USE OF ACTIVE PERSONAL DOSEMETERS IN INTERVENTIONAL RADIOLOGY/CARDIOLOGY: TESTS WITH CONTINUOUS AND PULSED FIELDS IN LABORATORY CONDITIONS – ORAMED PROJECT

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CONTEXT

One of the ORAMED work packages deals with the optimization of the use of **active personal dosemeters (APDs) in interventional radiology/cardiology (IR/IC)**

OBJECTIVES

- study the behavior of selected APDs in pulsed X-ray beams:
  - ✓ tests **in laboratory conditions** with continuous and pulsed X-ray beams → this presentation
  - ✓ tests using an X-ray facility in a **hospital** environment and in different European hospitals worn by interventionalists during routine practice → Struelens et al.
- provide **proposals for improvement** of active personal dosemeters used in interventional radiology/cardiology → Martin et al.
- provide **practical guidelines** related to the choice and the use of APDs in interventional radiology/cardiology → Daures et al.

CONTEXT

The work consisted in:

- making a **selection of APDs** deemed suitable for application in interventional radiology

- defining, by measurements under **laboratory conditions**, the dose equivalent, the dose equivalent rate, the energy and the angular response of selected commercial APDs, **with continuous X-ray beams**.

- studying, by measurements under **laboratory conditions,** the **effect of dose equivalent rate, pulse frequency and pulse width** on the APD response, **with pulsed X-ray beams**.

INTRODUCTION – GENERAL PROBLEMATIC

Interventional radiology/cardiology procedures can lead to relatively high doses to medical staff who is mostly exposed to radiation **scattered** by the patient.

For the adequate **dosimetry** of these scattered photons, APDs must be able to respond to:

- low-energy photons (20-100 keV)
- pulsed radiation with relatively high instantaneous dose equivalent rates.

Very few APD devices can detect low energy radiation fields.
None of them are specially designed for working in pulsed radiation fields.

TYPICAL FIELD PARAMETERS ENCOUNTERED IN IR/IC

Parameter	Range
High voltage	60-120 kVp
Intensity	5-1000 mA
Inherent Al equivalent filtration	4.5 mm
Additional Cu filtration	0.2 – 0.9 mm
Pulse duration	1 - 20 ms
Pulse frequency	1 – 30 s^{-1}
Dose equivalent rate in the direct beam (table)	2 to 360 $Sv.h^{-1}$
Dose equivalent rate in the scattered beam (operator – above the lead apron)	5.10^{-3} to 10 $Sv.h^{-1}$
Energy range of scattered spectra	20 keV – 100 keV

SELECTION OF APDs

Eight APDs were selected for the study:

MGPi
DMC2000XB

Siemens
EPD Mk2.3

Dosilab
EDM III

Polimaster
PM1621A

Rados
DIS-100

Unfors
EDD 30

Atomtex
AT3509C

Philips
DoseAware

SELECTION OF APDs

APD characteristics given by the manufacturer in the technical notice

	APD	Energy range		Dose equivalent rate range		Dose equivalent range		Detector type
		Min	Max	Min	Max	Min	Max	
1	**DMC 2000XB** MGPi	20 keV	6 MeV	0.1 µSv.h^{-1}	10 Sv.h^{-1}	1 µSv	10 Sv	Silicon diode
2	**EPD Mk2.3** Thermo	17 keV	6 MeV	1 µSv.h^{-1}	4 Sv.h^{-1}	1 µSv	16 Sv	Silicon diode
3	**EDM III** Dosilab	20 keV	6 MeV	0.5 µSv.h^{-1}	1 Sv.h^{-1}	1 µSv	1 Sv	Silicon diode
4	**PM1621A** Polimaster	10 keV	20 MeV	0.01 µSv.h^{-1}	2 Sv.h^{-1}	0.01 µSv	9.99 Sv	Geiger Muller tube
5	**DIS-100** Rados	15 keV	9 MeV	1 µSv.h^{-1}	40 Sv.h^{-1}	1 µSv	50 mSv	Specific detector
6	**EDD 30** Unfors	"interventional radiology energy range"		0.03 mSv.h^{-1}	2 Sv.h^{-1}	1 nSv	9999 Sv	Silicon diode
7	**AT3509C** Atomtex	15 keV	10 MeV	0.1 µSv.h^{-1}	5 Sv.h^{-1}	1 µSv	10 Sv	Silicon diode
8								

SELECTION OF APDs

APD characteristics given by the manufacturer in the technical notice

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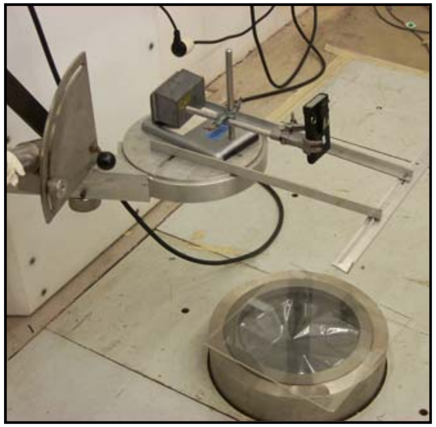
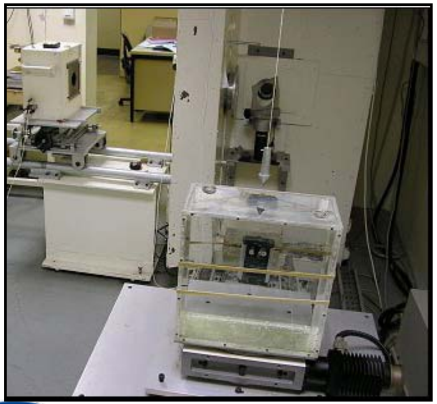
7	**AT3509C** Atomtex	15 keV	10 MeV	0.1 µSv.h^{-1}	5 Sv.h^{-1}	1 µSv	10 Sv	Silicon diode
8	**DoseAware** Philips	33 keV	118 keV	10 µSv.h^{-1}	50 mSv.h^{-1}	1 µSv	10 Sv	Silicon diode

TESTS PERFORMED WITH CONTINUOUS X-RAY BEAMS IN LABORATORY CONDITIONS

Calibration laboratories (SCK•CEN, Belgium and IRSN, France)





Dose equivalent response : S-Co, N-150 for DoseAware
Dose equivalent rate response from 0 to 10 $Sv.h^{-1}$: S-Co for all APDs, H-100 for EDD30, N-150 for DoseAware
Energy response: N-15, N-20, N-25, N-30, N-40, N-60, N-80, N-100, N-120, S-Cs and S-Co, from N-30 to S-Cs for DoseAware
Angular response at +/- 60°: N-25, N-30, N-40 and N-60, + N-80 for DoseAware

Three measurements per APD were made.
Two dosemeters of each type were tested, except for the EDD30 of which we had only one unit.

IEC 61526 standard (2010– 07)

International Electrotechnical Commission. 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 (2010 – 07) IEC 61526 Geneva: IEC

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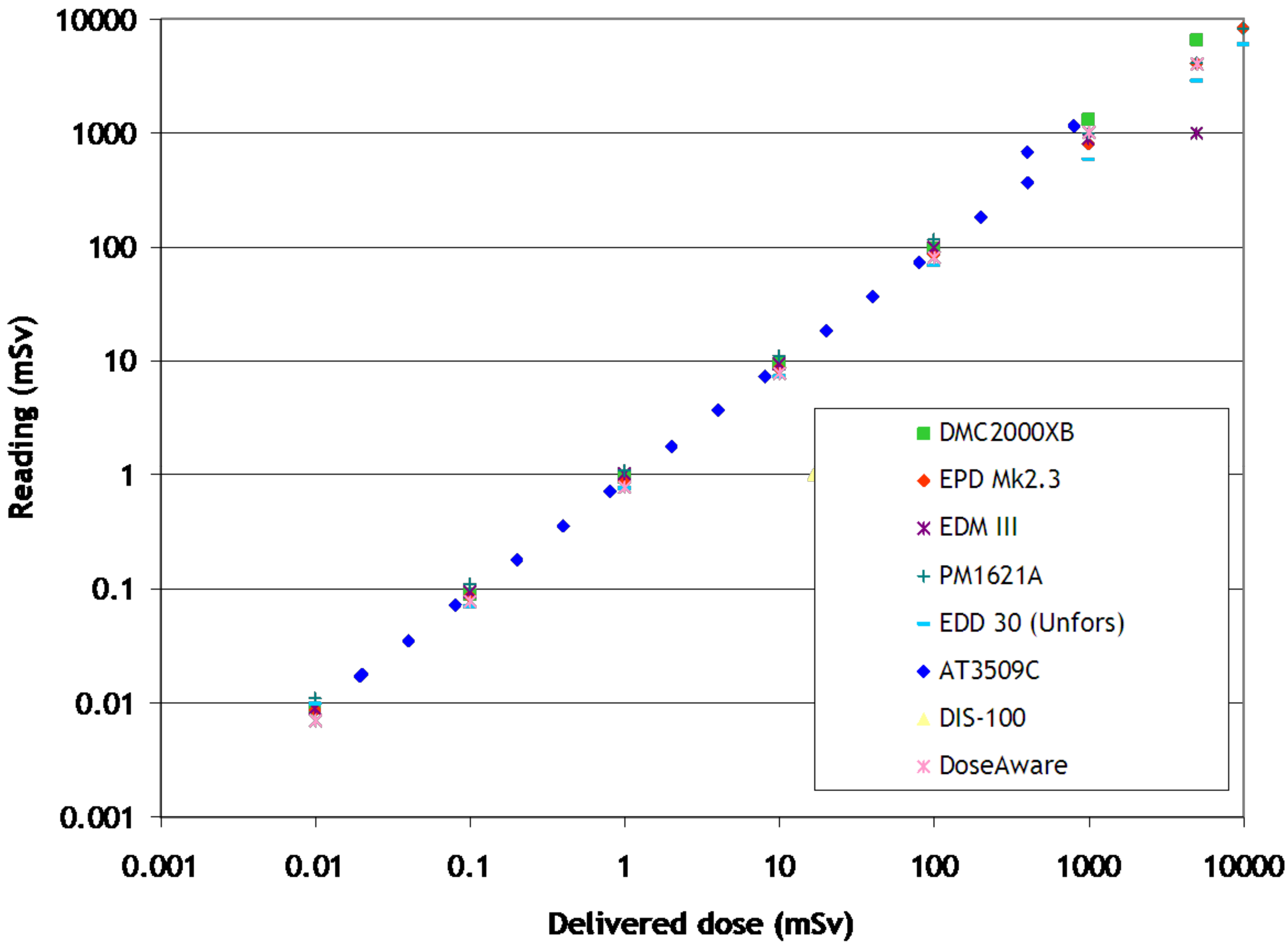
DOSE EQUIVALENT RESPONSE



The dose equivalent response of tested APDs is linear in the dose equivalent range of interest.

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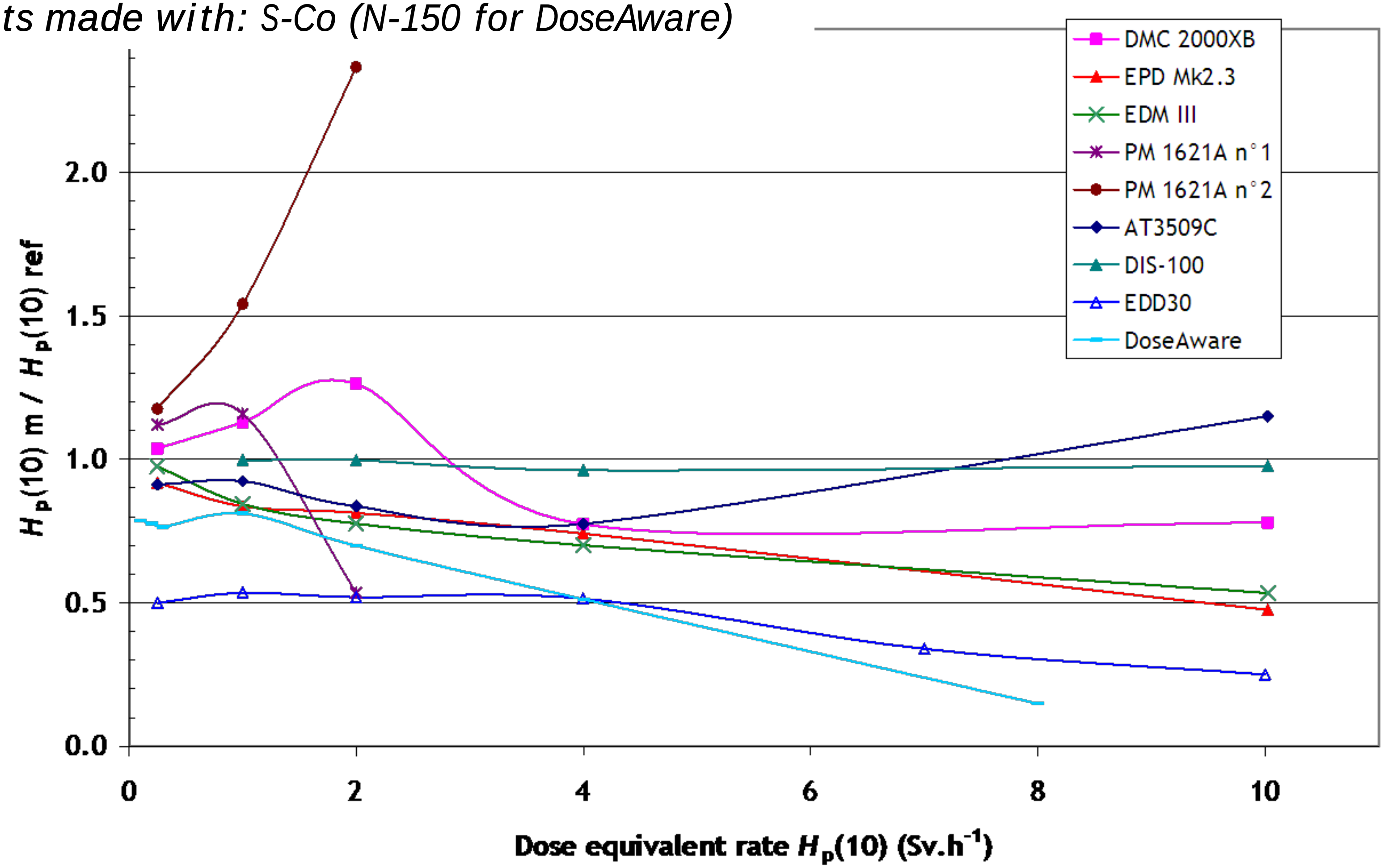
DOSE EQUIVALENT RATE RESPONSE

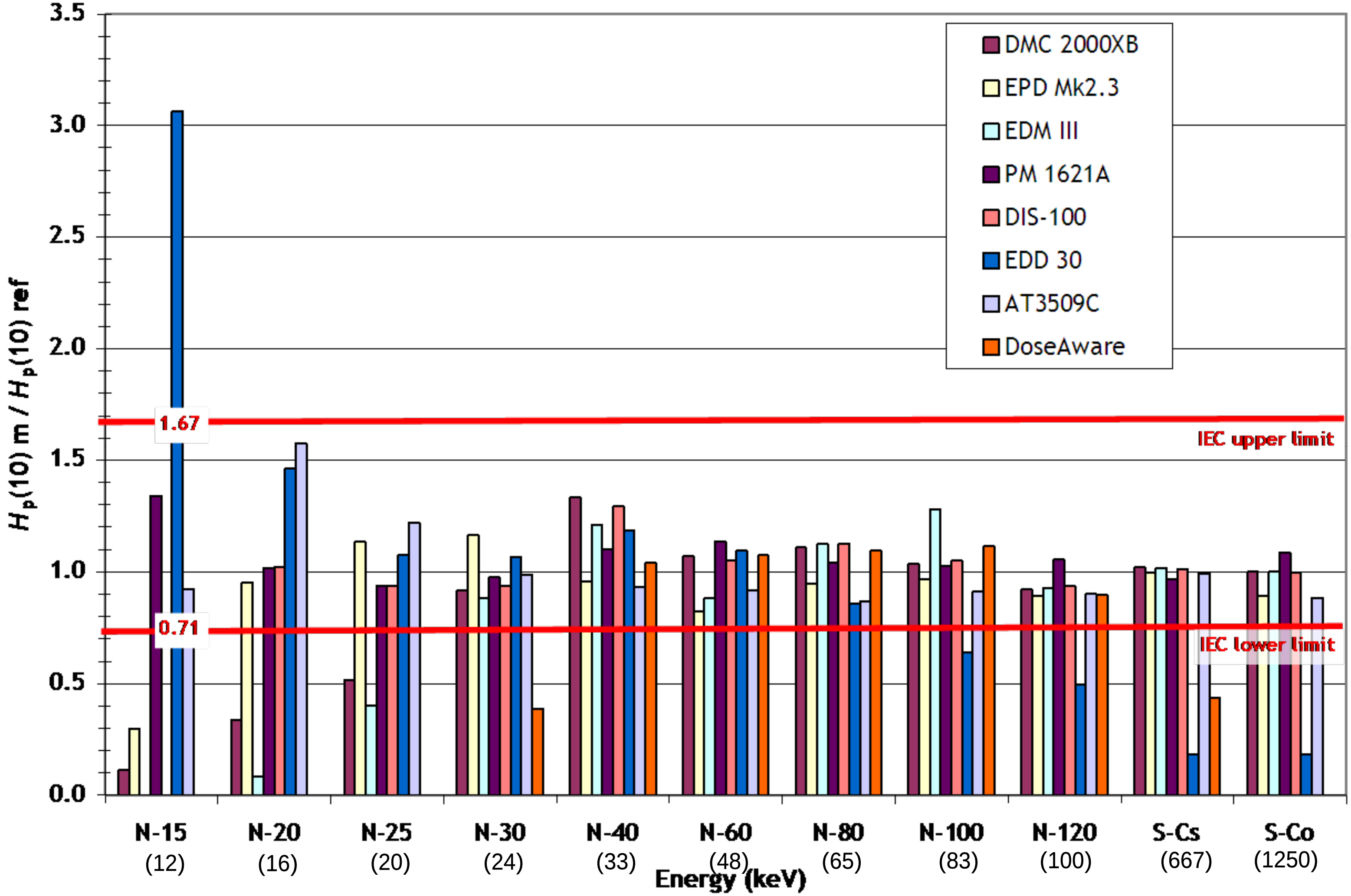
Tests made with: S-Co (N-150 for DoseAware)



Most APDs can stand high dose equivalent rates up to 10 Sv.h^{-1}, except:

- PM1621A for which the response is diverging rapidly from 1 Sv.h^{-1}
- EDD30 which saturates for dose equivalent rates above 2 Sv.h^{-1}
- DoseAware which saturates for dose equivalent rates above 4 Sv.h^{-1}

ENERGY RESPONSE



The energy response is within the interval [0.71 – 1.67] as required in the IEC 61526 standard from ^{137}Cs energy down to 24 keV for all APDs except EDD30 and DoseAware. For these two APDs, these results are consistent with characteristics given by the manufacturers.

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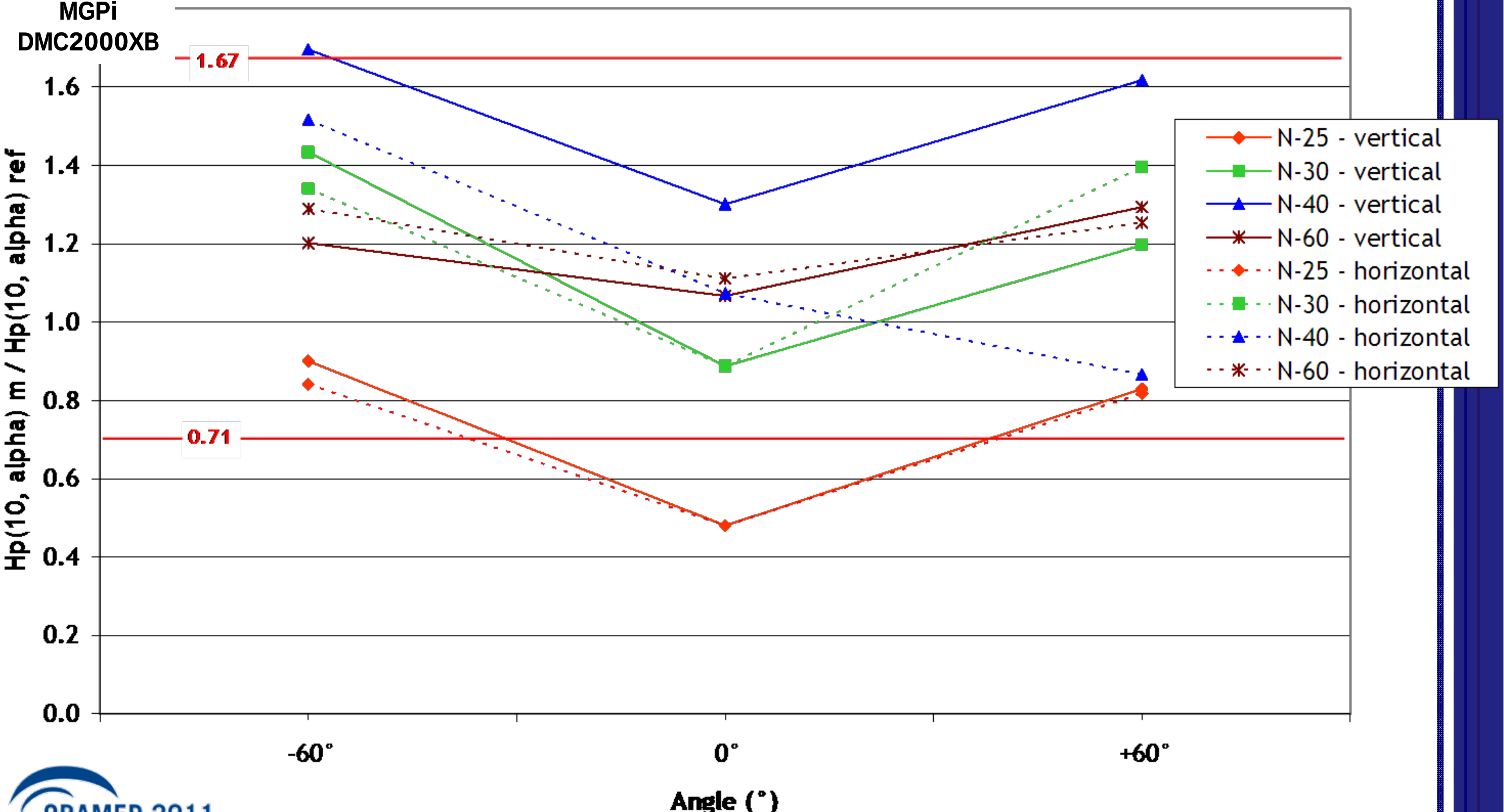
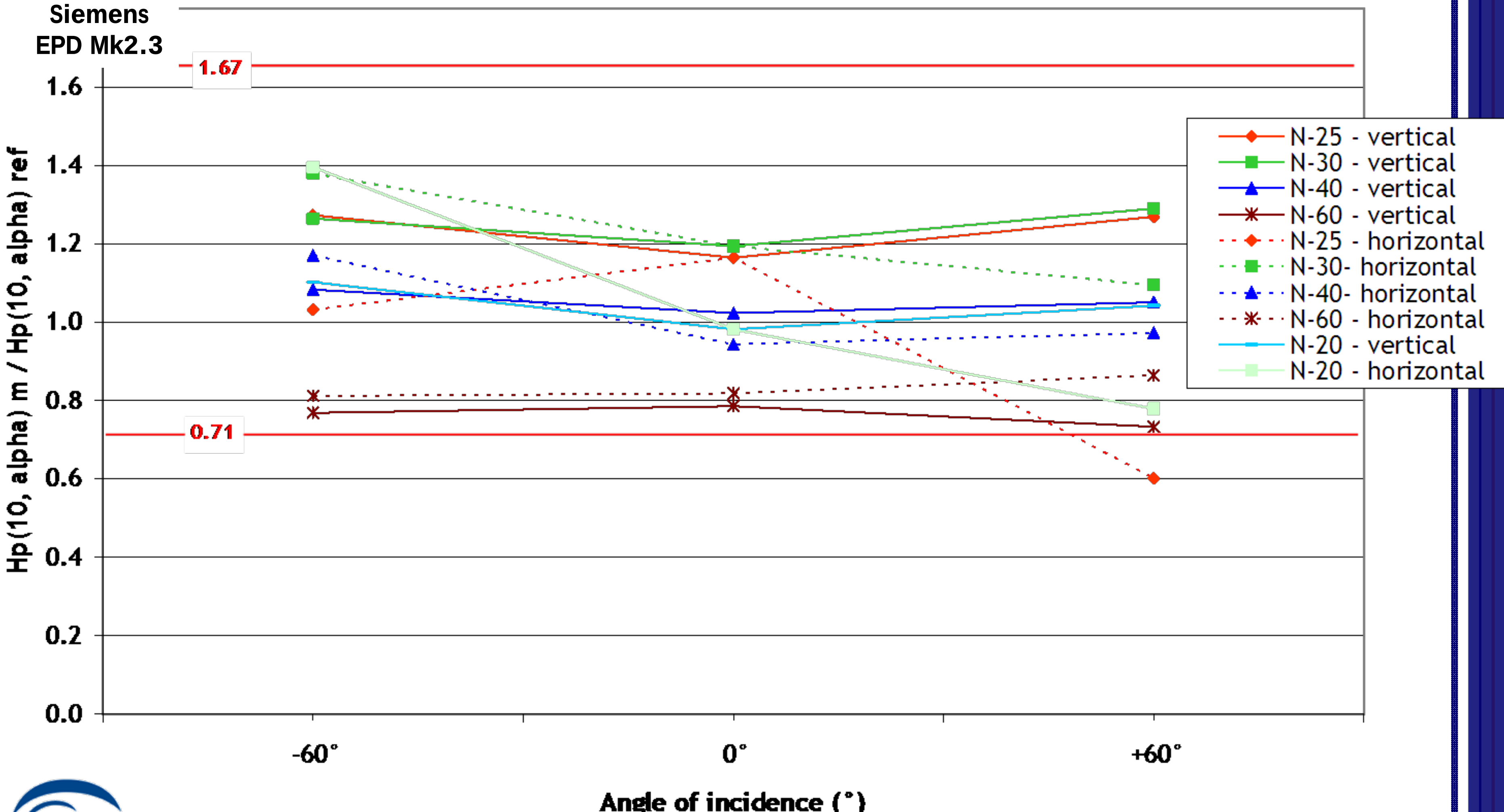
ANGULAR RESPONSE

MGPi DMC2000XB



ANGULAR RESPONSE

Siemens
EPD Mk2.3



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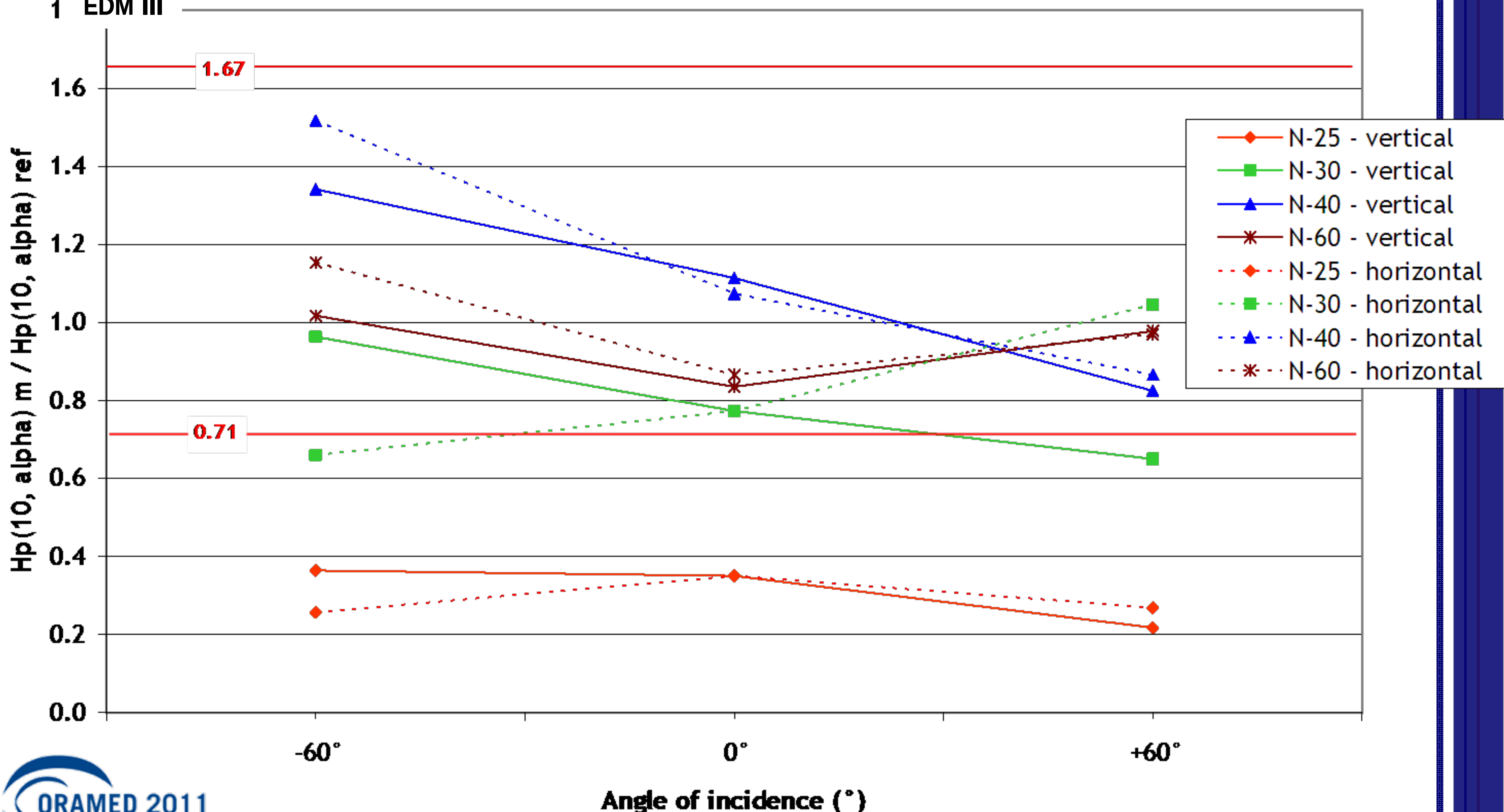
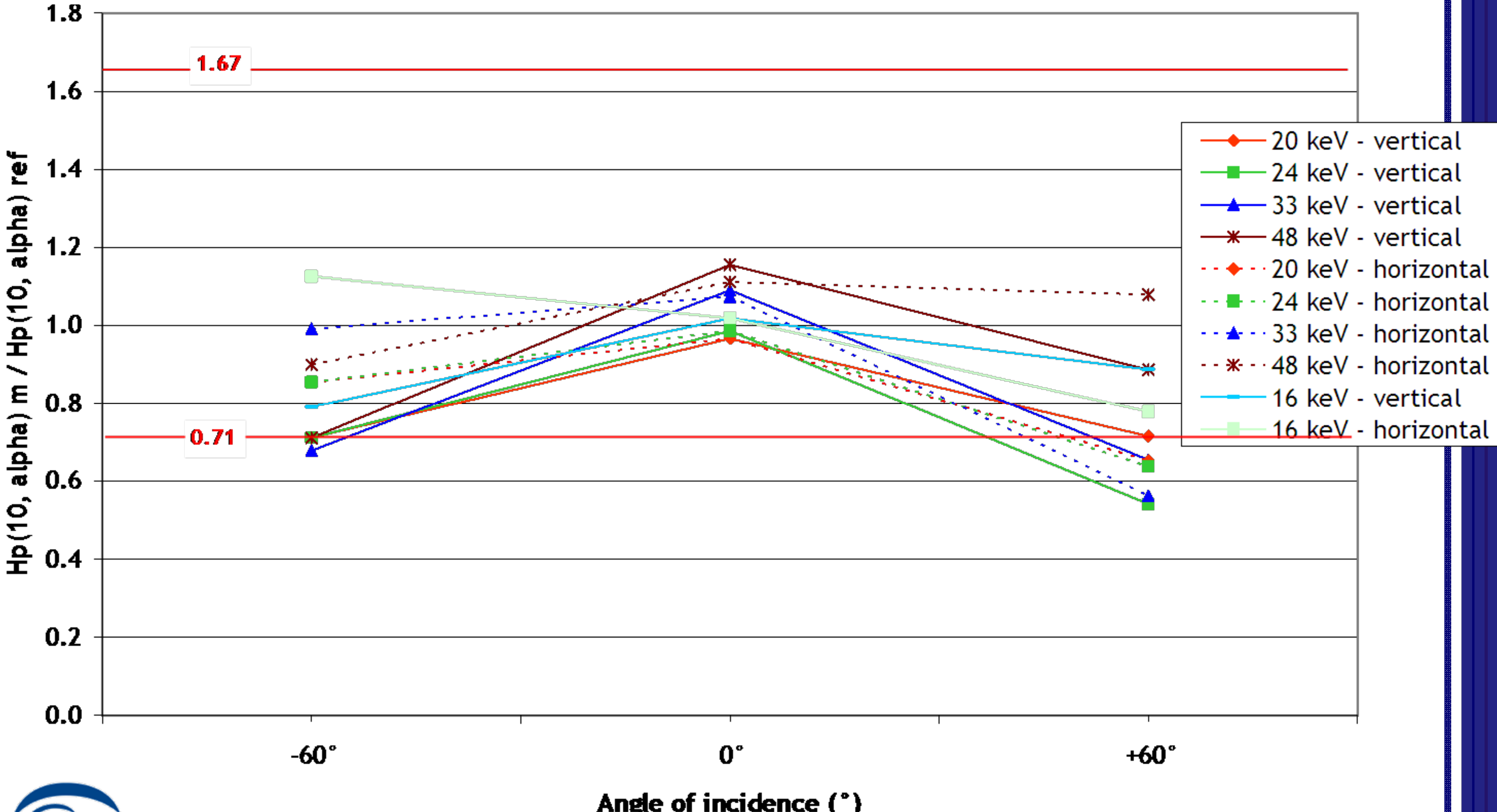
ANGULAR RESPONSE

Dosilab
EDM III



ANGULAR RESPONSE

Polimaster PM1621A



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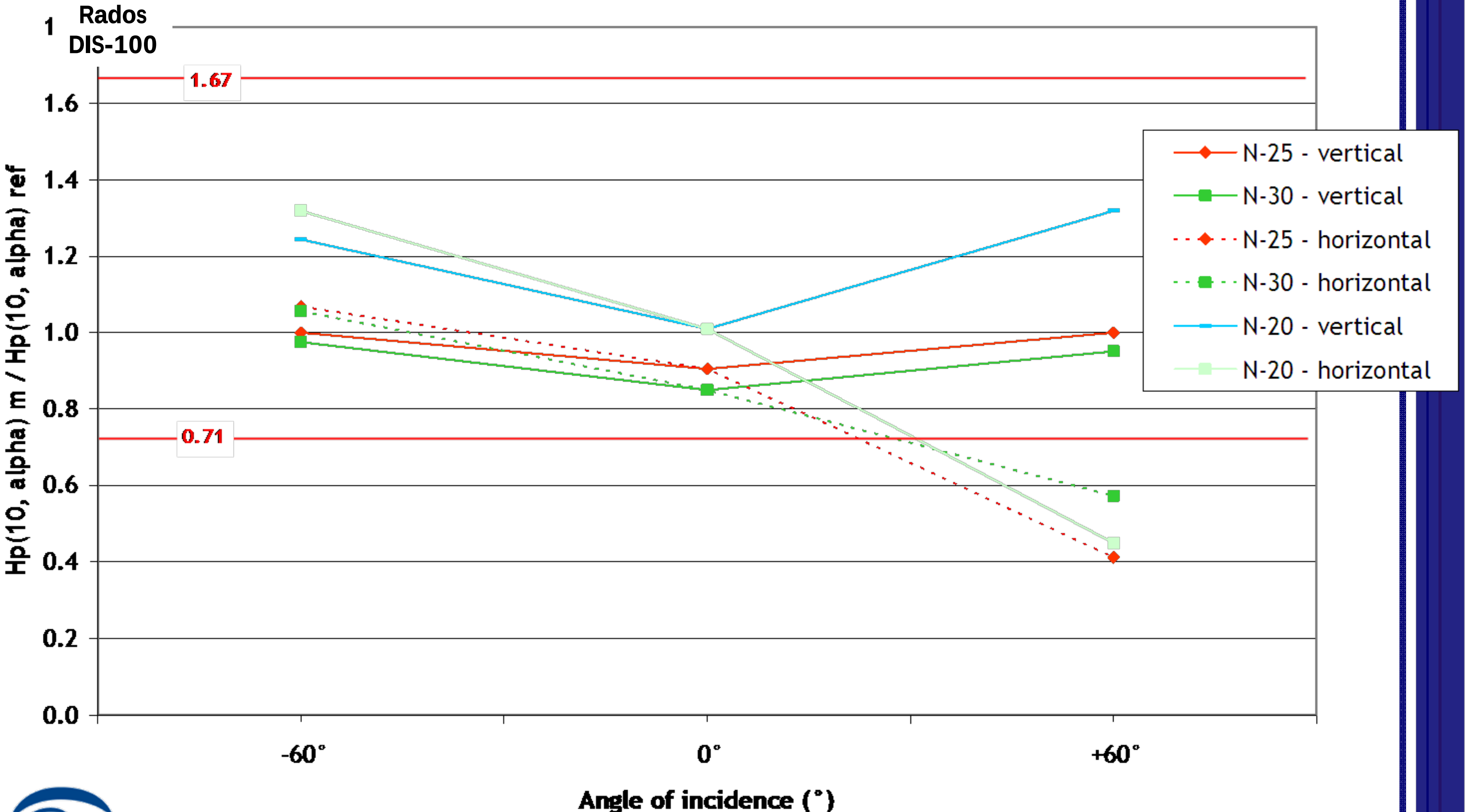
ANGULAR RESPONSE



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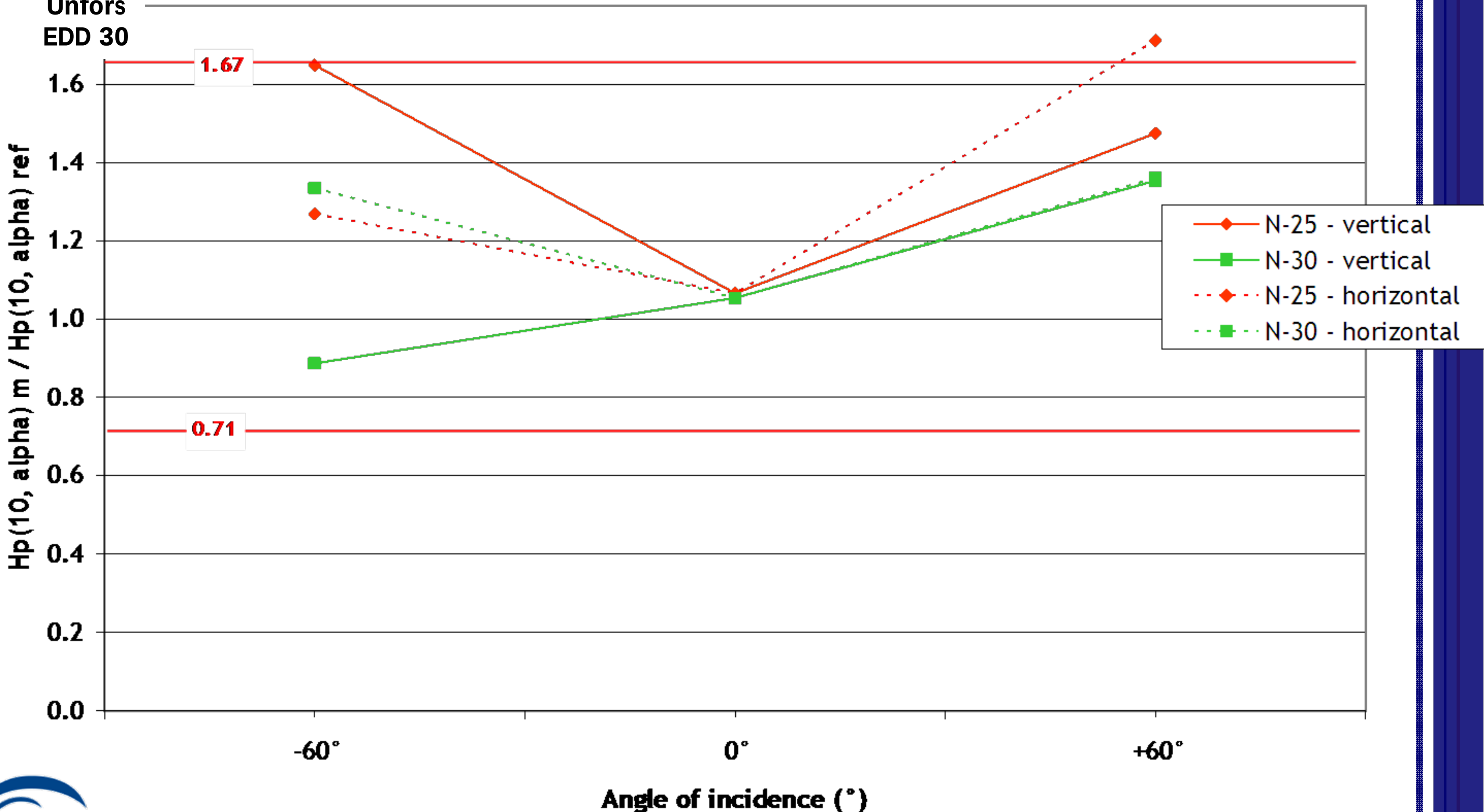
ANGULAR RESPONSE

Unfors EDD 30



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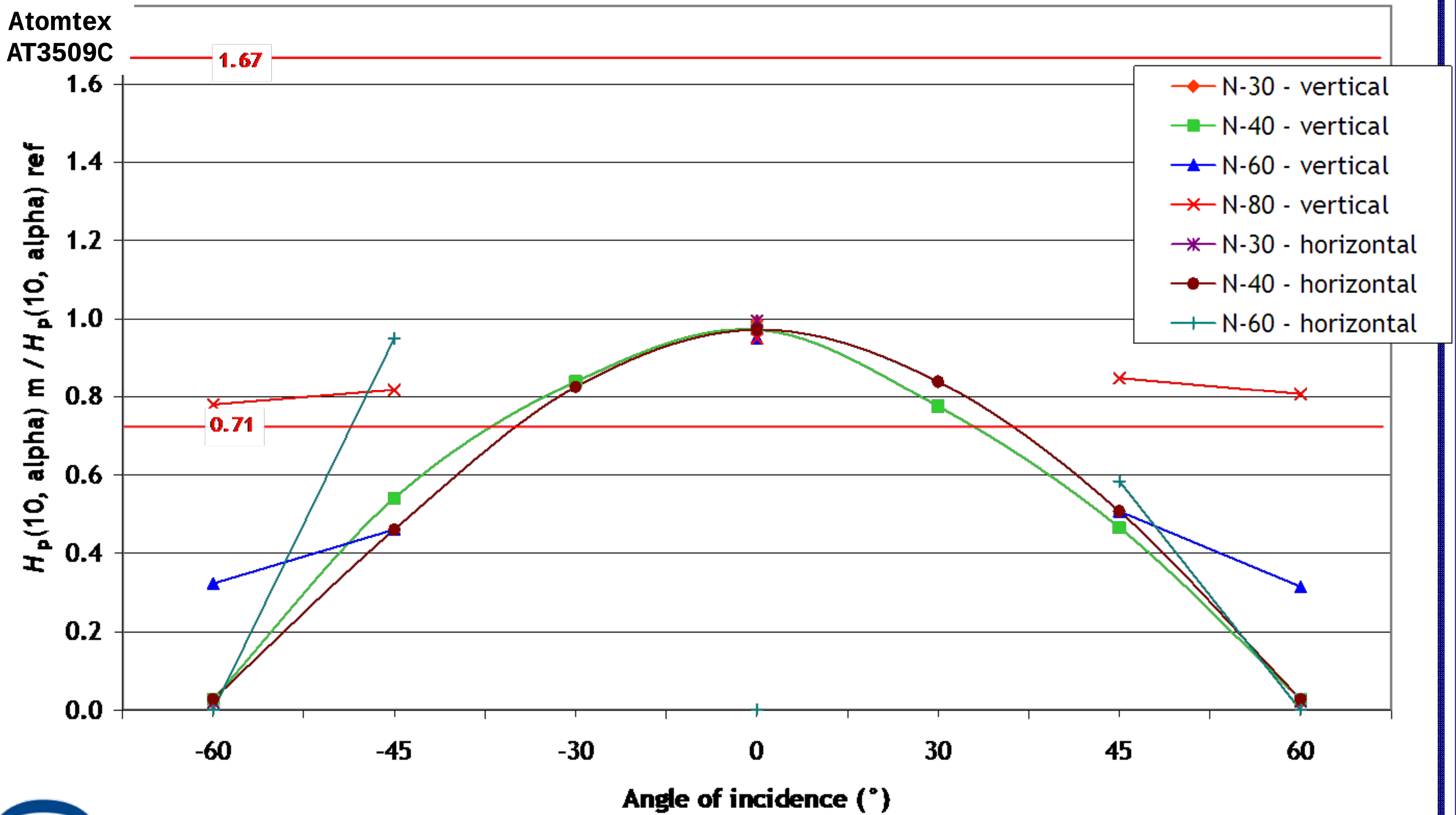
ANGULAR RESPONSE

Atomtex AT3509C



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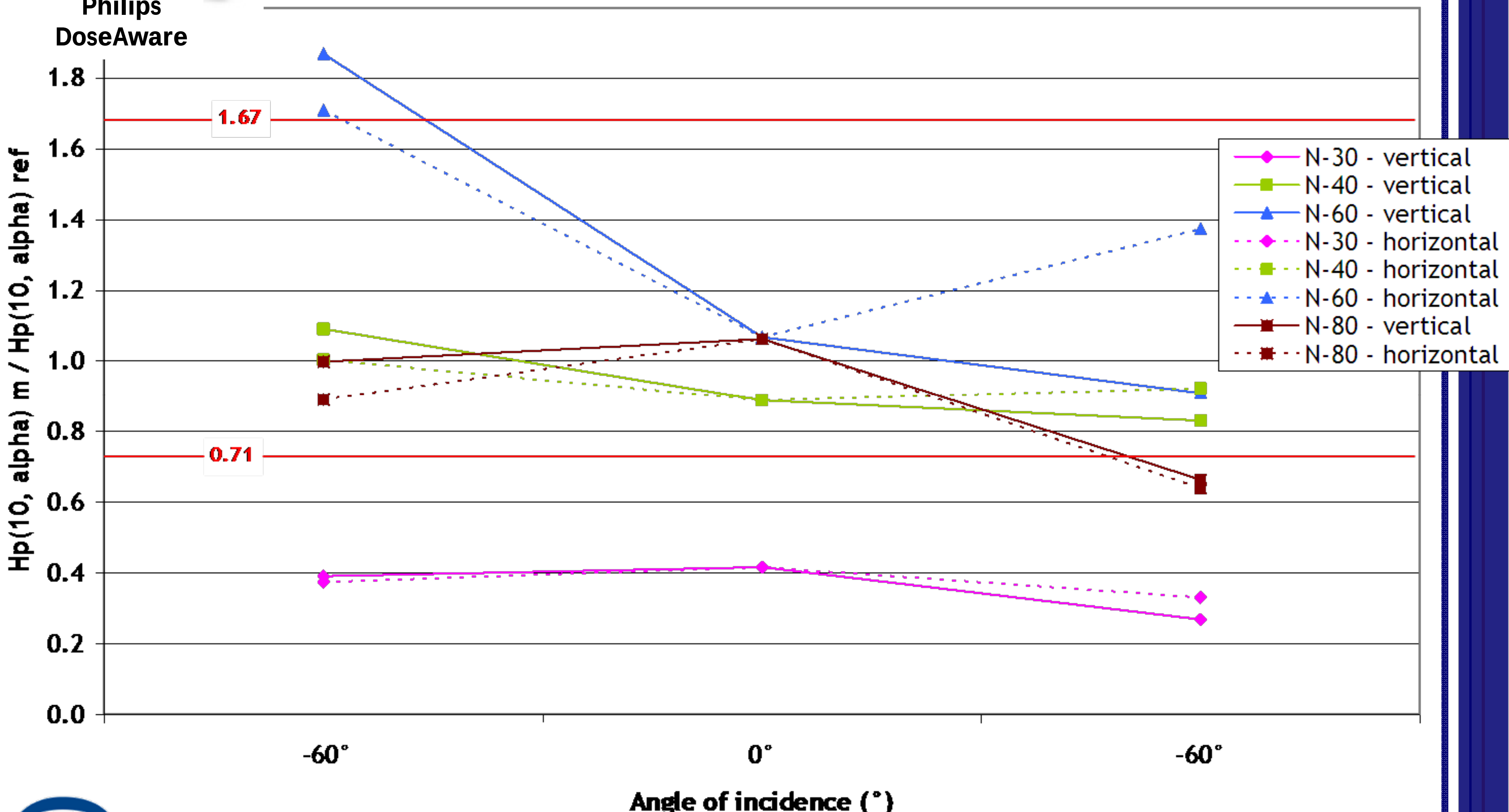
ANGULAR RESPONSE

Philips DoseAware



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CONCLUSIONS ON TESTS PERFORMED WITH CONTINUOUS X-RAY BEAMS

All APDs have a linear response with the dose equivalent and most of them have a satisfactory response at low energies from 24 keV.

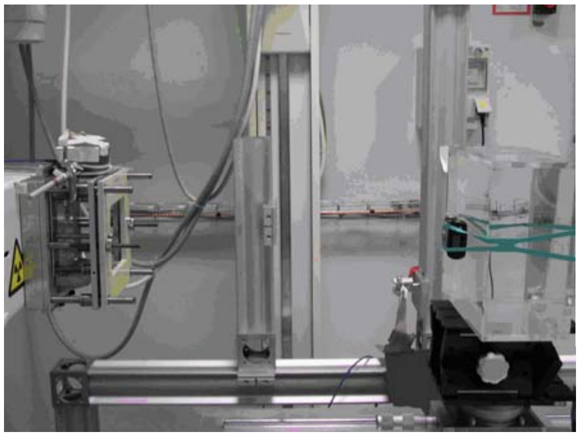
Most APDs can stand high dose equivalent rates up to 10 $Sv.h^{-1}$, except:

- PM1621A for which the response is diverging rapidly from 1 $Sv.h^{-1}$
- EDD30 which saturates for dose equivalent rates above 2 $Sv.h^{-1}$
- DoseAware which saturates for dose equivalent rates above 4 $Sv.h^{-1}$

All APDs have a satisfactory angular response from the energy of N-30 (except AT3509C: satisfactory angular response only from N-80)

TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

French standard laboratory for ionizing radiation (CEA LIST - LNE LNHB, France)



- Commercially available X-ray generator: GEHC PHASIX 80 (used in large number of radiology services)
- High Voltage: 70 kVp,
- Total filtration: 4.5 mm Al + 0.2 mm Cu,
- Half Value Layer: 5.17 mm Al.

→ Denozière et al. (poster)

In pulsed mode, the APD response was studied in laboratory conditions, corresponding to the operational conditions, in function of the variation of:

- the dose equivalent rate
- the pulse frequency
- the pulse width

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TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

APD response with dose equivalent rate variation (in multi-pulsed mode):
- **Pulse duration**: **20 ms** (it was not possible to perform tests for lower pulse durations for technical reasons),
- **Pulse frequency**: **10 pulses per second** (pps)
- **Dose equivalent rate variation**: **from 100 mSv.h^{-1} to 50 Sv.h^{-1}** (up to 1.8 Sv.h^{-1} for DoseAware)

APD response with pulse frequency variation (in multi-pulsed mode):
- **Dose equivalent rate: 1.8 Sv.h^{-1} and 6.8 Sv.h^{-1}** (908 mSv.h^{-1} and 1,8 Sv.h^{-1} for DoseAware)
- **Pulse duration: 20 ms,**
- **Pulse frequency variation: 1 pps, 10 pps and 20 pps** (1 pps and 10 pps for DoseAware)

APD response with pulse width variation (in single pulsed mode):
- **Pulse width variation: 20, 50, 100 and 1000 ms at 1.8 Sv.h^{-1}** (DoseAware not tested in this configuration)

TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

EFFECT OF DOSE EQUIVALENT RATE

For most APDs the response decreases when the dose equivalent rate increases.

For dose equivalent rates < 2 $Sv.h^{-1}$ the responses are, in general, close to 1 and fall down for higher dose equivalent rates, except for DIS-100 that stands relatively high dose equivalent rates.

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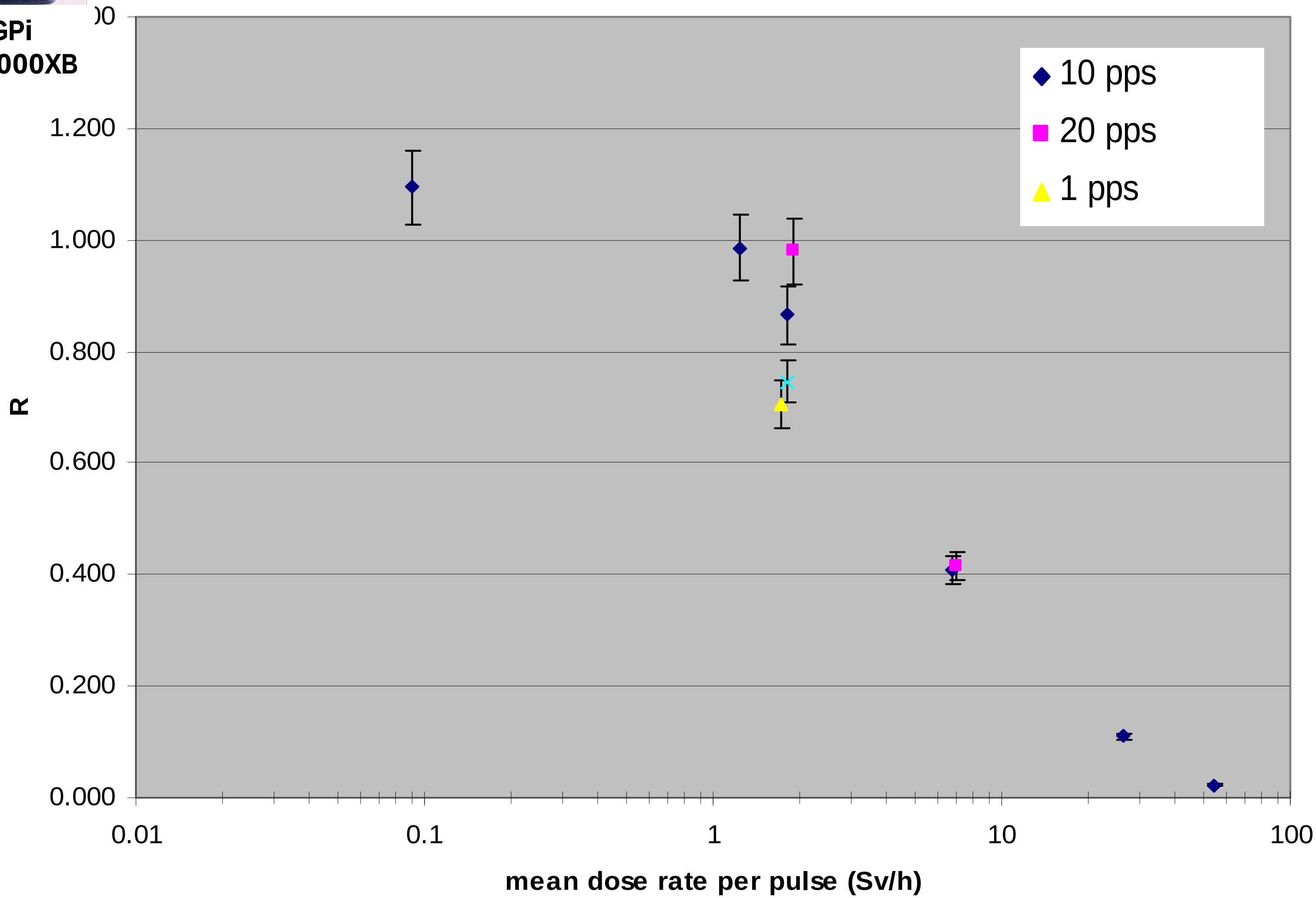
TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

MGPi DMC2000XB

EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY



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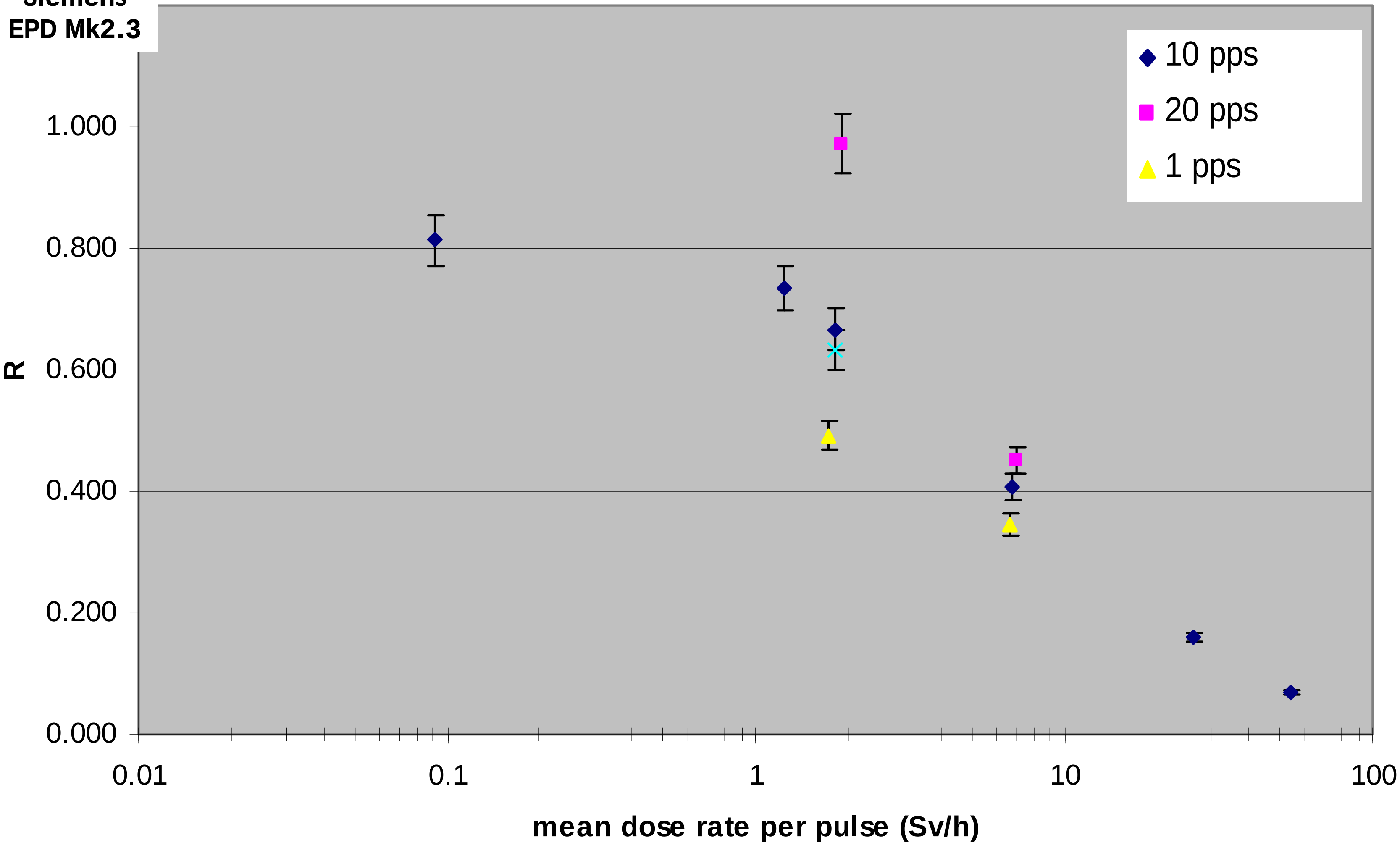
TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

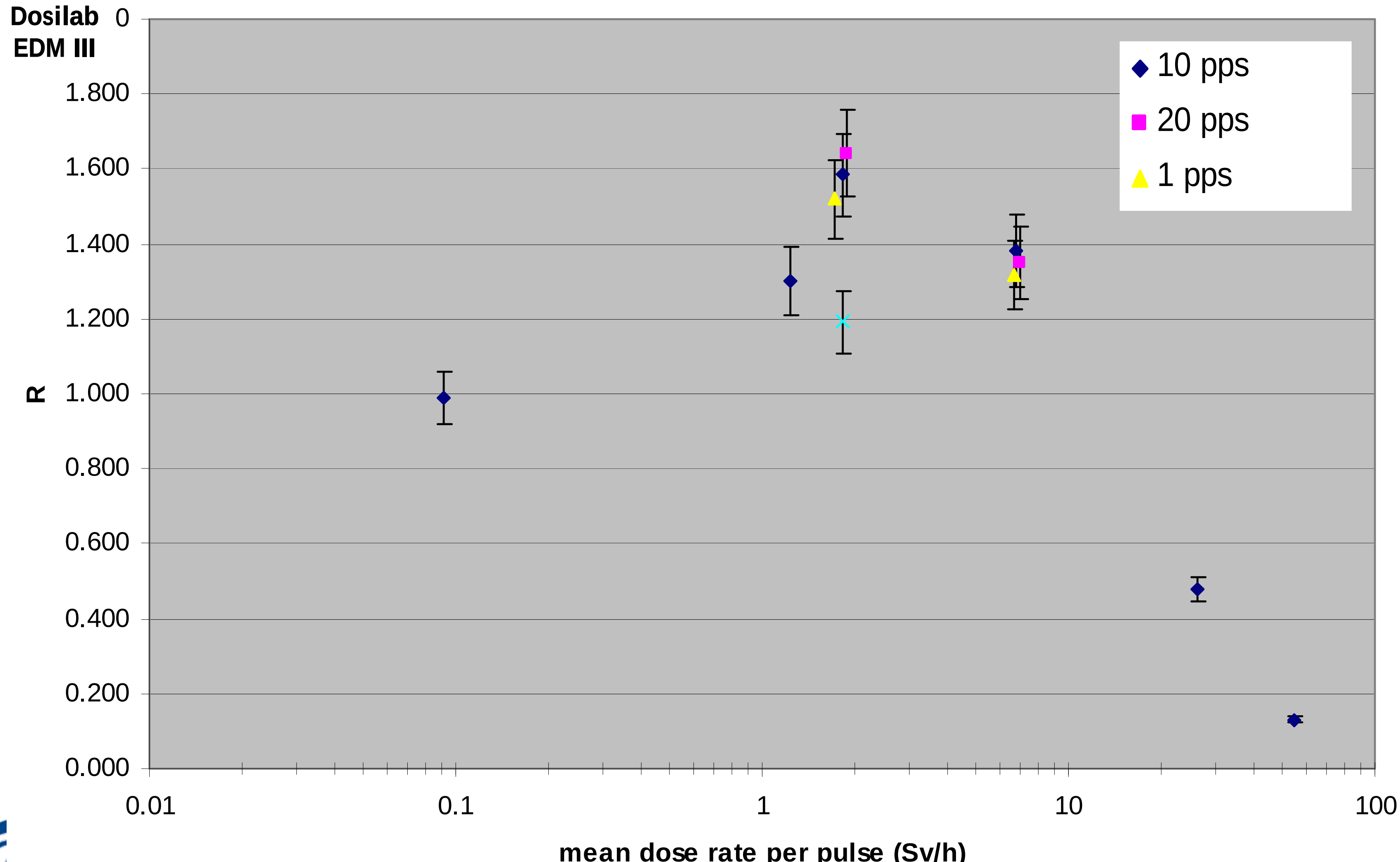
EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY

Siemens EPD Mk2.3



TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY



TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

Polimaster
PM1621A

EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY

NO SIGNAL IN PULSED MODE

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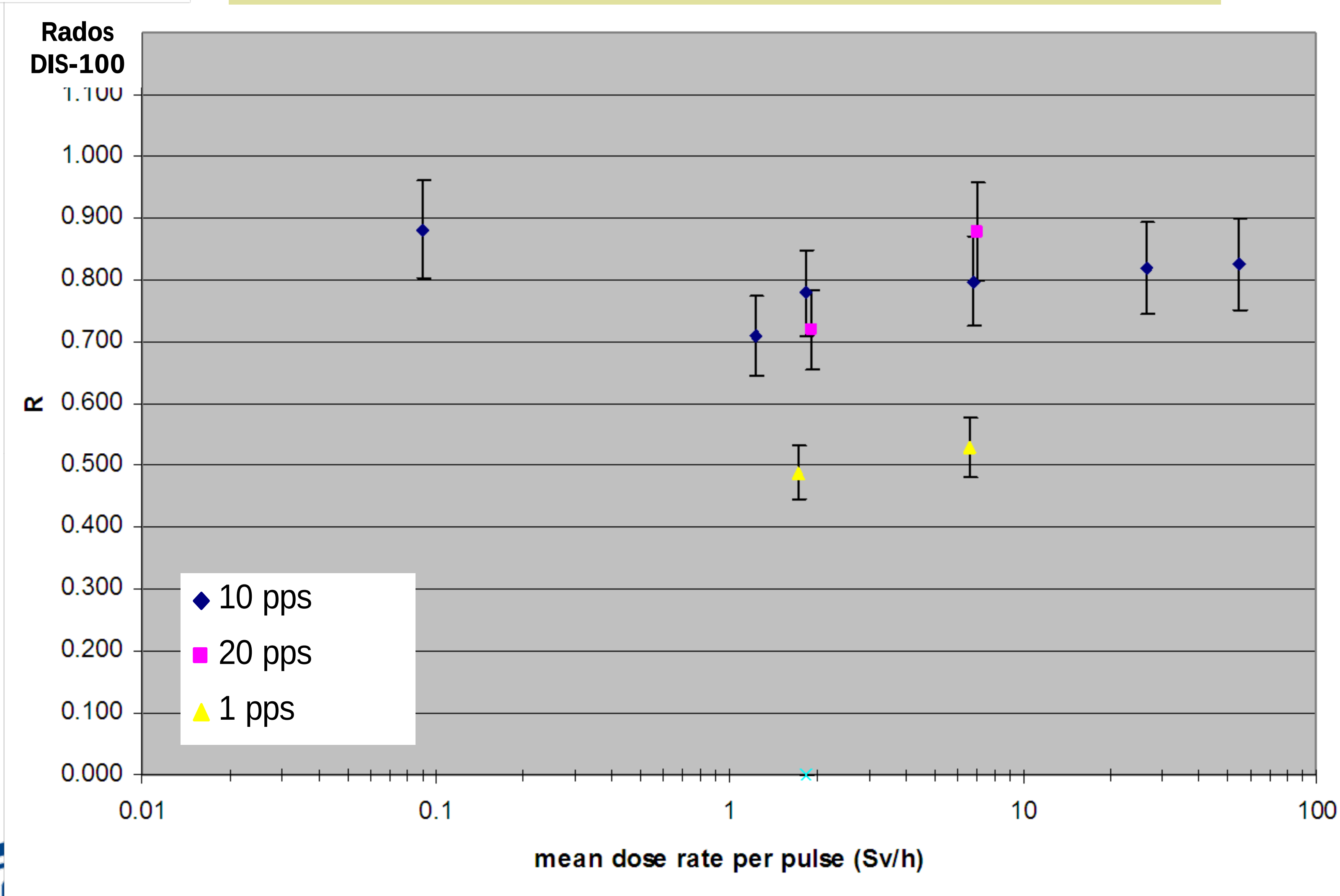
TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY



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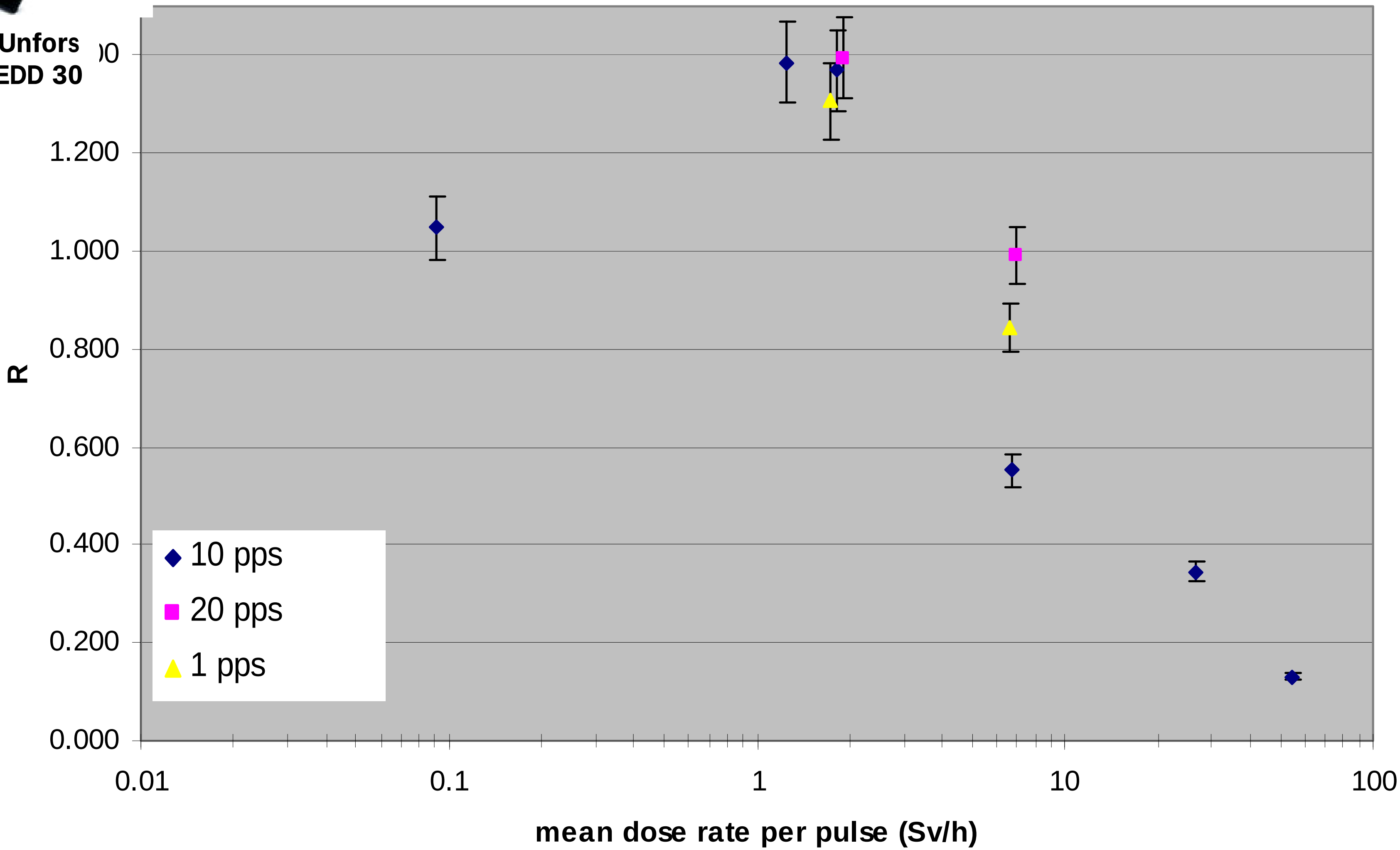
TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

Unfors
EDD 30

EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY



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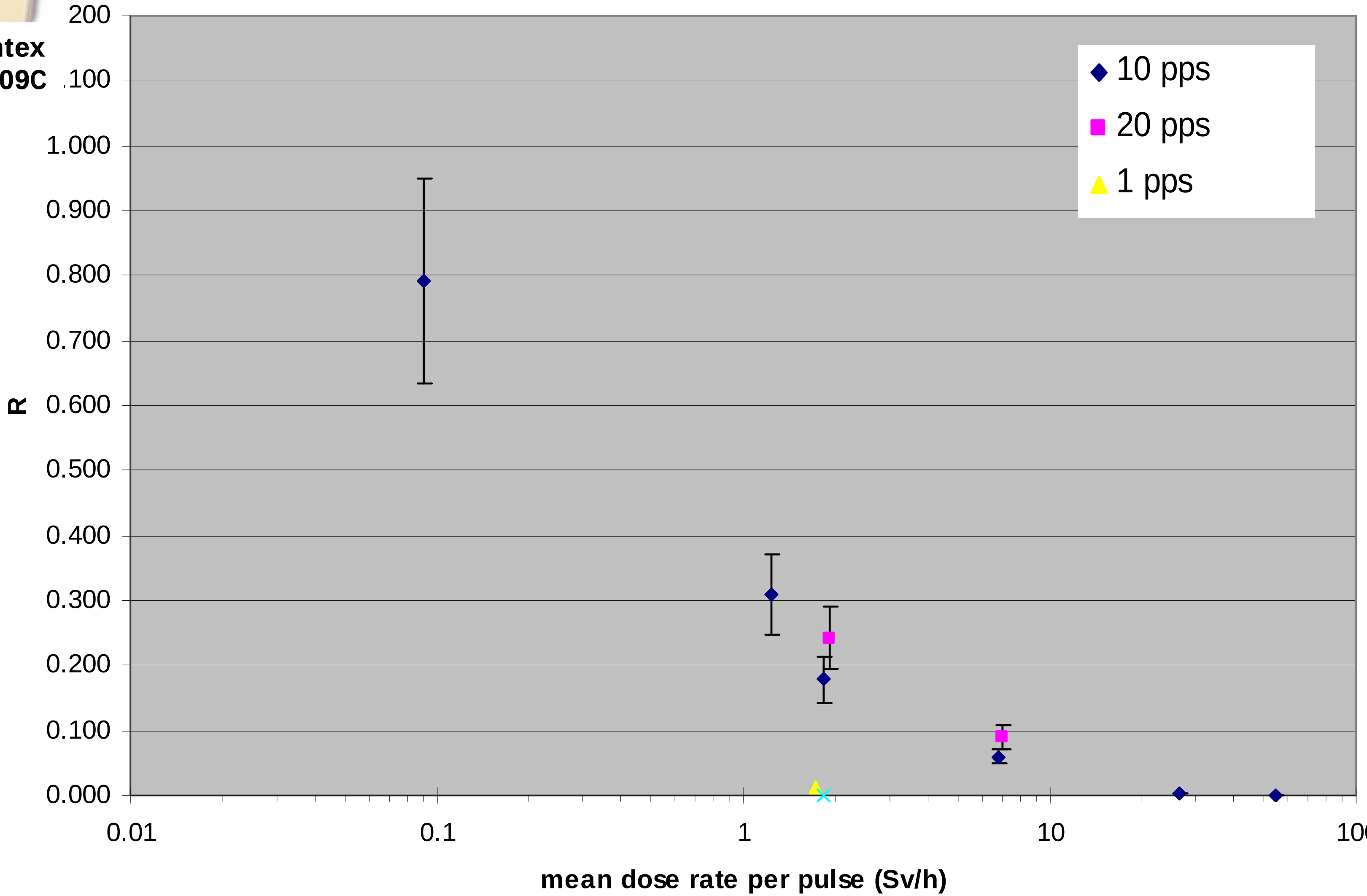
TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

Atomtex AT3509C

EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY



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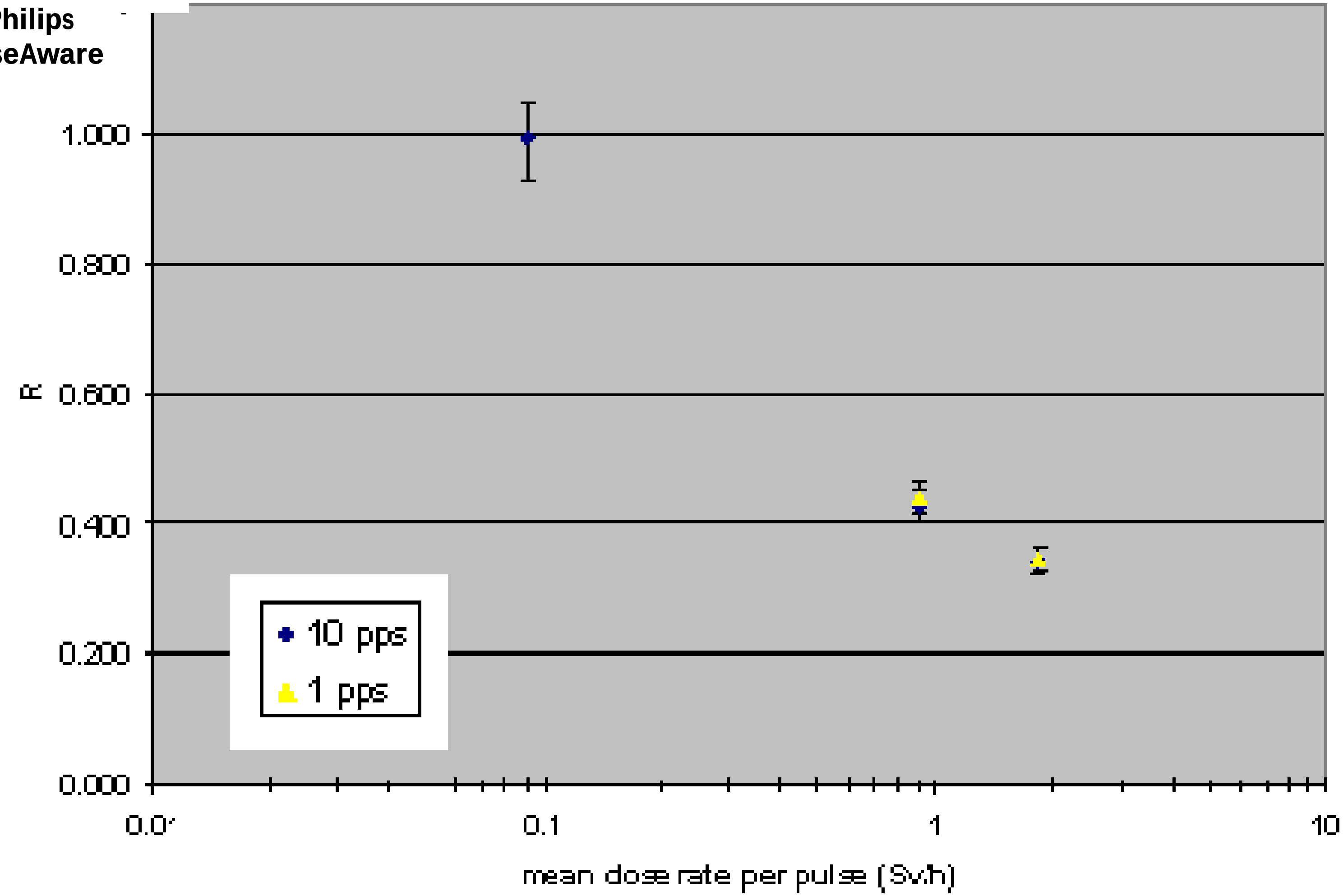
TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

EFFECT OF DOSE EQ. RATE AND PULSE FREQUENCY

Philips DoseAware



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TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

EFFECT OF DOSE EQUIVALENT RATE

Threshold in terms of dose equivalent rate ($Sv.h^{-1}$) for which the maximum APD response is divided by a factor 2.

APD	DMC 2000XB	EPD MK2.3	EDM III	PM1621A	DIS-100	EDD 30	AT3509C	Dose Aware
Dose equivalent rate ($Sv.h^{-1}$) for APD response divided by 2	5	7	20	NO SIGNAL	Response within +/- 30% for all dose equivalent rates up to 55 $Sv.h^{-1}$	10	3.5	0.8







TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

EFFECT OF PULSE FREQUENCY

Percentage of variation on the APD response from 1 to 20 pps

APD	DMC 2000XB	EPD MK2.3	EDM III	PM1621A	DIS-100	EDD 30	AT3509C	DoseAware
Variation on the APD response %	25-30	30-40	<10	NO SIGNAL	30	10 (1.8 Sv.h^{-1}) saturation from 2 Sv.h^{-1}	30: 10- 20 pps; No signal at 1 pps	<10 (between 1 and 10 pps)








TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

EFFECT OF PULSE WIDTH

When the pulse width is larger than 1 s: the responses in pulsed and in continuous radiation field are similar.

No significant effect of pulse width on the response for 20, 50, 100 and 1000 ms at 1.8 $Sv.h^{-1}$ was observed.

CONCLUSIONS ON TESTS PERFORMED WITH PULSED X-RAY BEAMS IN LABORATORY CONDITIONS

PM1621A, equipped with a Geiger-Muller tube, does not give any signal in pulsed mode.

The other APDs provide a response in pulsed mode.

DMC 2000XB, EPD Mk2.3, EDMIII, EDD30, AT3509C and DoseAware contain all a silicon detector, the differences of their response is likely to be due to the time response of the electronics.
The DIS has a “hybrid” technology between silicon and ionization chamber which presents correct results.

GENERAL CONCLUSIONS ON TESTS PERFORMED IN LABORATORY CONDITIONS (1/2)

The tests performed with **continuous X-ray beams** showed that all tested APDs have a satisfactory response at low energies typical of IR/IC. Most APDs provide a correct response for dose equivalent rates up to 10 $Sv.h^{-1}$.

However, the dose equivalent rates in the direct beam can be much higher than those tested here. So these tests cannot guarantee that the APDs will correctly measure the high dose equivalent rates in the direct beam.

The study in **pulsed mode** showed that, except PM1621A, all APDs provide a reading. Limitations of some APDs are mostly due to high dose equivalent rates rather than to pulse frequency.

GENERAL CONCLUSIONS ON TESTS PERFORMED IN LABORATORY CONDITIONS (2/2)

This study highlights the limitations of APDs in IR/IC and the need of improving the APDs technology as to fulfil all needs in the IR field. **Nevertheless, it is also shown that, with adequate correction factors, most of the tested APDs could be used as operational dosemeters provided that they are not exposed to the direct beam.**

- tests in **hospitals** → Struelens et al.
- proposals **for improvements of APDs** → Martin et al.
- **practical guidelines** related to the choice and the use of APDs in IR/IC → Daures et al.