibration, and testing. Space for comments in the free-text format was provided at the end of questionnaire. The full list of questions is provided in table 1. If a question was designed as multi-choice, the possible answers are given in the final column of table 1.

Results

Number of responses and use of APDs

In total 79 responses were received from which 74 responses were analysed, while the remaining five were excluded as the participants misreported the use of passive dosimetry systems. The responses created a pool of data of reasonable size from 19 European countries. The distribution of the responses by country is shown in figure 1.

From 74 responses used for further analysis, 24 participants reported that APDs are not used, 43 participants reported regular use of APDs, whereas seven reported occasional use in specific occupational exposure situations. These are: research purposes in radiation protection, monitoring of pregnant female workers, new exposure situations, or monitoring of specific working tasks.

Number and type of APDs used

The question about the number of APDs used in the hospital/institution was in the form of free text. For the purpose of analysis, responses were classified into groups, as presented in table 2. It can be seen from table 2, that 40% of the responses are related to the use of a relatively small number of dosimeters, i.e. less than ten.

The use of the largest number of dosimeters (>50) is linked to the routine use in interventional radiology and nuclear medicine departments in large teaching hospitals (in France and Germany). A small number of APDs (less than five), was mainly reported in smaller departments in which these dosimeters are mainly used for research purposes.

Participants were also asked to provide information about the model and manufacturer of the APDs used in their hospitals/institutions. Fifty participants reported the use of 34 different models of APDs from 17 different manufacturers. The distribution of APDs from different manufacturers for which more than one response was provided is presented in table 3.

The other manufacturers and models, reported by a single participant were: ALARA (ALARA OD), Automess (ADOS), Technical Associates(PDA 200+), Dositec (L6), Honeywell (DOSE RAE 2), Perspective Instruments (MINI 6100), Canberra (DOSICARD), Ecotest Radiation Detector (MKS), Vertec (BLEEPER SV), and Comdos (EDM III). Collected information revealed that the APDs that use silicon diodes as the detector are mainly

Table 1. List of questions related to use of APDs included in the questionnaire.

No	Question	Possible answers
1	Do you use APDs in your hospital on routine basis?	Yes/No/Other
2	How many APDs are used in your hospital/institution?	
3	Which type(s) of APDs are used in your hospital/institution? Please provide information on the model and manufacturer.	
4	In which department(s) do you use APDs?	Interventional radiology/interventional cardiology/nuclear medicine/radiotherapy/other
5	To test/calibrate your APDs, you perform	Regular functional tests/regular internal calibration/regular external calibration
6	How often are APDs used in your hospital/institution calibrated?	One per year/once in two years/Never/Other
7	In which radiation beam qualities are your APDs calibrated?	S-Cs/S-Co/ISO-N radiation quality/ISO-W radiation quality/Other[a]
8	What are the usual problems encountered with their use?	Lack of response to pulsed fields/Unreliable response to pulsed fields/Electromagnetic interference/Battery lifetime/Size and weight of APD/Other
9	For which purposes do you use APDs?	
10	Where are they usually worn?	Above the protective apron at collar level Above the protective apron at chest level Above the protective apron at waist level Under the protective apron (any location) I don't know Other
11	Is the audio alarm on?	In dose rate regime In integral dose regime In dose rate and integral dose regime There is no alarm/Other
12	What are the usual dose rates measured by an APD?	
13	Do you find the use of an APD convenient?	Yes/No/Other
14	Do you find use of an APD useful?	Yes/No/Other
15	COMMENTS/REMARKS	

[a] S-Cs and S-Co denotes calibration by means of gamma radiation emitted by radionuclides ^{137}Cs and ^{60}Co. ISO-N and ISO-W correspond to narrow and wide x-ray beam qualities as described in the ISO 4037-1 standard (ISO 1995).

used in interventional radiology and cardiology departments. Although there were some exceptions, most of the APDs that include a Geiger–Muller tube as the detector are used only in nuclear medicine departments. This finding was expected, as it has been demonstrated that APDs equipped with a Geiger–Muller tube do not give any signal in pulsed mode (Clairand *et al* 2011). The reason seems to be the high dose rate that can occur in the pulsed radiation field (up to about 100 Gy h^{-1}) and the short duration of the radiation field pulse (less than 100 ms). This is due to pile-ups of the counting pulses and to the fact that the radiation field pulses are much shorter than the measurement cycle of the instrument. Even if the dosimeter corrects for dead-time effects, a constant dose rate during a measurement cycle is assumed,

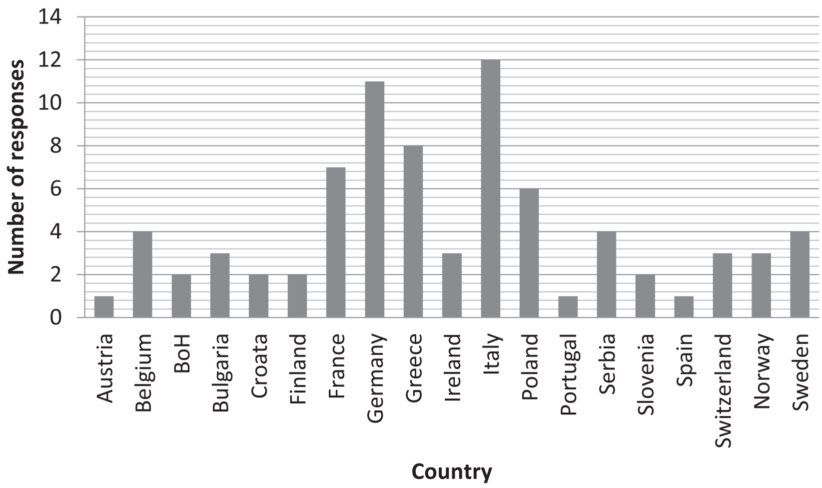

Figure 1. Number of responses received from various European countries.

Table 2. Number of APDs used in different hospitals/institutions.

N°of APDs	N° of hospitals/institutions	Percentage (%)
1–5	14	28
6–10	11	22
11–15	4	8
16–20	7	14
20–50	7	14
51–100	5	10
>100	2	4
Total	50	100

which is not the case for pulsed radiation (European Commission 2009). Such dosimeters, could be, however, used in constant dose rate radiation fields typical for nuclear medicine.

Departments in which APDs are used

The question related to the type of departments in hospital in which APDs are used was a multi-choice type, with possible answers: interventional radiology, interventional cardiology, nuclear medicine, radiotherapy, and other. Owing to the fact that multiple answers were possible, some of the participants provided information that APDs are used in more than one department in the hospital, e.g. interventional cardiology and nuclear medicine or radiotherapy. Out of 49 responses, 32 participants stated that APDs are used in more than one department. The most frequent uses are in interventional radiology (30%), nuclear medicine (29%), and interventional cardiology (24%), as presented in figure 2.

Calibration and testing of APD

Three questions were related to the calibration and testing of APDs. In the first of these three, participants were asked to provide information about calibrations and functional tests that are

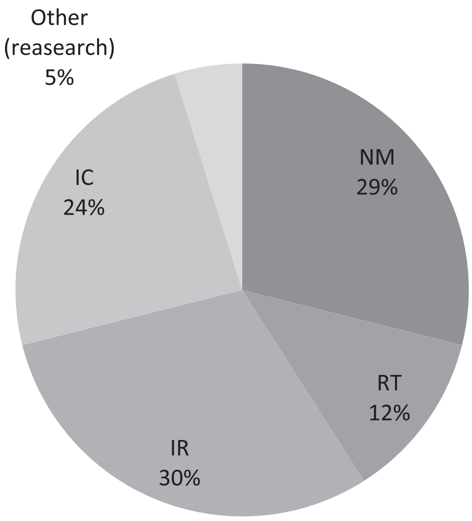

Figure 2. Distribution of departments in which APDs are used (IR-interventional radiology, IC-interventional cardiology, RT-radiotherapy, NM-nuclear medicine).

Table 3. Manufacturers and models of APDs reported by participants of the survey.

Manufacturer	Models	Number of hospitals/institutions	Type of detector
Mirion	DMC 2000, DMC 2000 X, DMC 2000 XB, DMC 3000, DMC 2000 s	22	Silicon diode
Mirion	RAD 50 s, RAD 51 s, RAD 52 s, RAD 62 s, RAD 60 s, RAD 60 R	14	Silicon diode
Thermo Scientific	MK2, EPD-G, N2	14	Silicon diode
RaySafe	I2, DOSEAWARE, EDD30, NED	8	Silicon diode
Polimaster	PM1610, PM1621	3	Geiger–Muller tube
IBA	DOSE GUARD S10	2	Silicon diode
Tracero	PED Blue	2	Geiger–Muller tube

potentially performed. As more than one answer was acceptable, some of the participants reported multiple activities.

From the results presented in figure 3, it can be concluded that only 38% of the users regularly calibrate their dosimeters externally; 24% of them regularly calibrate dosemeters internally, while 33% performs the functional tests between two calibrations. It is important to mention that only 18% of the participants reported both regular calibrations and functional tests between two calibrations. The two most frequent calibration intervals reported by participants were one year (34%) and two years (20%) according to the data presented in figure 4.

Another question related to the calibration procedure was related to the radiation beam qualities in which the calibrations were performed (ISO 1995). Possible radiation beam qualities included gamma radiation emitted by radionuclides ^{137}Cs (S-Cs) and ^{60}Co (S-Co), as well as x-ray beams qualities known as narrow (ISO-N) and wide (ISO-W) x-ray beam qualities, as described in the ISO 4037-1 standard (ISO 1995). Forty participants responded to this question.

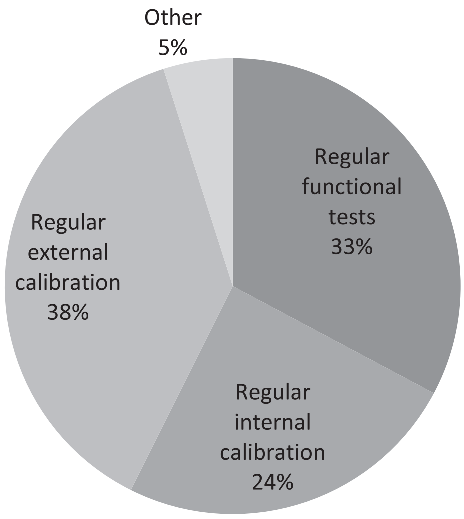

Figure 3. Distribution of activities related to the calibration and functional testing of APDs.

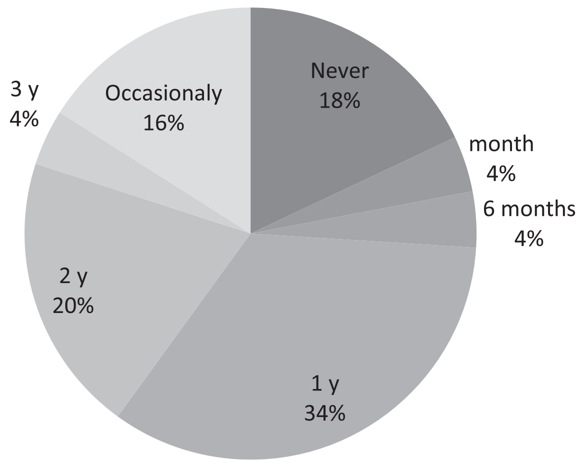

Figure 4. Calibration interval of APDs.

According to the data collected, more than half of the APDs are calibrated by means of gamma radiation emitted by a radionuclide and 30 of out of 40 participants use S-Cs (figure 5). In addition to the S-Cs calibration, an extra calibration in one x-ray beam quality, either in narrow beam quality (ISO-N) or wide beam quality (ISO-W) as described in the ISO 4037-1 standard (ISO 1995) was reported by nine participants. It is important to mention that 11% (6/40) of the users reported that their APDs are not calibrated and 7% (4/40) of responses, classified as 'other', were not able to provide exact information about beam quality used for calibration.

Interestingly, from 26 participants who reported the use of APDs in interventional radiology and cardiology, only six stated that their dosimeters are calibrated in one of the x-ray beam qualities. Most of them (16/26) calibrate their APDs in S-Cs beam quality, whereas four were not able to report the beam quality used for the calibration of APDs. It is

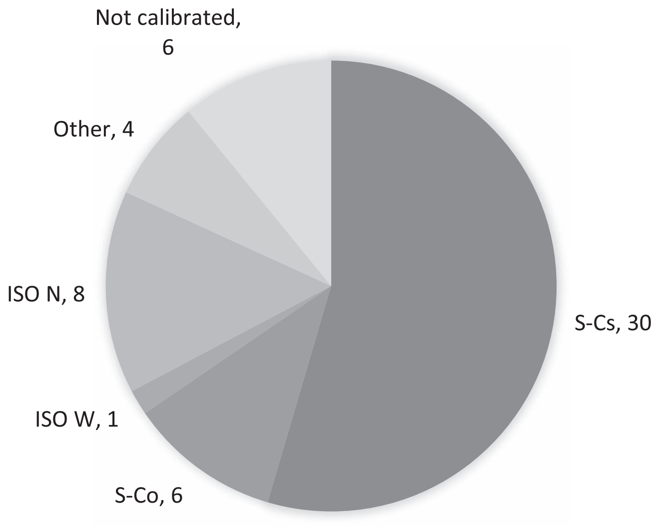

Figure 5. Distribution of responses over radiation beam qualities used for calibration of APDs.

important to note that 11 out of 16 participants whose APDs are calibrated in S-Cs beam quality are from large hospitals that use more than 20 and up to 170 dosimeters. Those who reported the absence of any calibration are mainly from smaller hospitals that use less than ten APDs.

General considerations related to the use of APDs

Participants were also asked to provide a set of information about the use of APDs, namely, in which departments and during which activities APDs are used, the position on the human body, the typical dose rates, and the use of an audio alarm.

Forty-six out of 50 participants provided information about the purpose of the use of dosimeters in the form of free text. Some responses included the use of APDs for dose/dose rate measurements, surveys, for radiation protection, occupational dose assessment, and monitoring and radiation protection of workers.

Other, more specific answers are classified in the following categories:

- To detect high dose/dose rate;
- For high dose operations in nuclear medicine and radioisotope production;
- Research in radiation protection;
- Education and training;
- For visitors and outside workers;
- Occasional exposures outside radiology departments;
- Additional eye dose monitoring;
- Pregnant staff;
- As a backup dosimeter;
- Optimisation of radiation protection in daily practice.

Most of the participants reported that APDs are usually worn at the chest level, above the protective apron, as presented in figure 6.

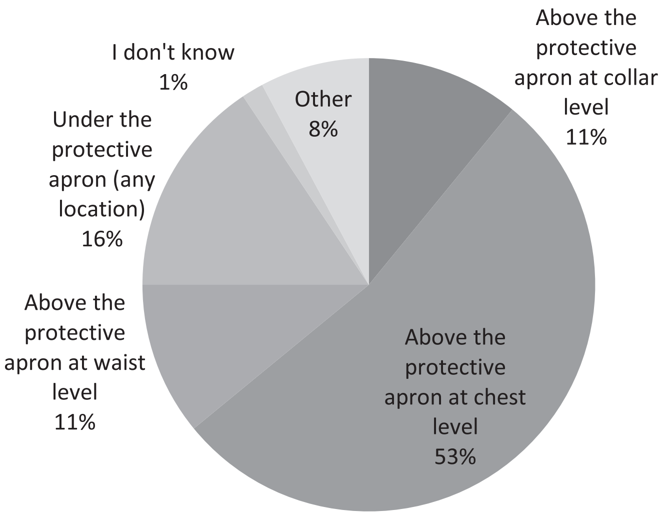

Figure 6. Positions on the human body on which the APDs are worn.

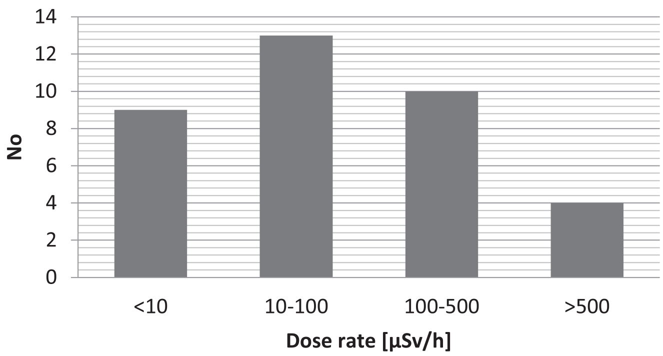

Figure 7. Typical dose rates measured by APDs.

The response stating that APDs are worn under the protective apron mostly came of one country (Germany), which is likely related to the national regulations. It is important to note that a few participants reported the use of APDs on any place on the body, either above, or under the protective apron.

The participants were asked to provide an estimation of typical dose rates measured by their APDs. This question was designed as a free text. The participants reported a large range of dose rates, from 1 μSv h^{-1} up to a few mSv/h. For the purpose of analysis, these were classified in the four dose rate intervals, as presented in figure 7. The data is related to the position of the APD over the protective apron.

According to information gathered from the survey, an audio alarm in different forms is readily used. The distribution of different types of audio alarms is presented in table 4. The responses classified as 'other' are related to cases when the audio alarm is disabled or when other means of indications such as vibration or visual colour coding are used.

Table 4. Use of audio alarm in APDs.

Alarm	No	%
In dose rate regime	14	29
In integral dose regime	6	12
In dose rate and integral dose regime	12	24
There is no alarm	7	14
Yes	6	12
Other	4	8
Total	49	100

Use of an alarm in dose rate or dose regime was reported by APD users in interventional cardiology and radiology and nuclear medicine departments. The alarm is less frequently on when the APDs are used for research purposes.

Other considerations

Three questions were related to the participants' opinion about the use of APDs in terms of usefulness, convenience, and problems encountered during their use.

Fifty participants responded to the question about the convenience of the use of APDs, of which 44 (88%) found it convenient, whereas four (8%) found it inconvenient. In two cases (4%) additional comments were provided both stating that in spite of their convenience, there are some practical problems related to the use of APDs. Some of the most frequently listed practical problems are: short battery lifetime, size and weight of the APD, difficulties in the selection of alarm levels, difficulties in the selection of working regimes, electromagnetic interference, etc. Interestingly, problems with electromagnetic interference were reported for different types of APDs from different manufacturers.

From a total of 50 responses related to the usefulness of APDs, all responses were positive, claiming that APDs are useful from a radiation protection point of view.

In the final question, participants were asked to provide comments related to the overall performance and use of APDs. A total of 13 comments were received, which can be classified in a few groups; those related to the use of APDs, dosimetry properties of APDs, the role of APDs in radiation protection, and those related to the link of APDs with an official dosimetry. The comments are summarised in the table 5.

Discussion

This survey revealed that nowadays in hospital workplaces APDs are frequently used in interventional radiology, interventional cardiology, and nuclear medicine. Most of the APDs use a silicon diode as the detector with an energy range that corresponds to the x-ray energy range used in diagnostic and interventional procedures, where the energy of the scattered spectra ranges from 20–100 keV (Clairand *et al* 2011). The energy range of APDs that use a silicon diode detector typically ranges from 15 or 20 keV up to a few MeV or more, with a declared accuracy of $\pm$ 30% or better within this energy range. Some of the APDs that use a silicon diode detector have an energy range starting from 60 keV (DMC 2000 s or RAD 60 s) which makes them inadequate for use in interventional cardiology and radiology. However, their use in interventional cardiology and radiology was reported in a few cases. Moreover, in

Table 5. Comments related to the overall performance and use of APDs.

Use of APDs	• Some APD are not user friendly and stable when used in hospitals • Setting up (alarm threshold, resetting the dose, record keeping etc) is complicated or requires special software • APDs are useful for research measurements, but medical staff often do not understand the meaning of the indicator on the APD • Use of APD under the lead apron is not very useful
Role of APD in radiation protection training	• APDs are useful for teaching/training purposes • Location of APD above the protective apron would be more useful, however, this is not a recommendation in some countries
Dosimetry properties	• Sensitivity is better than in passive dosimeter systems • Reliability in pulsed radiation fields • Need for APDs in neutron fields
Link of APD to legal dosimetry	• Suggestion to associate the electronic dosimeter with the passive dosimeter systems • Can the APD be used for legal dosimetry, taking into the account the reliability of measurements and record keeping

some hospitals APDs that use a Geiger–Muller tube (PM1610) as the detector and an energy dependence of −60% in the low x-ray energy range are used in interventional cardiology departments. Therefore, it can be seen that in some cases the energy response of APDs does not correspond to the range of x-ray energies that are used in hospitals. Regarding the use of APDs at nuclear medicine workplaces, the energy range required is different, higher energies can be encountered (for example 140 keV of ^{99m}Tc, 156 keV of ^{123}I or 364 keV of ^{131}I), and even response to beta radiation can be important (Sudbrock *et al* 2011).

It is important to be aware of the possible differences between the characteristics of the APDs and the clinical exposure conditions. Evidently, only certain types of APDs have simultaneously adequate performance in low energy, beta and pulsed x-ray beam quality. A series of tests have been performed on commercial APDs both in laboratory and in clinical conditions in order to evaluate their performance for use in IR/IC (Clairand *et al* 2011, Struelens *et al* 2011). It was noted that some of the APDs initially designed for applications other than medical use of x-rays are used in IC/IR workplaces. For example, APDs model RADOS 60/62 with an energy range of 60 keV to 3 MeV, DMC 2000 with an energy range of 50 keV to 6 MeV, and even PM1610 with a range of 20 keV to 10 MeV and relative response of −60% at x-ray energies used in diagnostic radiology, would certainly underestimate the occupational exposure. Therefore, it is important that the properties of the APDs intended to be used in particular fields of medical application of ionising radiation meet the requirements in terms of energy range. Moreover, it is significant that APDs meet the requirements outlined in the IEC 61526:2010 standard (IEC 2010), in particular, in terms of energy response, angular response, and dose rate range.

The findings of this survey underlined that APDs are not calibrated in approximately half of the cases which is on the contrary with the basic safety standards European directive and the requirements of the IAEA (European Commission 2014, IAEA 2011) according to which calibration of all measurement instruments, including APDs, is required. The most frequent beam quality used for the calibrations of APDs is the S-Cs, which is significantly different from the conditions in which APDs are used. This means that even if the APDs are calibrated, the radiation beam quality used for calibration does not correspond to the situation in the working environment. This is the case in the majority of hospitals that participated in the survey, including the large ones. Many APDs have a good and extended energy response, from low energy x-rays (20–150 keV) to gamma ray energies of radionuclides S-Cs (661.6 keV) and S-Co (1173.3 keV and 1332.5 keV) (ISO 1995). In this case, the radiation quality used for calibration is less important. But some devices do have a significant energy dependence (like the RaySafe system) so they should be calibrated in the correct energy range in which they will be used.

APDs need to measure dose rates typical for clinical conditions, e.g. from a few μSv/h, up to Sv/h. The dose rate range becomes even more important in pulsed radiation fields, as the dose rate in the radiation pulse may be significantly higher than the maximum measurable dose rate of the dosimeter and the indicated value for the acquired dose may be underestimated to a considerable extent (Zutz *et al* 2012). Measurements with several personal and area dosimeters in two pulsed photon fields showed that none of the tested APDs indicated dose values within a reasonable accuracy in pulsed fields ($\pm$30% or better), while passive dosimeters measured the dose correctly (Ankerhold *et al* 2009).

The pulsed radiation fields are not taken into account in the IEC 61526:2010 standard (IEC 2010), however in the interventional radiology and cardiology x-ray fields characterised by low energy photons and pulsed fields they are commonly used. The characteristics of active electronic dosimeters determined in a continuous radiation field cannot be transferred to those in pulsed fields (Ankerhold *et al* 2009). Therefore, APDs need to have suitable characteristics in pulsed x-ray fields and users have to be aware of such requirement. In the absence of international standards, different laboratory, and clinical tests are recommended (IEC 2012). A good response for pulsed radiation can be important, especially when accidental exposure to the direct beam occurs.

Operational protection of exposed workers is based on the implementation of basic radiation protection principles, including optimisation of radiation protection in all working conditions (European Commission 2014, IAEA 2011). APDs present some advantages over passive detectors as they provide a real-time measurement capacity and the dose rate alarm can be set to alert when a certain value is exceeded. It is well understood that APDs are a useful tool to optimise protection (Ginjaume 2011) and thus reduce occupational exposure. From this point of view, it is recommended to locate the dosimeters above the lead apron. In addition, it is recommended to use the audio or visual alarm, both in dose and dose rate regime. The dose and dose rate level to which an alarm would be set depends on the type of practice and characteristics of both the dosimeter and radiation field (Ambrosi *et al* 2010).

Although, there are no technical reasons to prevent recognition of certain APD types to be used as official dosimeters (Ginjaume *et al* 2007), it is important to take into consideration all relevant aspects of personal dosimetry providers like accreditation, quality assurance, as well as the transfer of the relevant records to the official dose registry.

Limitations of the survey

Although responses were received from a large number of European countries, the major limitation is the uncertainty related to the correct interpretation of the questionnaire and if it reached the right person in each of the participating hospitals. Moreover, not all participants provided complete answers, while some of them misunderstood the questions and provided answers related to the use of passive dosimetry systems. Nonetheless, some useful data about the current situation related to use of the APDs across the Europe has been collated, analysed, and summarised.

Conclusions

The survey organised by the EURADOS Working Group 12 confirmed that there is extensive use of APDs in European hospitals. APDs are used in many workplaces, from radiology (mainly interventional procedures) to nuclear medicine and radiotherapy. It was concluded that in the majority of the cases calibration of APDs is not adequately addressed, as radiation beam qualities in which dosemeters are calibrated differ from those in which dosimeters are used. Guidance from regulatory authorities and professional organisations about testing and calibration of APDs used in hospital would likely improve the current situation.

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