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

Deliverable 3.1: Report on systematic studies on APDs in laboratory conditions and in real conditions

Jean-Marc Bordy, CEA-LIST Laboratoire National Henri Becquerel (CEA LNHB), France
Eleftheria Carinou, Greek Atomic Energy Commission (GAEC), Greece
Isabelle Clairand, WP3 leader, Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France
Josiane Daures, CEA-LIST Laboratoire National Henri Becquerel (CEA LNHB), France
Jacques Debroas, Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France
Marc Denozière, CEA-LIST Laboratoire National Henri Becquerel (CEA LNHB), France
Laurent Donadille, Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France
Mercé Ginjaume, Institute of Energy Technology, Universitat Politècnica de Catalunya (UPC), Spain
Christian Itié, Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France
Christina Koukorava, Greek Atomic Energy Commission (GAEC), Greece
Sabah Krim, Belgian Nuclear Research Centre (SCK•CEN), Belgium
Pascal Martin, MGP Intruments (MGPi), France
Marta Sans Merce, Institut Universitaire de Radiophysique Appliquée (IRA), Switzerland
Lara Struelens, Belgian Nuclear Research Centre (SCK•CEN), Belgium
Mirjana Tosic, University Hospital Center Vaudois (CHUV), Switzerland
Filip Vanhavere, ORAMED coordinator, Belgian Nuclear Research Centre (SCK•CEN), Belgium

ORAMED contract – grant agreement n°211361

October 2009

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1 Context and objectives

The optimization of active personal dosemeters (APDs) in interventional radiology and cardiology is performed by work package 3 (WP3) of the ORAMED project, which is a Collaborative Project supported by the European Atomic Energy Community's 7th Framework Programme.

APDs are used for the monitoring of occupational doses in many applications of ionising radiation. In interventional radiology/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 and being exposed to radiation scattered by the patient. They could also give an alarm when exposure to the primary beam takes accidentally place. A lack of appropriate equipment is identified in the field of APDs for typical fields in interventional radiology. Few devices can detect low energy fields (10-100 keV), and none of them are really designed for working in pulsed radiation fields. This problem was clearly highlighted during two international intercomparisons: one performed in the framework of the CONRAD project, a coordination action supported by the European Commission within its 6th Framework Program [1,2] and a previous one organised by EURADOS and IAEA [3].

The general objectives of WP3 of ORAMED are:

1. To study the real radiation field characteristics encountered in interventional radiology in terms of energy, angular distribution, dose rate and pulse characteristics,
2. To make a selection of APDs deemed suitable for application in interventional radiology according to the previous results of the CONRAD and IAEA-EURADOS groups,
3. To define, by measurements under laboratory reference conditions, the dose, the dose rate, the energy and the angular response of commercial APDs,
4. To study the effect of the frequency and width of pulses on the APD response by testing dosemeters in real conditions on site in different hospitals and under laboratory reference conditions,
5. To prepare guidelines related to the use of APDs in interventional radiology/cardiology, to define corrections that would eventually be applied,
6. To propose technical solutions to improve the response of APDs in collaboration with the manufacturer MGPi,
7. To test the different technical solutions (with continuous feedback) developed by the manufacturer MGPi under laboratory conditions and on site in hospitals.

This deliverable deals with objectives 1, 2, 3 and 4.

The typical fields and parameters encountered in IR/IC were 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.
Then, an evaluation of the behaviour of 7 commercial APD models deemed suitable for application in IR/IC was performed through tests in laboratory conditions with continuous and pulsed X-ray beams. In addition, tests in different hospitals were done to evaluate the response of APDs in real conditions compared with passive dosemeters.

2 Determination of typical fields characteristics encountered in interventional radiology/cardiology and selection of APDs

2.1 Typical fields in interventional radiology/cardiology

2.1.1 Compilation of data from questionnaires, literature and quality controls output

A questionnaire was spread in several European countries to find out the main types of interventional operations performed and the technical conditions applied (type of devices used, kilo-Voltage, filtration of the tube, number of frames, etc.). This information was compared and completed by analyzing the output of several quality control studies performed on X-ray systems used in IR/IC departments. During these quality controls, the X-ray systems were tested at both typical and extreme situations in fluoroscopy and acquisition mode, in order to obtain the range of dose rate values possibly encountered.
Moreover, the Monte Carlo code MCNPX [4] was used to calculate the dose rate in the scattered beam at the level of the operator for tube positions of 0° and 90°.

The compilation of the data (Table 1) gathered from the questionnaires and from the quality control measurements gave an overview of typical radiation fields encountered in IR/IC whatever the considered procedure. The dose rate obtained by measurements in the direct field at the level of the table ranges from 2 to 360 $Gy.h^{-1}$. The dose rate in the scattered beam at the level of the operator for tube positions of 0° and 90° was found to range from 5.10^{-3} to around 10 $Gy.h^{-1}$.

Table 1. Typical radiation field characteristics in interventional radiology and cardiology

Parameter	Range
High voltage	60-120 kVp
Intensity	5-1000 mA
Inherent filtration	4.5 $mmAl_{eq}$ [3 – 6 mm Al_{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 rate in the direct beam (table)	2 to 360 $Gy.h^{-1}$
Dose rate in the scattered beam (operator)	5.10^{-3} to 10 $Gy.h^{-1}$

*pps = pulse per second

2.1.2 Calculation of scattered spectra

The scattered spectra at the operator position were calculated using the Monte Carlo codes MCNPX [4] and Penelope [5] for tube high voltages equal to 50, 70, 90, 120 kV and for different filtrations: 4.5 mmAl with different additional Cu filtration [0.1 - 0.3 - 0.6 - 0.9 mmCu]. The scattered spectra calculated with the Monte Carlo codes and the incident beam spectra calculated with the software XCOMP5 [6] are presented in figures 1 to 4 for different tube high voltages.
These figures highlight that the calculated scattered spectra do not have photons of energies lower than 20 keV.

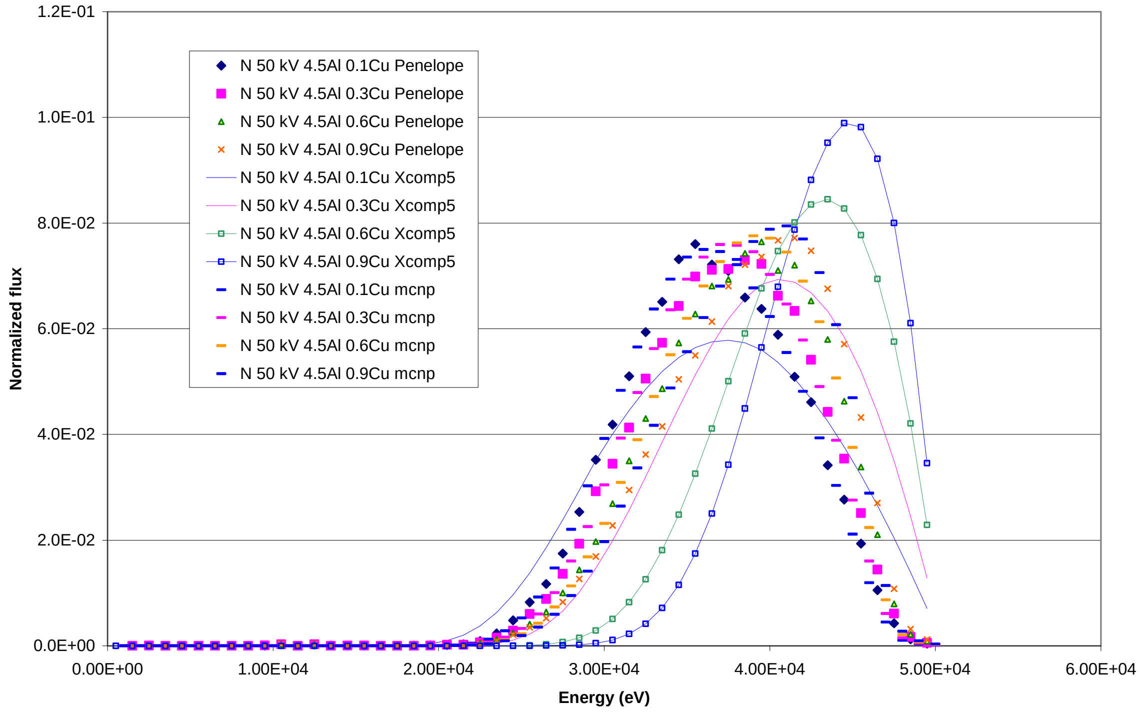

Figure 1. Scattered spectra calculated with MCNPX and Penelope and incident beam spectra calculated with XCOMP5 for a tube high voltage equal to 50 kV

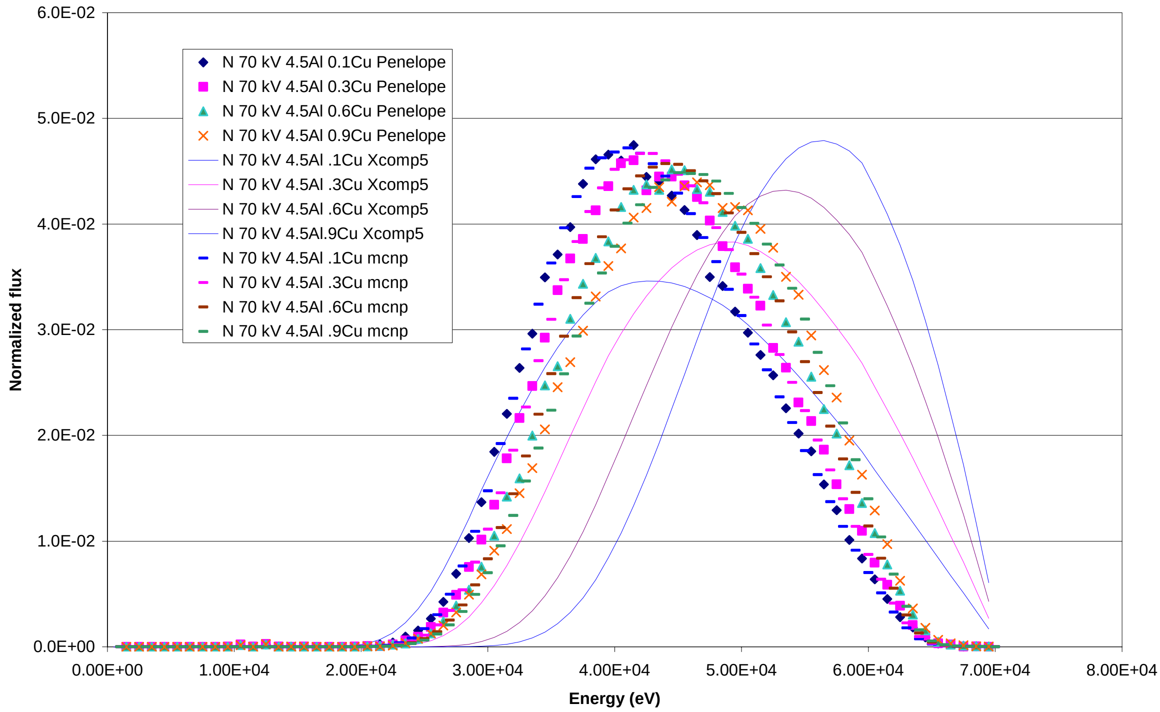

Figure 2. Scattered spectra calculated with MCNPX and Penelope and incident beam spectra calculated with XCOMP5 for a tube high voltage equal to 70 kV

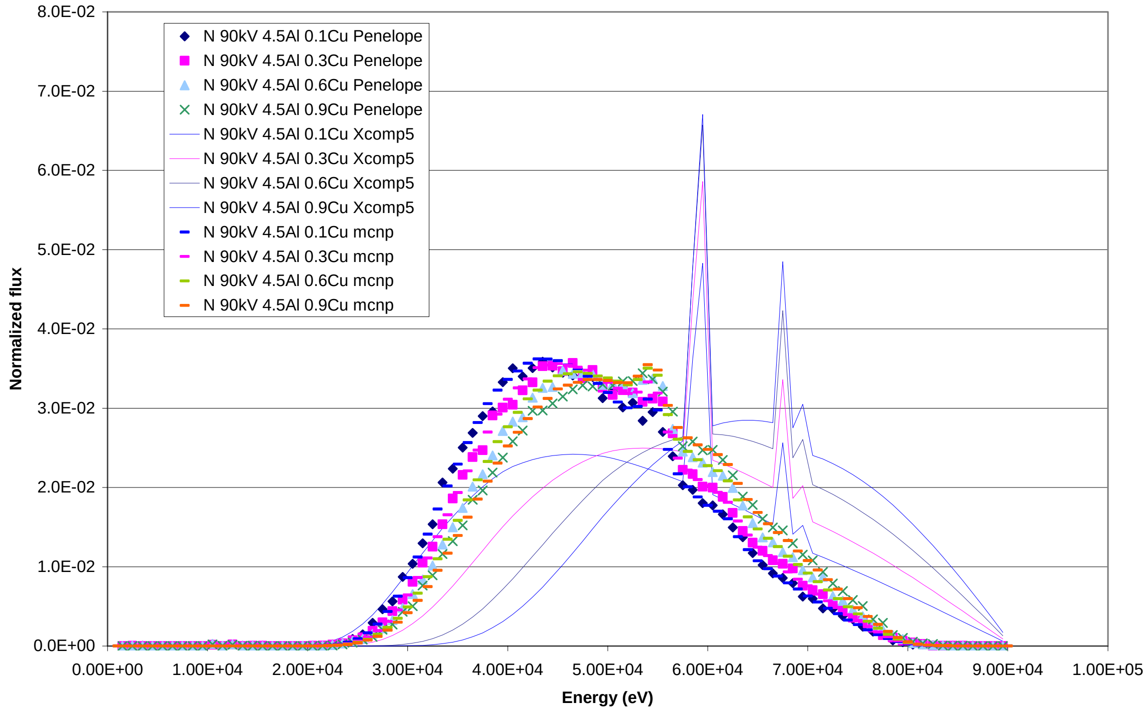

Figure 3. Scattered spectra calculated with MCNPX and Penelope and incident beam spectra calculated with XCOMP5 for a tube high voltage equal to 90 kV

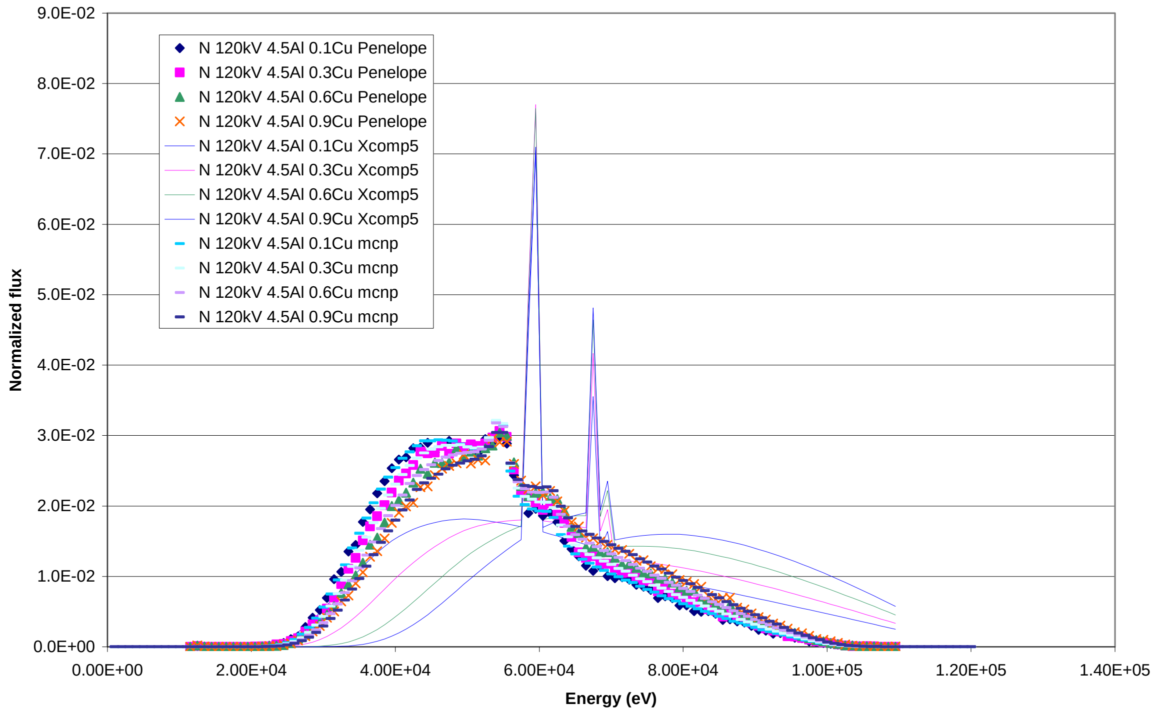

Figure 4. Scattered spectra calculated with MCNPX and Penelope and incident beam spectra calculated with XCOMP5 for a tube high voltage equal to 120 kV

2.2 Selection of APDs

The selection of APD models was based on the results from two international intercomparisons: one performed in the framework of the CONRAD project, a coordination action supported by the European Commission within its 6th Framework Program [1,2] and a previous one organized by EURADOS and IAEA [3] and, on the available usage data from different European countries.
A pre-requisite for consideration was that each unit should measure photon energies down to 20 keV since it should correspond to the lowest photon energy of scattered spectrum at the level of the operator, as this was demonstrated in the previous paragraph. Another criterion is that we selected only APDs that can be sold in the EC.

Seven APDs were selected for the study (Figure 5): DMC 2000XB (MGPI), EPD Mk2.3 (Siemens - Thermo), EDMIII (Panasonic - Dosilab), PM1621A (Polimaster), DIS-100 (Rados - Mirion), EDD30 (Unfors) and AT3509C (Atomtex). It is important to indicate that these dosemeters are commercial devices bought especially for the study without informing the manufacturer of these tests.
The dosemeter EDD30 is presented by the manufacturer Unfors as an "educational direct dosemeter" dedicated to fluoroscopy applications. Even if this dosemeter cannot be considered as an APD strictly speaking, it was interesting to test the behaviour of this device since it is the only personal dosemeter specifically designed for IR/IC field.
Table 2 gives the main characteristics of these APDs as given by the manufacturers in the technical note available on a website or provided with the devices.

Figure 5. Active personal dosemeters tested in this study

Table 2. Main characteristics of tested APDs as provided by the manufacturers in the technical note (annex)

APD	Energy range		Dose rate range		Dose range		Detector type
	Min	Max	Min	Max	Min	Max	
DMC 2000XB MGPi	20 keV	6 MeV	0.1 µSv.h^{-1}	10 Sv.h^{-1}	1 µSv	10 Sv	Silicon diode
EPD Mk2.3 Siemens	17 keV	6 MeV	1 µSv.h^{-1}	4 Sv.h^{-1}	1 µSv	16 Sv	Silicon diode
EDM III Dosilab	20 keV	6 MeV	0.5 µSv.h^{-1}	1 Sv.h^{-1}	1 µSv	1 Sv	Silicon diode
PM1621A Polimaster	10 keV	20 MeV	0.01 µSv.h^{-1}	2 Sv.h^{-1}	0.01 µSv	9.99 Sv	Geiger Muller tube
DIS-100 Rados	15 keV	9 MeV	1 µSv.h^{-1}	40 Sv.h^{-1}	1 µSv	50 mSv	Specific detector
EDD 30** Unfors	*	*	0.03 mSv.h^{-1}	2 Sv.h^{-1}	1 nSv	9999 Sv	Silicon diode
AT3509C Atomtex	15 keV	10 MeV	0.1 µSv.h^{-1}	5 Sv.h^{-1}	1 µSv	10 Sv	Silicon diode

*not indicated in the technical note

3 Tests of APDs in laboratory conditions

3.1 Tests of APDs in continuous mode

3.1.1 Material and methods

The tests in continuous mode were made in the calibration laboratories of the Institute of Radiological Protection and Nuclear Safety (IRSN) in Fontenay-aux-Roses (France) and of the Belgian Nuclear Research Center (SCK•CEN) in Mol (Belgium).

3.1.1.1 Description of the facilities

IRSN

Some of the tests were performed at the secondary standard metrology laboratory of IRSN. The laboratory is accredited according to the ISO 17025 standard [7].
Several beam qualities indicated in the ISO 4037-3 standard [8] were applied: N-15, N-20, N-25, N-30, N-40, N-60, N-80, N-100, N-120, S-Cs and S-Co.
Four types of installations were used at IRSN:

- X-ray generator 320 kV for N-60, N-80, N-100 and N-120 (Figure 6)
- X-ray generator 100 kV for N-15, N-20, N-25, N-30 and N-40 (Figure 7)
- gamma irradiator containing several sources of ^{137}Cs and ^{60}Co (Figure 8)
- gamma irradiator containing one source of ^{60}Co of high activity (148 TBq on February 2002) (Figure 9)

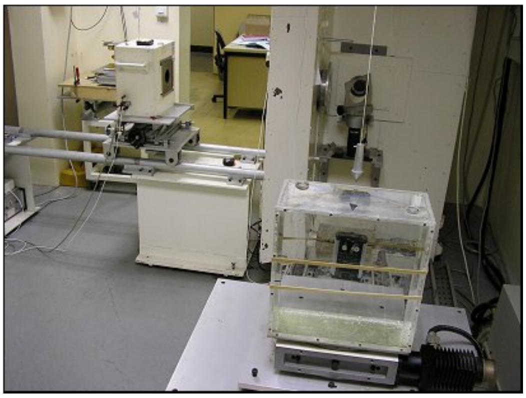

Figure 6. X-ray generator 320 kV used for N-60, N-80, N-100, N-120 (IRSN)

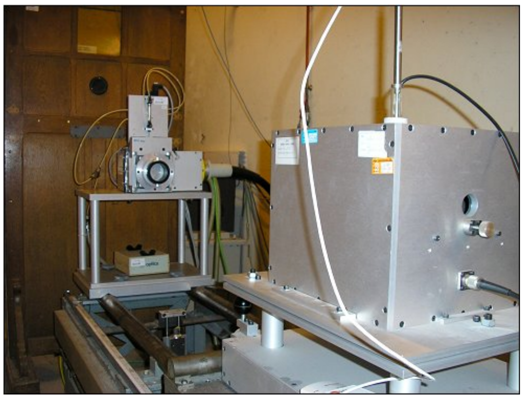

Figure 7. X-ray generator 100 kV for N-15, N-20, N-25, N-30, N-40 (IRSN)

Figure 8. Multi-sources gamma irradiator (IRSN)

Figure 9. Gamma irradiator containing one source of ^{60}Co (IRSN)

SCK•CEN

Some of the tests were performed at the secondary standard metrology laboratory of SCK•CEN. The laboratory is accredited according to the ISO 17025 standard [7].
Several beam qualities indicated in the ISO 4037-3 standard [8] were applied: N-40, N-60 and S-Co.
Two types of installations were used at SCK•CEN:

- X-ray generator Pantak HF420 (Figure 10)
- gamma irradiator ^{60}Co (Figure 11) :

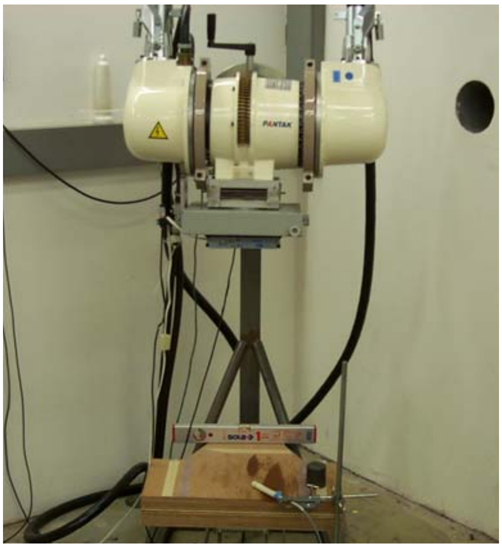

Figure 10. X-ray generator Pantak HF420

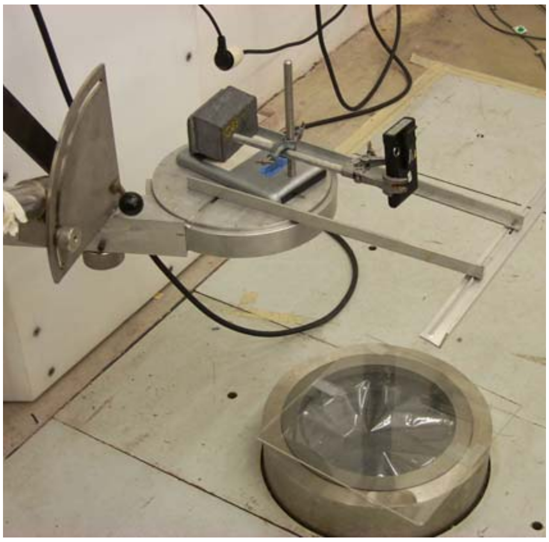

Figure 11. Gamma irradiator ^{60}Co

3.1.1.2 Tests performed

The following tests were performed on APDs.

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

The dose rate response was tested at low energy (H-100, mean energy 57 keV) for EDD30 since this dosemeter is calibrated in this energy range.
Three measurements per APD were made. Two dosemeters of each type were tested, except for the EDD30 of which we had only one unit. Dosemeters were placed on an ISO slab phantom.

The results were analysed considering the requirements of the IEC 61526 standard "Radiation protection instrumentation. Measurement of personal dose equivalent Hp(10) and Hp(0.07) for x, gamma, neutron and beta radiation: Direct reading personal dose equivalent and/or dose equivalent rate dosemeters" [9].

3.1.2 Results

3.1.2.1 Dose response - linearity check

The dose response (Figure 12) of the tested APDs is linear in the dose range of interest in radiation protection, i.e. up to 500 mSv.

3.1.2.2 Dose rate response

The dose rate response of APDs is presented in figure 13. For all types, the average between the two devices is plotted, except for the PM1621A.
Most APDs can stand high dose rates until 10 Sv.h^{-1}, except EDD30 and PM1621A:

- EDD30: for the H-100 beam, the response is equal to 0.5 up to a dose rate registered by the APD lower than 2.4 Sv.h^{-1} (4.4 Sv.h^{-1} really applied); for higher dose rates up to 10 Sv.h^{-1},the

dosemeter saturates, that is it indicates always the same value (2.4 $Sv.h^{-1}$) and it indicates "Hi.Si". This is consistent with the technical note that indicates "If the dose rate exceeds a maximum limit of about 2 $Sv.h^{-1}$ the measured dose and dose rate start to be inaccurate. When the dose rate exceeds the maximum limit, momentarily "Hi.Si" (= High Signal) is displayed and 5 beeps are activated".

- PM1621A: a problem was observed for the two PM1621A dosemeters for which the response is diverging rapidly from 1 $Sv.h^{-1}$; moreover, the two PM1621A models tested behave completely different on dose rate response.

It is interesting to notice that most APDs can stand dose rates higher than those indicated in their technical note (Table 2).

3.1.2.3 Energy response

The response due to photon radiation energy for the tested APDs is presented in figure 14. The energy response is within the interval [0.71 – 1.67] as required in the IEC 61526 standard [9] from ^{137}Cs energy down to N-30 for all APDs except EDD30. For EDD30, these results are consistent with the fact that this APD is calibrated at low energy, and not at ^{137}Cs. For energies of N-25 and/or lower, energy responses lower than 0.5 are observed for DMC2000XB, EPDMk2.3 and EDMIII. However, as it was already stated, no energies lower than 20 keV were observed in the scattered radiation fields for IR/IC applications.

3.1.2.4 Angular response

The angular response (Figures 15 to 21) is within the interval [0.71 – 1.67] [9] for energies down to N-30 for all APDs except:

- AT 3509C, for which the angular response is inside the interval at 60° only from N-80, the angular response is correct for 30° from N-40,
- DIS-100, for which some points are slightly outside the interval at N-30.

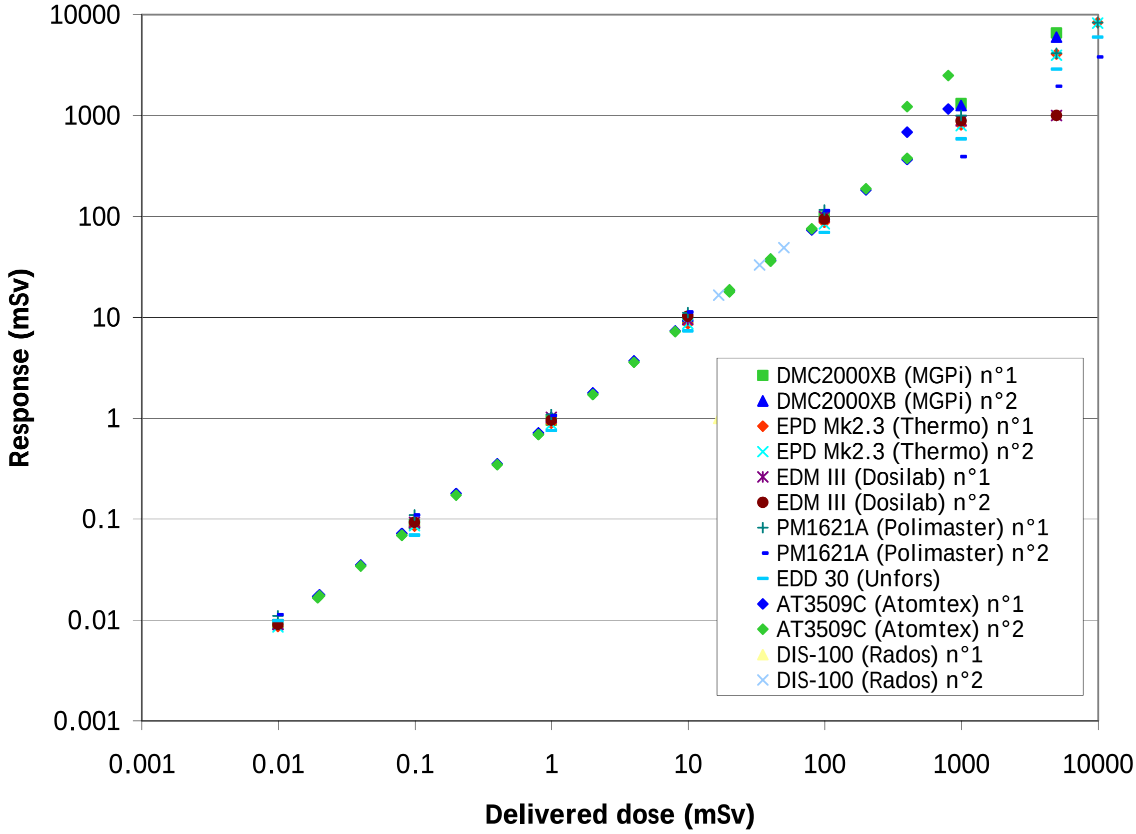

Figure 12. Dose response of APDs

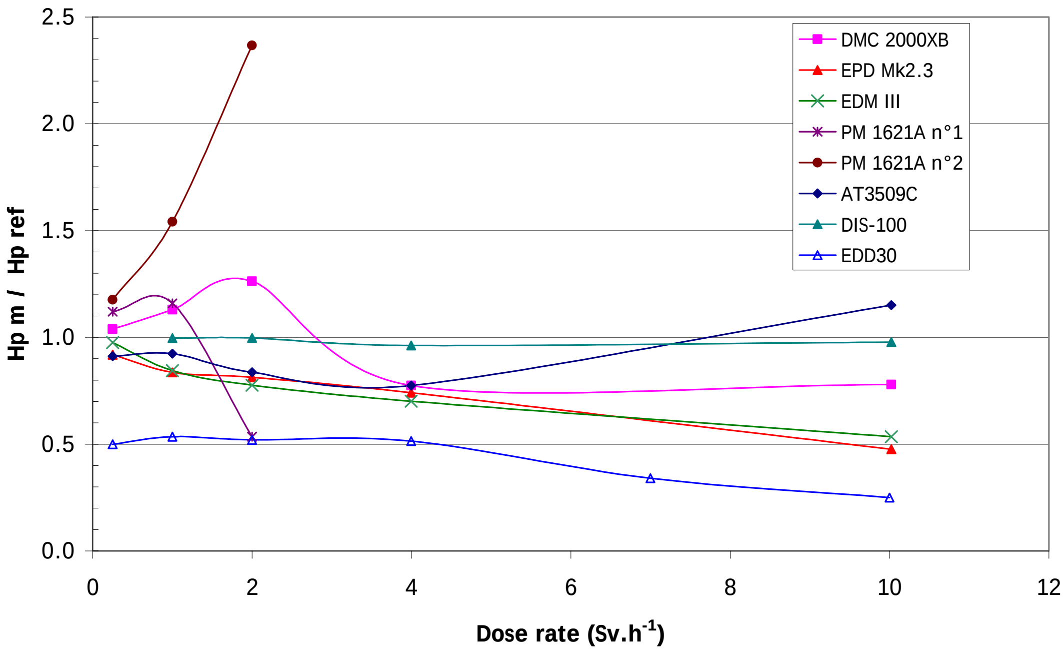

Figure 13. Dose rate response of APDs

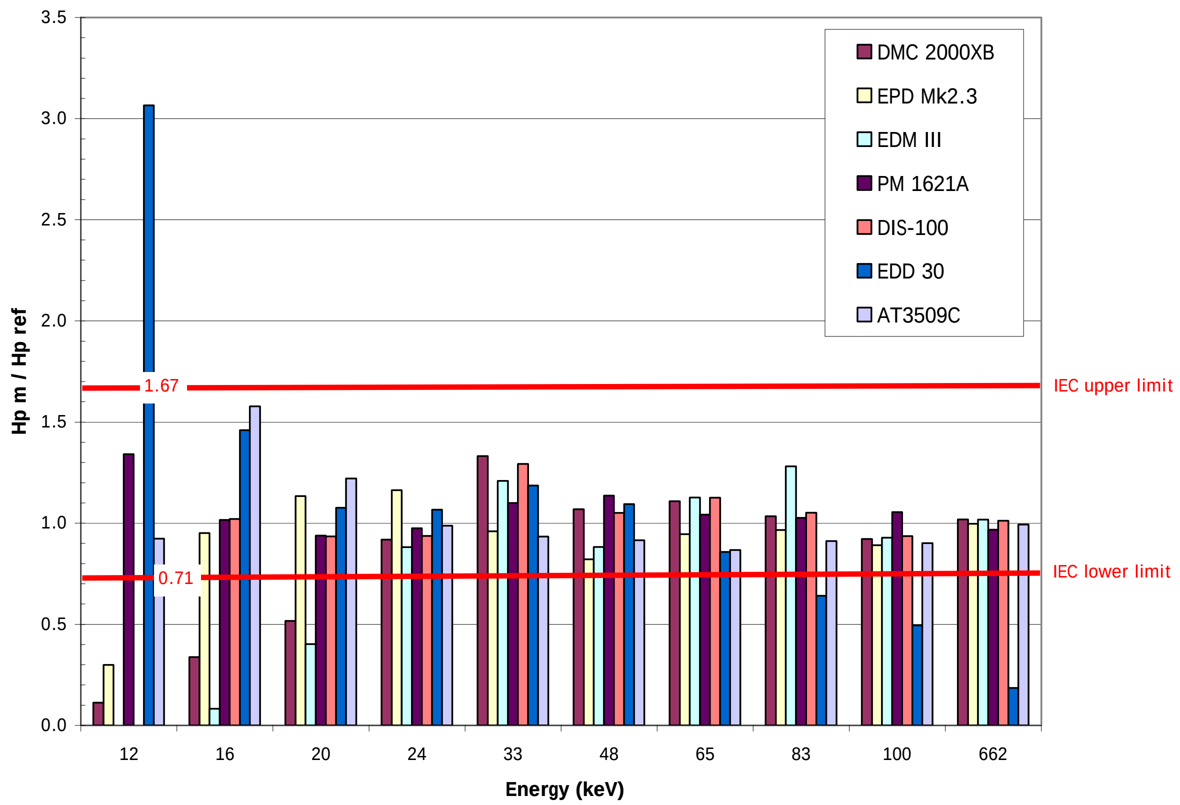

Figure 14. Energy response of APDs (relative to average energy of the N-series)

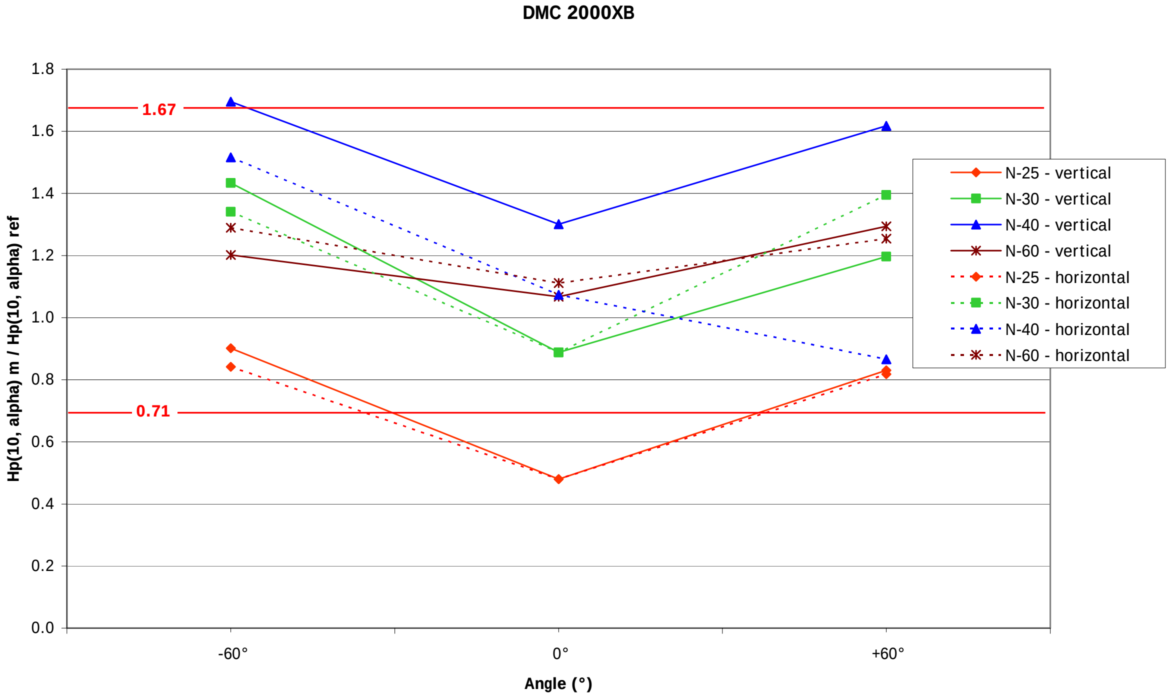

Figure 15. Response of APDs at different photon radiation energies and angles of incidence – DMC 2000XB

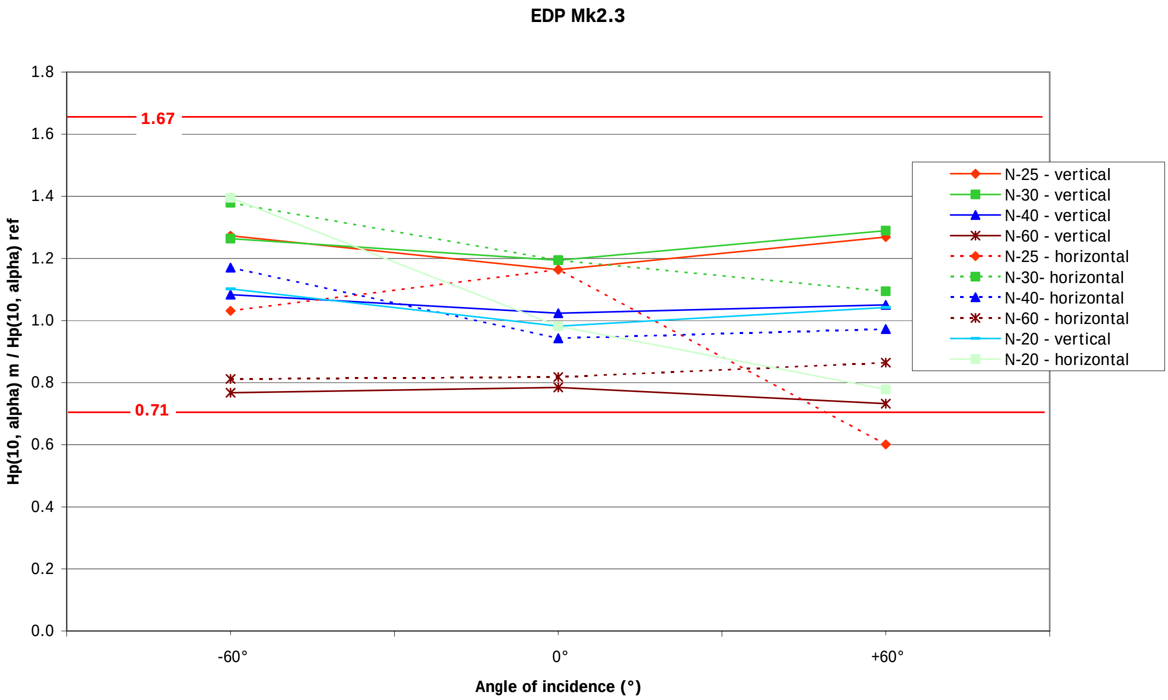

Figure 16. Response of APDs at different photon radiation energies and angles of incidence – EPD Mk2.3

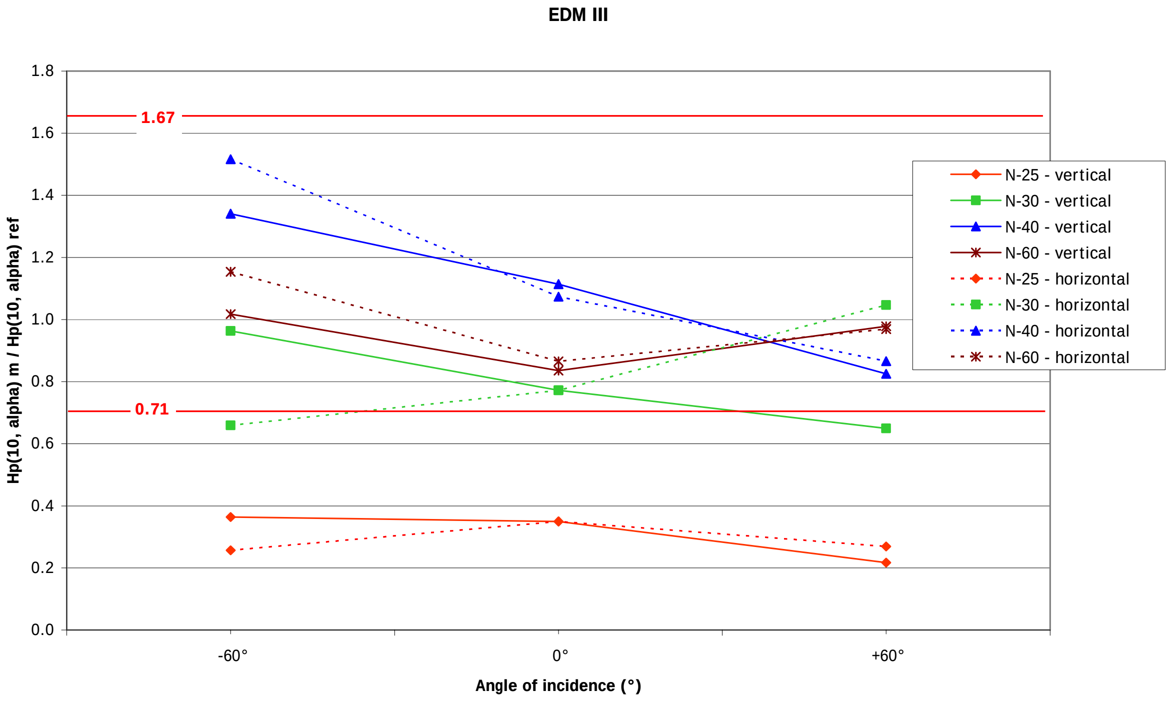

Figure 17. Response of APDs at different photon radiation energies and angles of incidence – EDM III

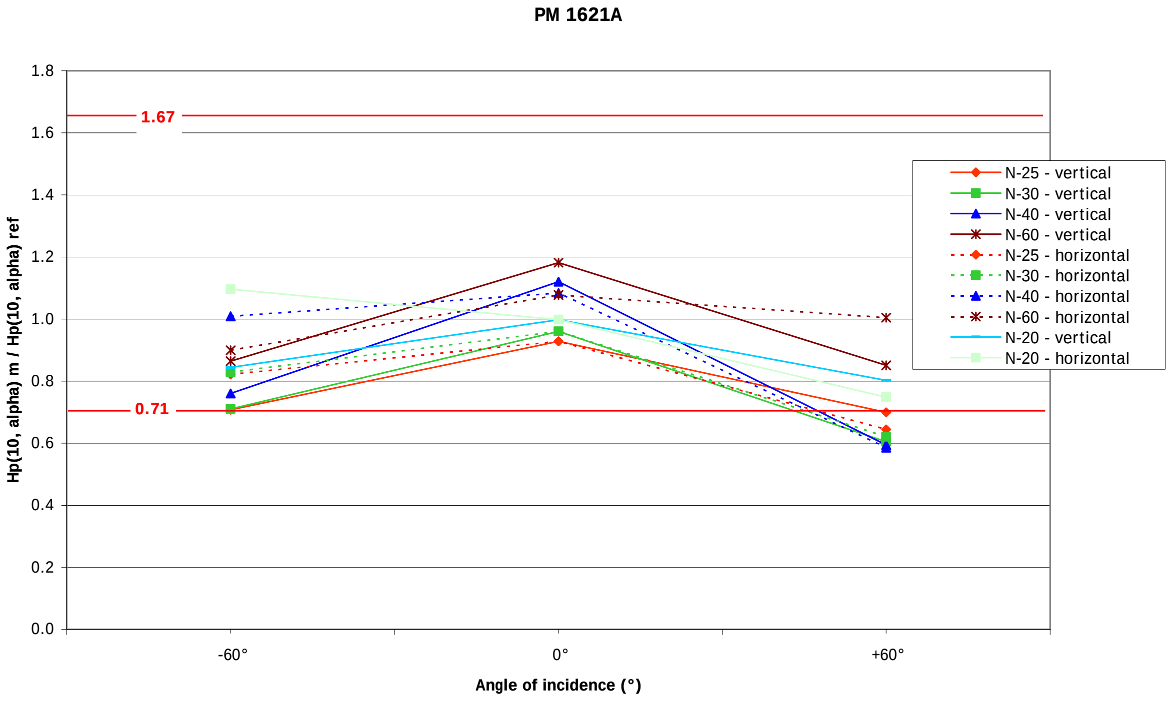

Figure 18. Response of APDs at different photon radiation energies and angles of incidence – PM 1621A

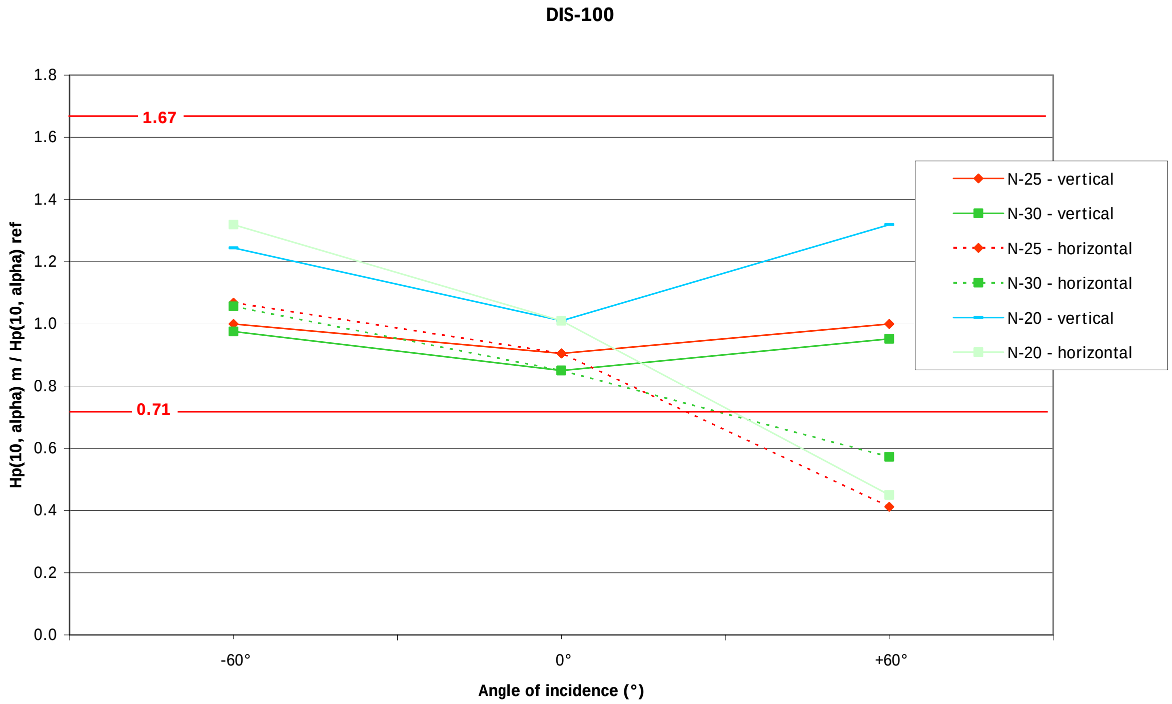

Figure 19. Response of APDs at different photon radiation energies and angles of incidence – DIS-100

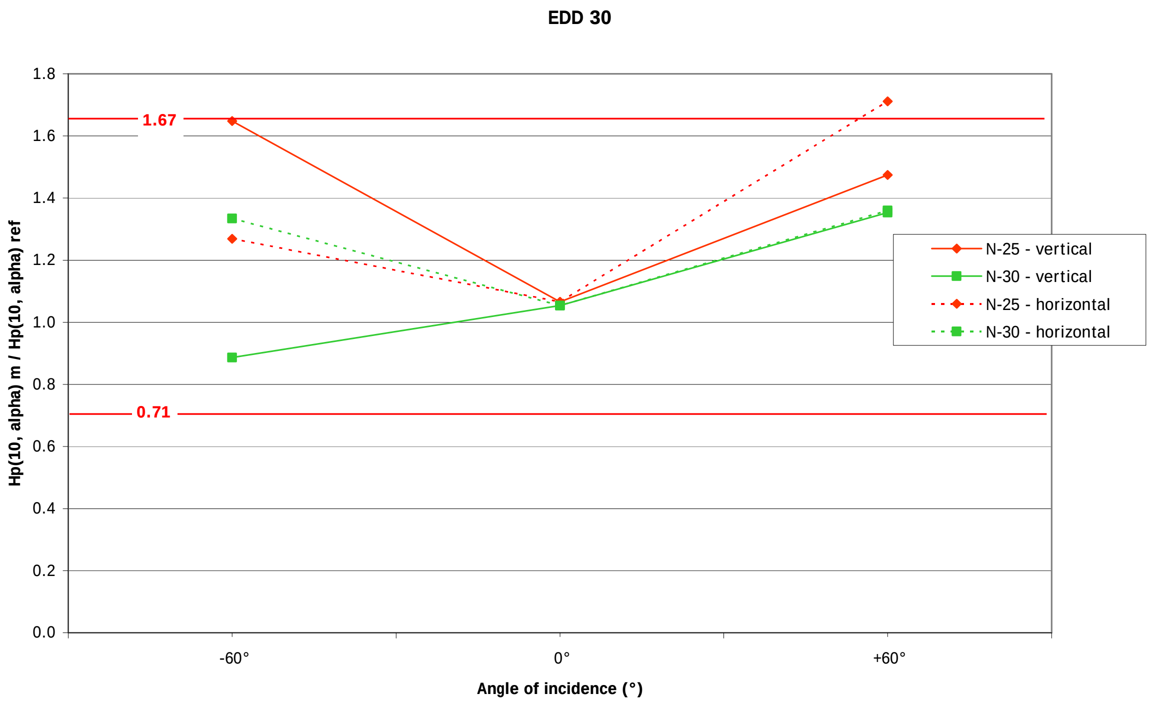

Figure 20. Response of APDs at different photon radiation energies and angles of incidence –EDD 30

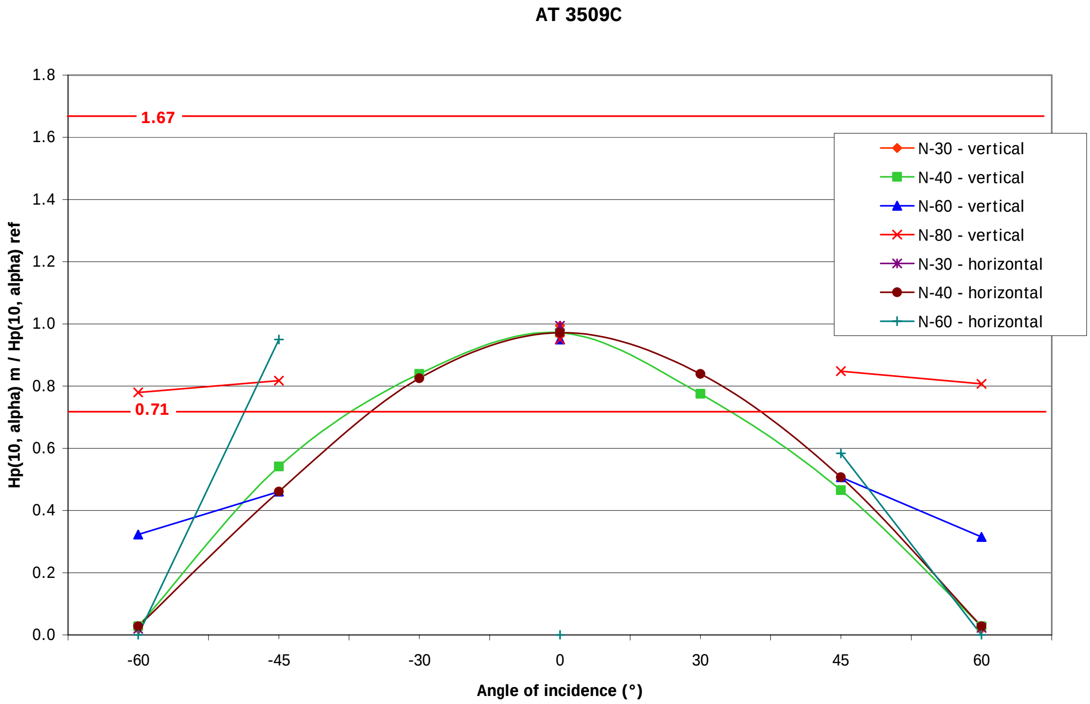

Figure 21. Response of APDs at different photon radiation energies and angles of incidence –AT 3509C

3.1.3 Conclusions on tests in continuous mode - response of each APD

DMC2000XB

- Dose response: linear response with the dose up to 500 mSv
- Dose rate response: response varies between 1.3 and 0.7 up to 10 $Sv.h^{-1}$
- Energy response: response within the interval [1.67 – 0.71] required in IEC standard [9] from ^{137}Cs energy down to N-30
- Angular response: response within the interval [1.67 – 0.71] required in IEC standard [9] down to N-30

EPD Mk 2.3

- Dose response: linear response with the dose up to 500 mSv
- Dose rate response: response decreases from 0.9 to 0.5 from 1 to 10 $Sv.h^{-1}$
- Energy response: response within the interval [1.67 – 0.71] required in IEC standard [9] from ^{137}Cs energy down to N-20
- Angular response: response within the interval [1.67 – 0.71] required in IEC standard [9] down to N-30

EDM III

- Dose response: linear response with the dose up to 500 mSv
- Dose rate response: response decreases from 1 to 0.5 from 1 to 10 $Sv.h^{-1}$
- Energy response: response within the interval [1.67 – 0.71] required in IEC standard [9] from ^{137}Cs energy down to N-30
- Angular response: response within the interval [1.67 – 0.71] required in IEC standard [9] down to N-30

PM1621A:

- Dose response: linear response with the dose up to 500 mSv
- Dose rate response: the response is diverging rapidly from 1 $Sv.h^{-1}$. Moreover, the two PM1621A models tested behave completely different on dose rate response.
- Energy response: response within the interval [1.67 – 0.71] required in IEC standard [9] from ^{137}Cs energy down to N-15
- Angular response: response within the interval [1.67 – 0.71] required in IEC standard [9] down to N-30

DIS-100:

- Dose response: linear response with the dose up to 500 mSv
- Dose rate response: response very close to 1 from 1 to 10 $Sv.h^{-1}$
- Energy response: response within the interval [1.67 – 0.71] required in IEC standard [9] from ^{137}Cs energy down to N-20
- Angular response: response within the interval [1.67 – 0.71] required in IEC standard [9] down to N-40, some points are slightly outside the interval at N-30.

EDD30:

- Dose response: linear response with the dose up to 500 mSv
- Dose rate response: saturates for dose rates higher than 2 $Sv.h^{-1}$
- Energy response: response within the interval [1.67 – 0.71] required in IEC standard [9] from N-80 down to N-20 (these results are consistent with the fact that this APD is calibrated at low energy, and not at ^{137}Cs)
- Angular response: response within the interval [1.67 – 0.71] required in IEC standard [9] down to N-30

AT3509C:

- Dose response: linear response with the dose up to 500 mSv
- Dose rate response: response varies between 0.9 and 1.2 up to 10 $Sv.h^{-1}$
- Energy response: response within the interval [1.67 – 0.71] required in IEC standard [9] from ^{137}Cs energy down to N-15
- Angular response: response is inside the interval at 60° only from N-80, the angular response is correct for 30° from N-40

All APDs have a linear response with the dose and most of them have a satisfactory response at low energies from N-30, which is sufficient for IR/IC. Most APDs can stand high dose rates up to 10 $Sv.h^{-1}$, except PM1621A for which the response is diverging rapidly from 1 $Sv.h^{-1}$ and EDD30 which saturates for dose rates above 2 $Sv.h^{-1}$. However, as indicated in table 1, the dose rates in the direct beam can be much higher than those tested here. So these tests in continuous fields do not mean that the APDs will correctly handle these very high dose rates in the direct beam. In addition, a problem of angular response at low energies was observed with AT3509C.

3.2 Tests of APDs in pulsed mode

3.2.1 Material and methods [11]

The tests in pulsed mode were made at the French standard laboratory for ionizing radiation (Laboratoire National Henri Becquerel –LNHB) belonging to the CEA LIST in Saclay (France).

3.2.1.1 Description of the facilities

The beam quality used for the tests in pulsed mode is defined as follows:

1. X-ray generator: GEHC PHASIX 80 in graphy mode and multi-pulsed mode,
2. High Voltage: 70 kV,
3. Total filtration: 4.5 mm Al + 0.2 mm Cu,
4. Half Value Layer: 5.17 mm Al.

Distance between X-rays source and reference point: 1 m
Beam dimensions in reference plane: 30 cm x 30 cm

A typical HV waveform in multi-pulsed mode is presented in Figure 22.

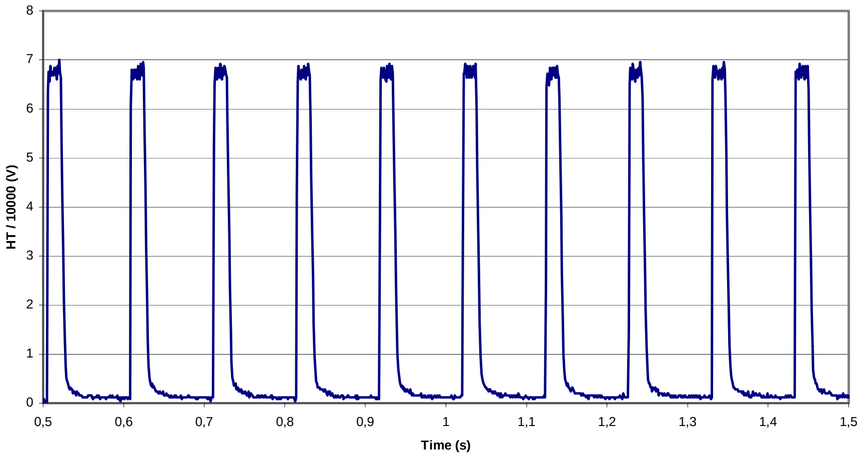

Figure 22. Typical HV waveform in multi-pulse mode (70 kV, 10 pps)

3.2.1.2 Tests performed

The APD response was studied in function of the variation of the dose rate, the pulse frequency and the pulsed width.

APD response with dose rate variation:
Multi-pulsed mode:

- Pulse duration: 20 ms,
- Pulse frequency: 10 pps,
- Dose rate variation: from 1 to 50 Sv.h^{-1}

APD response with pulse frequency variation:
Multi-pulsed mode:

- Dose rate: 1.8 Sv.h^{-1},
- Pulse duration: 20 ms,
- Pulse frequency variation: 1 pps, 10 pps and 20 pps

APD response with pulse width variation:
Single-pulsed mode:

- Dose rate: 1.8 Sv.h^{-1} and 6.8 Sv.h^{-1},
- Pulse duration variation: 20, 50, 100 and 1000 ms.

3.2.1.3 Determination of reference air-kerma

For determination of the reference air-kerma values, the free air chamber MD03 LNHB primary standard was used.
The results are expressed in terms of:
- "mean air-kerma per pulse" = total air-kerma measured during the irradiation time divided by the number of pulses;
- mean "air-kerma rate per pulse" = mean air-kerma per pulse duration (*i.e.* 20 ms).

The beam was monitored with a parallel flat chamber (PTW 233612) placed behind the collimator in a shielding lead box in order to reduce the influence of the scattered component from the phantom (Figure 23).

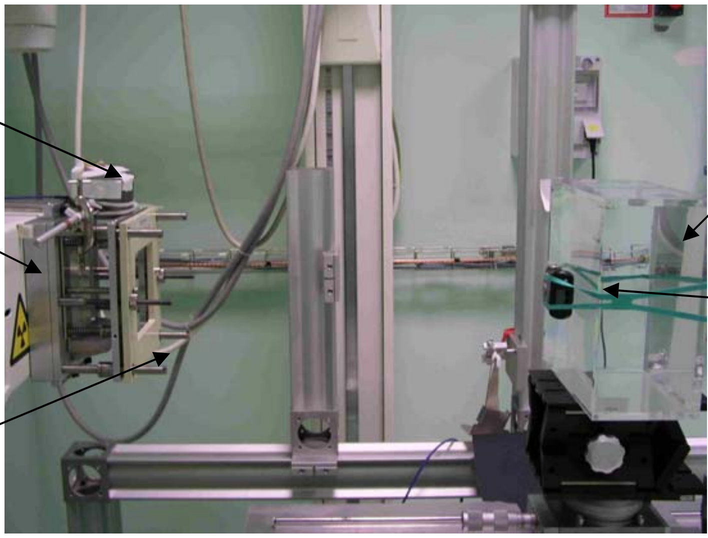

Figure 23. Experimental set up for tests in pulsed mode

The monitor was calibrated against the primary standard (free-air chamber MD3).
Then the calibration coefficient NKair (in Gy/C) was used to measure air-kerma during APDs irradiations.
The dose equivalent Hp(10) was calculated with conversion coefficient HP(10)/Kair = 1.65 Sv/Gy calculated from the following equation:

$$\mathrm{H_p(10)/K_{air}} = \frac{\sum h_{HK}(E)\cdot\phi(E)\cdot dE}{\sum \phi(E)\cdot dE}$$

where $h_{HK}(E)$ is the conversion coefficient at energy E, tabulated in ICRU report 57 [10] and $\phi(E)$ the fluence spectra of the incident beam calculated with the XCOMP5 software program [6]. The mean personal dose equivalent rates are given in table 3.
The relative standard uncertainty on air-kerma is 2.2%
The relative standard uncertainty on the conversion coefficient is 3.0 %.
Therefore the combined relative standard uncertainty on the dose equivalent is 3.7%.

Table 3. Air-kerma rate and personal dose equivalent rate in multi-pulsed mode

pps	current in X-ray tube (mA)	$\dot{K}_{air}$ (Gy.h^{-1})	$\dot{H}_p(10)$ (Sv.h^{-1})
1	32	1.1	1.82
	100	4.1	6.77
10	20	0.75	1.24
	32	1.1	1.82
	100	4.1	6.77
	400	16	26.4
	800	33	54.5
20	32	1.1	1.82
	100	4.1	6.77

3.2.2 Results [11]

The combined relative standard uncertainties on the response of the APDs are given in table 4. The table 5 sums up the percentage of variation on the response at constant dose rate for each APD and table 6 indicates the threshold in term of dose equivalent rate for achieving a response higher than a certain percentage of the maximum response for each APD. The detailed results of the responses of each type of ADP in multi-pulsed and single-pulsed modes are presented in figures 24 to 40.

Table 4. Relative uncertainties on APDs responses

APD	DMC 2000XB	EPD MK2.3	EDM III	PM 1621A	DIS 100	AT3509C	EDD30
u(R)/R (%)	6	5	7	no signal	9	20	6

All tested APDs give a signal in pulsed mode, except PM1621A which does not respond at all. The capability to register a signal due to a pulsed radiation is linked to the time response of the detector itself (linked to the mobility of the charge carriers) and the time response of the electronic. Taking that in mind it is not surprising that the response PM1621A is zero for all configurations of pulsed X-ray beam, since this dosemeter is based on a Geiger-Muller detector which has a rather long time response.

General remarks on results:

- Past comparisons (AIEA EURADOS and CONRAD works [1-3]) have showed that when pulse width is larger than 1 s the response in pulsed and in continuous radiation field are similar. The results of this test confirm this tendency.
- For most APDs the response decreases when the dose rate increases. For personal dose equivalent rates lower than 2 $Sv.h^{-1}$ the responses are, in general, close to the unity and fall down for higher dose rate. Looking at the curves where the response is plotted versus the means dose rate per pulse, it can be seen that, for the dose rate higher than 2 $Sv.h^{-1}$, the response of APDs decreases, except for DIS-100.. This suggests some problems with the dead time correction.
- For pulse width lower than 20 ms there is no response from APDs except EDMIII.

Table 5. Effect of the frequency of the pulses (1 to 20 pps), percentage of variation on the response at constant dose rate

APD	DMC 2000XB	EPD MK2.3	EDM III	PM1621A	DIS -100	EDD30	AT3509C
Variation %	25-30	~40(1.8 $Sv.h^{-1}$) ~25(6.8 $Sv.h^{-1}$)	<10	no signal	~30	~10(1.8 $Sv.h^{-1}$) saturation from 2 $Sv.h^{-1}$	30 (from 10 to 20 pps ; no signal at 1pps)

Table 6. Threshold in term of dose equivalent rate ($Sv.h^{-1}$) for achieving a response higher than XX% of the maximum response

APD	DMC 2000XB	EPD MK2.3	EDM III	PM1621A	DIS -100	EDD30	AT3509C
30%	~3	~3.5	~10	no signal	no threshold up to 55 (30%)	~6	~1.8
40%	~4	~4	~15	no signal		~7	~2.5
50%	~5	~7	~20	no signal		~10	~3.5

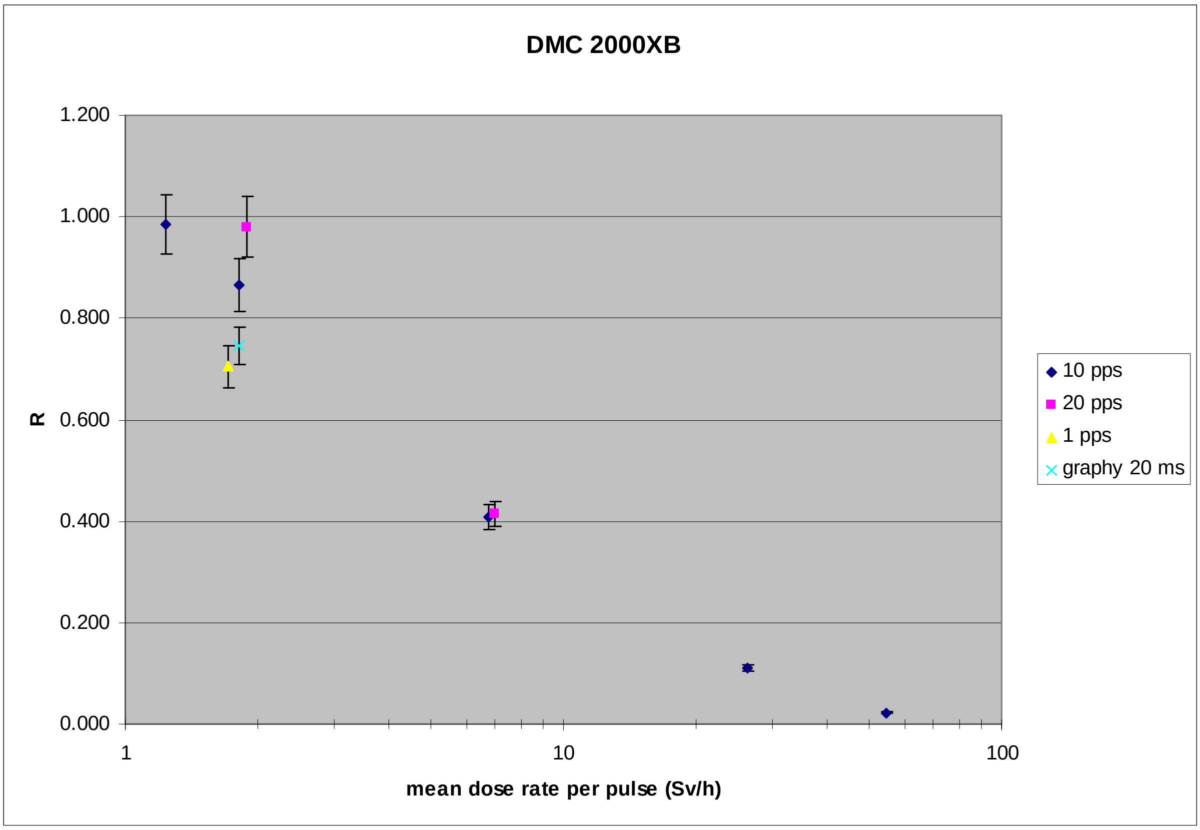

Figure 24. Response of DMC 2000XB in multi-pulsed mode

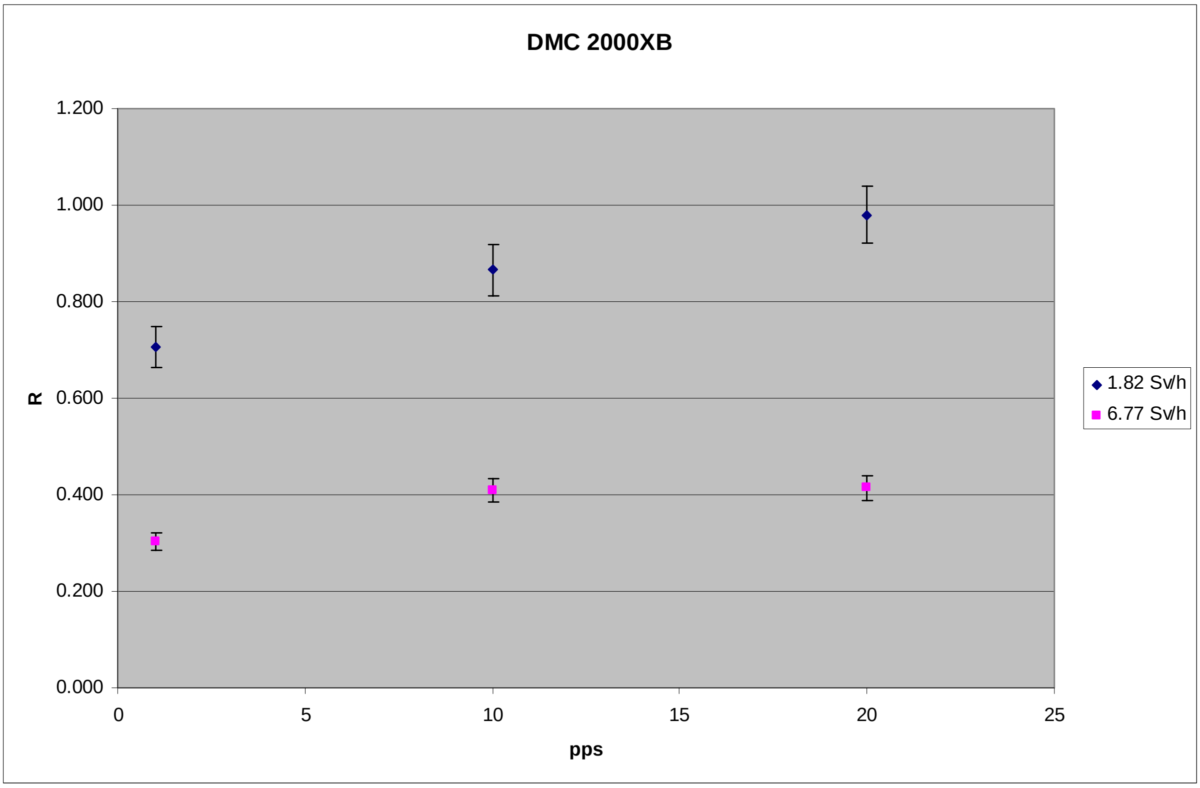

Figure 25. Response of DMC 2000XB in multi-pulsed mode vs pps

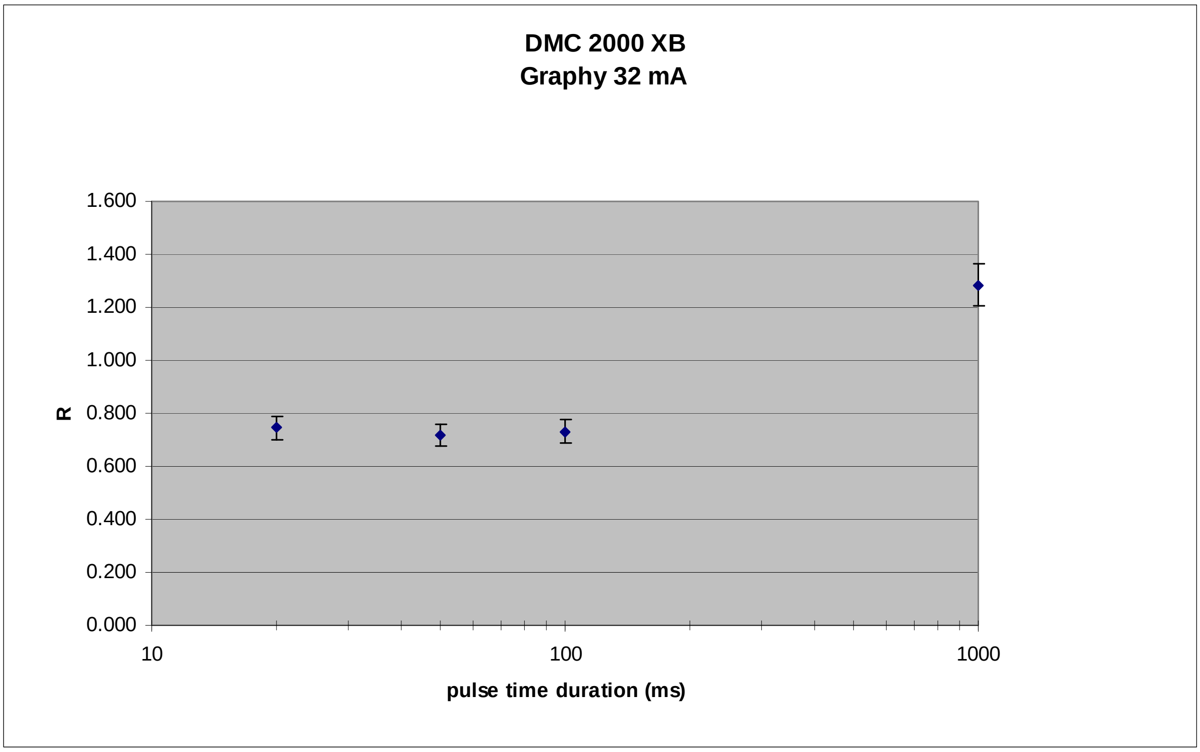

Figure 26. Response of DMC 2000XB in single pulsed mode

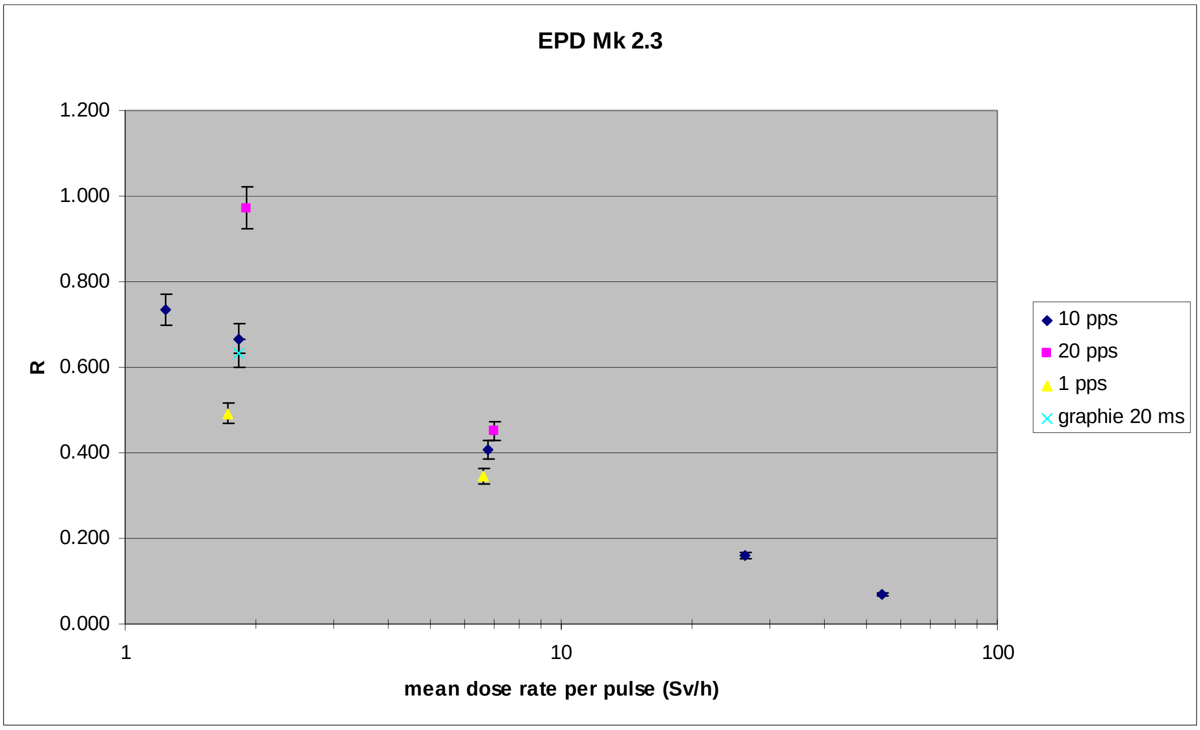

Figure 27. Response of EPD Mk2.3 in multi-pulsed mode

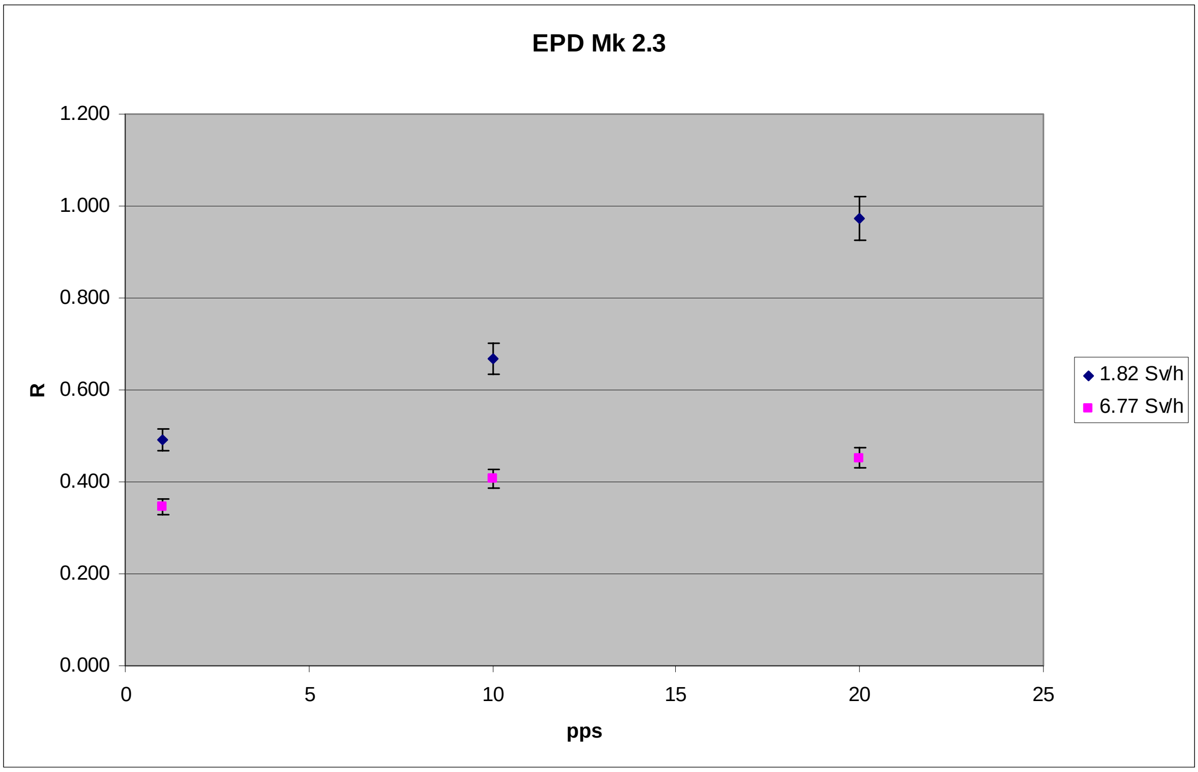

Figure 28. Response of EPD Mk2.3 in multi-pulsed mode vs pps

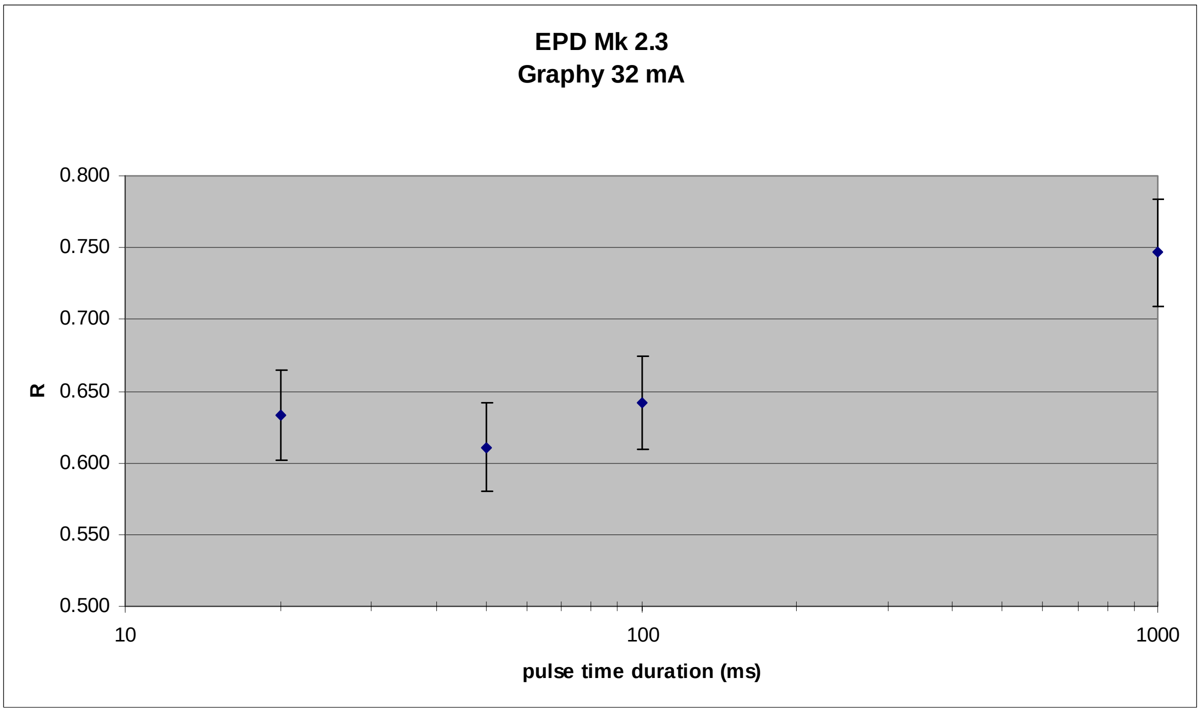

Figure 29. Response of EPD Mk2.3 in single pulsed mode

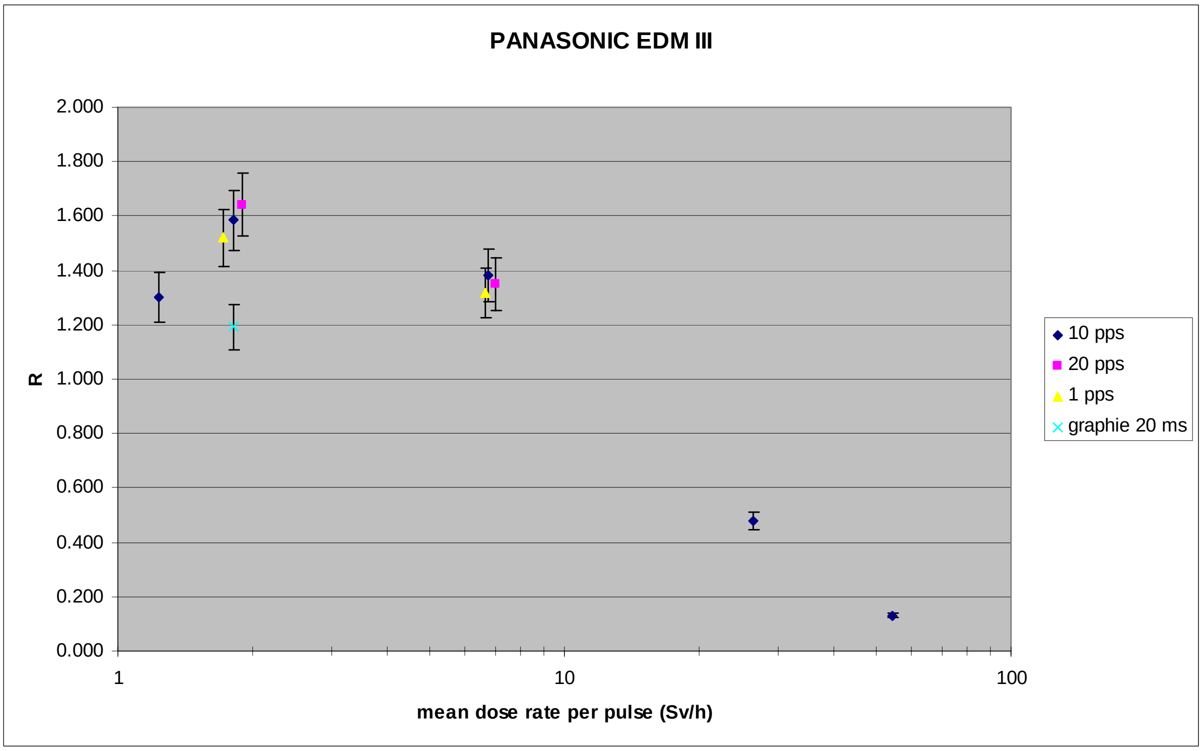

Figure 30. Response of EDM III in multi-pulsed mode

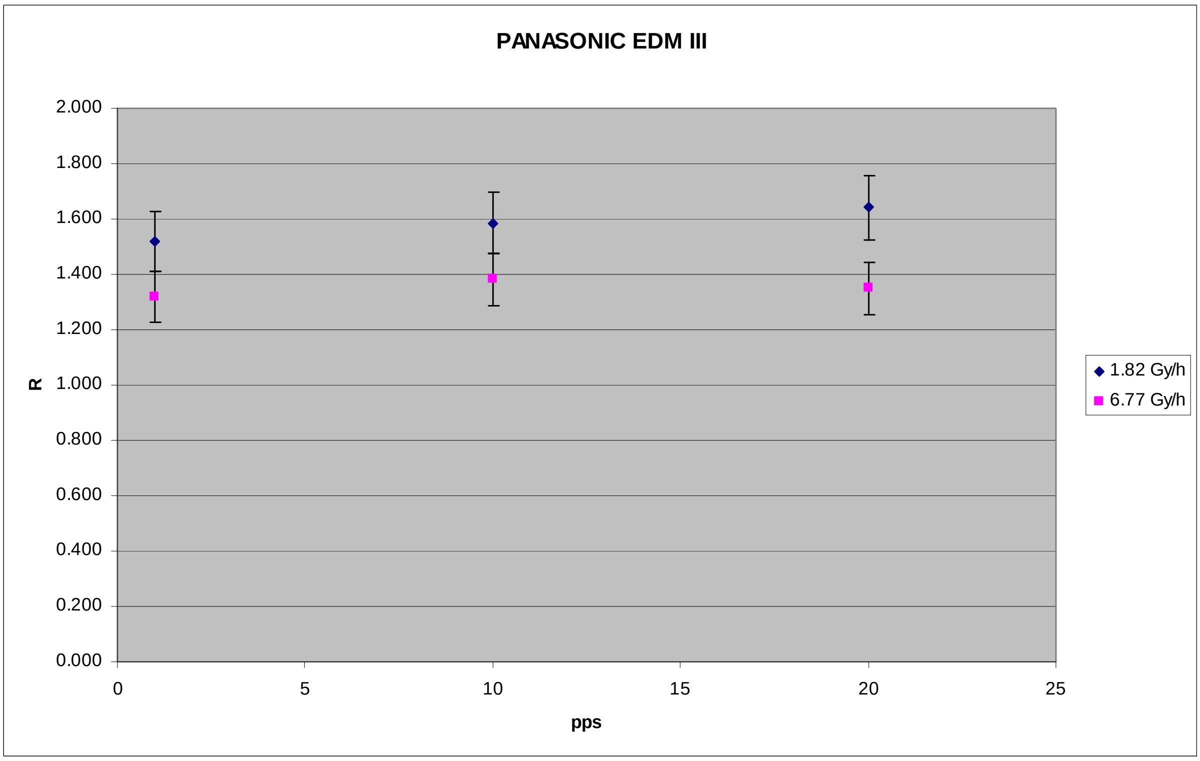

Figure 31. Response of EDM III in multi-pulsed mode vs pps

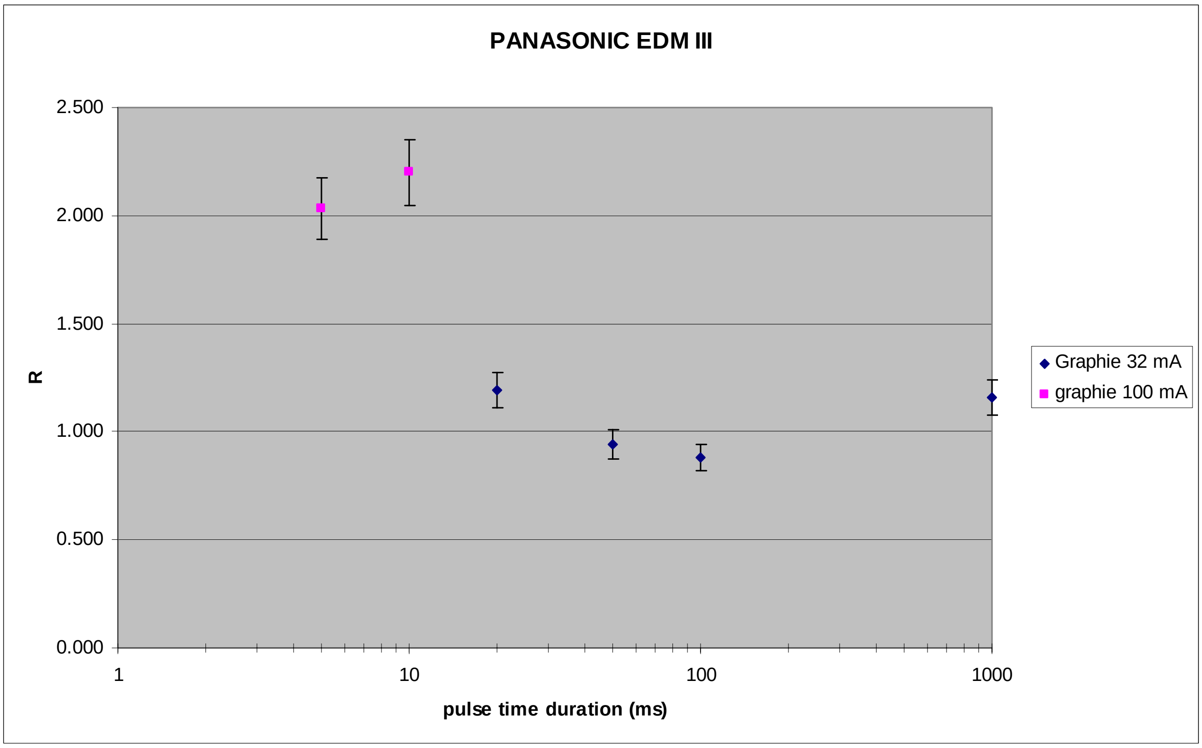

Figure 32. Response of EDM III in single pulsed mode

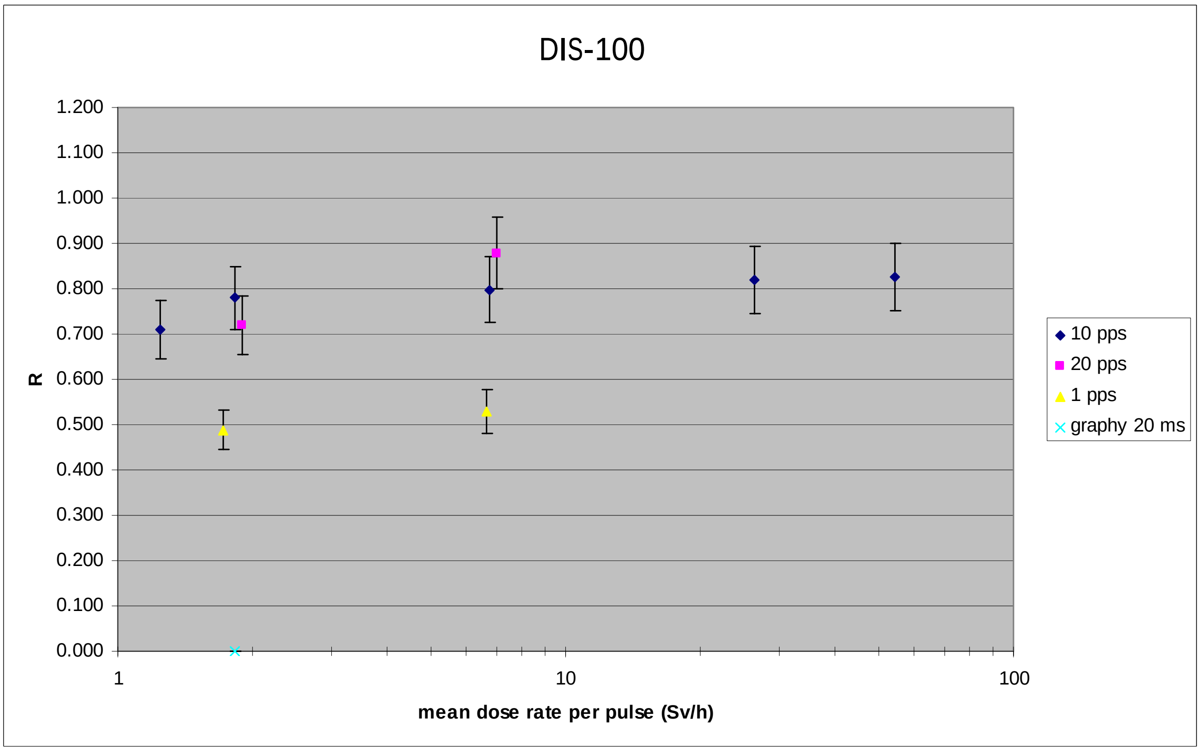

Figure 33. Response of DIS-100 in multi-pulsed mode

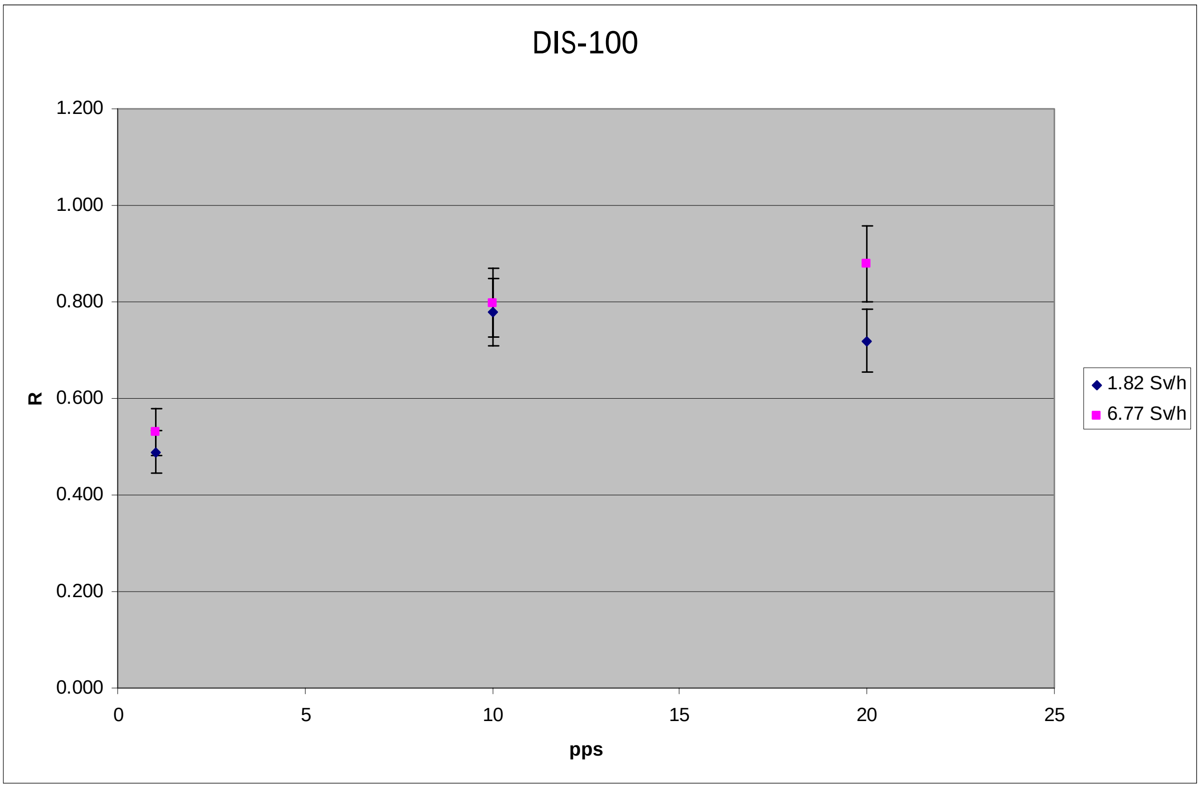

Figure 34. Response of DIS-100 in multi-pulsed mode vs pps

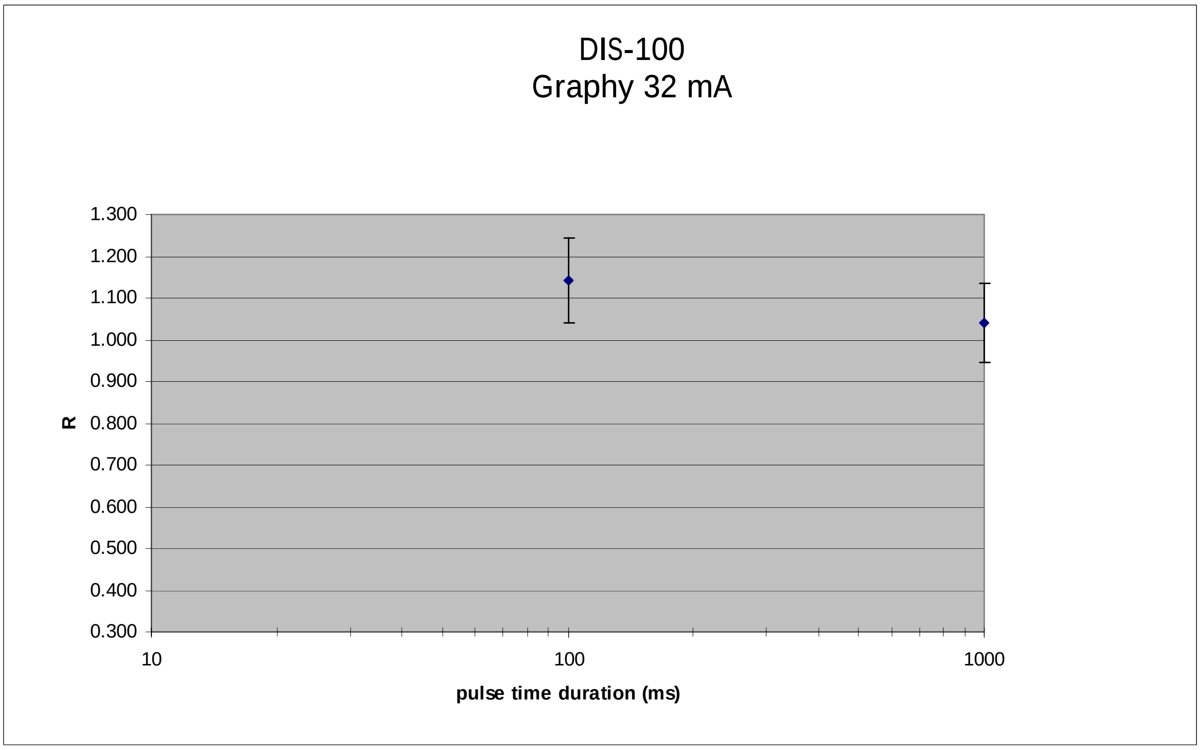

Figure 35. Response of DIS-100 in single pulsed mode

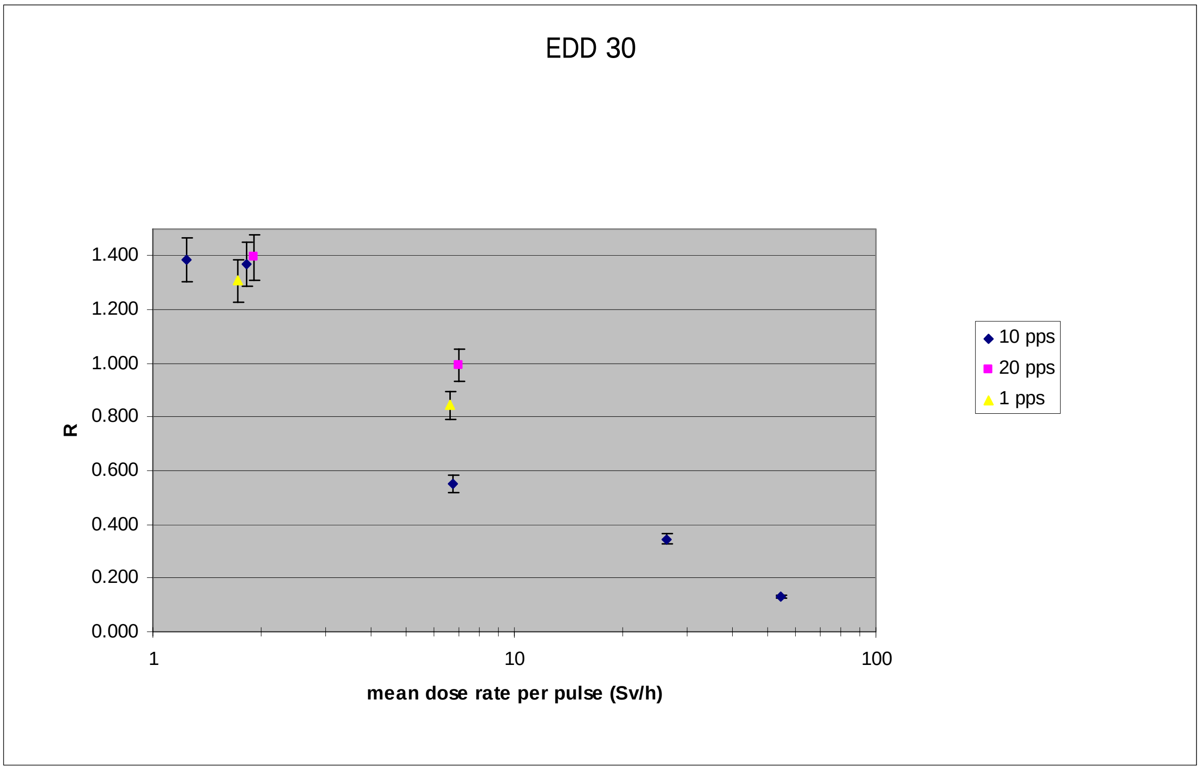

Figure 36. Response of EDD 30 in multi-pulsed mode

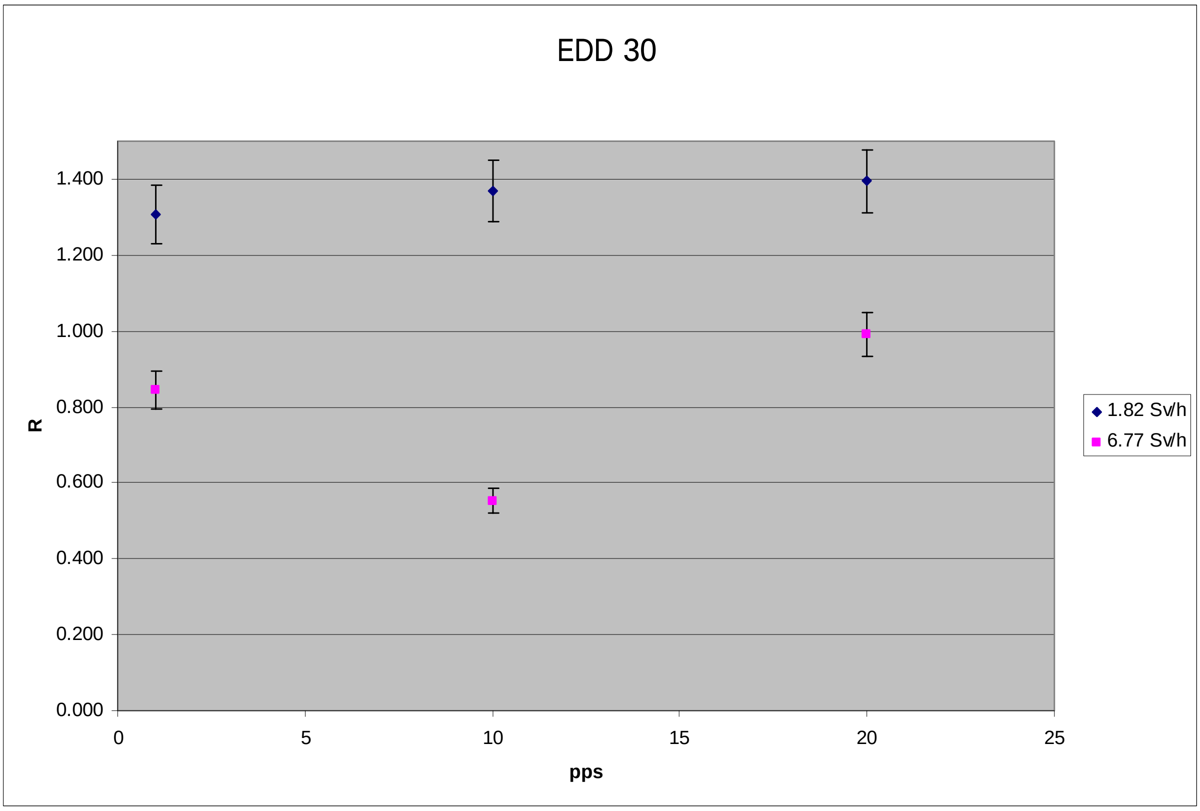

Figure 37. Response of EDD 30 in multi-pulsed mode vs pps

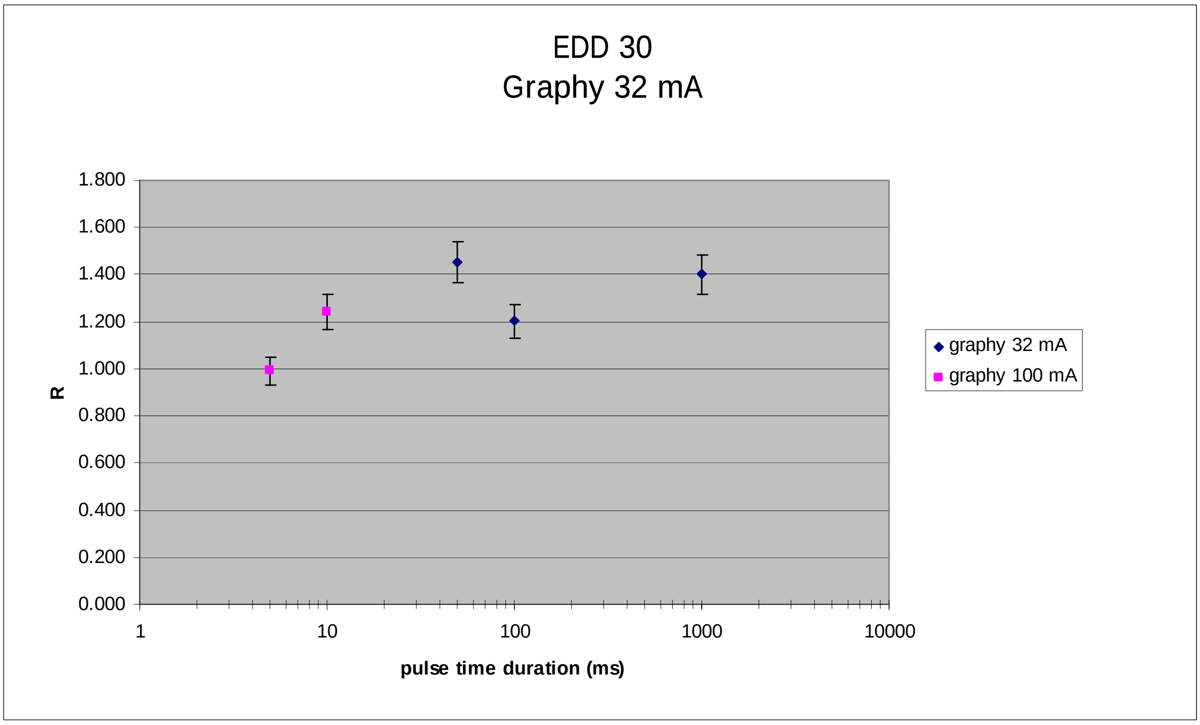

Figure 38. Response of EDD 30 in single pulsed mode

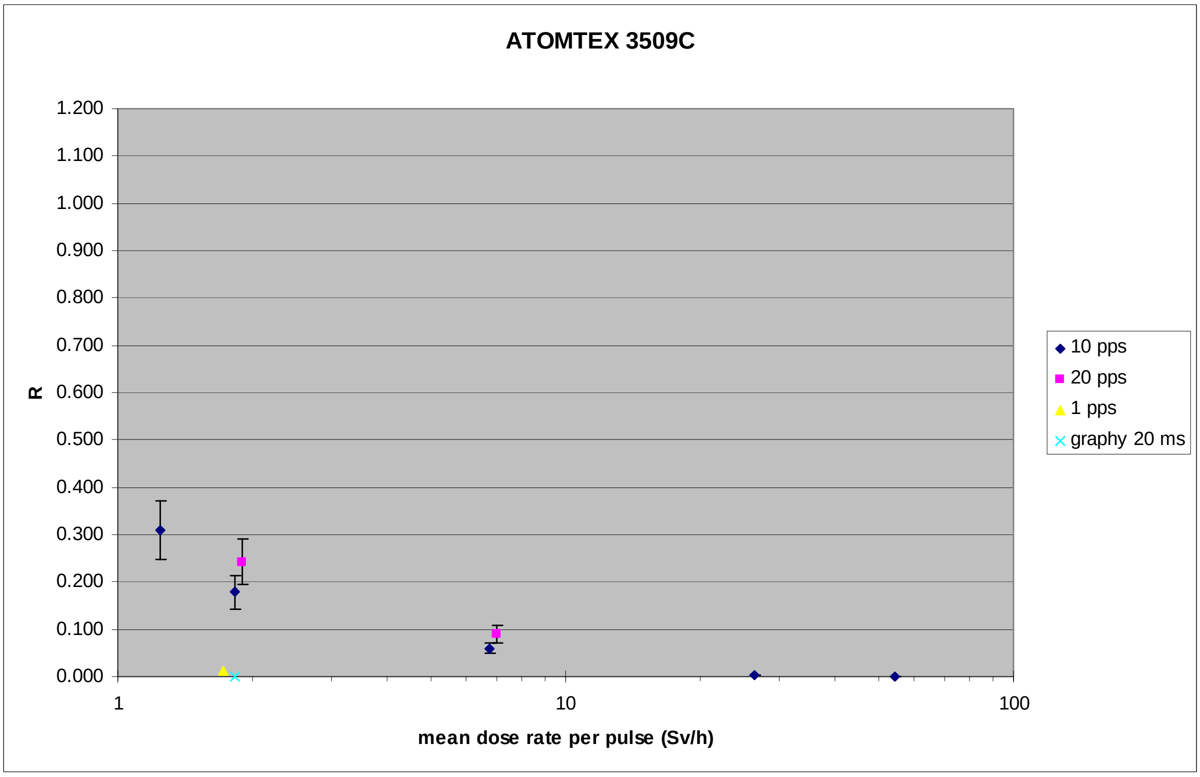

Figure 39. Response of AT 3509C in multi-pulsed mode

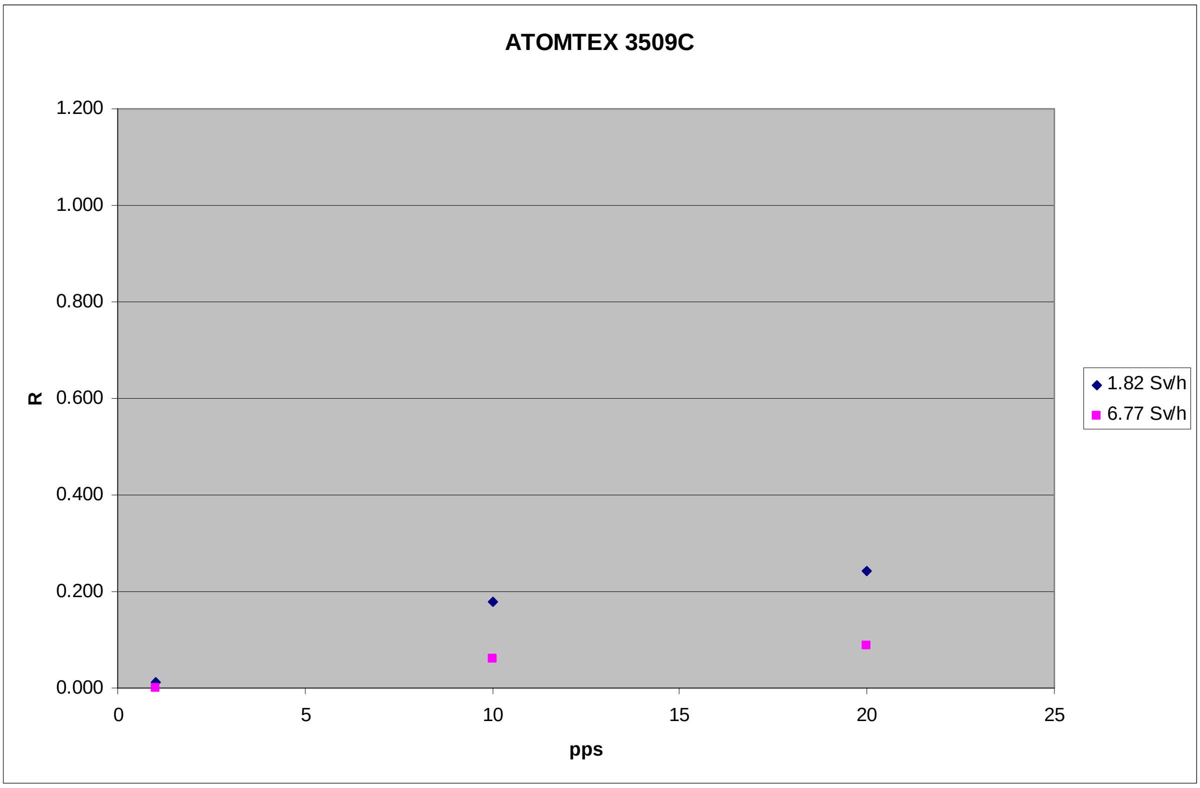

Figure 40. Response of AT 3509C in multi-pulsed mode vs pps

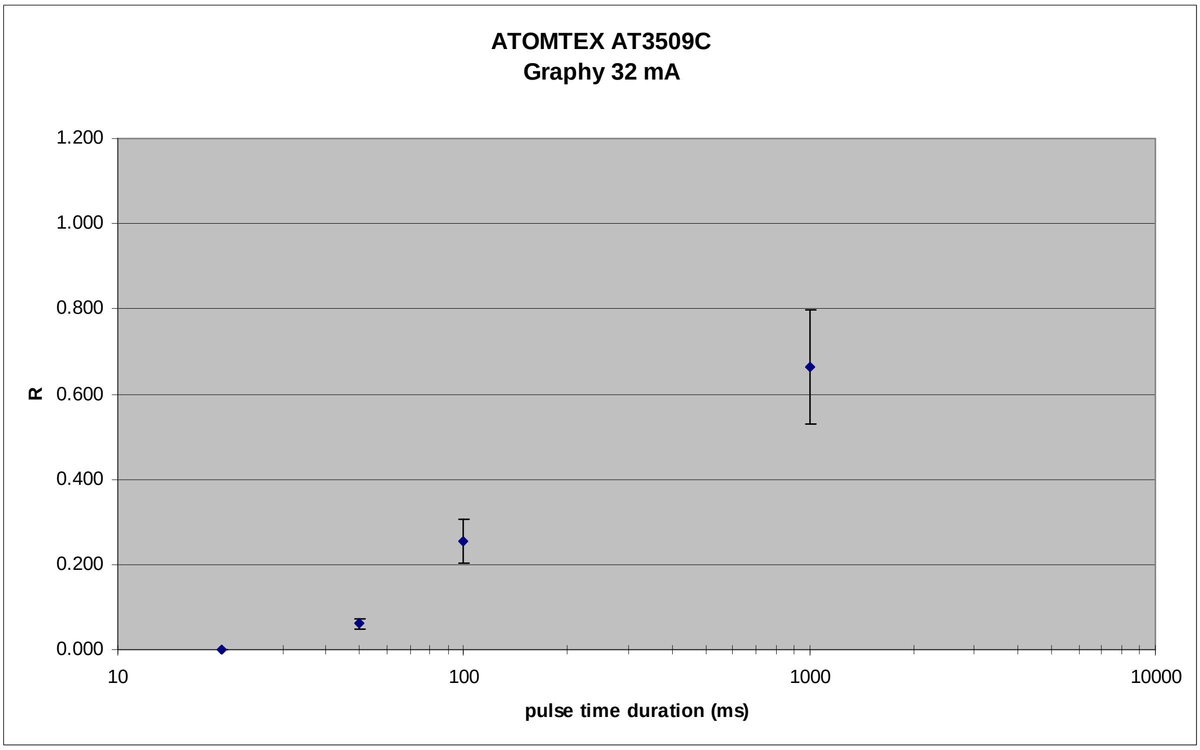

Figure 41. Response of AT 3509C in multi-pulsed mode

3.2.3 Conclusion on tests in pulsed mode - response of each APD

DMC2000XB

Effect of pulse frequency

- Variation of response : 25 to 30%
- Response better for 20 pps (close to 1) because conditions close to continuous field
- At 1 pps, the pulse frequency is low enough to give the same response in single pulsed mode
- 20% difference between 1 and 20 pps at 1.8 $Sv.h^{-1}$

Effect of dose rate

- Response within +/- 30% up to 1.8 $Sv.h^{-1}$
- Response decreasing with dose rate
- Response 0.5 at 5 $Sv.h^{-1}$ (extrapolated value) with respect to response in continuous mode
- Response 0.4 at 6 $Sv.h^{-1}$
- Response lower than 0.1 for dose rate higher than 20 $Sv.h^{-1}$

Effect of pulse width

- Response 0.7 for 20 ms to 100 ms and 1.2 for 1000 ms
- For 1000 ms: response consistent with continuous mode
- Increasing of 40% between 100 and 1000 ms

EPD Mk 2.3

Effect of pulse frequency

- Variation of response : 40% at 1.8 $Sv.h^{-1}$ and 25% at 6 $Sv.h^{-1}$
- 40% difference between 1 and 20 pps at 1.8 $Sv.h^{-1}$

Effect of dose rate

- Response within +/- 30% up to 1.8 $Sv.h^{-1}$
- Response decreasing with dose rate
- Response 0.4 at 6 $Sv.h^{-1}$
- Response 0.5 at 5 $Sv.h^{-1}$ (extrapolated value) with respect to response in continuous mode
- Response lower than 0.1 for dose rate higher than 50 $Sv.h^{-1}$

Effect of pulse width

- Response 0.6 for 20 ms to 100 ms and 0.75 for 1000 ms
- For 1000 ms: consistent with continuous mode
- Increasing of 20% between 100 and 1000 ms

EDM III

Effect of pulse frequency

- Variation of response : <10%
- Less than 10% difference between 1 and 20 pps at 1.8 $Sv.h^{-1}$

Effect of dose rate

- Response within +/- 30% at 1.2 $Sv.h^{-1}$
- Over-response from 1.8 $Sv.h^{-1}$ to around 10 $Sv.h^{-1}$
- Response decreasing with dose rate from 1.6 to 0.1 from 1.8 to 50 $Sv.h^{-1}$
- Response 0.5 around 26 $Sv.h^{-1}$ with respect to response in continuous mode
- Response lower than 0.1 for dose rates higher than 50 $Sv.h^{-1}$

Effect of pulse width

- For 1.8 $Sv.h^{-1}$: response within +/- 30%
- For 1000 ms: consistent with continuous mode

PM1621A:
No signal in pulsed mode

DIS-100:

Effect of pulse frequency
- Variation of response : 30%
- 15% difference between 1 and 20 pps at 1.8 $Sv.h^{-1}$

Effect of dose rate
- Response within +/- 30% for all dose rates up to 55 Sv.h-1,

Effect of pulse width
- A large dispersion of the results is observed. It is probably due to the resolution of the reading (10 µSv). Indeed, the total dose equivalent received by the detector during the measurements was of about 80 mSv and as the annealing procedure of the detectors cannot be used between measurements, therefore one does not know which detector (among the three detectors which composed the DIS dosemeter) is used for measurements.

EDD30:

Effect of pulse frequency
- Variation of response : 10% at 1.8 $Sv.h^{-1}$ and 40% at 6 $Sv.h^{-1}$

Effect of dose rate
- Response within +/- 30% up to 6 $Sv.h^{-1}$ for 20 pps
- Response decreasing with dose rate: the effect of saturation observed in continuous mode for dose rates higher than 2 $Sv.h^{-1}$ is confirmed
- Response 1 at 6 $Sv.h^{-1}$ for 20 pps,

Effect of pulse width
- Response between 1 and 1.4 between 20 and 1000 ms
- Increasing of 10% between 100 and 1000 ms

AT3509C:

Effect of pulse frequency
- Variation of response : 30% for 10 to 20 pps
- No response at 1 pps

Effect of dose rate
- Response decreasing with dose rate
- Response 0.3 at 1.2 $Sv.h^{-1}$
- Response 0.5 at 1 $Sv.h^{-1}$ (extrapolated value)
- Response lower than 0.1 for dose rates higher than 6 $Sv.h^{-1}$

Effect of pulse width
- Decreasing from 0.3 to 0 from 100 ms to 20 ms
- Response at 1000 ms: consistent with continuous mode

PM1621A, equipped with a Geiger-Muller tube, does not give any signal in pulsed mode.
The other APDs provide a response in pulsed mode, this means that they could be used in routine dosimetry with correction factors.
DMC 2000XB, EPD Mk2.3, EDMIII, EDD30 and AT3509C contain all a silicon detector, the differences of their response is probably due to the time response of the electronics.
The DIS has a "hybrid" technology between silicon and ionisation chamber which presents correct results, on the other hand the procedure for annealing the detector is a constraint.

4 Tests of APDs in hospitals

4.1 Introduction

Two different series of tests of APDs in real conditions in hospitals were done.

The first type of tests consisted in using a real IR facility and phantoms to simulate the operator and the patient, considering different realistic set-ups. Hp(10) reference value was measured with thermoluminescent dosemeters. The objective was to study the behaviour of APDs in realistic conditions with an accurate knowledge of field parameters. These tests were not intended as type tests since the real reference dose was not known. The intention was just to identify some trends in the behaviour of the APDs, and to compare the values with a typical passive dosemeter used in practice.

The second series of tests was made in different European hospitals in routine practice. The interventional radiologists and cardiologists were asked to wear an APD and an additional passive dosemeter above their lead apron during daily practice. The dosemeters were worn several days to integrate doses of at least 300 μSv for several types of IR or IC procedures. The main objective of these tests was to have an overview of differences between active and passive dosimetry in routine practice in hospitals, where all kinds of procedures and parameter settings are used and without an accurate knowledge of the field parameters.

4.2 Tests of APDs on phantoms

4.2.1 Material and methods

4.2.1.1 Introduction

The first series of tests of APDs in real conditions was made positioning the APDs on an ISO slab phantom representing the operator and using an anthropomorphic Rando-Alderson phantom representing the patient. The dosemeters were irradiated with a facility able to reproduce some main conditions of procedure fields. The tests were performed in the EHSAL University School for teaching in Medical Imaging, Brussels, Belgium.
The following APDs were tested: DMC 2000XB, EPD Mk2.3, EDMIII, PM1621A, DIS-100 and EDD30. The AT3509C was not tested because it was not available at the period of the measurements.

4.2.1.2 Facility description

The X-ray tube is a PHILIPS BZR79 Optimus tube (Figure 42). The tube voltage ranges from 40 to 150 kVp and the tube load from 0.5 to 850 mAs. The total inherent filtration of the tube corresponds to 3.5 mm aluminium equivalent. Extra aluminium and copper filters can be added. Only one filtration was chosen, together with 3 kVp settings.

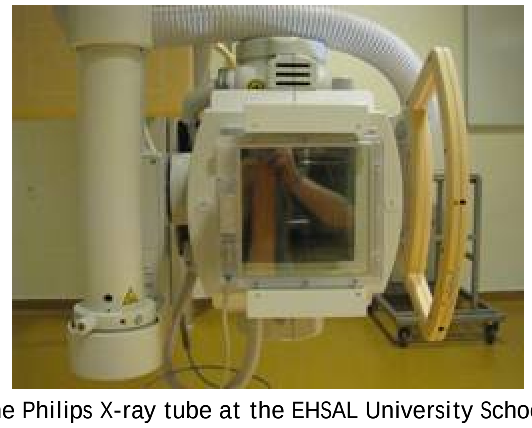

Figure 42. The Philips X-ray tube at the EHSAL University School: front view

4.2.1.3 Tests performed

The operator was represented by an ISO slab phantom and the patient by a Rando-Alderson phantom (Figure 43).
APDs were located on the ISO slab phantom together with a TLD as “reference”.

Figure 43. General set-up (left) and positioning of APDs and TLD reference on ISO slab phantom (right)

Four realistic set-ups were used to test the APDs (Figure 44):

1. Set-up AP direct: antero-posterior direct, tube head at 0°, slab at the level of the thorax of the Rando phantom
2. Set-up L direct: lateral direct, tube head at 90°, slab at the level of the thorax of the thorax of the Rando phantom
3. Set-up L indirect: lateral indirect, tube head at 90°, slab shifted towards the pelvis of the RA-phantom
4. Set-up AP indirect: antero-posterior indirect, tube head at 0°, slab shifted towards the pelvis of the RA-phantom

For all set-ups:

- The field size was 13.5 cm * 13.5 cm and was centred at the level of the thorax of the Rando phantom
- The additional filtration applied during the tests was 0.2 mm Cu + 1 mm Al.

The passive dosemeter used in the tests was the routine thermoluminescent dosemeter of the Belgian Nuclear Research Centre. This dosimetry service is approved by the Belgian Federal Agency of Nuclear Control, and accredited according to ISO 17025 standard [7]. The dosemeter uses TLD100 detectors (LiF:Mg,Ti) behind appropriate filters to estimate Hp(10) in most practical encountered spectra. The overall uncertainty, not including energy and angular dependence was of the order of 10% for these tests. For these tests specific energy calibrations were performed with respectively N-100, N-80 and N-60 radiation qualities (ISO 4037-3 standard [8]). These calibration factors were used for the different kVp's used in the test. With these specific calibration factors, an additional 20% uncertainty can be expected on the final TL results.

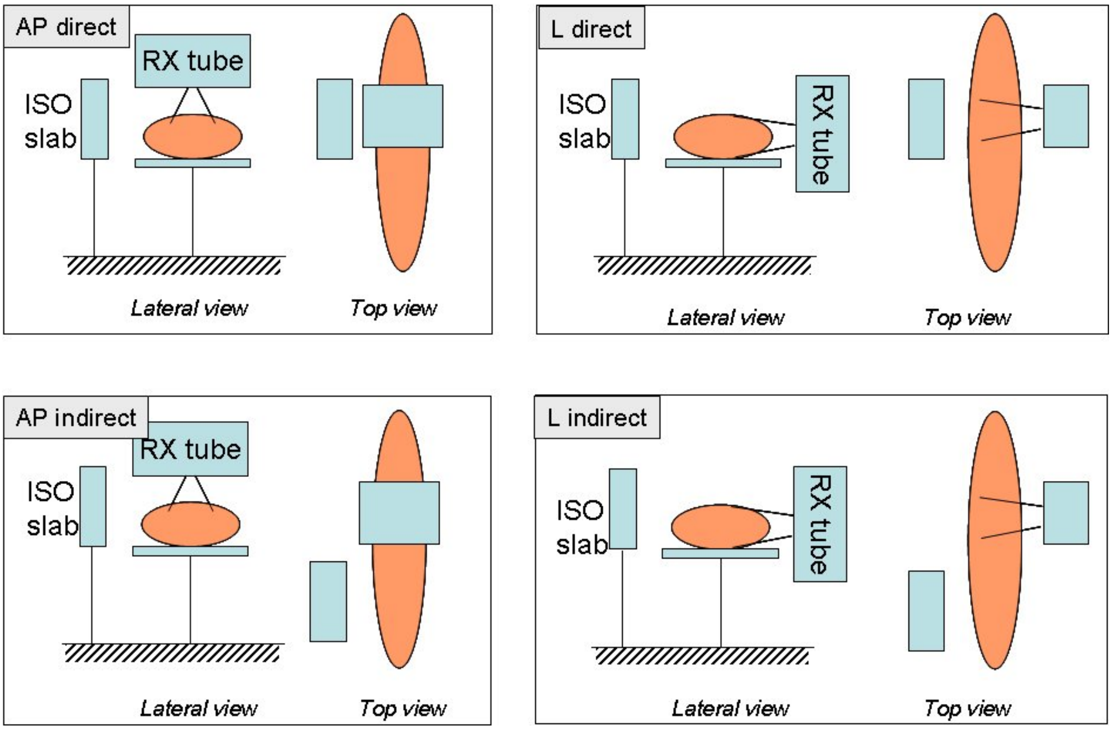

Figure 44. Set-ups used for tests of APDs on phantoms in realistic conditions

The effect of the variation of several parameters was studied:

- the dose rate,
- the kilo-Voltage,
- the duration of the pulse width.

The uniformity of the delivered dose on the surface of the ISO slab phantom was checked; it was found to be lower than 20%.

4.2.2 Results

4.2.2.1 Influence of dose rate

Figure 45 presents the effect of the dose rate, at 80 kV, on the APD response. For this figure all irradiations (so different set-ups, different mAs) were put together. So next to dose rate, other effects might come into play. However, it can clearly be seen that the APD response is globally within the interval +/- 50%, except:

- PM1621A which does not respond at all. This result is consistent with tests in laboratory conditions in pulsed mode,
- EDMIII which in general over-estimates the personal dose equivalent, this is consistent with tests in laboratory conditions.

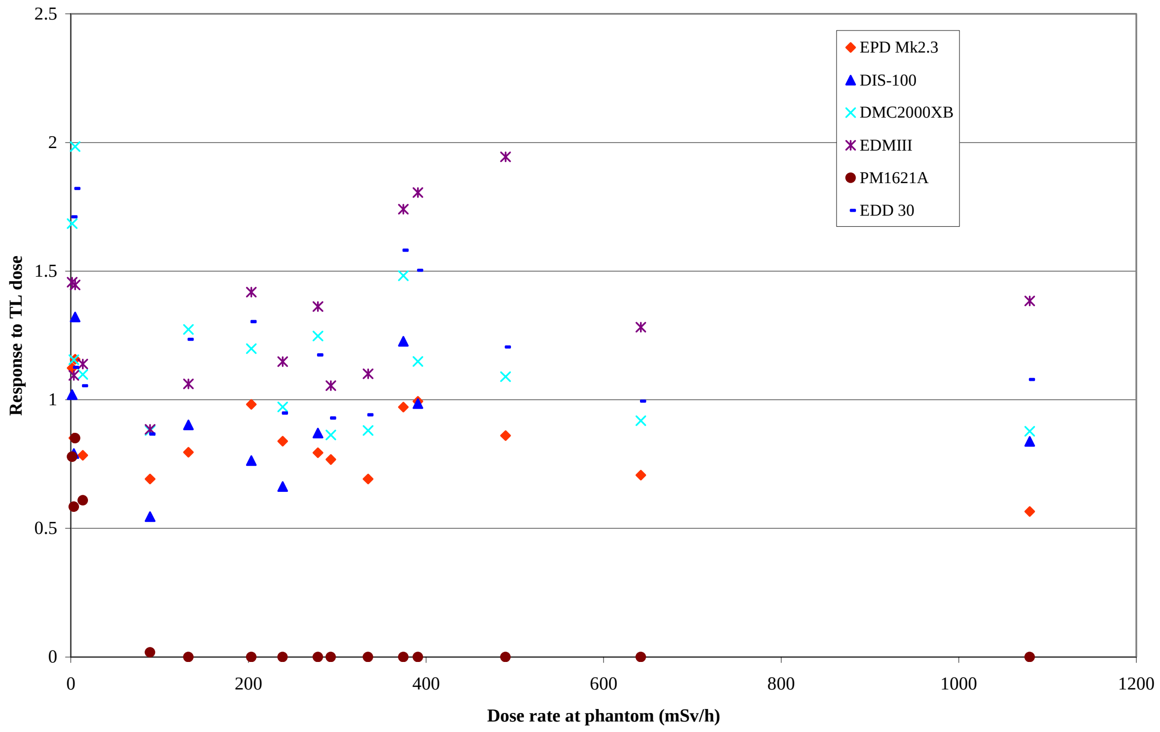

Figure 45. Influence of dose rate on APD response at 80 kV at set up AP direct.

4.2.2.2 Effect of kilo-Voltage compared to TLD

The figures 46 to 50 present the effect of the applied kilo-Voltage. The beam intensity and pulsed width were kept fixed: 625 mA and 20 ms.

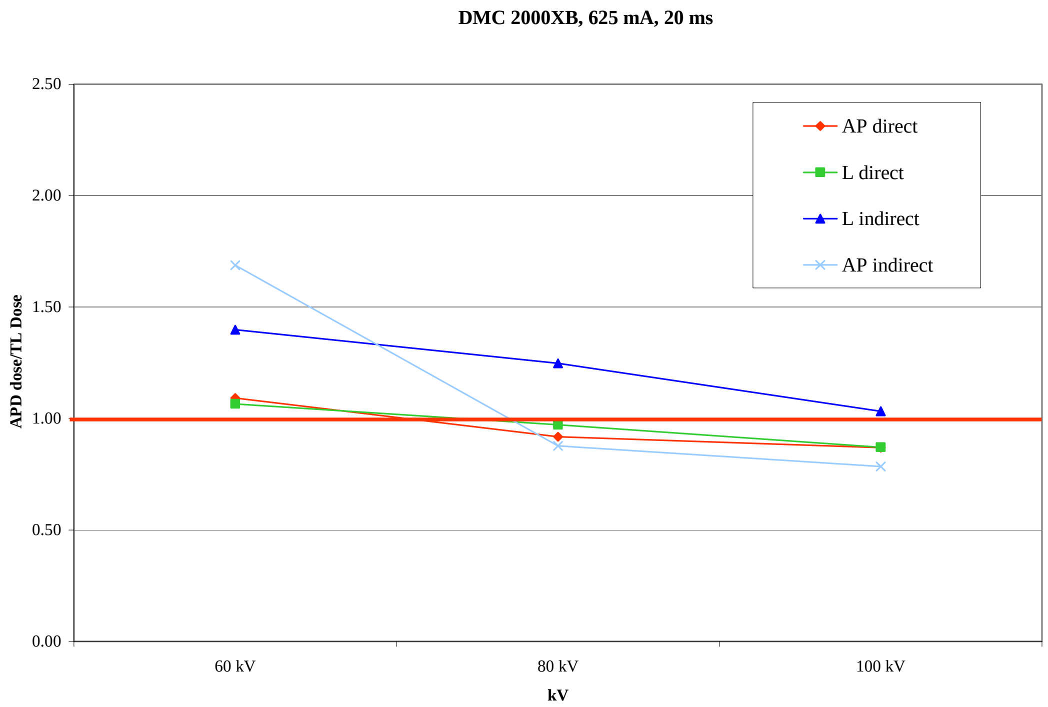

Figure 46. Influence of kV on APD response (625 mA, 20 ms) for DMC 2000XB

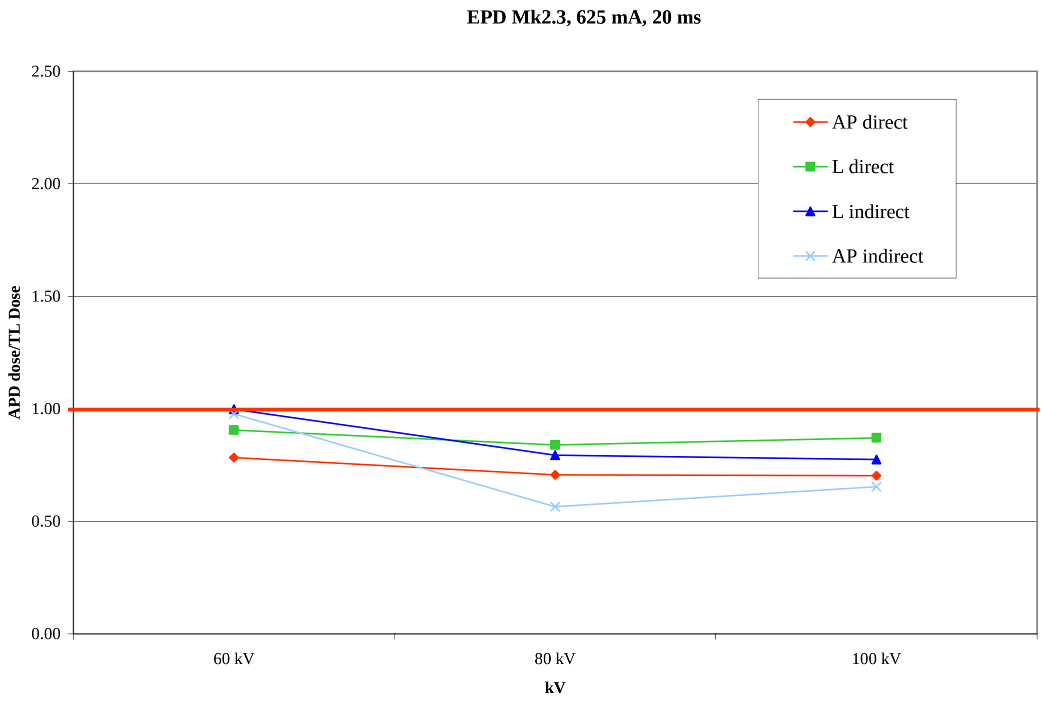

Figure 47. Influence of kV on APD response (625 mA, 20 ms) for EPD Mk2.3

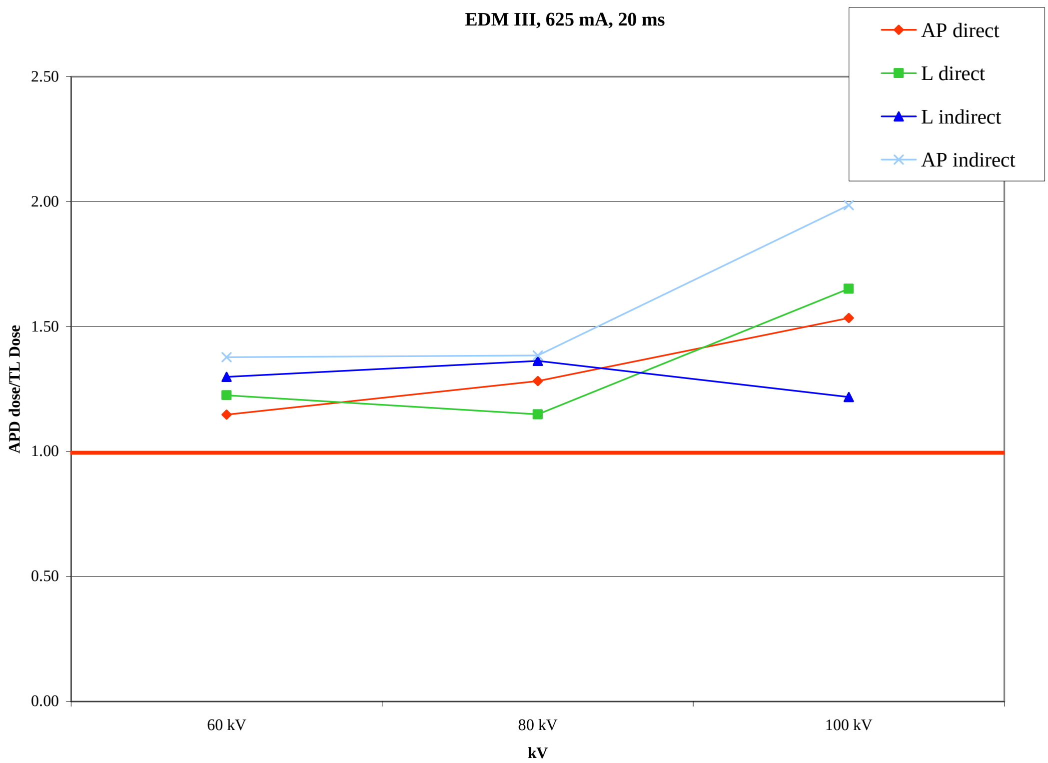

Figure 48. Influence of kV on APD response (625 mA, 20 ms) for EDM III

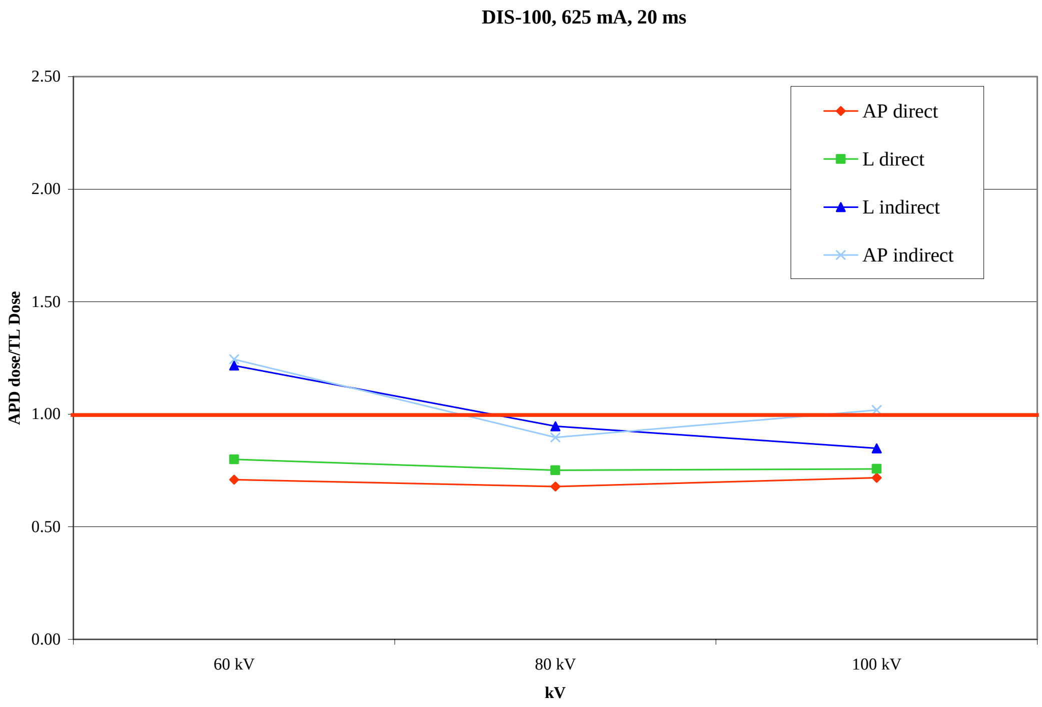

Figure 49. Influence of kV on APD response (625 mA, 20 ms) for DIS-100

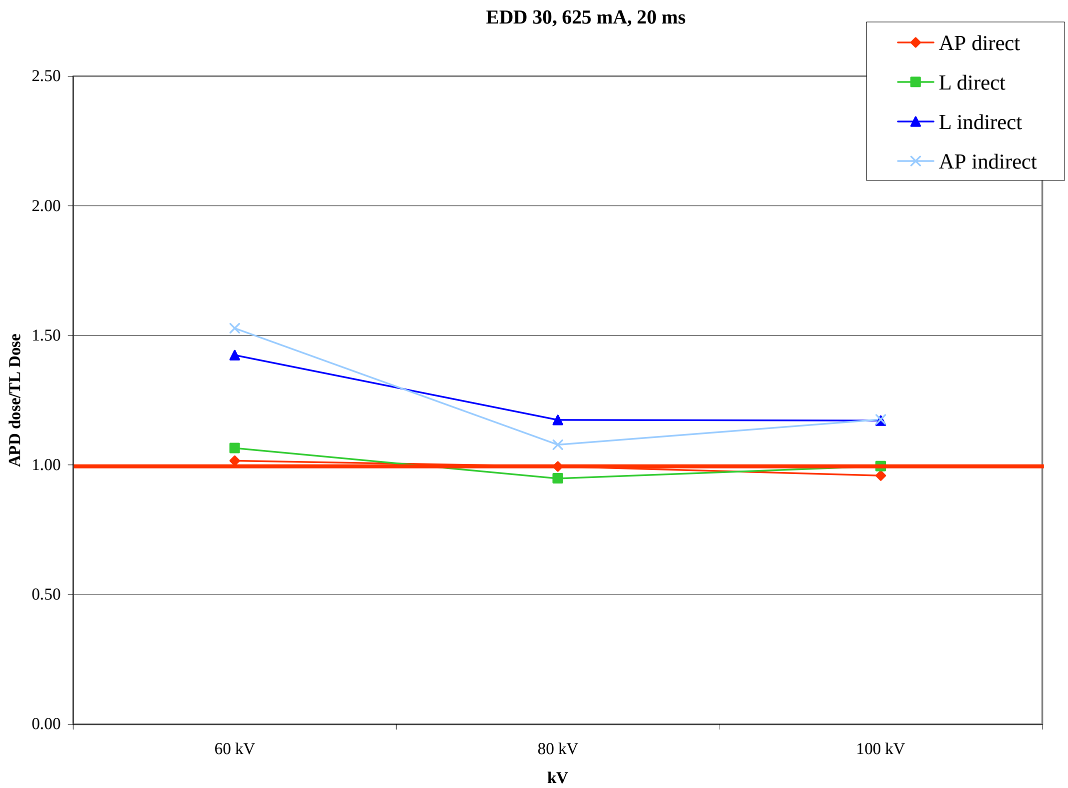

Figure 50. Influence of kV on APD response (625 mA, 20 ms) for EDD 30

4.2.2.3 Effect of pulse width

The figures 51 to 55 present the effect of pulsed width.

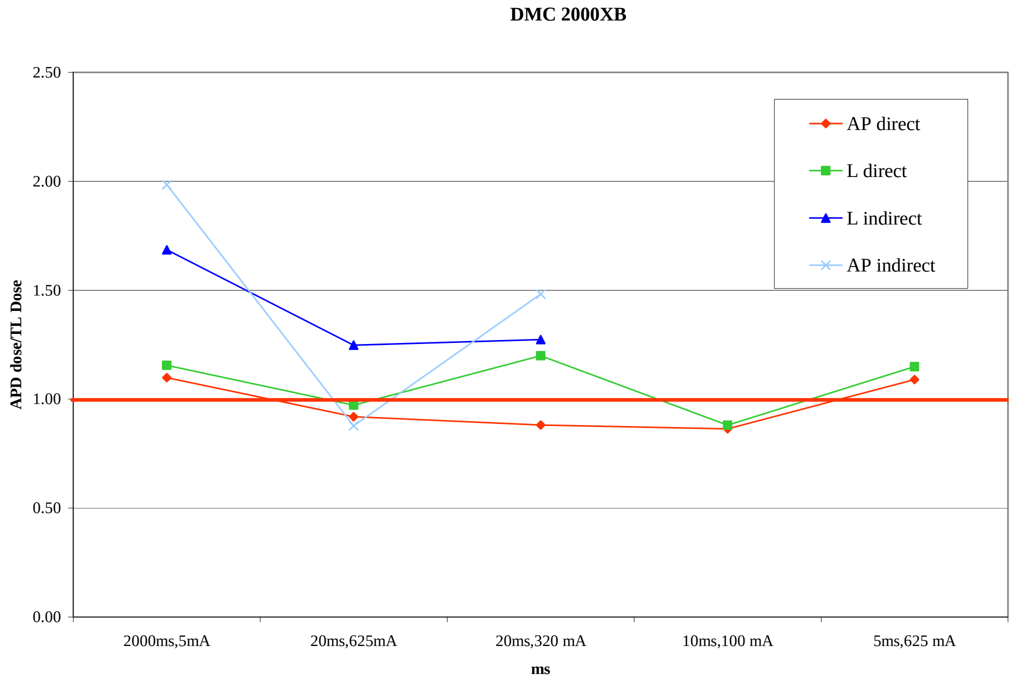

Figure 51. Influence of pulse width on APD response (625 mA, 20 ms) for DMC 2000XB

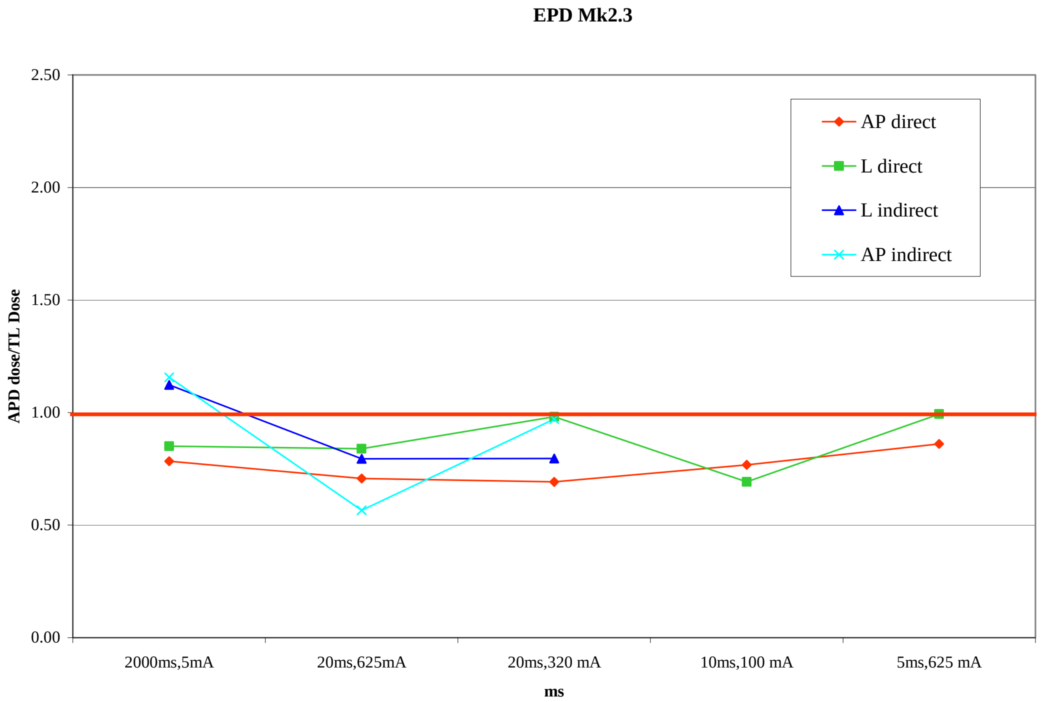

Figure 52. Influence of pulse width on APD response (625 mA, 20 ms) for EPD Mk2.3

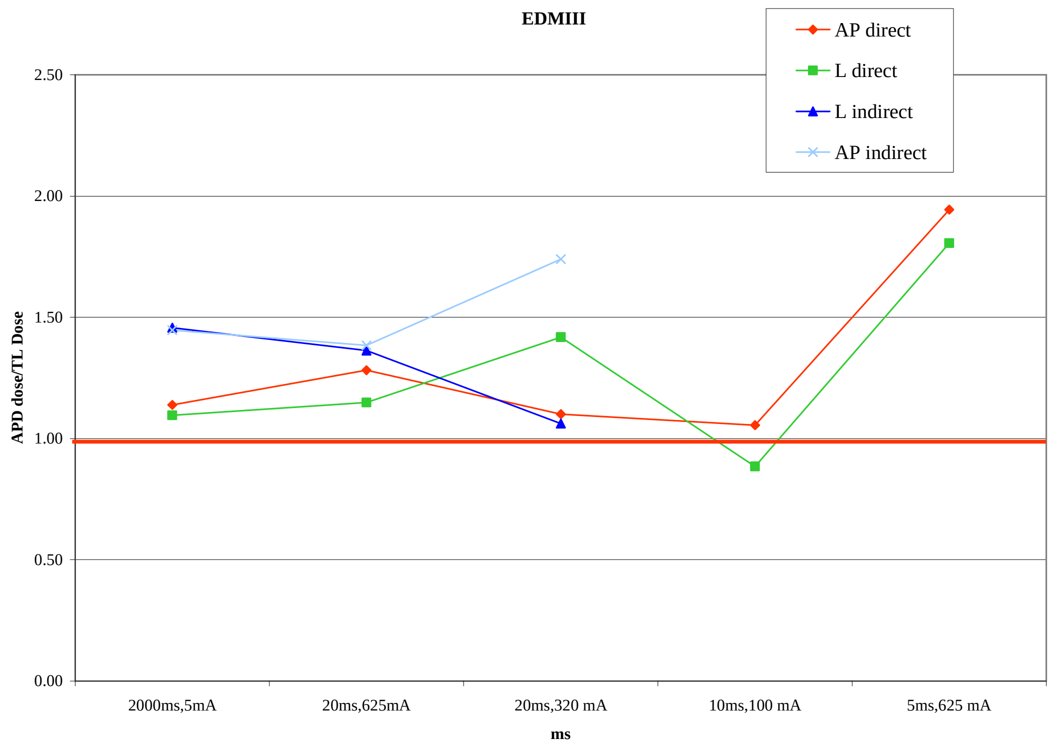

Figure 53. Influence of pulse width on APD response (625 mA, 20 ms) for EDM III

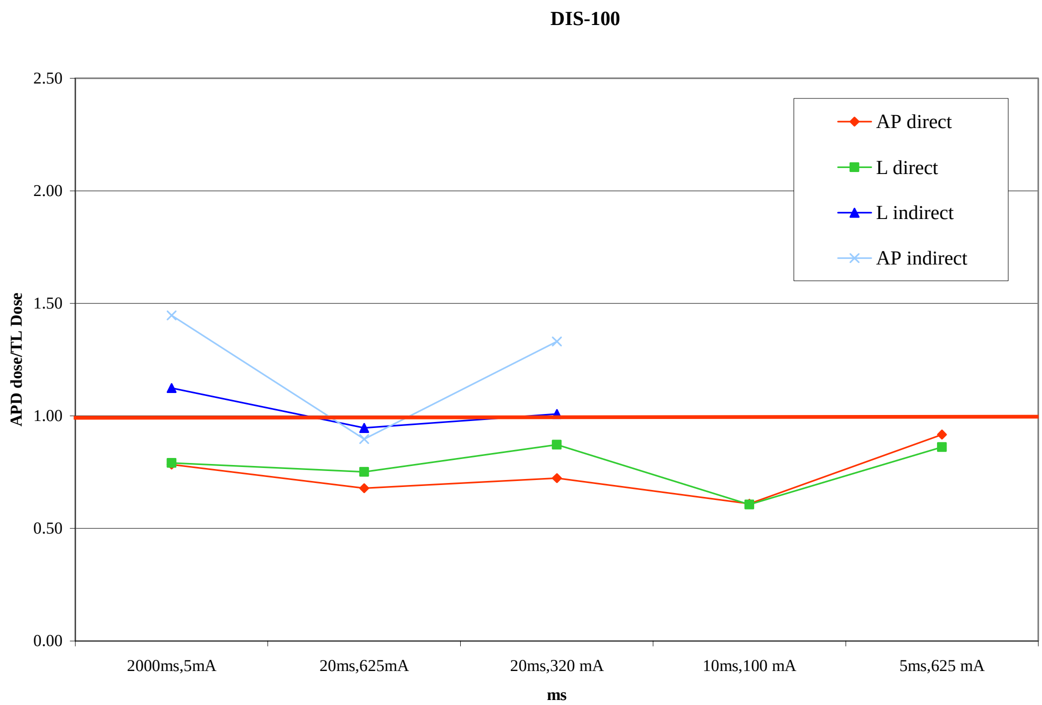

Figure 54. Influence of pulse width on APD response (625 mA, 20 ms) for DIS-100

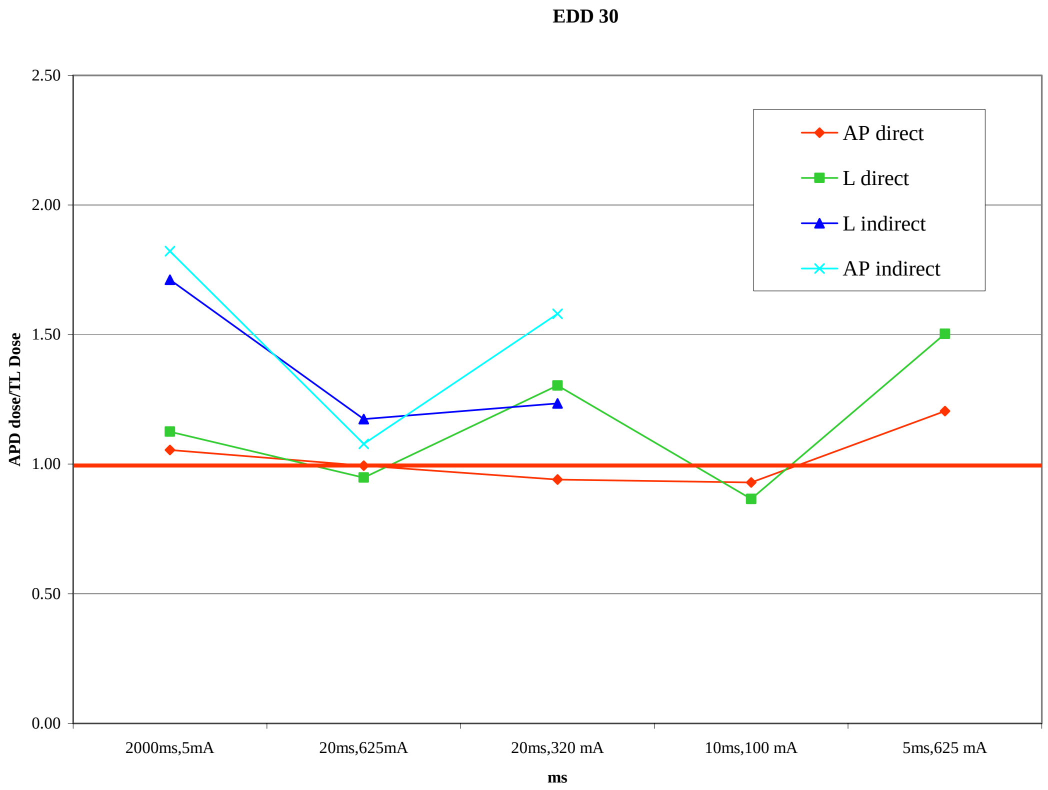

Figure 55. Influence of pulse width on APD response (625 mA, 20 ms) for EDD 30

4.2.3 Conclusion

For several realistic set-ups with different kVp and pulse width settings, the response of all APDs is roughly within the interval +/- 30% considering the passive dosemeter as the reference. In general this agreement is very satisfactory. The DMC 2000XB and EDD30 slightly overestimate compared to the TLD whereas the EPD Mk2.3 and the DIS-100 slightly underestimate. The EDM III gives higher responses, within 50%. For none of the APD's no important influence of the kVp nor pulse width was seen. This means that, for these realistic exposures, the problems encountered in the pulsed mode tests do not occur, probably because the dose rate was lower than 1 $Sv.h^{-1}$. The PM1621A did not respond in any pulsed field test, as was also observed in laboratory tests. It must be noted that these tests have only tested the APDs in scattered fields, not the direct beam.

4.3 Tests of APDs on operators

4.3.1 Material and methods

Operators had to wear, side by side, one additional APD and additional passive dosemeter above the lead apron. The dose provided by the passive dosemeter was given according to the routine measurement protocol (background removed).
At least 300 µSv were integrated by the passive dosemeter for each measurement which covered different IR/IC procedures.
The tests were conducted in parallel in different hospitals in different European countries.

Four dosemeters were tested: DMC 2000XB, EPD Mk2.3, EDMIII and DIS-100.

4.3.2 Results

The results are presented in Figure 56 as the distribution of APD response compared to the response of the passive dosemeter.
Globally, with respect to passive dosemeters:

- DMC 2000XB (mean 0.95), EPD Mk2.3 (mean 0.69) and DIS-100 (mean 0.87) have a slight under-response,
- EDMIII seems to have a different behaviour, but since only a few data were collected, statistics are not reliable enough to make some final conclusions yet.

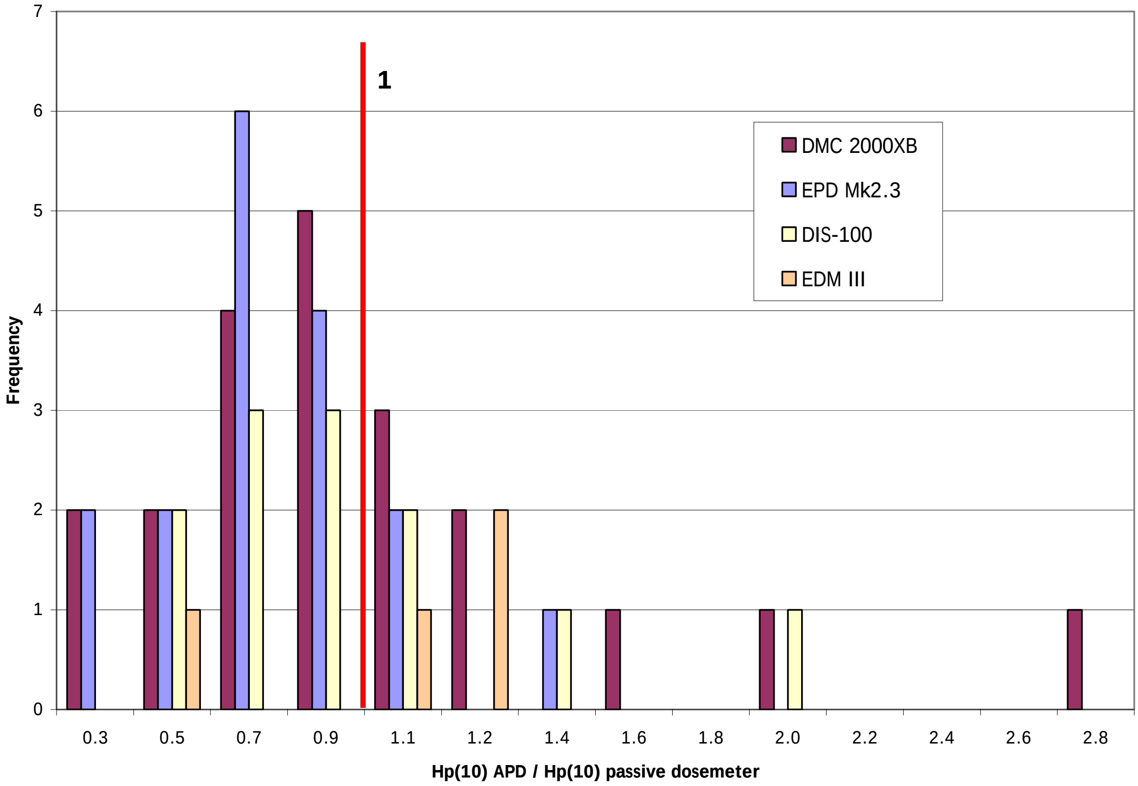

Figure 56. Distribution of APD response compared with passive dosemeter response in realistic conditions

4.3.3 Conclusion

Four dosemeters were tested in fully realistic conditions: DMC 2000XB, EPD Mk2.3, EDMIII and DIS-100. Three dosemeters have a slight under-response with respect to passive dosemeters (DMC 2000XB, EPD Mk2.3 and DIS-100), of course with a large spread in results. In general these results agree with the laboratory and static hospital tests. Statistics are not reliable enough to identify a tendency for EDMIII.

5 General conclusions

This work determined first the real radiation field characteristics encountered in IR/IC and identified seven APDs deemed suitable for application in this field.
The tests performed with reference continuous X-ray beams allowed to define the dose, the dose rate, the energy and the angular response of these dosemeters. All APDs have a linear response with the dose and most of them have a satisfactory response at low energies from 24 keV, which is sufficient for IR/IC. Most APDs can stand high dose rates up to 10 $Sv.h^{-1}$, except PM1621A for which the response is diverging rapidly from 1 $Sv.h^{-1}$ and EDD30 which saturates for dose rates above

2 Sv.h^{-1}. However, as indicated in table 1, the dose rates in the direct beam can be much higher than those tested here. So these tests in continuous fields do not mean that the APDs will correctly handle these very high dose rates in the direct beam. In addition, a problem of angular response at low energies was observed with PM1621A.

The influence of the frequency and duration of pulses on the APD responses was studied with reference pulsed X-rays beams.
PM1621A, equipped with a Geiger-Muller tube, does not give any signal in pulsed mode. The other APDs provide a response in pulsed mode, this means that they could be used in routine dosimetry, if some correction factors are applied. This aspect will be treated in the guidelines (objective n°5 of this WP). These results show that it is important to add tests in pulsed mode in Type-Test on APDs in IEC 61526 standard [9].

The behaviour of APDs was confirmed with tests in real conditions in hospitals. Four dosemeters were tested in fully realistic conditions: DMC 2000XB, EPD Mk2.3, EDMIII and DIS-100. Three APDs have a slight under-response with respect to passive dosemeters (DMC 2000XB, EPD Mk2.3 and DIS-100). Statistics are not reliable enough to identify a tendency for EDMIII.

All the tests show roughly the same trends and indicate that most of tested APDs could be used in routine dosimetry (possibly with correction factors), if no exposure to the direct beam takes place. This aspect will be treated in the guidelines that are the objective n°5 of this WP.

6 References

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ANNEXE (technical notes of APDs)

DMC2000XB (MGPi) (part 1/2)

http://www.mirion.com/en/products/datasheets/hp/144271EN-B_DMC2000XB.pdf

MIRION TECHNOLOGIES

DMC 2000XB
Active Dosimetry - Dosimeters

FEATURES

The DMC 2000XB is an X-ray/gamma and beta detection dosimeter, featuring dose rate and programmable alarms. The DMC 2000XB is user friendly, lightweight and water resistant.

- X-ray/gamma energies: 20 keV to 6 MeV
- Beta energies 60 keV to 3.5 MeV
- Dedicated to simultaneous measurements of X-ray, gamma and beta radiations
- Small, light, ergonomic, compact and rugged
- Compliant with international standards and local rules
- Hand free communication reading system with data centralization

DMC 2000XB

Personal Electronic Dosimeter

The use of β particle emitters for radiation therapies (treatments of eye tumors, coronary arteries, or inflammatory joint diseases) has significantly increased during recent years, and this has made the use of dedicated β dosimeters essential.

The DMC 2000XB was designed, to allow simultaneously deep dose equivalent Hp(10) and shallow dose equivalent Hp(0.07) measurements for X-ray, gamma and beta emissions. Furthermore it can be used as an operational dosimetry system for all medical risk assessment including radiological exposures, and in addition has applications in radioactive source production facilities, nuclear power plants and other nuclear facilities.

RELATED PRODUCTS

MGP Instruments offers a range of products which can be used with the DMC 2000XB to create integrated dosimetry systems including:

- LDM 220, LDM 230 proximity readers
- LDM 2000 pass-by data exchange
- DOSISERV dosimetry centralization and access control software
- DOSIMASS dosimeter configuration software
- DOSICARE and DOSIFAST operational dosimetry software
- IRD 2000 irradiator for dosimeters

DMC2000XB (MGPi) (part 2/2)

http://www.mirion.com/en/products/datasheets/hp/144271EN-B_DMC2000XB.pdf

PHYSICAL CHARACTERISTICS

- Complies with IEC 61526 Ed 1
- Measurement and display:
  - display units: mSv, µSv or mrem
  - dose display: 1 µSv to 10 Sv (0.1 mrem to 1000 rem)
  - dose rate display: 0.01 mSv/h to 10 Sv/h (1 mrem/h to 1000 rem/h)
  - measurement range: 0.1 µSv/h to 10 Sv/h
- Linearity:
  - < ± 20 % up to 1 Sv/h (100 rem/h)
  - < ± 30 % up to 10 Sv/h (1000 rem/h) for X, γ > 60 keV and β
  - < ± 25 % up to 3 Sv/h (300 rem/h) for X < 60 keV
- Energy response:
  - X, γ rays: 20 keV to 6 MeV
  - β E_{mean} > 60 keV (E_{max} : 0.22 MeV to 2.3 MeV)
- Accuracy: < ± 10 % (^{137}Cs, – 30 mSv/h, including ± 5% of extended uncertainty K=2)

ELECTRICAL CHARACTERISTICS

- Li MnO_2 standard CR2450 battery: battery life > 9 months (8h per day in run mode)

MECHANICAL CHARACTERISTICS

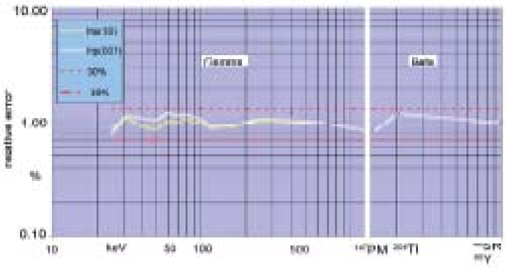
- Dimensions: 87 x 48 x 28 mm (3.4 x 1.9 x 1.1 in) with clip
- Weight with battery: < 59 g (2 oz)
- Worn by a replacable clip

ENVIRONMENTAL CHARACTERISTICS

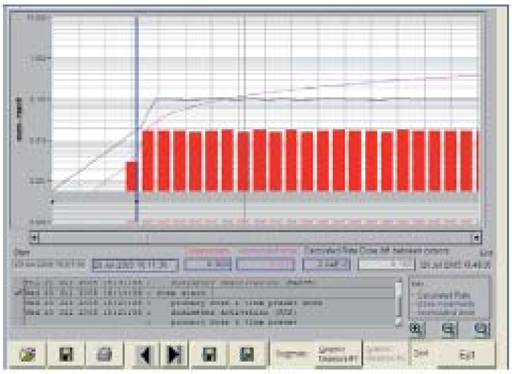
- Temperature range: -10°C to 50°C (14°F to 122°F)
- Humidity: < 90 % at 42°C (108°F)
- Storage: -30°C to 71°C (-22°F to 160°F)
- Shock, vibration and drop resistant, water resistant IP42
- EMC: complies and exceeds CE standards

CUSTOMIZATION

- setup can be acchieved by user with DOSIMASS software



DMC 2000XB energy response



The history enables detailed event reconstruction for efficient analysis of incident situation circumstances.

Hp(10) - deep dose

Hp (0.07) - shallow dose

With the display directly visible to the wearer, many functions are available using alphanumeric characters.

Technician using the hands-free capability of the DMC 2000S with LDM 2000 reader.

MIRION TECHNOLOGIES Health Physics Division

www.mirion.com
144271EN-B

Mirion Technologies (MGPI) Inc
5000 Highlands Parkway
Suite 150
Smyrna Georgia 30082
USA
T +1.770.432.2744
F +1.770.432.9179

Mirion Technologies (MGPI) SA
BP 1
F-13113 Lamanon
France
T +33 (0) 4 90 59 59 59
F +33 (0) 4 90 59 55 18

Mirion Technologies (RADOS) Oy
P.O. Box 506
FIN-20101 Turku
Finland
T +358 2 468 4600
F +358 2 468 4601

Mirion Technolgies (RADOS) GmbH
Ruhrstrasse 49
DE-22761 Hamburg
Germany
T +49 (0)40 851 93-0
F +49 (0)40 851 93 256

EPD Mk2.3 (Siemens) (part 1/2)

http://www.thermo.com/eThermo/CMA/

Product Specifications

The EPD® Mk2 combines unequalled radiological performance with advanced software and hardware features.

EPD® Mk2

Electronic Personal Dosimeter

Advanced radiological performance

Detector technology based upon the well proven EPD® Mk1

Small and lightweight

Ergonomic rugged design

The EPD® Mk2 is suitable for use as a single stand-alone dosimeter or as part of a comprehensive dosimetry management system using renowned hardware and software packages. The high quality and standard battery contribute to competitive lifetime costs.

- Uses standard AA battery
- Excellent response to gamma, beta and x-radiation
- Loud, audible alarm.
- Rapid Infra-red communications to reader/PC or stand-alone operation
- Excellent immunity to electromagnetic interference
- Easy to read display with optional backlighting

leaders in radiation measurement & protection

Thermo ELECTRON CORPORATION

EPD Mk2.3 (Siemens) (part 2/2)

http://www.thermo.com/eThermo/CMA/

System Specifications

Radiological

- Sensitive to X and γ radiation, β particles
- Direct readout of dose equivalents Hp(10) (deep/whole body) and Hp(0.07) (shallow/skin)
- Display Units: Sv and rem (with prefixes), OR scaled in Sv and cGy (with prefixes)
- Neutron response <2%
- Dose display and storage 0μSv to >16Sv (0 mrem to >1600 rem) auto ranging
- Resolution for display 1μSv (0.1 mrem), up to 10mSv (1 rem)
- Resolution for storage 1/64μSv (=1.5 μrem)
- Dose rate display 0μSv/h to >4Sv/h (0 mrem/h to >400 rem/h) auto ranging
- Alarms dual Hp(10) dose and dose rate alarms; Hp(0.07)dose and dose rate alarms
- Energy response:

Photon, Hp(10)
±50% 15keV to 17keV (ref. 137Cs)
±20% 17keV to 1.5MeV (ref. 137Cs)
±30% 1.5MeV to 6MeV (ref. 137Cs)
±50% 6MeV to 10MeV (ref. 137Cs)

Photon,Hp(0.07)
±30% 20keV to 6MeV (ref.137Cs)
±50% 6MeV to 10MeV (ref. 137Cs)

Beta, Hp(0.07)
±30% 250keV to 1.5MeV E (ref.90Sr/90Y)

- Angular response:

Hp(10) 137Cs ±20% up to ±75°

Hp(10) 241Am ±50% up to ±75°

Hp(0.07) 90Sr/90Y ±30% up to ±55°

- Accuracy

Hp(10) 137Cs
±10% Hp(0.07) 90Sr/90Y ±20%

- Dose rate linearity

Hp(10) 137Cs
±10% <0.5Sv/h (<50 rem/h)
±20% 0.5Sv/h to 1Sv/h(50 to 100 rem/h)
±30% 1Sv/h to 2Sv/h(100 to 200 rem/h)
±50% 2Sv/h to 4Sv/h(200 to 400 rem/h)
Between 4Sv/h and 50Sv/h continues to accumulate dose at a rate > 4Sv/h

Hp(0.07) 90Sr/90Y
±20% <1Sv/h (<100 rem/h)
Between 1Sv/h and 50Sv/h continues to accumulate dose at a rate > 1Sv/h

Memory

- 10 year data retention without battery
- Short term dose registers for Hp(10) and Hp(0.07)
- Approved Dosimetry Service (Dose of Record) dose memory area with password protection
- Peak dose rates with time of occurrence
- All stored times have 1 second resolution
- Count down timer, 1 hour 39 minutes 59 seconds maximum, resolution 1 second
- Event log, 23 entries for time recording of alarms, etc., for incident assessments
- Dose profile history: settable interval from 2 seconds to 35 hours, stores transitions of Hp(10) and Hp(0.07) at a resolution of 1μSv (0.1mrem); will store up to 579 records for transitions up to 127μSv or less

Alarms

- Audible and visual alarms for dose, dose rate, count down time, read time and failure modes.
- Hp(10) dose chirp settable from 0.01μSv/chirp to 100μSv/chirp (1μrem to 10 mrem/chirp)

Electrical and Mechanical

- Power supply: single AA battery 1.5V alkaline cell for typically 8 weeks continuous operation, OR 3.6V lithium for typically 5 months continuous operation (interchangeable)
- Alarm sounder: fully sealed typically 97dB(A) at 20cm with multiple modes
- Communications: IR interface up to 1 meter range (39")
- Display and function control by a single button on front (recessed to prevent inadvertent operation)
- Size: 85 x 63 x 19 mm (3.3" x 2.5" x 0.8") excluding clip
- Weight: 95 g (3.2 oz) including battery and clip
- Case material: high impact polycarbonate/ABS blend

Environmental

- Operating temperature: -10 °C to +40 °C (+15 °F to +105 °F)
- Humidity: 20% to 90% RH non-condensing
- Vibration: IEC 1283: 2g, 15min., 10-33Hz
- Shock: 1.5m drop on each surface onto concrete
- EMI/EMC: Exceeds MIL STD 461D RS103

USA:
504 Airport Road
Santa Fe, NM 87507
USA
(505) 471 3232
(505) 428 3535 fax

UK:
Bath Road
Beenham, Reading RG7 5PR
England
+44 (0) 118 971 2121
+44 (0) 118 971 2835 fax

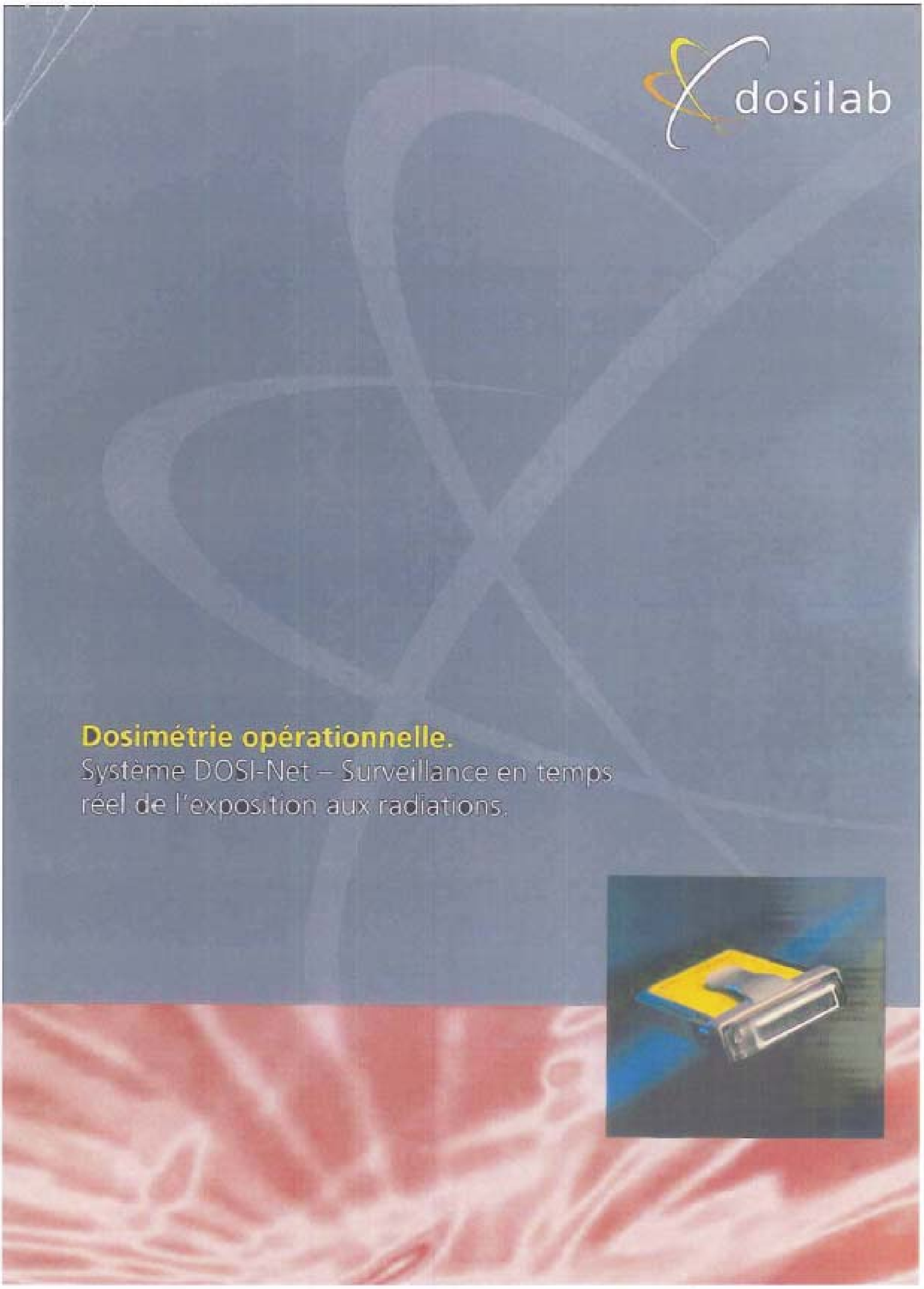
Rest of Europe:
Frauenauracher Strasse 96
D 91056 Erlangen
Germany
+49 (0) 9131 909-0
+49 (0) 9131 909-205 fax

Rest of World:
Viktoriastrasse 5
D 42929 Wermelskirchen
Germany
+49 (0) 21 96 72 28 0
+49 (0) 21 96 72 28 24 / 25

Thermo
ELECTRON CORPORATION

EDM III (Panasonic - Dosilab) (part 1/2)

http://www.dosilab.fr



EDM III (Panasonic - Dosilab) (part 2/2)

http://www.dosilab.fr

Caractéristiques techniques de l'APD.

L'APD utilisé dans le système de dosimétrie de Dosilab est fabriqué par Panasonic. Il est en totale conformité avec la norme IEC 61526 Ed.2.0 2005.

Objet	Spécification	Remarques
Modèle No.	ZP-1463AC1	
Dimensions	95 x 60 x 15 mm	L x H x l
Poids	100 g	
Alimentation	3.6 V 360 mAh Li-ion	Batterie rechargeable
Autonomie	> 16h	Temps de recharge < 4h
Système d'alarme	LED & Buzzer	Visuel & Auditif / programmable
Réponse aux Rayonnements		
Gamme de Dose	1µSv – 1 Sv	Hp(10) & Hp(0.07)
Gamme de débit de dose	0.5µSvh – 1 Svh	drHp(10) & drHp(0.07) affichage à partir de 1µSvh par pas de 1µSvh
Réponse en énergie	γ : 20KeV – 1.5 MeV ± 15% γ : 1.5MeV – 6.0 MeV ± 30% β : 500 KeV – 6.0 MeV ± 30%	rayons Gamma et X (photons) Particules Beta
Précision des doses	< ± 20% 5µSv - 10µSv < ± 10% 10µSv - 100µSv < ± 5% >100µSv	
Précision des débits de dose	± 15% 10µSvh - 50µSvh ± 10% 50µSvh - 100µSvh ± 5% >100µSvh	
Réponse angulaire	γ : ± 20% jusqu'à 60 ° β : ± 20% jusqu'à 60 °	^{137}Cs ^{241}Am
Alarmes du système		
Dépassement débit de dose	1Svh – 10 Svh	Alarme & affichage 999.9 mSvh
Dépassement de dose	> 999,9 mSv	Alarme & affichage 999.9 mSv
Batterie	< 2h autonomie	
Alarme d'utilisateur		
Alarme dose limite	1µSv – 999µSv	
Alarme débit de dose limite	1µSvh – 999µSvh	Configurables dans le profil d'utilisateur
Alarme de temps	1 min – 24 h	
Communication		
Sans fil / Bluetooth™	10 mètres	Requiert la station APD-Xmit
interface IR		

PM1621A (Polimaster) (part 1/2)

http://www.polimaster.com/products/electronic_dosimeters/personal/pm1621/

POLIMASTER

Innovating Radiation Detection Technologies Since 1992

X-RAY AND GAMMA RADIATION ELECTRONIC PERSONAL DOSIMETER

PM1621/PM1621A

The most efficient dosimeter available, unique features, high sensitivity, durability, reliability.
For Law Enforcement, Security, Scientists, Medical Professionals and other professionals exposed to radiation.

Due to unique characteristics,dosimeter capable to measure user's exposure levels when working with X-ray and to gamma radiation sources and record even minor fluctuations of natural background.

Dosimeter meets requirements of IEC 61526 standard.

The PM1621/PM1621A are designed to provide continuous measurementof:

- Personal dose equivalent rate of external photon radiation Hp(10)
- Personal dose equivalent of external photon radiation Hp(10)
- Time of dose accumulation.

Features

- Easy to use,two-button operation
- PC communication by IR interface
- Wide energy range 10 keV – 20 MeV
- Wide dose rate range - from least values of natural background up to 2 Sv/h
- Two independent dose and dose rate alarm thresholds
- Audible and visual alarms when thresholds are exceeded
- Storage of user PIN and 1000 readings of dose accumulation history (dose rate changes)
- LCD display, electroluminescent backlight
- Shockproof hermetic case
- Light weightand small dimensions

ALARM

LOCATION

MEASUREMENT

IRDA

Applications

- Medical professionals
- Personal of nuclear facilities
- Radiological and isotope laboratories
- Emergency service
- Scientist
- Other professionals exposed to radiation

Versions

- PM1621- up to 0.2 Sv/h
- PM1621A - up to 2 Sv/h

www.polimaster.com www.polismart.com

PM1621A (Polimaster) (part 1/2)

http://www.polimaster.com/products/electronic_dosimeters/personal/pm1621/

POLIMASTER

Innovating Radiation Detection Technologies Since 1992

X-RAY AND GAMMA RADIATION ELECTRONIC PERSONAL DOSIMETER

PM1621/PM1621A

SPECIFICATIONS

Detector	**Geiger-Muller tube**
Dose equivalent rate (DER) range Hp(10) **PM1621** **PM1621A**	 **0.01 μSv/h - 0.2 Sv/h** **0.01 μSv/h - 2 Sv/h**
Dose rate and dose threshold range	**within all measurement range**
Dose equivalent (DE) range Hp(10)	**0.01 μSv - 9.99 Sv**
Accuracy of DER measurement in the range: - 0.1 μSv/h - 0.1 Sv/h for PM1621 - 0.1 μSv/h - 1 Sv/h for PM1621A H is the dose equivalent rate, μSv/h	**±(15 + 0.0015/H + 0.01H)%**
Accuracy of DE measurement in the range 1 μSv- 9.99 Sv	**±15%**
Energy range	**10 keV - 20 MeV**
Energy response relative to 0.662 MeV (Cs-137) within the full energy range	**±30%**
Response time at discontinuous variation of DER (according to IEC 61526), no more than	**5s - at increase** **10s - at decrease**
Coefficient of variation	**< 15 %**
Survive after momentary influence of maximum permissible gamma radiation: PM1621 **PM1621A**	**1 Sv/h** **10 Sv/h**
Additional functions	**PC communication mode**
Drop test on concrete floor	**0.7 m**
Power supply	**One AA battery**
Battery lifetime	**12 months**
Battery discharge indication (partial and critical)	**indication on LCD**
Operating conditions: - temperature range - LCD indication - relative humidity (at 35°C) - pressure	 **- 40 ... + 60 °C** **- 20 ... + 60 °C** **up to 98%** **84 - 106.7 kPa**
Protection degree of case	**IP67**
Dimensions	**87 x 72 x 35 mm**
Weight (with battery), no more than	**150 g**

Design and specifications of the device can be changed without further notice.

CE ISO 9001

www.polimaster.com www.polismart.com

POLIMASTER, 112, M. Bogdanovich st., Minsk, 220040, Republic Belarus, phone: (375 17)217 70 80, fax: (375 17)217 70 81

DIS-100 (Rados) (part 1/2)

Technical note provided with the device

The World Leader in Personal Radiation Safety

SAFETY IS EFFICIENCY — RADOS

DIS-100

Wide Energy Personal Dosimeter

The revolutionary Direct Ion Storage detector used in the new DIS-100 Wide Energy Personal Dosimeter provides features never seen in pocket size before. A unique concept of combining traditional ion chamber and most modern solid state memory cell allows operation and radiological features not matched by any other detector type.

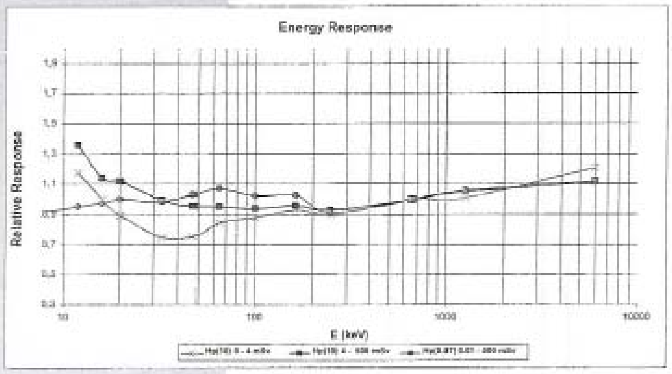
The energy response is much wider than in silicon diode detectors as currently used in electronic dosimeters. Also its response to pulsed fields, generated by X-ray machines and linear accelerators is perfect.

The detachable DIS-1 detector used in DIS-100 Wide Energy Personal Dosimeter has features that make it an ideal detector for personal dosimeter: due to the ion chamber based construction it operates totally without an external power supply and is therefore completely immune to external electro-magnetic fields, that are a common problem for today's electronic dosimeters. These features set the DIS detector truly on its own regarding reliability and makes the DIS-100 a real alternative for a legal dosimeter (making film badge or TLD unnecessary).

The dose accumulation of DIS-100 is linear up to 40 Sv/h dose rates, even in pulsed radiation fields. This guarantees accurate dose assessment in all accident situations.

These features make this new electronic dosimeter a unique choice for several applications, including medical, health care, military and nuclear industry.

The DIS-100 Wide Energy Personal Dosimeter can be used individually or as a part of computer based dosimetric access control system by using the PCR-1PC Adapter Unit and Rados DoseControl I Dosimetry Software Package.



The revolutionary Direct Ion Storage detector provides several unique features not matched in pocket size ever before

- **extremely wide energy range for photons**
  from 6 keV to 9 MeV for Hp(0.07)
  from 15 keV to 9 MeV for Hp(10)
- **perfect dose rate linearity**
  from 1uSv/h to 40 Sv/h with minimal variance
- **solid response for pulsed fields**
  better than 90% response to pulsed X-rays and accelerators
- **totally immune to EMI**
  absolutely no response to cellular telephones or radars
- **continuous dose integration even with battery off**
  the DIS detector is measuring continuously without external power

RADOS
synOdys group

Rados Technology Oy
Mustionkatu 2
P.O.Box 506
FIN-20101Turku
Finland
Tel. +358-2-468 4600
Fax +358-2-468 4601
www.rados.com

DIS-100 (Rados) (part 2/2)

Technical note provided with the device

DIS-100 Wide Energy Personal Dosimeter

Specifications

Radiation detected:	gammas, betas and X-rays
Detector type:	three chamber Direct Ion Storage detector DIS-1
Measurement range:	dose: Hp(10) 1 µSv - 50 mSv or 0.1 mrem - 5 rem* Hp(0.07) 10 µSv - 50 mSv or 1 mrem - 5 rem* dose rate: Hp(10) 0.1 mSv/h - 1 Sv/h or 100 mrem/h - 100 rem/h Hp(0.07) 1 mSv/h - 1 Sv/h or 1 rem/h - 100 rem/h * DIS-1 detector dose range is up to 500 mSv (resettable) and up to 40 Sv (non resettable) for external read out in case of accident
Calibration:	better than ± 5 % (Cs-137 1 mSv), Hp(10) better than ± 10 % (Cs-137 10 mSv), Hp(0.07)
Energy response:	photons: Hp(10) ± 30% from 15 keV to 9 MeV Hp(0.07) ± 30% from 6 keV to 9 MeV beta: Hp(0.07) + 10…-50% from 60 keV (Emean)
Angular response:	Hp(10) ±20% up to 60° at 65 keV Hp(0.07) ±20% up to 60° at 65 keV
Dose rate linearity:	better than ± 10 %, up to 40 Sv/h (4000 rem/h)
Audible alarms:	nine separate alarms, sound level typically better than 85 dBA at 30 cm - integrated dose; Hp(10), Hp(0.07) - dose rate; Hp(10), Hp(0.07) - dose overflow - dose rate display overflow - low battery 1 and 2 - defect
Alarm thresholds:	stand-alone mode: nine preset values and one user programmable value each for integrated dose and dose rate (separate for Hp(10) and Hp(0.07)) system mode: multilevel dose alarm system with five successive alarm levels
Display modes:	dose Hp(10) or Hp(0.07)**, dose rate Hp(10) or Hp(0.07), alarm levels and other parameters selected by push button operation ** display resolution is 1µSv for the first 5 mSv of total dose of DIS-1 detector; thereafter 10µSv until discharge
Histogram:	998 samples can be stored in 1 - 255 min. interval
Power supply:	one AAA-size alkaline cell, life typically 400 h in background field
Reader communication:	by infrared through bottom part; by using PCR-1 PC interface
Temperature range:	-10 - +50 °C operational, humidity up to 90% RH, non-condensed

The PCR-1 PC Adapter Unit connects DIS-100 Wide Energy Personal Dosimeter to your PC for individual configurations or just to record dose information to a dosimetric database.

Rados Dose Control I Dosimetry Software Package allows flexible dose recording for persons, companies and different activities.

Radas Technology Oy reserves the right to change product specifications without notice.

FINLAND: RADOS Technology Oy, P.O. Box 506, FIN-20101 Turku, Tel. +358-2-468 4600, Fax +358-2-468 4601.
GERMANY: RADOS Technology GmbH, P.O. Box 50 12 45, D-22712 Hamburg, Tel. +49-40-85 193-0, Fax +49-40-85 19 3-256.
Representatives in more than 30 countries.

EDD30 (Unfors) (part 1/2)

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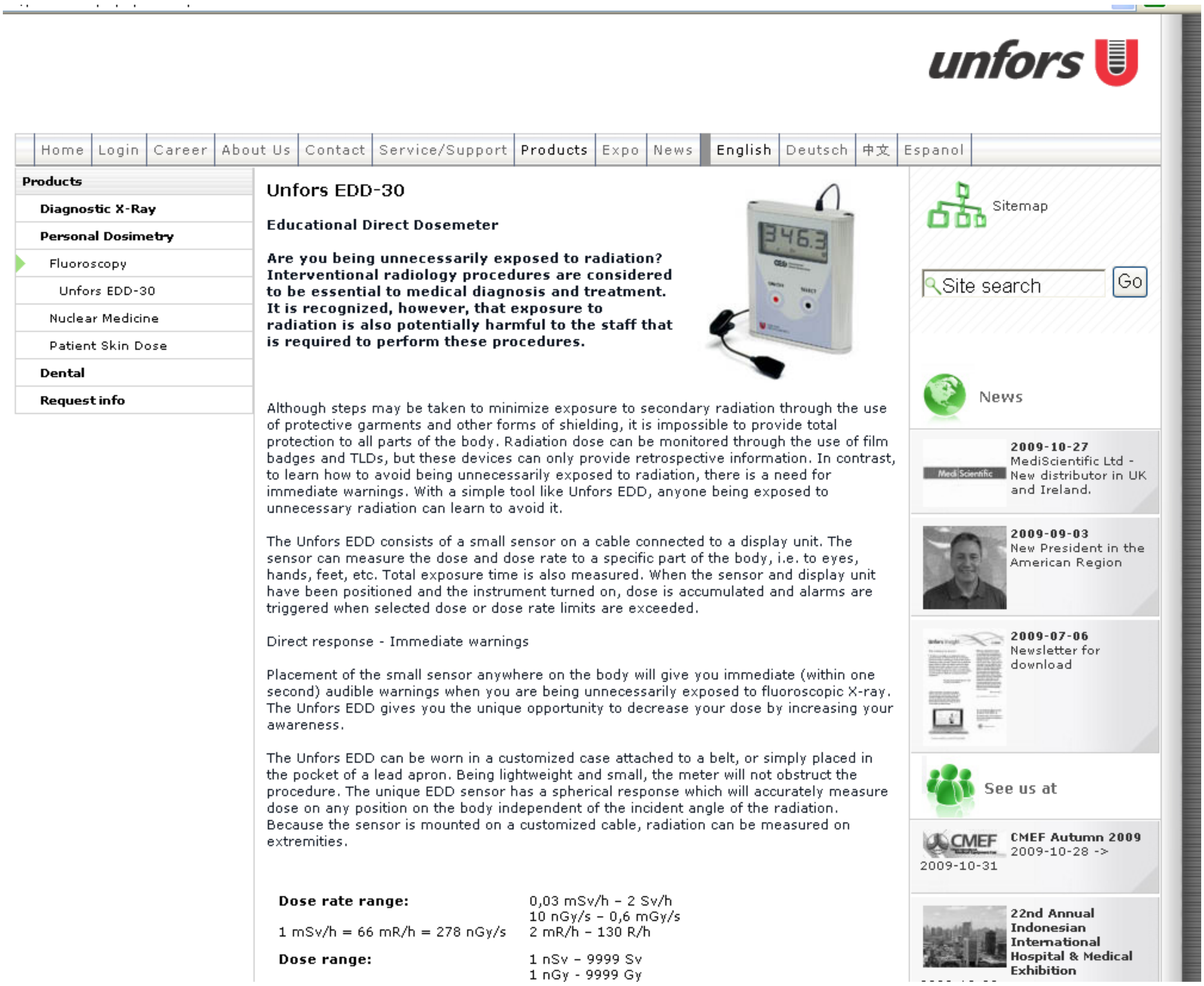

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Unfors EDD-30

Educational Direct Dosemeter

Are you being unnecessarily exposed to radiation? Interventional radiology procedures are considered to be essential to medical diagnosis and treatment. It is recognized, however, that exposure to radiation is also potentially harmful to the staff that is required to perform these procedures.

Although steps may be taken to minimize exposure to secondary radiation through the use of protective garments and other forms of shielding, it is impossible to provide total protection to all parts of the body. Radiation dose can be monitored through the use of film badges and TLDs, but these devices can only provide retrospective information. In contrast, to learn how to avoid being unnecessarily exposed to radiation, there is a need for immediate warnings. With a simple tool like Unfors EDD, anyone being exposed to unnecessary radiation can learn to avoid it.

The Unfors EDD consists of a small sensor on a cable connected to a display unit. The sensor can measure the dose and dose rate to a specific part of the body, i.e. to eyes, hands, feet, etc. Total exposure time is also measured. When the sensor and display unit have been positioned and the instrument turned on, dose is accumulated and alarms are triggered when selected dose or dose rate limits are exceeded.

Direct response - Immediate warnings

Placement of the small sensor anywhere on the body will give you immediate (within one second) audible warnings when you are being unnecessarily exposed to fluoroscopic X-ray. The Unfors EDD gives you the unique opportunity to decrease your dose by increasing your awareness.

The Unfors EDD can be worn in a customized case attached to a belt, or simply placed in the pocket of a lead apron. Being lightweight and small, the meter will not obstruct the procedure. The unique EDD sensor has a spherical response which will accurately measure dose on any position on the body independent of the incident angle of the radiation. Because the sensor is mounted on a customized cable, radiation can be measured on extremities.

Dose rate range:	0,03 mSv/h – 2 Sv/h
	10 nGy/s – 0,6 mGy/s
1 mSv/h = 66 mR/h = 278 nGy/s	2 mR/h – 130 R/h
Dose range:	1 nSv - 9999 Sv
	1 nGy - 9999 Gy

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EDD30 (Unfors) (part 2/2)

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the pocket of a lead apron. Being lightweight and small, the meter will not obstruct the procedure. The unique EDD sensor has a spherical response which will accurately measure dose on any position on the body independent of the incident angle of the radiation. Because the sensor is mounted on a customized cable, radiation can be measured on extremities.

Dose rate range: 1 mSv/h = 66 mR/h = 278 nGy/s	0,03 mSv/h – 2 Sv/h 10 nGy/s – 0,6 mGy/s 2 mR/h – 130 R/h
Dose range: 1 Sv = 66 R	1 nSv – 9999 Sv 1 nGy - 9999 Gy 0,1 µR – 9999 R
Trigger level:	0,05 mSv/h [15 nGy/s]
Disinfections:	Sensor, cable and instrument housing can be wiped off with 70 % medical alcohol
Power source: **Battery life time:** **Auto Power off:**	Two LR06 (size AA) alkaline type 130 hours After two hours without radiation or key activities
Display:	4 digit LCD
Size of instrument housing:	82 x 98 x 21 mm
Total weight incl. batteries:	200 gr
Accessories included:	Hard carrying case. Waist case with belt and a bracelet. EDD Quick Guide, placed in the waist case pocket. Practical clip on the sensor cable for easy positioning of the sensor.
Sensor Specifications Sensor size: Sensor cable length:	 6 x 8 x 25 mm 1,5 m

Specifications

Case	Unfors RP Case 1
Delivery	7-10 days, ARO

Unfors EDD-30

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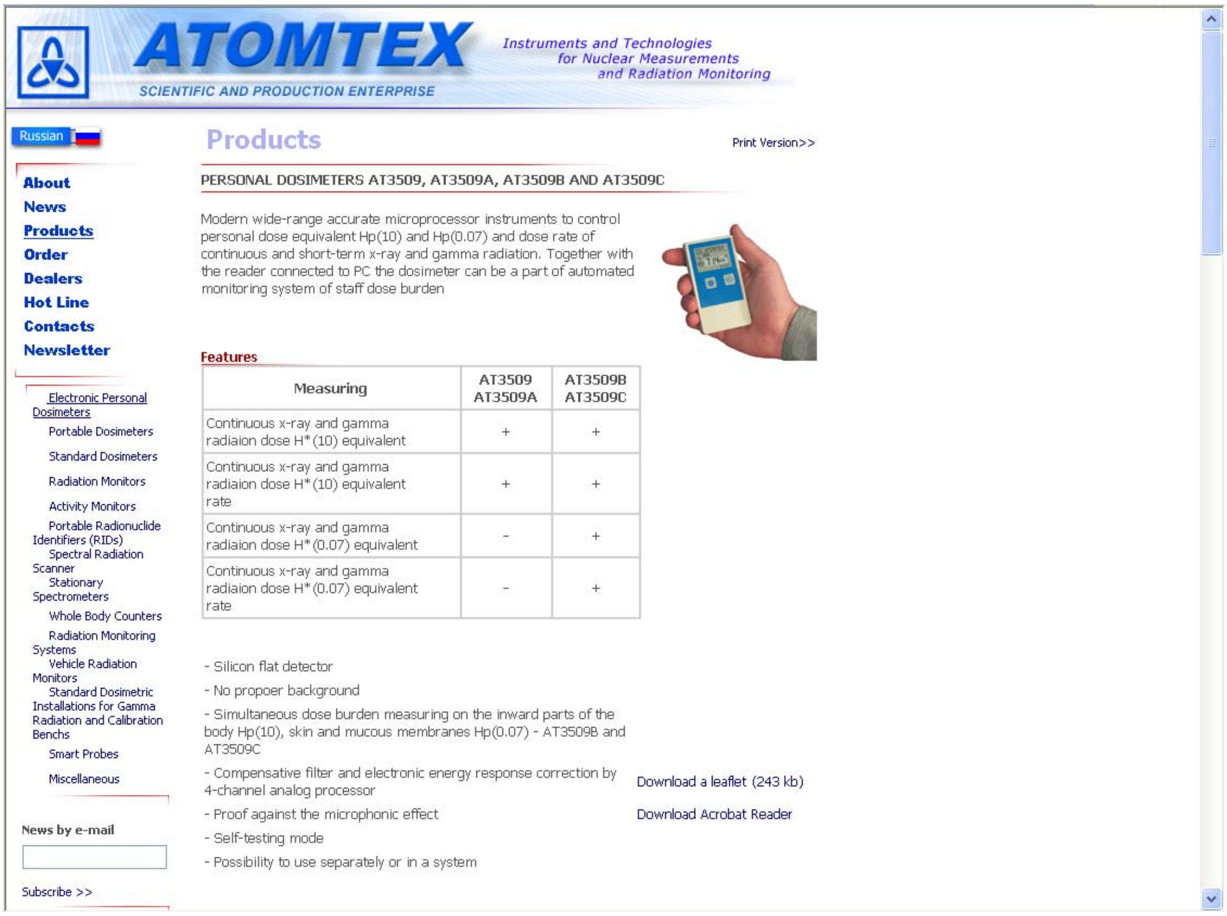
AT3509C (Atomtex) (part 1/2)

http://www.atomtex.com/producte.phtml?r=23&id=20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PERSONAL DOSIMETERS AT3509, AT3509A, AT3509B AND AT3509C

Modern wide-range accurate microprocessor instruments to control personal dose equivalent Hp(10) and Hp(0.07) and dose rate of continuous and short-term x-ray and gamma radiation. Together with the reader connected to PC the dosimeter can be a part of automated monitoring system of staff dose burden

Features

Measuring	AT3509 AT3509A	AT3509B AT3509C
Continuous x-ray and gamma radiaion dose H*(10) equivalent	+	+
Continuous x-ray and gamma radiaion dose H*(10) equivalent rate	+	+
Continuous x-ray and gamma radiaion dose H*(0.07) equivalent	-	+
Continuous x-ray and gamma radiaion dose H*(0.07) equivalent rate	-	+

- Silicon flat detector
- No propoer background
- Simultaneous dose burden measuring on the inward parts of the body Hp(10), skin and mucous membranes Hp(0.07) - AT3509B and AT3509C
- Compensative filter and electronic energy response correction by 4-channel analog processor
- Proof against the microphonic effect
- Self-testing mode
- Possibility to use separately or in a system

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AT3509C (Atomtex) (part 2/2)

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- Possibility to use separately or in a system

Application

- Radiology
- Radiotherapy
- Nuclear medicine
- Cosmic dosimetry
- Accelerators
- Nuclear research
- X-ray and fluorescent analysis
- Electronic equipment

The dosimeters are intended to measure personal dose equivalent and dose equivalent rate x-ray and gamma radiation. They measure dose rate in a wide range and have separate audible and visual alarm. Microprocessor processing and proper background detection ensure high accuracy of dose measurement within the wide dose rate measuring range. The microprocessor controls operation modes over, calculates, outputs data on a backlit LCD and performs self-testing. The nonvolatile memory keeps the accumulated dose and its accumulation history when the dosimeter is off. The dosimeter is calibrated on a water phantom of 30 x 30 x 15 cm according to the ISO4037-3 International standard requirements. The instruments are watertight, electromagnetic and shock proof (fall from 1.5 m).

The dosimeter can operate singly or in a dosimetry monitoring system: dosimeter - reader - PC. The dosimeter connects to the reader via IR channel, and the reader connects to PC via RS232.

The dosimeter software is intended to:

- Read/setup personal and serial dosimeter numbers;
- Change dose and dose rate thresholds;
- Disable/enable to change dosimeter thresholds by the dosimeter button;
- Change the dose accumulation interval in the range from 1 to 255 min and evaluate accumulated dose for each time interval within a work shift;
- Save automatically up to 800 dose values in the nonvolatile memory accumulated for the selected accumulation interval;
- Reset accumulated dose;
- Disable/enable to reset accumulated dose by the dosimeter button;
- Save automatically data in the data base and print them.

The operation modes are "Dose ", "Dose rate ", "Economical", "Menu", "Reset dose", "Dose threshold", "Dose rate threshold" and "Data exchange with PC".

Specification

Measuring range	
personal dose equivalent (in increment of 0.1 μSv)	
AT3509, AT3509A Hp(10)	1 μSv - 10 Sv
AT3509B Hp(10), Hp(0.07)	1 μSv - 10 Sv
AT3509C Hp(10), Hp(0.07)	1 μSvв - 10 Sv
personal dose equivalent rate	

Specification

Measuring range	
personal dose equivalent (in increment of 0.1 μSv)	
AT3509, AT3509A Hp(10)	1 μSv - 10 Sv
AT3509B Hp(10), Hp(0.07)	1 μSv - 10 Sv
AT3509C Hp(10), Hp(0.07)	1 μSvв - 10 Sv
personal dose equivalent rate	
AT3509, AT3509A	0.1 μSv/h - 1 Sv/h
AT3509B	0.1 μSv/h - 1 Sv/h
AT3509C	0.1 μSv/h - 5 Sv/h
Intrinsic dose measurement error with no accompanying beta radiation	± 15 %
Intrinsic dose rate measurement error	
from 0.1 to 1 μSv/h	± 30 %
from 1 μSv/h to 1 Sv/h	± 15 %
from 1 Sv/h to 5 Sv/h (AT3509)	± (15·0.0001·Hp)%
Calibration error on ^{137}Cs	± 5 %
Energy range	
AT3509, AT3509B, AT3509C	15 keV - 10 MeV
AT3509A	30 keV - 10 MeV
Energy sensitivity response	
Hp(10)	
15 keV - 1.5 MeV	± 25 %
1.5 MeV - 10 MeV	± 60 %
Hp(0.07) AT3509B, AT3509C	
15 keV - 300 keV	± 30 %
Response time to dose rate change when dose rate > 10 μSv/h	5 s
Anisotropy within ±75º	
for ^{137}Cs and ^{60}Co	± 20 %
for ^{241}Am	± 50%
Alarm thresholds (independent)	
dose: 30 μSv; 200 μSv; 1 mSv; 4,2 mSv; 12.5 mSv; 50 mSv; 100 mSv; 1 Sv	
dose rate: 0.3 μSv/h; 3 μSv/h; 30 μSv/h; 300 μSv/h; 3 mSv/h; 30 mSv/h; 300 mSv/h; 1 Sv/h	
customized thresholds	
Radiation overload	up to 10 Sv/h