RADIATION PROTECTION DOSIMETRY IN PULSED RADIATION FIELDS

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Abstract

The application of pulsed radiation fields for research, security screening and medical examinations has increased remarkably in the last years. Testing of active personal and area dosemeters for the operation in pulsed radiation fields is a necessity to judge the suitability of the dosemeter. Up to now, radiation protection dosemeters have only been tested in continuous fields, although they are used for measurements in pulsed radiation fields as well. Many of the conventional electronic dosemeters do not determine reliable dose values in these pulsed fields any more. The reasons for this are based on the measurement principle (mostly the counting technique) in combination with the characteristics of the pulsed radiation field (e.g. high dose rate during the short radiation pulse).

The definition of reference fields is a basic requirement for the development, testing and calibration of radiation protection dosemeters as well as for the further development of radiation sources for the range of pulsed radiation. Therefore, a new international ISO 18090 TS standard for pulsed reference fields [1], dealing with the requirements for such fields, is in preparation.

Thus, in cooperation with the Siemens Company, a novel equipment has been developed which will make it possible for the first time to adjust all parameters of pulsed X-ray reference fields and to determine the performance limits of dosemeters with respect to pulsed radiation. Worldwide, it is the first equipment of its kind.

For active direct reading dosemeters, which use pulse counting techniques to determine the measured dose value, a concept of requirements and testing procedures have been developed and tested. This concept is included in the new international IEC 62743 TS standard for the type testing of dosemeters [2].

1. Introduction

During measurements in pulsed fields at X-ray scanners [3] and in medical X-ray fields [4] the PTB became aware of the fact that electronic dosemeters could have difficulties to measure in pulsed fields. First measurements under laboratory conditions using an X-ray flash unit and a conventional medical diagnostic X-ray unit have confirmed this. [5]. The German government decided in 2008 to prohibit the use of active electronic personal dosemeters in pulsed fields for legal dosimetry. This has led to problems in the radiation protection surveillance of e.g. pregnant women in the field of medical X-ray diagnostics. If the dosemeter is worn underneath the protective clothing, see figure 1, and the person is only exposed to scattered radiation, the dosemeter measures correctly. But in the case of an accident, the dose rate below the protective clothing can reach values above 1 Sv/h and the dosemeter could measure considerably wrong, or even fail completely.

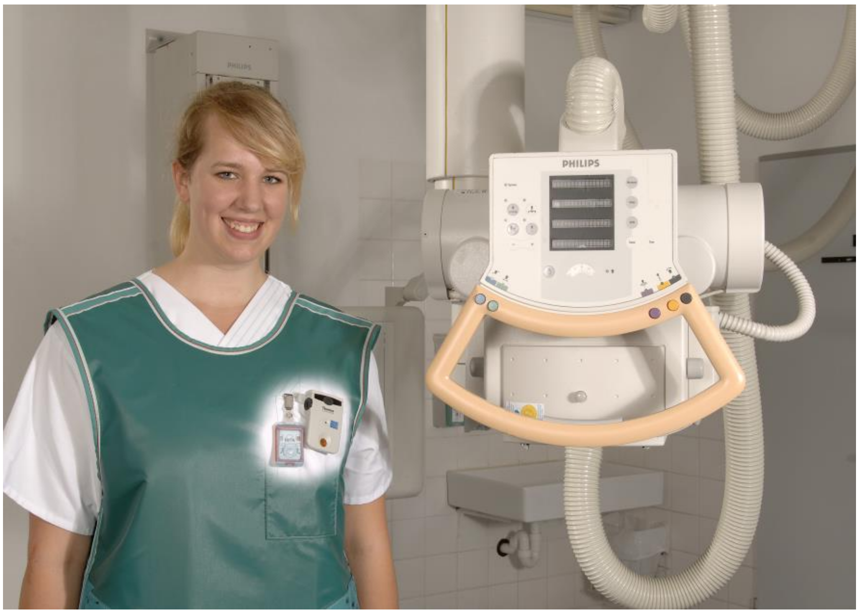

Figure 1: Active electronic dosemeter in a typical pulsed radiation field used at medical diagnostic X-ray units. The protective clothing has been made invisible at the position of the dosemeters to show the correct position of the dosemeters (film dosemeter as the legal dosemeter and an additional electronic direct reading dosemeter).

At the same time, similar findings were made during the research project ORAMED with the aim to investigate the optimization of radiation protection in medicine [6], supported by the European Commission within its 7th framework program.

Up to this date, type test requirements in pulsed fields have been excluded from all standards. Therefore a large effort was made to solve this urgent open problem and to set-up preliminary type test requirements for electronic counting dosemeters in pulsed fields on the one hand and to define pulsed reference fields on the other.

2. Novel reference field for pulsed radiation

The novel X-ray unit, shown in figure 2, developed by PTB in collaboration with Siemens Health Care is based on modified standard angiography equipment. As the possible range of parameters used is quite large, e.g. pulse duration from a few nanoseconds up to seconds and pulse dose rates from a few microsieverts per hour up to several kilosieverts per hour [5], it was not possible to build one single machine to cover the whole range. Since the main application area for pulsed radiation is in the medical sector, the focus has been set on the characteristics of these radiation fields.

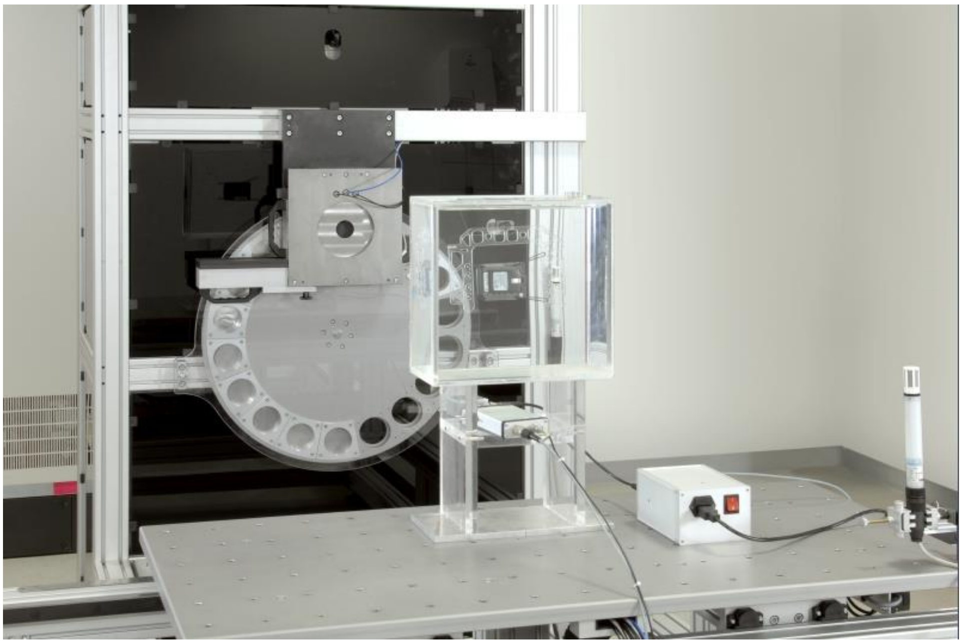

Figure 2: Novel X-ray unit for pulsed reference fields at PTB. The generator is shown on the left. The X-ray tube is contained within the black housing, while the installed monitor ionization chamber and the filter wheel with installed filters for N-series [7] and RQR-series [8] are in front. On the movable experimental table, used for adjusting the distance and the alignment of the device undergoing testing, a typical set-up with an electronic dosemeter is shown.

In order to realize defined pulse durations with short pulse rise and fall times, the X-ray tube is grid controlled. In the case of generator control, which is common for standard medical X-ray units, the voltage generator is switched on and off for an X-ray pulse. This leads to pulse fall times in the range of 300 µs up to 3 ms depending on the pulse parameters and as a consequence to a dependence of the mean energy of the radiation pulse on its duration. Therefore, the basic assumption in a type test, that each parameter should be adjustable separately, is not fulfilled. By the use of a grid control, pulse rise and fall times of approx. 50 µs could be realized [9]. In table 1 the relevant parameter ranges of the pulse X-ray unit are listed.

Table 1. Parameters of the novel X-ray unit. The abbreviations used are adapted to the ISO proposal [IS02012].

Parameter	Minimum	Maximum	Uncertainty
Tube voltage U_{pulse}	40 kV	125 kV	max. 1.7 %
Tube current I_{tube}	0.5 mA	800 mA	max. 1.7 %
Radiation pulse duration t_{pulse}	0.2 ms	10 s / cw	max. 3.5 % for 0.2 ms
Electric power in cw mode		cw: 3 kW	
Electric power for 300 ms		80 kW	
Pulse repetition frequency f_{pulse}	0.1 Hz	100 Hz	
Radiation pulse rise time $t_{pulse, rise}$ and radiation pulse fall time $t_{pulse, fall}$	about 50 µs		
Focus to dosemeter distance	32 cm	250 cm	0.1 cm
Field diameter	5.5 cm	52.5 cm	
Dose per radiation pulse H_{pulse} ($H_p(10)$)	100 nSv	300 mSv	
Radiation pulse dose rate $\dot{H}_{pulse}$ ($H_p(10)$)	4 mSv/h	3700 Sv/h	

3. Measurement technique

The radiation dose is determined by the time-resolved measurement [3] with an ionization chamber (monitor). Thanks to this time-resolution, it is possible to separate the amount of leakage charge from the charge being produced within the short time of irradiation.

An additionally installed Si-PIN monitor diode (Hamamatsu S3590-19) is positioned within the direct beam but without influencing the measurement with a dosemeter. It measures the pulse shape by measuring the time dependent voltage across the PIN diode, U_{diode}. From this signal the radiation pulse duration, t_{pulse}, is determined. The time dependent behaviour of the measured signals of the tube voltage, U_{pulse}, the tube current, I_{tube}, and, U_{diode}, can be visualized via an oscilloscope [9].

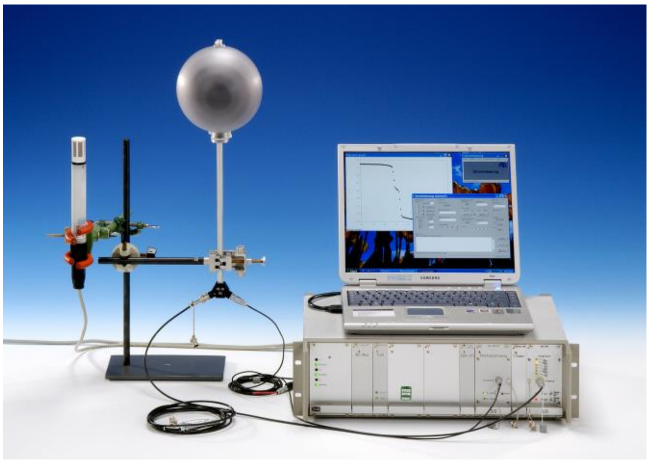

Figure 3: Time resolved measurement equipment with different ionization chambers. Here a 1 liter ionization chamber is connected to the equipment.

Depending on the dose in the radiation pulse, different ionization chambers can be chosen, see figure 3. For pulse durations shorter than the charge collecting time of the ionization chamber, the saturation loss is related to the dose in the pulse and is independent of the dose rate. Therefore, for measurements of low doses, ionization chambers with large volumes, specially developed for radiation protection purposes, are used. For the measurements of higher doses in the radiation pulse, a Farmer-type chamber with a much smaller volume, designed for therapy dosimetry, is chosen.

Radiation fields that are produced continuously could also appear as pulsed fields for the dosemeter, e.g. as used for X-ray security scanners when the object is moved across a fan-shaped X-ray beam. The measuring conditions at X-ray scanners are very demanding. The pulse-like X-ray beam has a high dose rate of up to 4 sieverts per hour. In combination with very short irradiation times of a few milliseconds, however, the resulting dose values are only in the order of the values produced by the natural environmental radiation within a few hours [3].

4. Measurements

First measurements on electronic dosemeters have already been performed at the novel pulsed X-ray unit. The proposed type test requirements of the IEC 62743 standard have been tested on a counting dosemeter [10].

Measurements of single radiation pulses with the electronic personal dosemeter EPD Mk2 (Mk2.3, firmware version 11, 12 and 14, by Thermo Fisher Scientific) and a DMC 2000S (Mirion Technologies (Rados) GmbH) have been performed at a constant dose per radiation pulse but with different pulse durations, t_{pulse}, and therefore with different pulse dose rates. With these measurements, it was possible to give a recommendation for the use of this dosemeter for measurements in the scattered radiation in medical diagnostics, according to [11]. In figure 4 the response of the dosemeters, normalized to the response value at 0.4 Sv/h, is plotted vs. the pulse dose rate. The dose of each single pulse was $H_p(10)$ = 1 mSv. It can be seen, that both dosemeters measure well as long as the pulse dose rate is only a few sieverts per hour. At higher pulse dose rates, the response drops very sharply. The dose rate in the scattered radiation field is in the order of a few mSv/h, but in the direct beam, the dose rate can be up to 400 Sv/h where the response is very low.

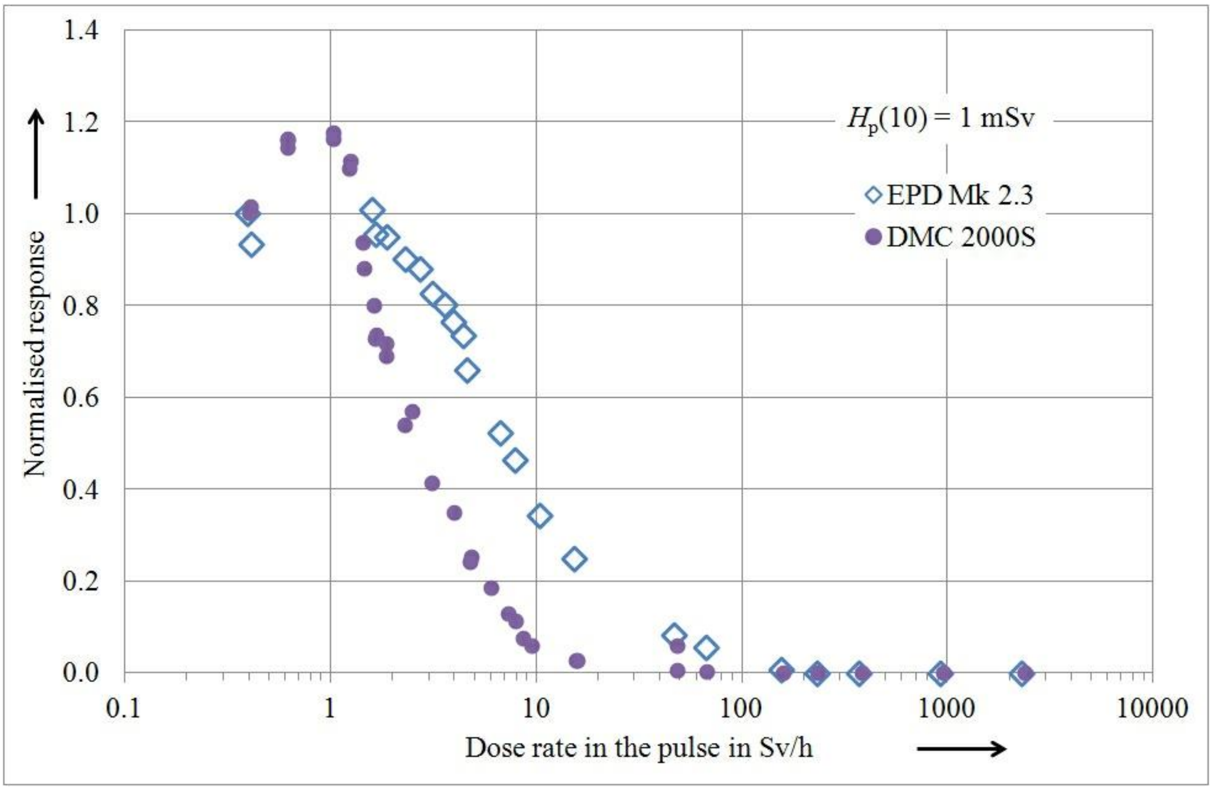

Figure 4: Response of an EPD Mk2 (Mk2.3) and a DMC 2000S for a constant dose per pulse of 1 mSv (RQR8) at decreasing pulse duration and therefore increasing pulse dose rate. The uncertainty of the response is in the order of about 7 %.

In figure 4, the measured response of the electronic personal dosemeter EPD Mk2 is shown vs. increasing pulse dose rate. Because of the fact that the pulse dose was kept constant at 1 mSv, the pulse dose rate increases with decreasing duration. Up to now, type tests are performed only in radiation fields with pulse durations longer than 10000 ms. By performing measurements at constant pulse dose, but different pulse duration (pulse doserate), the usability of a dosemeter for measurements in pulsed fields can be estimated. This kind of measurement does not need any information about the model function of the dosemeter, as demanded by the type test requirements proposed by the IEC 62743 TS.

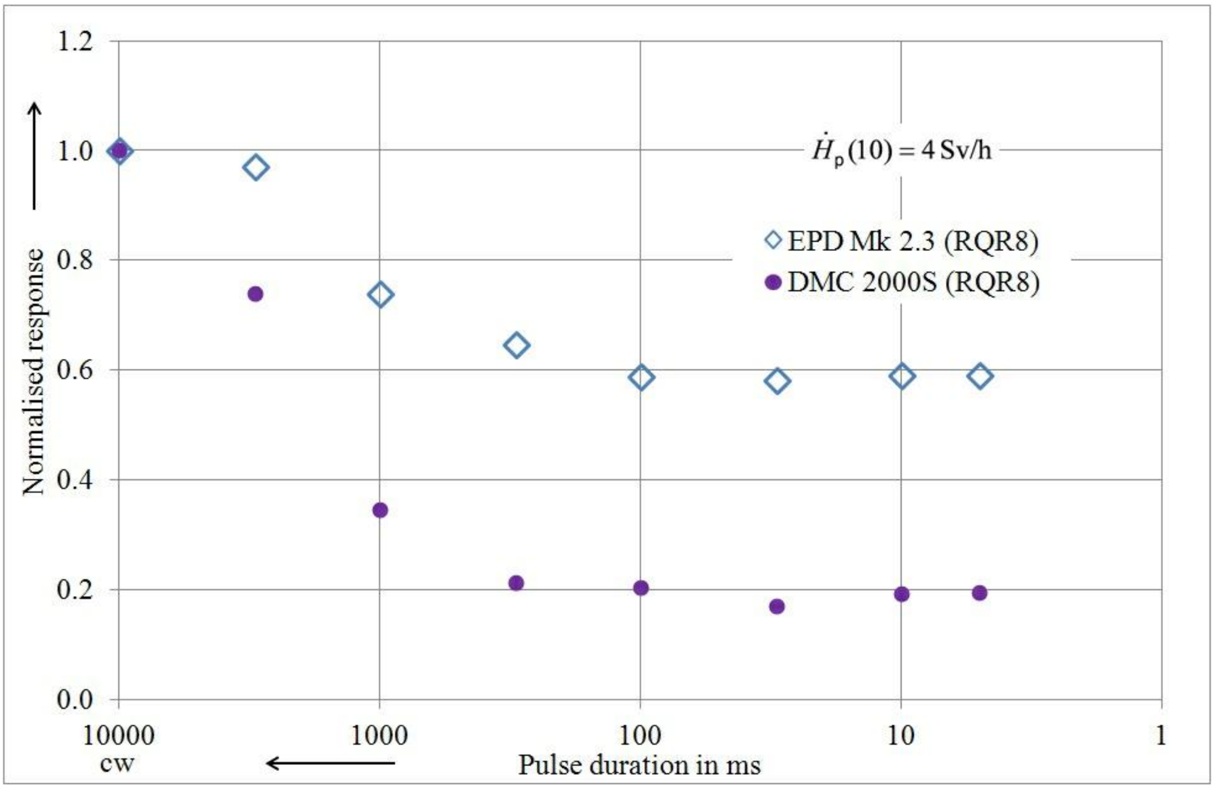

Figure 5: EPD Mk2 (Mk2.3) and DMC 2000S, measured at a constant pulse dose rate of about 4 Sv/h vs. decreasing pulse duration (pulse dose). The uncertainty of the response is in the order of about 7 %.

In figure 5, the behaviour of the dosemeter's response with decreasing pulse duration at constant pulse doserate, is shown. It seems that the correction factor for dead time loss gets ineffective for short pulses of about 100 ms. It can be seen that the correction factor for the two types of dosemeters differs significantly. Therefore, a correction factor for a given dose rate can be determined at a pulse duration of about t_{pulse} = 100 ms.

5. Summary

The novel X-ray equipment for pulsed photon radiation has been installed and characterized at the PTB. The relevant ISO 18090 TS standard to define reference pulsed radiation fields has been started.

The equipment for measurements in pulsed fields is established and approved in different types of radiation fields. But there is still an urgent need for commercially available active electronic area and personal dosemeters for measurements in pulsed radiation fields. Requirements for a type test are described in the new IEC62743 TS standard for testing counting dosemeters, which will be published soon.

Further investigations to define the parameters of real workplace fields are urgently needed. The designed type test requirements have to be checked for their suitability in existing workplace radiation fields.

6. Acknowledgments

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7. Reference

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