Nuclear Instruments and Methods in Physics Research A 372 (1996) 318–321

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

ELSEVIER

Investigation of the PDM-303 neutron pocket dosemeter in various neutron fields

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Received 23 October 1995;

Abstract

Following a calibration by Physikalisch-Technische Bundesanstalt (PTB) of the Aloka PDM-303 neutron pocket dosemeter in an energy range from thermal to neutrons of 19 MeV the response of the instrument has been further investigated in various neutron fields. Measurements were performed at the Paul Scherrer Institut (PSI) in nearly monoenergetic neutron beams of 35 and 55 MeV. Furthermore, the response has been evaluated experimentally in well characterized neutron fields at the Cadarache calibration facility and at the CERN high-energy calibration facility. The experimental results are compared with calculated values established by convoluting the known response function of the detector with the spectra of the neutron fields. The results indicate that the dosemeter is a promising active instrument for personnel dosimetry, particularly in high-energy fields, but that efforts should still be made to improve its dose equivalent response.

1. Introduction

The "MYDOSE-mini" PDM-303 model pocket electronic dosemeter [1], produced by the Japanese company Aloka Co. Ltd allows the measurement of the integrated neutron dose equivalent and indicates it on a digital display. It consists of a single sensor Si-photodiode, makes use of the nuclear reaction $^{6}Li + n \rightarrow \alpha + ^{3}T$ and is sensitive to neutrons only [2]. The PDM-303 is designed to measure neutrons from thermal energies up to about 15 MeV [1]. Fast neutrons are detected by means of the albedo method. The dosemeter has a convenient size (145 mm × 30 mm × 12 mm) and weighs only about 70 g.

During the past years the PDM-303 dosemeter has been investigated by several laboratories [3–5] such that its dose equivalent response function is now accurately known in the neutron energy range from thermal to 19 MeV.

This paper presents the results of the investigation carried out on two prototypes of the PDM-303 (Nos. X0084 and X0097) that Aloka has offered to CERN for test purposes. This investigation covers the calibration of the PDM-303 with monoenergetic neutrons of 35 and 55 MeV, and measurements performed in three different, well characterized, neutron fields.

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SSDI 0168-9002(95)01305-9

2. Measurement conditions

2.1. The PSI calibration beams

The dosemeter was calibrated at the Paul Scherrer Institut (PSI), Villigen, with quasi monoenergetic neutron beams of 35 and 55 MeV, produced at the injecting cyclotron, in bombarding a 2 mm thick ^{9}Be target with protons of 40 and 65 MeV respectively. The diameter of the neutron beams was 40 mm. A detailed description of the production of the neutron beams and their monitoring is given by Schuhmacher and Alberts [6].

2.2. The Cadarache realistic neutron calibration field

The Cadarache realistic neutron calibration field simulates a situation that is typically encountered in operational radiation protection at nuclear reactors. The field is produced using a 14 MeV generator, a uranium converter and different filters [7]. Its neutron spectrum is presented in Fig. 1 [8].

2.3. The CERN high-energy calibration fields

The CERN high-energy reference fields are produced in the North experimental hall with a secondary hadron beam from the Super Proton Synchrotron (SPS) [9]. This beam

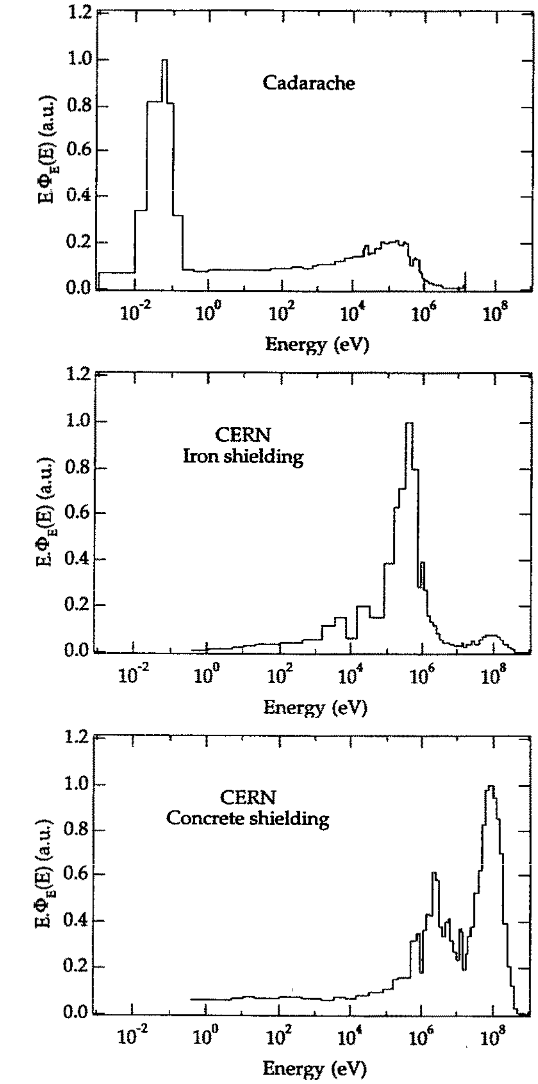

Fig. 1. Neutron fluence spectra of the fields used for the investigation of the PDM-303 electronic pocket dosemeter.

of 205 GeV/c hadrons (protons and pions) interacts with a 50 cm long, 7 cm diameter copper target. The secondary radiation emitted at large angles up to 90° from this target passes through shields of either 80 cm of concrete or 40 cm of iron. The radiation arrives in bursts of 2.5 s duration with a repetition time of 14.4 s. Two measurements were carried out, one on the concrete and the second on the iron shielding. The neutron spectra of these fields are shown in Fig. 1 [10].

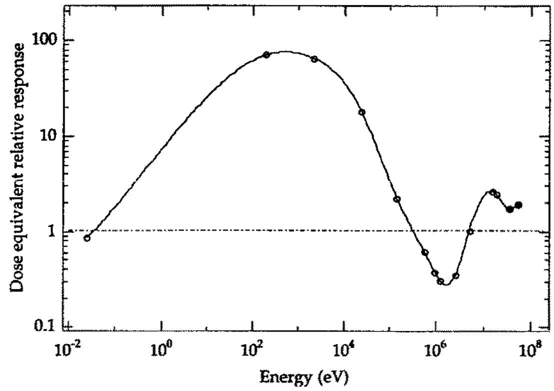

Fig. 2. Dose equivalent response of the PDM-303 electronic pocket dosemeter. The empty symbols are the PTB calibration points [5]. The full symbols correspond to the PSI calibration points [4].

2.4. Irradiation geometry

At the PSI the PDM-303 was exposed on a plexiglas phantom with dimensions: $10 \times 10 \times 5\ \mathrm{cm}^3$, at Cadarache on a plexiglas phantom with standard dimensions: $30 \times 30 \times 15\ \mathrm{cm}^3$, and at CERN on a polyethylene pseudo-sphere of 25 cm diameter.

3. Results and discussion

A detailed evaluation of the results of the calibration irradiations at PSI is given elsewhere [4]. Table 1 summarizes the results for the PDM-303. The reference value is based on the assumption of monoenergetic neutrons in the beams, their fluence determination, and on fluence to dose equivalent conversion factors according to the work of Schuhmacher and Alberts [6]. Both dosemeters apparently overrespond to high-energy neutrons while the agreement between the reading of the two detectors is excellent at 35 MeV, and within less than 15% at 55 MeV.

Fig. 2 shows the response curve for the PDM-303 established by PTB to which the results given in Table 1

Table 1
Dose equivalent response of the PDM-303 dosemeter to 35 and 55 MeV neutrons (dose equivalent in nSv/monitor unit)

	$E_n = 35$ MeV			$E_n = 55$ MeV		
	Reference	Measurement	Meas./Ref.	Reference	Measurement	Meas./Ref.
X0084	53.8	91.4	1.70	70	142	2.03
X0097	53.8	91.1	1.69	70	126	1.80
Mean	53.8	91.2	1.69	70	134	1.91

Table 2
Dose equivalent response of the PDM-303 at the Cadarache neutron field (dose equivalent in mSv)

Dosemeter	Reference	Measurement	Meas./Ref.
X0084	2.2	16.6	7.5
X0097	2.2	15.9	7.2
Mean	2.2	16.2	7.4
Convolution			13.8

have been added. The whole set of data was fitted by a spline function to establish the continuous curve shown in Fig. 1 and which is going to be referred to as the dose equivalent response function of the dosemeter.

The results of the measurements at Cadarache are summarized in Table 2. The agreement between the two detectors is good, within less than 5%. However, they overestimate the dose equivalent in the neutron field by more than a factor of 7. Such a behaviour is expected when looking at the response curve in Fig. 2. When convoluting the response function of the dosemeter given in Fig. 2 with the measured spectrum presented in Fig. 1 this overestimation should be even a factor of 14 (last column of Table 2). This factor of 2 between the calculated and measured relative response appears to be nearly insignificant compared with the overall overestimation of the PDM-303 in typical neutron fields around reactors.

The results of the measurements at the CERN high-energy reference field facility are summarized in Table 3. The agreement between the two detectors, except in one case, is rather good. Here again the last column of Table 3 gives the value of the dose equivalent response evaluated by convoluting the response function of the dosemeter given in Fig. 2 with the measured spectra (on concrete and iron shielding) presented in Fig. 1. The agreement between measured and calculated relative response of the dosemeter is reasonable for the concrete shielding. For the iron shielding however, the two results are significantly different and, considering the neutron spectrum involved, incomprehensible. In the case of the iron shielding the total dose rates were about an order of magnitude higher than on the concrete shielding with an even higher neutron fluence in the intermediate energy range. Therefore, and in view of the pulsed nature of the radiation which furthermore leads to an increase in the instantaneous dose rate, a saturation effect of the detector cannot be excluded. In fact the manufacturer indicates a measurement range between 0.01 and 99.99 mSv (for a calibration with 4.5 MeV Am–Be neutrons, on a phantom). From Fig. 2 one sees that the relative response of the dosemeter at this energy is close to unity. However, for intermediate energies the relative response is up to two orders of magnitude higher. In this energy range the dosemeter is therefore likely to show problems of linearity not at 100 mSv but already around 1 to 2 mSv which would also explain the underestimation by a factor of 2 in the Cadarache field. At CERN the integrated dose equivalent for all measurements was between 4 and 6 mSv, and at Cadarache it was even higher (around 16 mSv). Further measurements in the intermediate energy range are necessary to clear up the behaviour of the dosemeter at high doses and dose rates.

4. Conclusion

The investigation described in this report shows that the PDM-303 neutron pocket dosemeter can be used in high-energy radiation stray fields around an accelerator if a certain overestimation is accepted. The overestimation noticed in high-energy radiation fields confirms observations when the instrument was carried on aircraft during continental flights, where higher dose equivalents were obtained than could be reasonably expected [11]. A sensitivity to high-energy charged particles would explain the observed overestimation in high-energy stray fields.

While the response in high-energy fields is comprehensible and acceptable, the behaviour in neutron fields of lower energy is not well understood. In fact, considering the measured response function of the instrument a considerable overestimation is expected. This is not confirmed in the case of two practical neutron fields.

This active dosemeter must be considered useful for

Table 3
Dose equivalent response of the PDM-303 at the CERN neutron fields (dose equivalent in 10^{-10} Sv/monitor unit)

	Measurement 1			Measurement 2			Overall mean	Convolution
	Ref.	Meas.	Meas./ref.	Ref.	Meas.	Meas./ref.		
Concrete shielding								
X0084	2.7	10.2	3.8	2.6	15.1	5.8		
X0097	2.6	15.9	6.1	2.7	15.5	5.7		
Mean			4.9			5.8	5.4	3.6
Iron shielding								
X0084	14.4	23.8	1.7	14.4	15.4	1.1		
X0097	12.9	25.6	2.0	12.9	16.8	1.3		
Mean			1.8			1.2	1.5	5.7

individual dosimetry, due to its small size and weight, if further efforts are made to improve its dose equivalent response.

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