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## Current problems in the field of radiation protection technique - Use of Active Personal Dosimeters (APD) in pulsed radiation fields

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### Abstract:

This paper provides a short review about limitations of active personal dosimeters observed during operation in pulsed radiation fields. This report is part of a project which is funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). The project is focused on radiation protection techniques, including issues of quality control in radiotherapy or diagnostic X-Ray techniques as well as of dosimetry. In this context, the use of active personal dosimeters in pulsed radiation fields is considered.

Pulsed ionizing radiation occurs in medical diagnostics and therapy, material testing as well as for person control purposes. The detection of pulses, in particular rather short pulses and high dose rates may cause problems in dosimetry with active personal dosimeters. These dosimeters are often used for instant and direct reading of the individual dose of occupational exposed persons.

## 1 INTRODUCTION

In the last decades, the number and variety of applications using ionizing radiation have increased significantly, especially in the context of medical diagnostics and therapy as well as for material testing purposes. Mainly all of them operate in a pulsed mode, with pulse durations between femtoseconds and a few seconds.

In 2007, about 314 000 persons [1] were classified as occupationally exposed in Germany. Since most of them (about 241 000) work in the medical field, this work area is of special concern. The occupational radiation exposure has to be monitored in Germany. Therefore, the body dose of occupationally exposed persons is determined with personal dosimeters. The legal assessment of this dose requires the use of passive dosimeters in Germany.

Since active personal dosimeters (APD) have a lot of advantages over passive ones, they are used by occupationally exposed persons in addition to passive ones. One of the most important advantages is that they display the dose rate in real time during exposure. Furthermore, dose rate alarm thresholds can be set to avoid unexpected high doses. APDs are a useful and common tool for optimization in radiation protection.

## 2 LEGAL REQUIREMENTS FOR DETERMINING THE PERSONAL DOSE

According to the Radiation Protection Ordinance (StrlSchV) and the X-Ray Ordinance (RöV), several scenarios require determining the individual dose without undue delay. This cannot always be afforded by passive dosimeters, which are mandatory for the legal assessment. In these cases, an additional active personal dosimeter has to be used. Based on legal requirements, the following scenarios for using APDs may occur.

- At the request of the person to be supervised, a dosimeter shall be placed at his disposal by means of which the individual dose may be determined at any time (§ 41 para. 5 StrlSchV, § 35 para. 6 RöV).
- Immediately when a woman has informed her employer that she is pregnant, her occupational radiation exposure per working week shall be determined and communicated to her (§ 41 para. 5 StrlSchV, § 35 para. 6 RöV)
- Supporting persons (i.e. persons who e.g. help fixing an animal during X-ray diagnostics) shall be informed of the possible risks of exposure to radiation before entering the restricted access area. Measures shall be taken to restrict the radiation exposure of such persons (§ 81 para. 5 StrlSchV, § 25 para. 5 RöV).
- The competent authority may rule that the individual dose needs to be measured by some other suitable method or by two independent methods (§ 41 para. 3 StrlSchV, § 35 para. 8 (3) RöV).
- The body dose of persons, staying in the controlled area for other reasons than medical or dental-medical diagnostics or treatment, shall be determined immediately (§ 35 para. 1 RöV).
- For persons under the age of 18, the limit of the effective dose shall be 1 mSv during any one calendar year (§ 55 para. 3 StrlSchV, § 31a para. 3 RöV).

These scenarios may require the use of APDs for the immediate determination of the individual dose. As shown in the following chapters, the detection of doses caused by pulsed radiation is not reliably detectable. This may cause problems in dosimetry with active personal dosimeters.

## 3 CHARACTERISTICS OF PULSED RADIATION AND ITS APPLICATION

Mainly all ionizing radiation used in the field of medical diagnostics, therapy and material testing occur as pulsed radiation. Pulsed radiation usually consists of a sequence of short pulses, but also single pulses are used e.g. in conventional X-ray diagnostics or for material characterization with non-destructive methods using X-rays.

Pulsed radiation is either generated by an electronic control circuit or chopped from continuous radiation using mechanical methods. The length of a pulse varies between femtoseconds up to a few seconds. Though the dose applied in a single pulse is usually very low, the dose rate ranges up to a few 100 Sv/h in medical diagnostics and up to  $10^7$  Sv/h for material testing.

Some examples for applications using pulsed radiation together with their characteristics are listed in Table 1.

**Table 1:** Examples of applications and the characteristics of their pulsed radiation [2].

Application	Generation principle	Pulse length [s]	Dose rate in 1m distance [Sv/h]	Dose per pulse [ $\mu$ Sv]
Scanner for persons and goods	Chopped from an X-ray tube	$10^{-3}$	1	0,1
Material testing	X-ray flash tube	$10^{-10}$	$10^5 - 10^7$	1 - 100
Human and veterinary medicine	Rotating anode	$10^{-3} - 10^1$	100	100
Human medicine (therapy)	Electron accelerator	$10^{-6}$	$10^5$	$10^3$
Research	Laser plasma	$< 10^{-12}$	$10^6$	$10^{-4}$

#### 4 TYPES OF DOSIMETERS

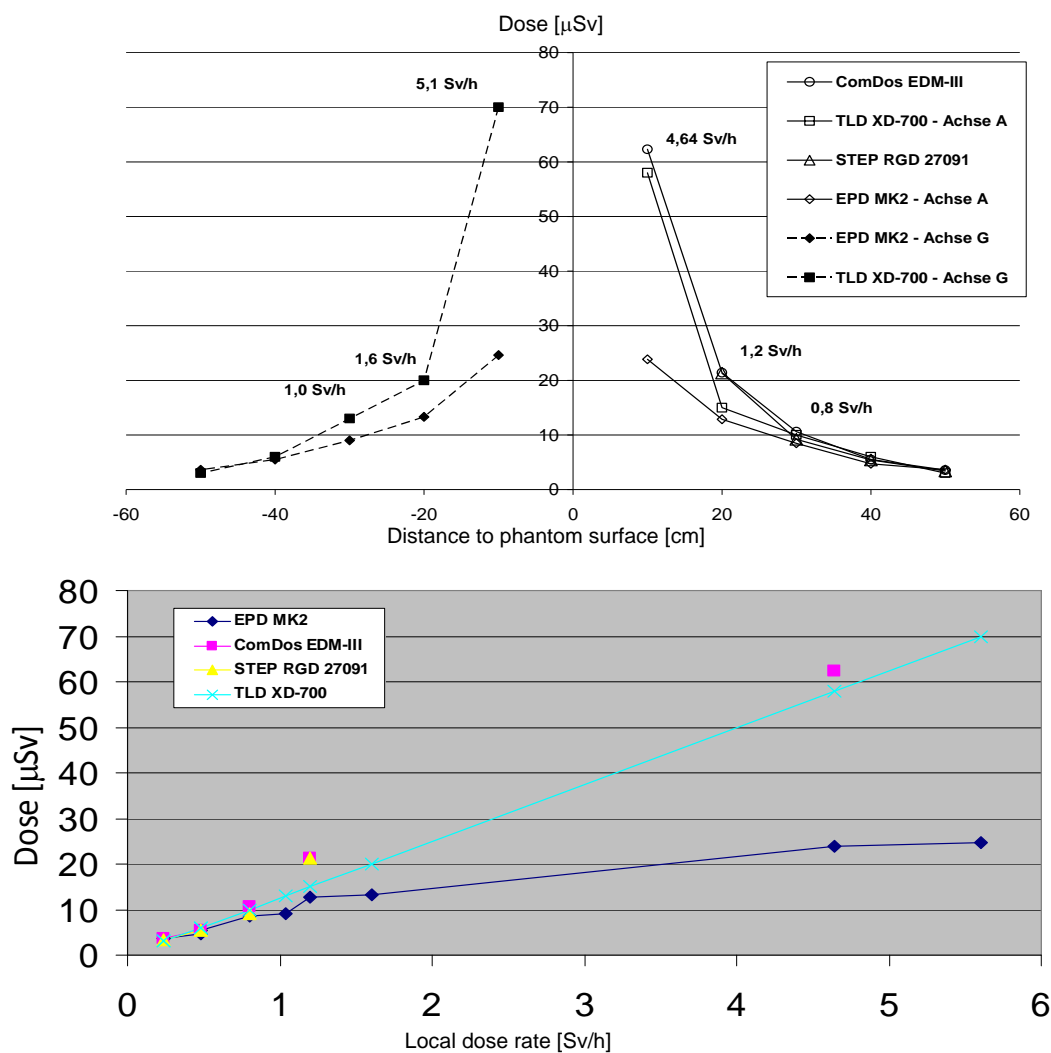
The dosimeters currently in use are divided into two general types, active and passive dosimeters. All passive dosimeters integrate the dose over the measurement time. Well-known examples are film badges, glass dosimeters and thermoluminescence dosimeters. As long as the maximum allowed dose is not exceeded, they are suitable to measure the dose in pulsed radiation fields. The main disadvantage of passive dosimeters is that dose rates are not measured. Therefore an alarm function is not available. Furthermore, usually a special readout is mandatory, which does not allow reading the personal dose obtained in real time.

The second type, an active dosimeter, combines a detector with an electronic readout and is usually able to display the current dose rate. The detector either consists of a Geiger-Müller (GM) counter or a PIN-diode. Because of size limitations for active personal dosimeters, PIN-diodes are preferred. But as a disadvantage, the use of PIN-diodes is restricted to a small dose rate region.

#### 5 LIMITATIONS OF ACTIVE ELECTRONIC DOSIMETERS ACCORDING TO PULSED RADIATION FIELDS

Active personal dosimeters show detection deficiencies for dose rates above about 1 Sv/h (cf. Figure 1), usually due to saturation effects. Such high dose rates occur in the beam spot of pulsed radiation fields in combination with short pulse durations, because the dose rate during a pulse increases with shorter single pulse duration assuming a constant average dose rate. At best, for higher dose rates, the APDs only become imprecise. But above a certain technical dose rate limit, which depends on technical properties, they fail to determine the dose rate and the alarm function may not be available.

The dose rate in the field of scattered radiation and in particular under a radiation protection apron is of course lower than in the direct beam. In that case, exceeding the maximum allowed dose is not expected. In a former research project about X-ray examinations in veterinary medicine [3] dose measurements show that the dose rates above the radiation protection apron could be higher than 1 Sv/h also in the field of scattered radiation near the patient during X-ray diagnostics as presented in Figure 1. Furthermore, it has to be stressed that dosimeters should be able to measure these high dose rates e.g. in case of an accident.



**Figure 1:** Measured doses (high voltage: 66 kV, exposure time: 45 ms) for different dosimeters as a function of the distance to the phantom surface (upper plot) and as a function of the local dose rate (lower plot). [3].

In national standards, characteristics of APDs are defined only with respect to fields of continuous radiation. Requirements for pulsed radiation are currently not covered by type tests [4], which have to be granted prior to a usage in Germany by the PTB, the national metrology institute providing scientific and technical services. In order to extend the requirements for type tests for pulsed radiation fields, the PTB is constructing a new test facility (completion expected end of 2009) [5].

For a detailed analysis, a dedicated seminar was organized in November 2007 by the PTB [2]. The difficulties associated with APDs were discussed between vendors, users and legal authorities. As a consequence, due to the observed detection deficiencies, the usage of APDs in controlled areas with pulsed radiation fields with the aim to fulfill the legal requirements as stated above is prohibited since November 2008 [6]. This applies in particular to pregnant women and persons under 18 years of age. For that reason, competent measuring bodies already offer as a solution a weekly determination of the occupational radiation exposure for pregnant women using film badges [7].

## 6 RECENT INVESTIGATIONS ON APDS IN PULSED RADIATION FIELDS

A lot of analyses have been performed in the last years, from which a few examples are given in the following.

In a joined IAEA and EURADOS (European Radiation Dosimetry Group) project [8], the response of 13 different active dosimeters in two different pulsed radiation fields has been compared. Both fields are defined in IEC 61267 (Medical Diagnostic X-ray Equipment - Radiation Conditions for Use in the Determination of Characteristics) [9], RQR4 (high voltage: 60 kV, pulse width: 1.6 s, dose rate: 1.68 Sv/h) and RQR9 (high voltage: 120 kV, pulse width: 1.6 s, dose rate: 1.49 Sv/h). Only three devices have given satisfactory results for both fields.

As a second example, the use of APDs in interventional radiology was evaluated by the Working Group 9 (radiation protection dosimetry of medical staff) of the CONRAD (Coordinated Network for Radiation Protection Dosimetry) project, which is a coordination action supported by the European Commission within its sixth Framework Program [10]. For the configuration of the pulsed field, a realistic scenario used in interventional radiology was chosen. A medical X-ray unit was used to generate single pulses (high voltage: 70 kV, pulse width: 100 ms, dose rate: 4.03 Sv/h). Out of five different APDs, four are sensitive to the pulsed radiation used in this study, from which only three fulfill the requirement of IEC standard [11] in terms of energy response. The study shows that the capability of measuring pulsed radiation depends on the detection principle of each dosimeter.

The PTB performed a study [12], where five different types of dosimeters (one film badge, one active personal dosimeter and three different active area dosimeter) were irradiated by two different pulsed fields. A commercial diagnostic X-ray facility for human medicine (one pulse of 40 ms, 14 Sv/h) was used to generate the first field. The second field was generated by a special X-ray flash unit (pulse width: 50 ns, dose rate:  $1.3 \cdot 10^5$  Sv/h) with a repetition frequency of 29 Hz (99 pulses) until the same  $H_p(10)$  value of 0.16 mSv as for the first field was reached. The four active dosimeters were all of different types (GM counter, ionization chamber, PIN-diode and a scintillator). The irradiated dose as well as the photon energy are within their technical specifications. Whereas the film badge measured both doses correctly, all electronic dosimeters show an insufficient response in at least one field. Some devices are nearly insensitive to both fields, others provide in at least one field a reliable response within reasonable limits.

In the context of the seventh Framework Program of the European Commission, the collaborative project ORAMED (Optimization of radiation protection for medical staff) has been funded since 2008. In this project, the response of APDs in pulsed radiation fields will be determined within medical facilities [13].

## 7 CONCLUSIONS AND OUTLOOK

Though a lot of measurements concerning the usability of active personal dosimeters in pulsed radiation fields are already performed, further investigations are necessary. Measurements have been performed e.g. by a joint IAEA and EURADOS project, within the framework of the CONRAD project or by the PTB in Germany. In order to perform further measurements within medical facilities, the ORAMED project started in 2008.

Detailed knowledge of the technical details of the dosimeters is necessary to understand the limitations of APDs in pulsed radiation fields. In addition, the work-place fields have to be characterized in more detail, since active personal dosimeters could be blind to pulsed radiation fields. International and national standards for pulsed radiation are needed, in particular

requirements for type testing. Only with more information available, it could be decided to possibly use APDs to determine the body dose in extreme situations in pulsed fields.

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