Active Personal Dosemeters: EURADOS activities and application in interventional radiology

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Thessaloniki May 17th, 2011

- Introduction to EURADOS
- EURADOS working group on active personal dosemeters
    - APD catalogue
    - IAEA intercomparison
    - APD for legal dosimetry?
- CONRAD project
- ORAMED project

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EURADOS

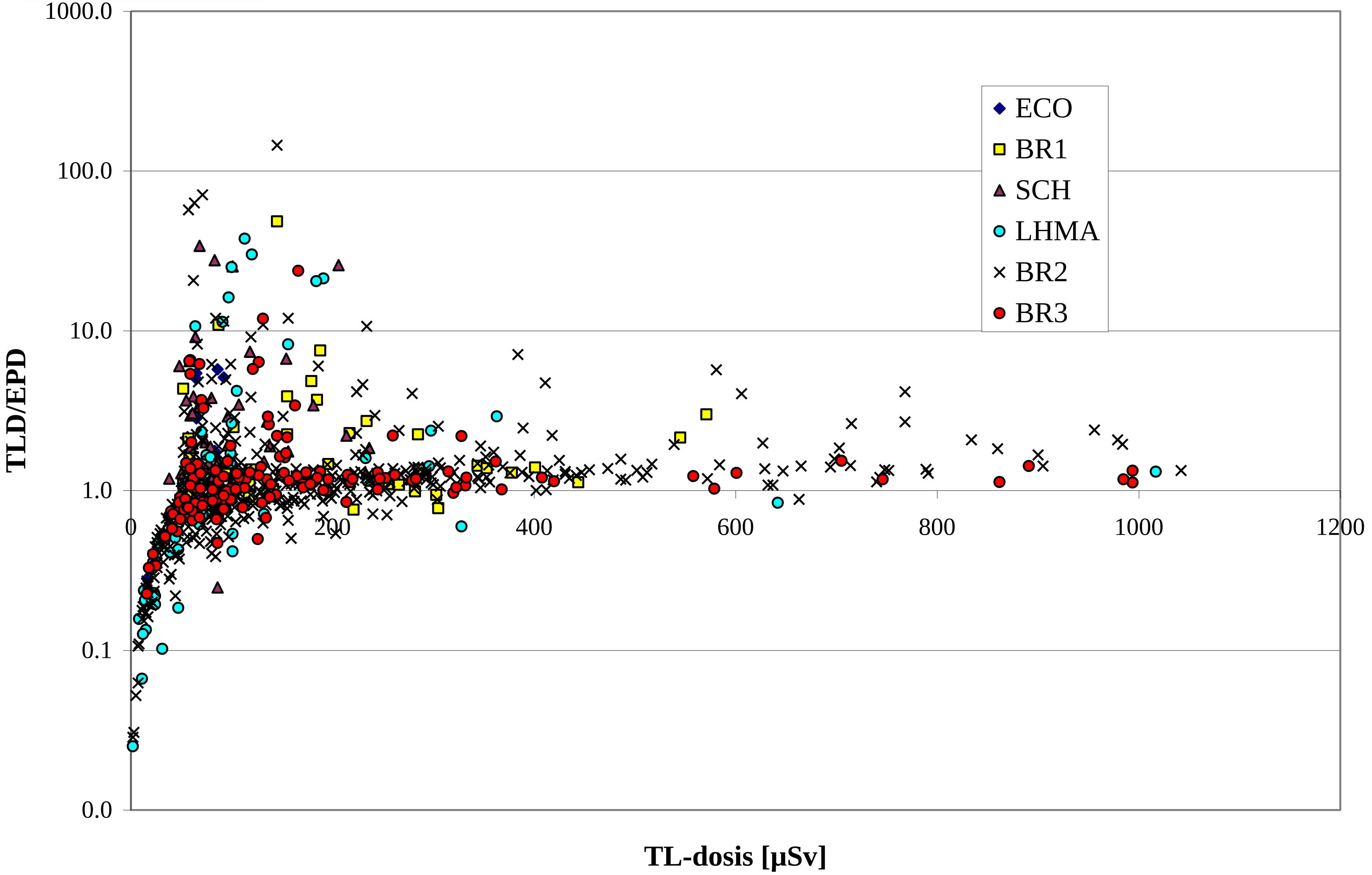
- EURADOS:
  - is an organisation (1981) to *advance the scientific understanding and the technical development of the dosimetry of ionizing radiation* by promoting collaboration between European laboratories.
  - Currently 57 voting members (=institutes)
    - One Greek member: GAEC
  - Council: 12 persons
    - Chairperson: Helmut Schuhmacher (PTB)
    - Vice chair: Elena Fantuzzi (ENEA)
    - Treasurer: Joao Alves (ITN)
    - Secretary: Filip Vanhavere (SCK-CEN)
  - Associate members: individual scientists

- EURADOS operates by setting up Working Groups:
  - WG2: Harmonization + intercomparisons (J. Alves)
  - WG3: Environmental dosimetry (S. Neumaier)
  - WG6: Computational dosimetry (G. Gualdrini)
  - WG7: Internal dosimetry (M.A.Lopez)
  - WG9: Radiation Protection dosimetry in medicine (R. Harrison)
  - WG10: Retrospective dosimetry (P. Fattibene)
  - WG11: High energy radiation fields (W. Ruhm)
  - WG12: Medical ALARA network (F. Vanhavere)

Active Personal Dosemeters: General characteristics

- Active personal dosemeter: APD
  - Direct reading capability
  - Some APD's have no alarm function (e.g. Direct Ion Storage)
- Interesting characteristics compared to passive devices:
  - Instant or direct reading
  - Data transfer to and from computer network
  - Lower detection limit
  - Possibility for audible alarms
  - Dose memory options for distant read-out
- Often both are used
  - Legal dosemeter: passive
  - ALARA dosemeter: active

Comparison APD-passive dosemeter at SCK-CEN



EURADOS WG2 work: Catalogue of APD's

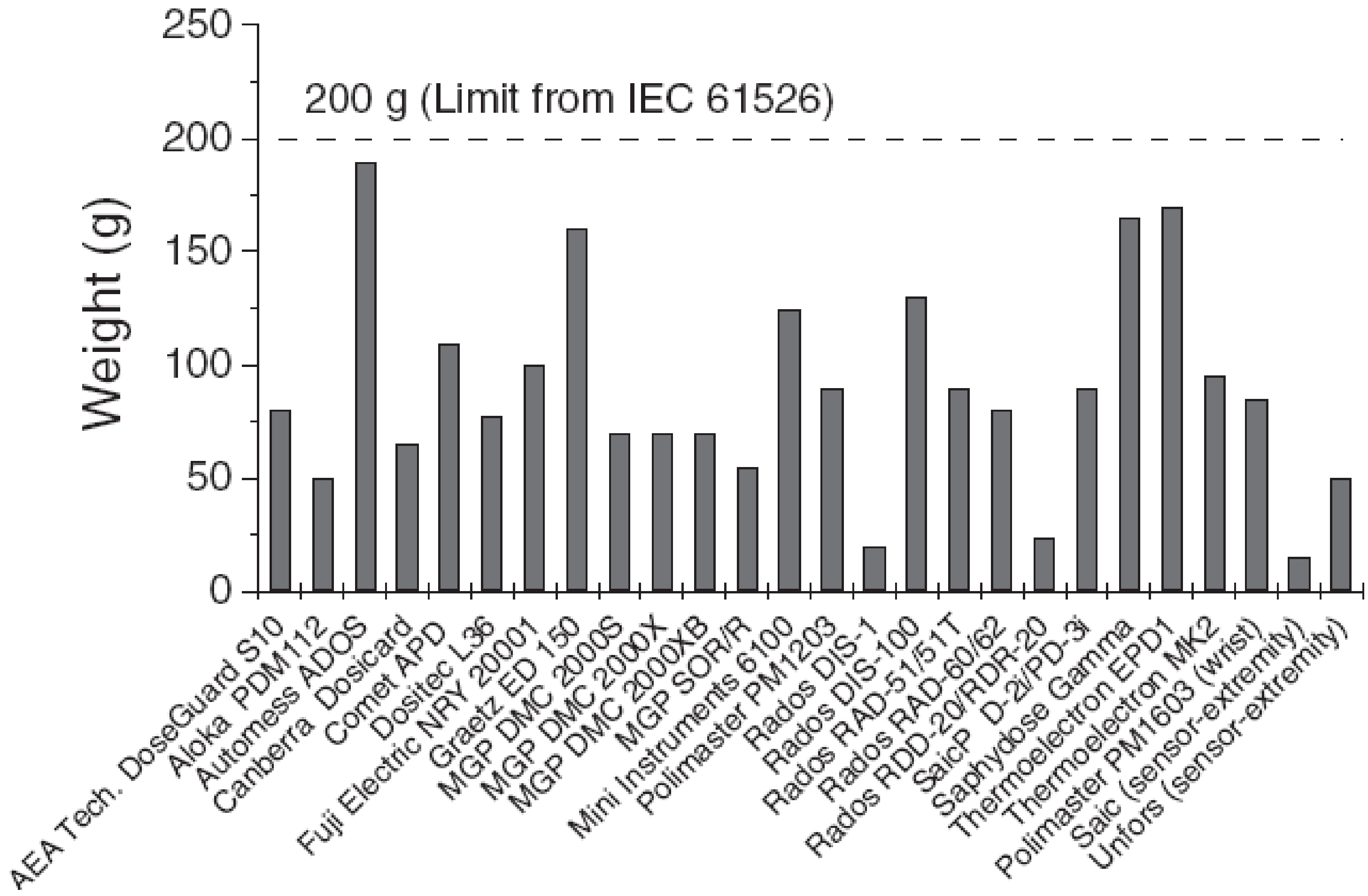
- Selection of 31 dosemeters from 16 manufacturers
- Three types
  - Photon dosemeters with Geiger-Muller tube
    - Automess, Graetz, Mini Instruments, Polimaster, SAIC
  - Photon or beta-photon dosemeters with one or more silicon detectors
    - AEA Technology, Aloka, Canberra Dosicard, Comet, Dositec, Fuji Electric, MGP, Saphymo, Rados, Thermo Electron
  - Others:
    - Rados DIS dosemeter, Unfors (extremity)

Comparing APD's with standards

Charateristic	IEC 61526 requirement	Typical values for APD
Size	< 250 cm³	100 cm³ (31/31)
Mass	< 200 g	80 g (31/31)
Mechanical resistance	10%, 1.5 m drop test	Some do not pass (25/31)
Environmental immunity	10%, e-m interference	Older types do not pass (28/31)
Range	1 μSv – 1 Sv	1 μSv – 1 Sv (25/31)
Photon fields (33 keV-2 MeV)	15%	50 keV – 2 MeV (11/31)
Beta fields ($^{90}Sr/^{90}Y$, ^{204}Tl)	15%	(4/31)

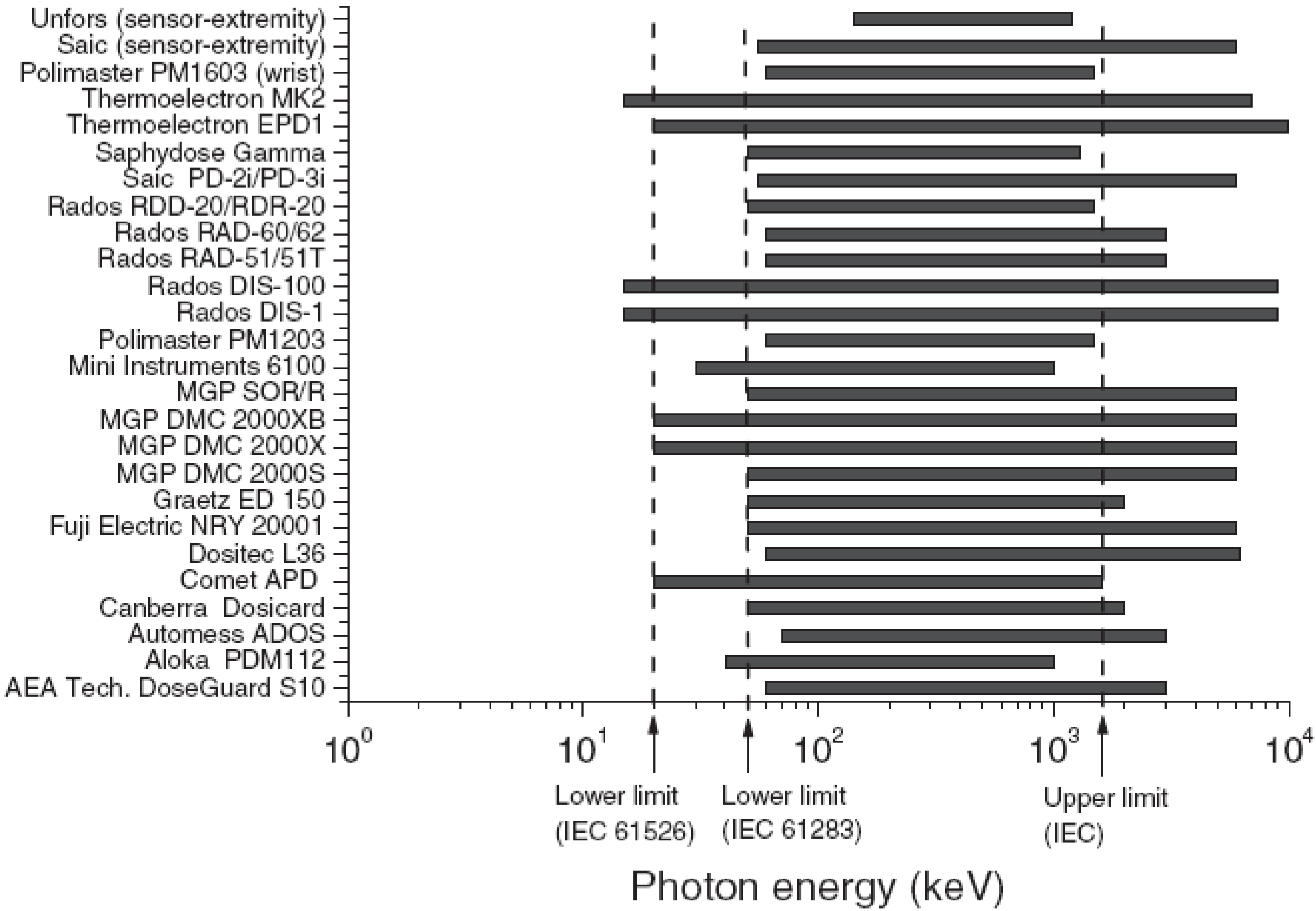
IEC 61526: Radiation protection instrumentation – *measurement of personal dose equivalent $H_p(10)$ and $H_p(0.07)$ for X, gamma, neutron and beta radiation* - Direct reading personal dose equivalent monitors – **(2005)**

Weight

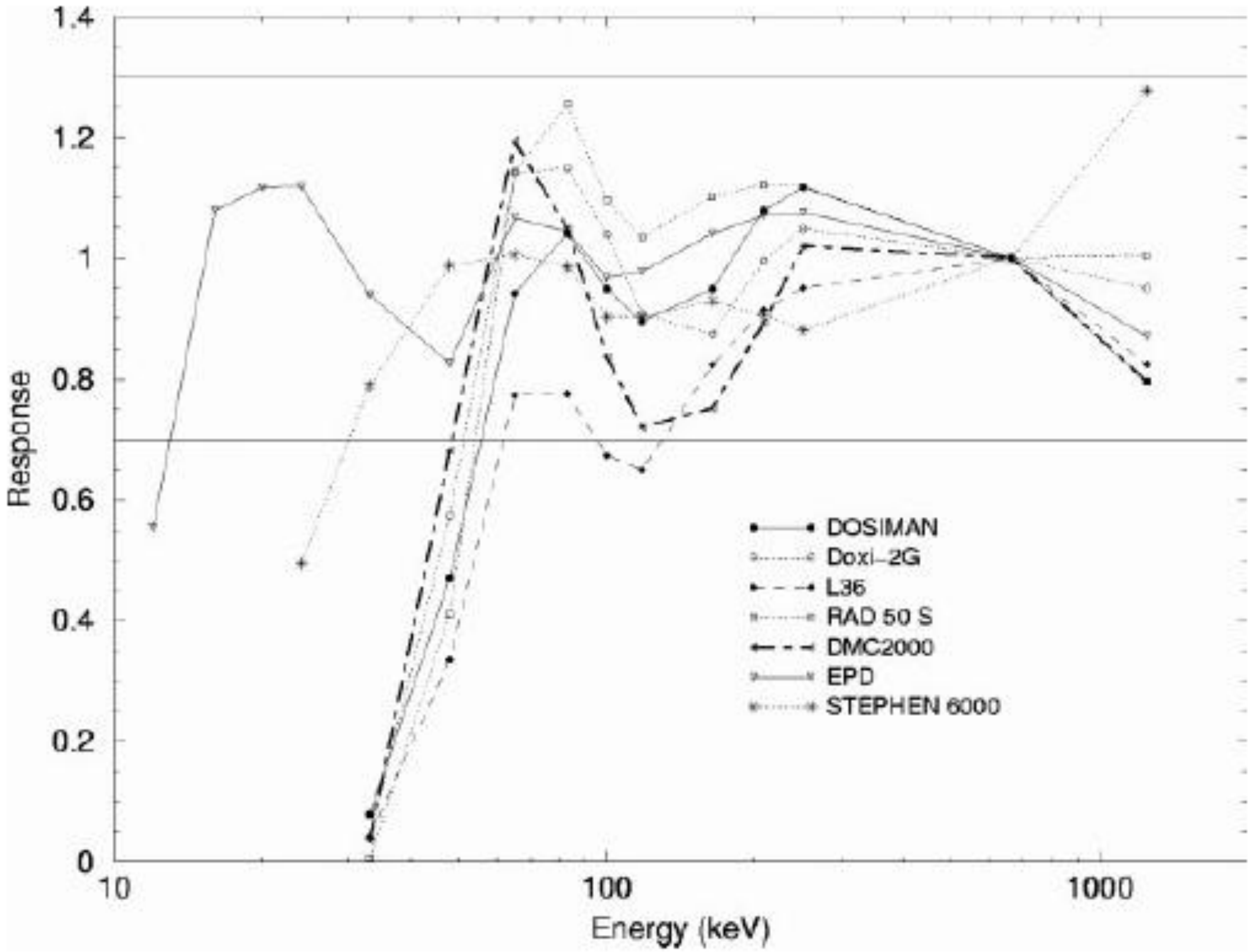


200 g (Limit from IEC 61526)
Weight (g)
0
50
100
150
200
250
AEA Tech. DoseGuard S10
Aloka PDM112
Automess ADOS
Canberra Dosicard
Comet APD
Dositec L36
Fuji Electric NRY 20001
Graetz ED 150
MGP DMC 2000S
MGP DMC 2000X
MGP DMC 2000XB
MGP SOR/R
Mini Instruments 6100
Polimaster PM1203
Rados DIS-1
Rados DIS-100
Rados RAD-51/51T
Rados RAD-60/62
Rados RDD-20/RDR-20
SaicP D-2i/PD-3i
Saphydose Gamma
Thermoelectron EPD1
Thermoelectron MK2
Polimaster PM1603 (wrist)
Saic (sensor-extremity)
Unfors (sensor-extremity)

Relevant standards



Energy response of some APD's

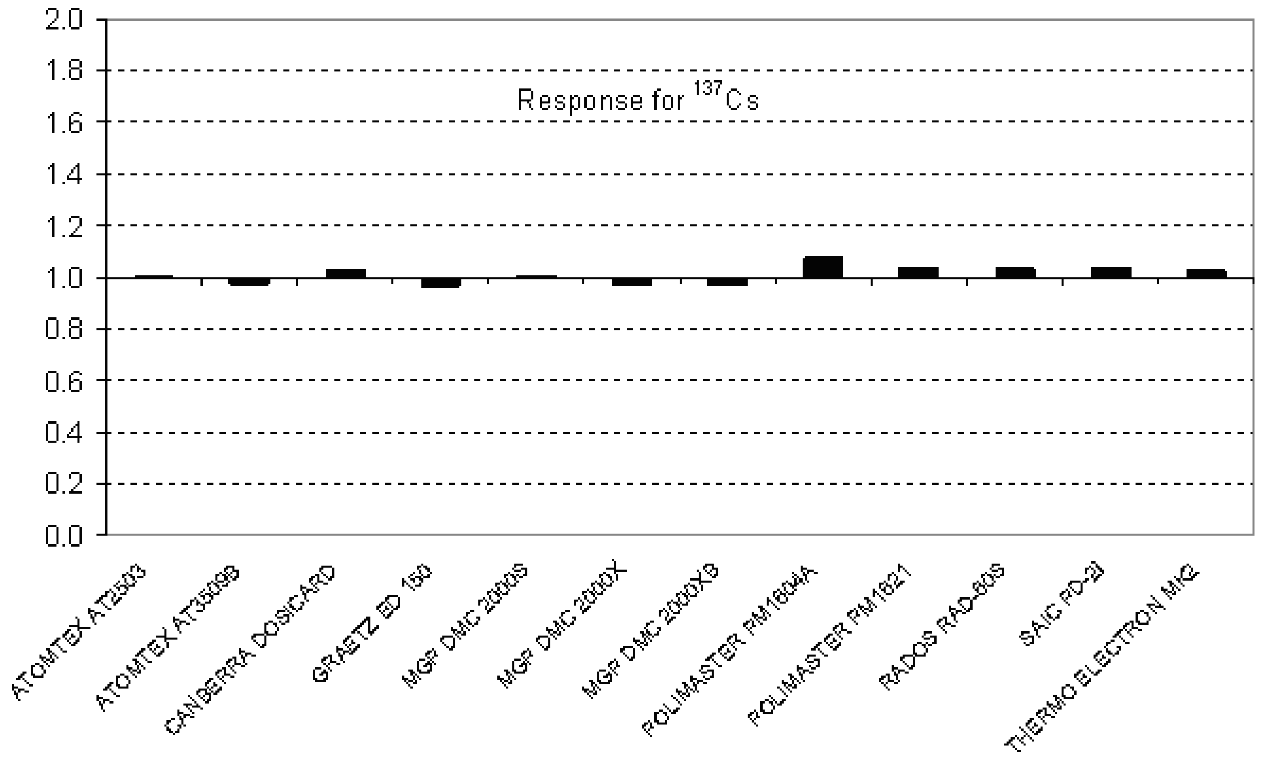


IAEA/EURADOS intercomparison of APD

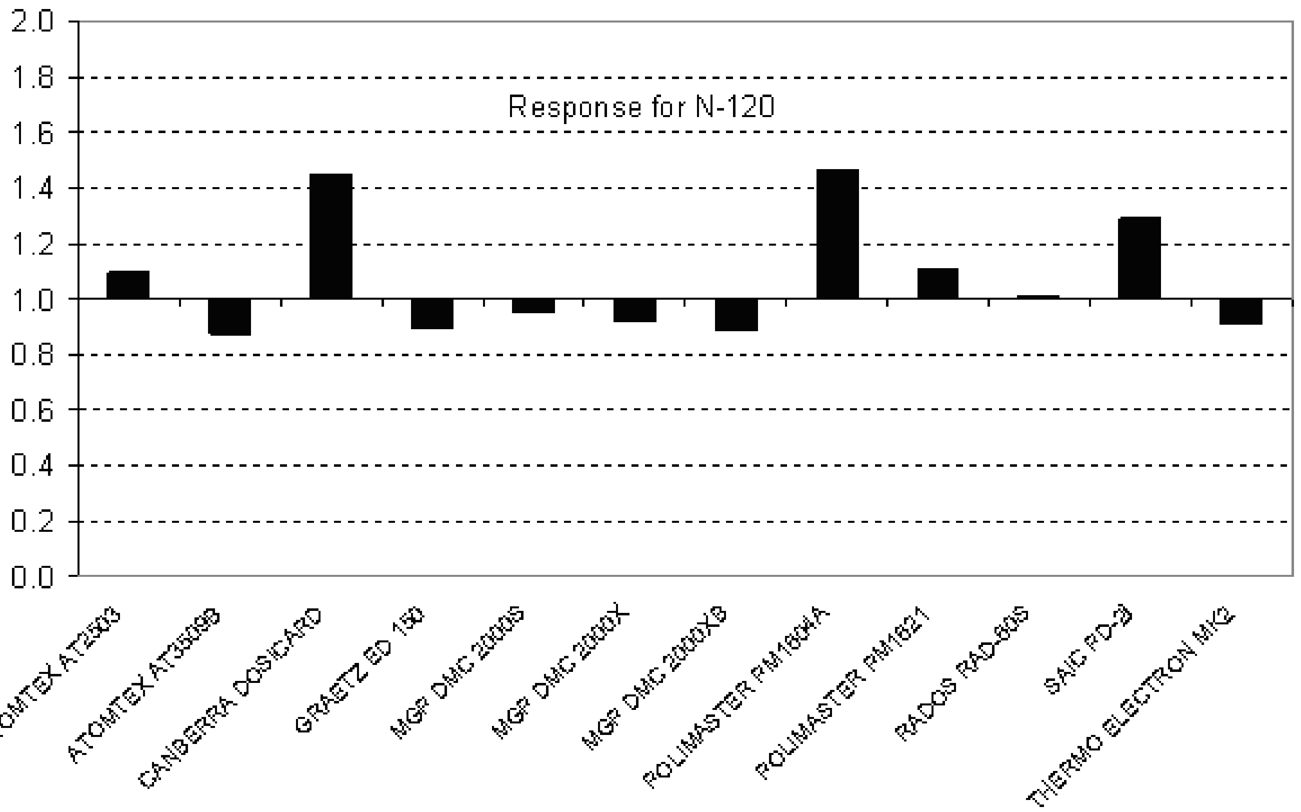
- Scope
  - Assess capabilities of APD to measure $H_p(d)$ in photon and beta radiation fields
    - Compared to IEC 61526 standard
    - In realistic fields
  - To help member states achieving accurate knowledge on APD’s
  - To provide guidelines for improvements to manufacturers
- 13 different models, 9 suppliers
- Results: IAEA Tecdoc 1564

IAEA/EURADOS intercomparison of APD

Results: Cs-137: very good



Results: N-120



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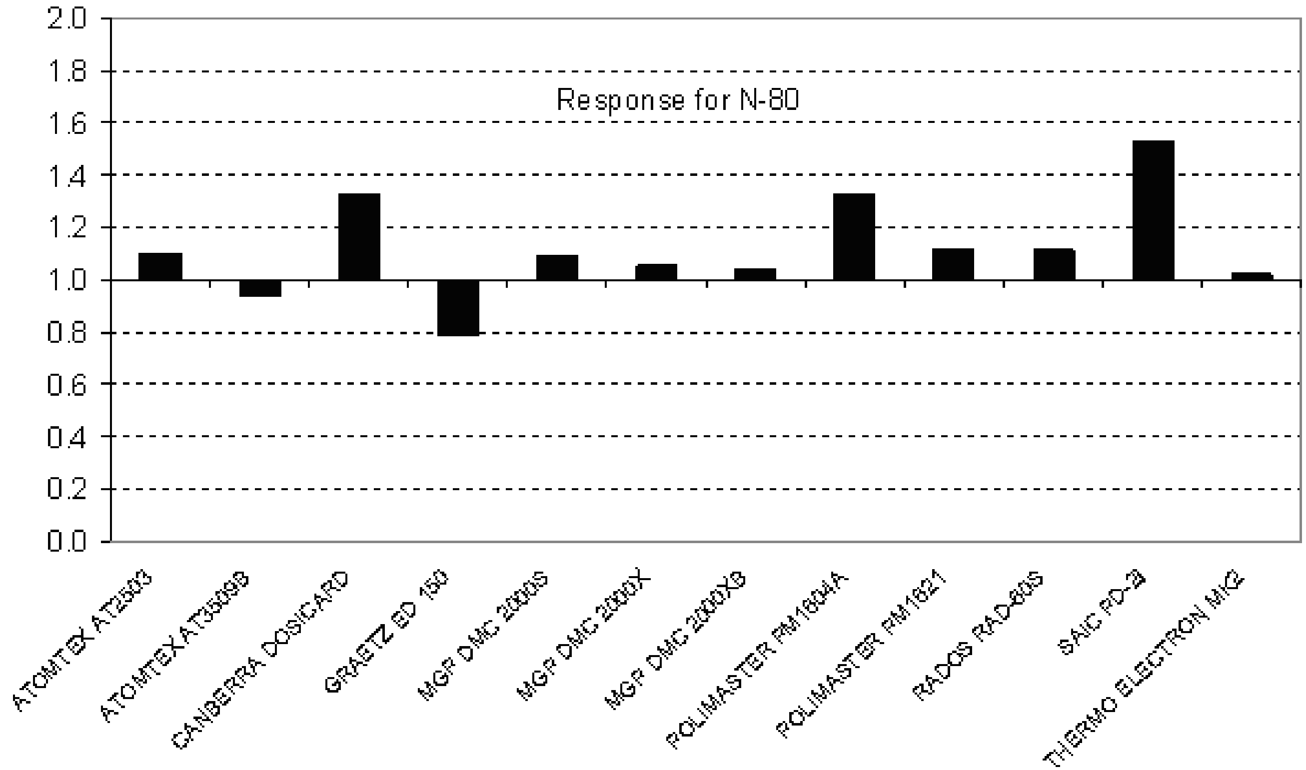
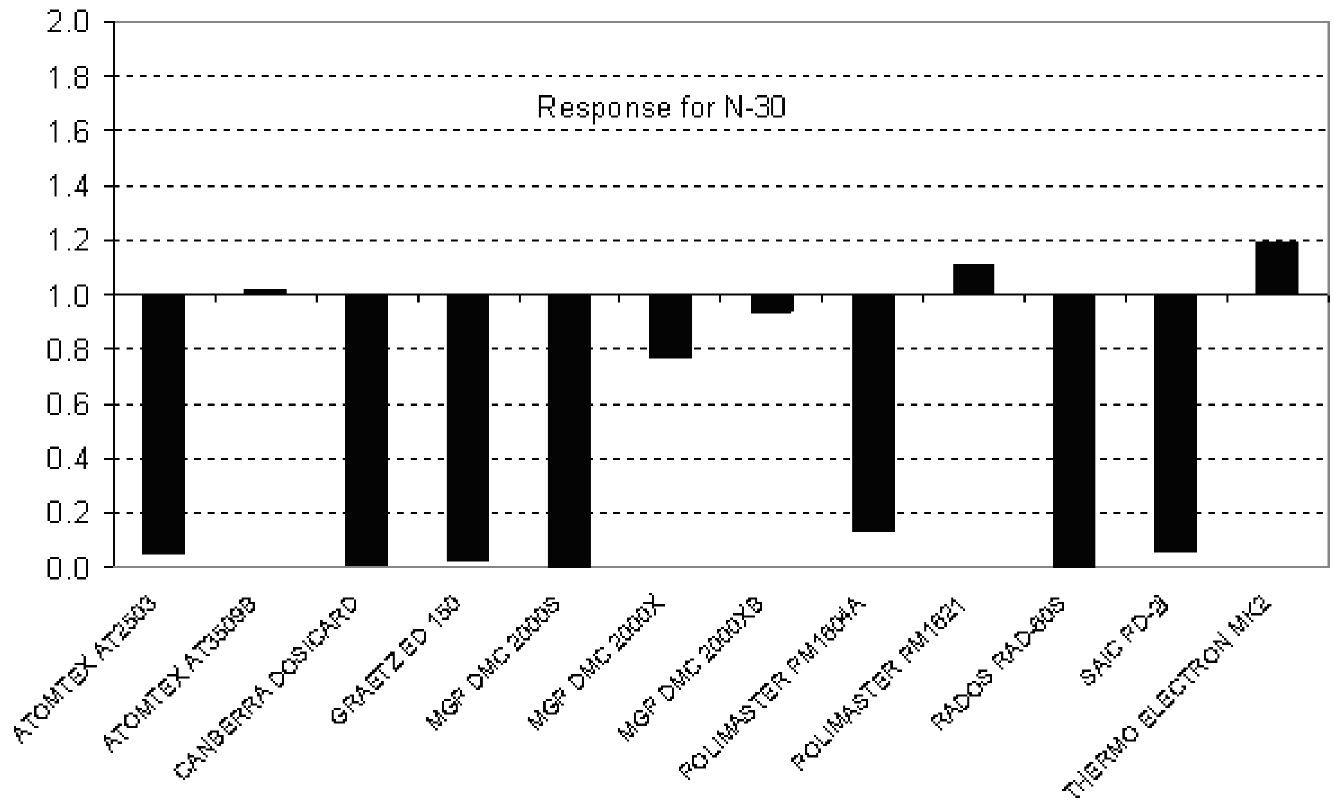
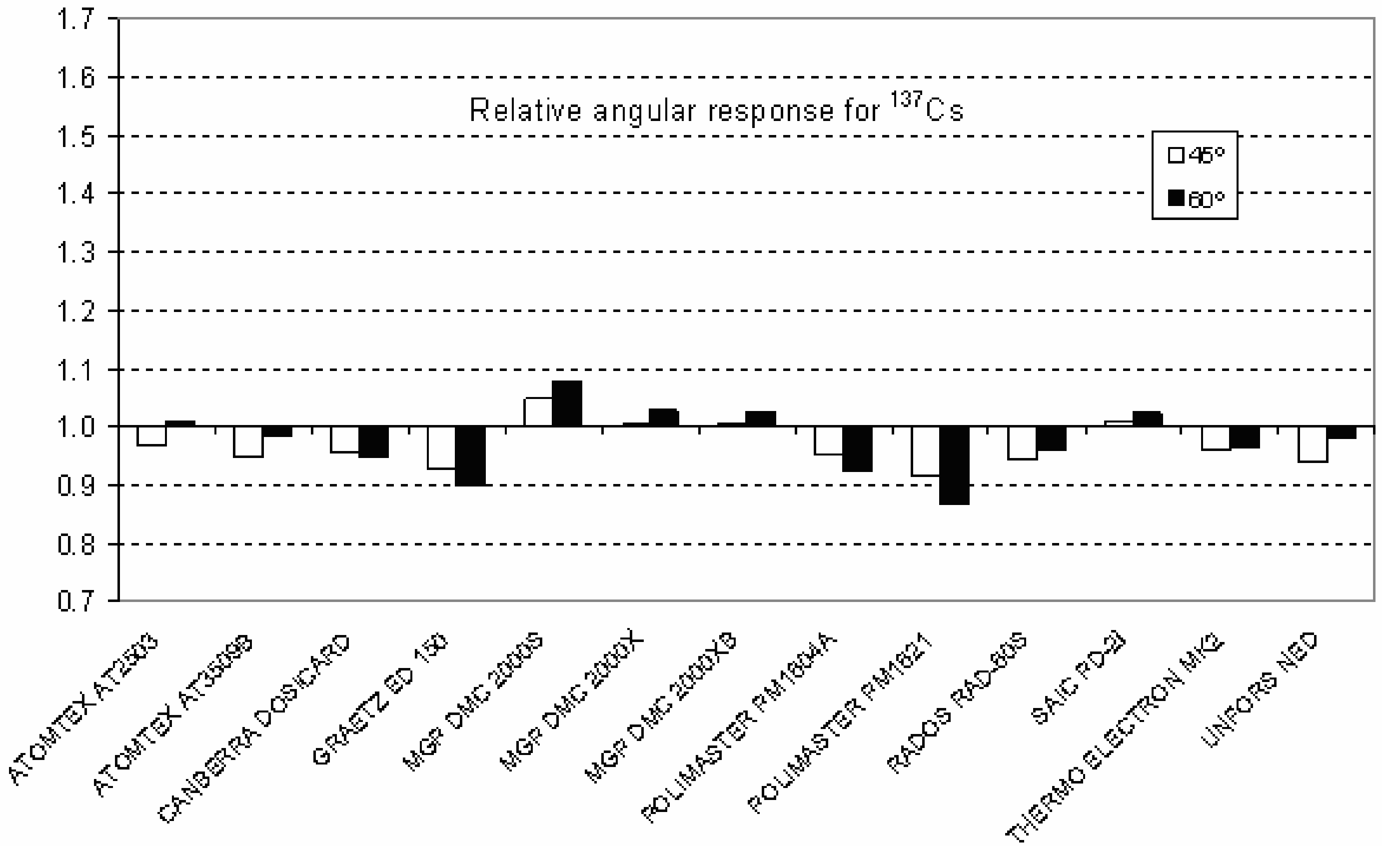
Results: N-80



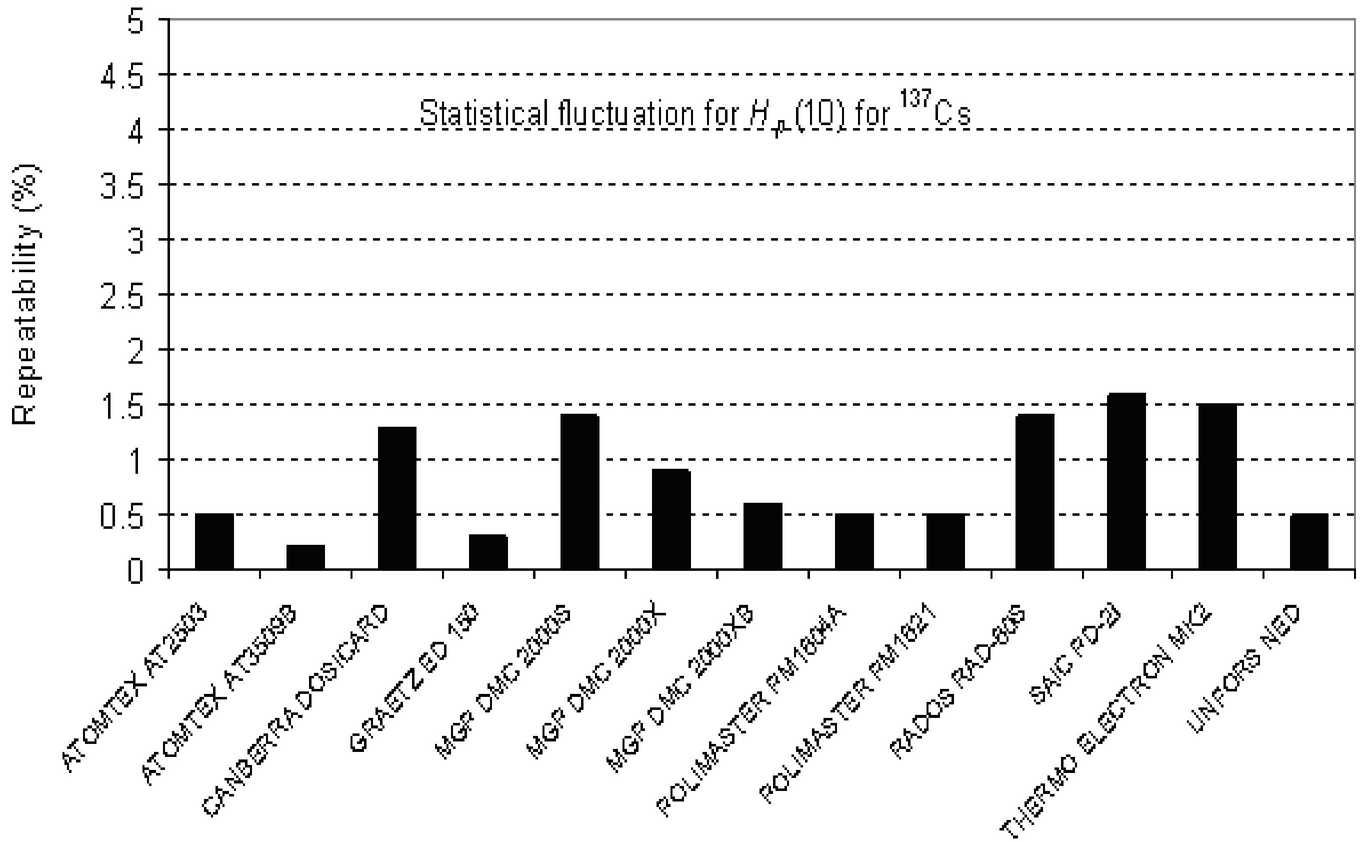
Results: N-30: only few dosemeters measure low energy X-rays



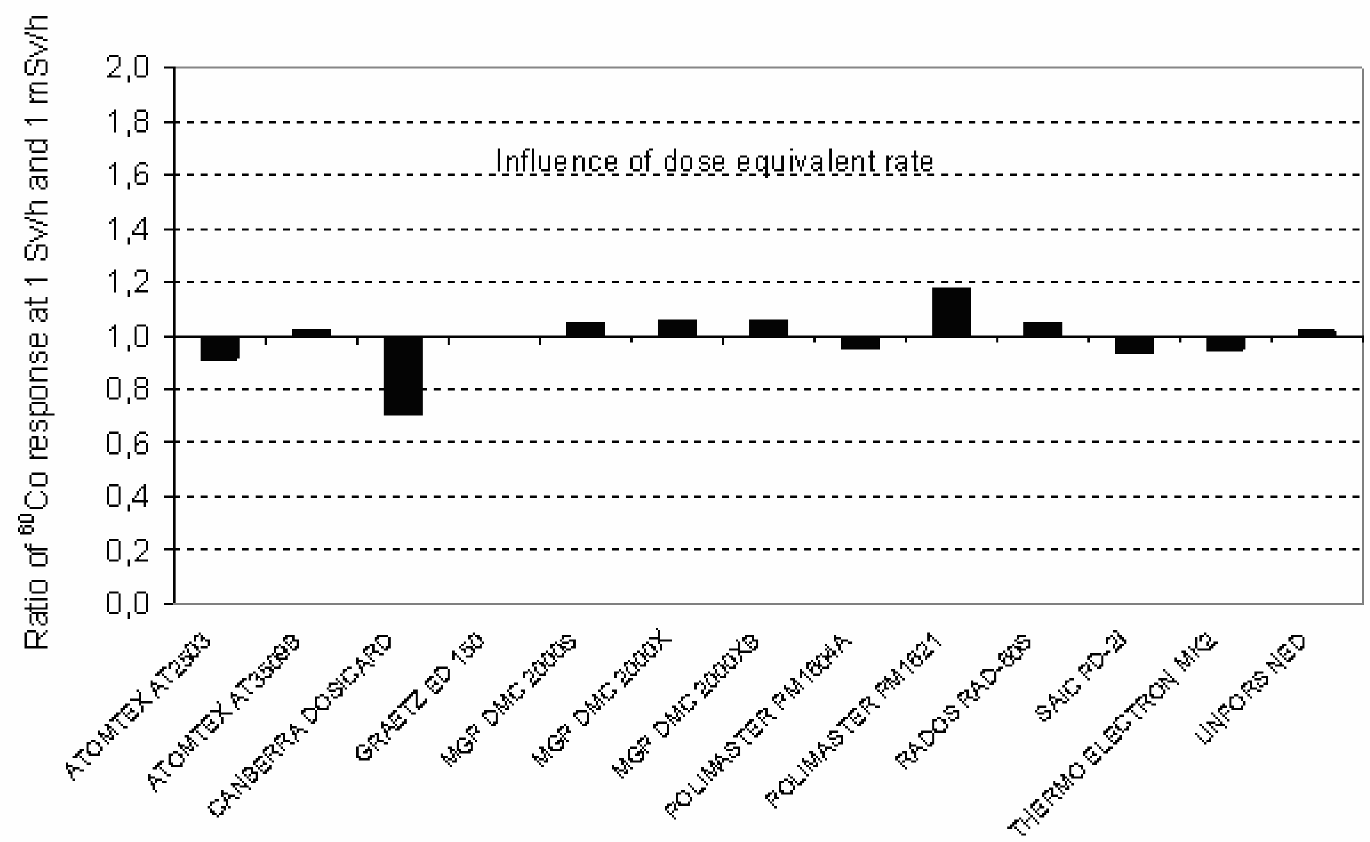
Angular response: no problem



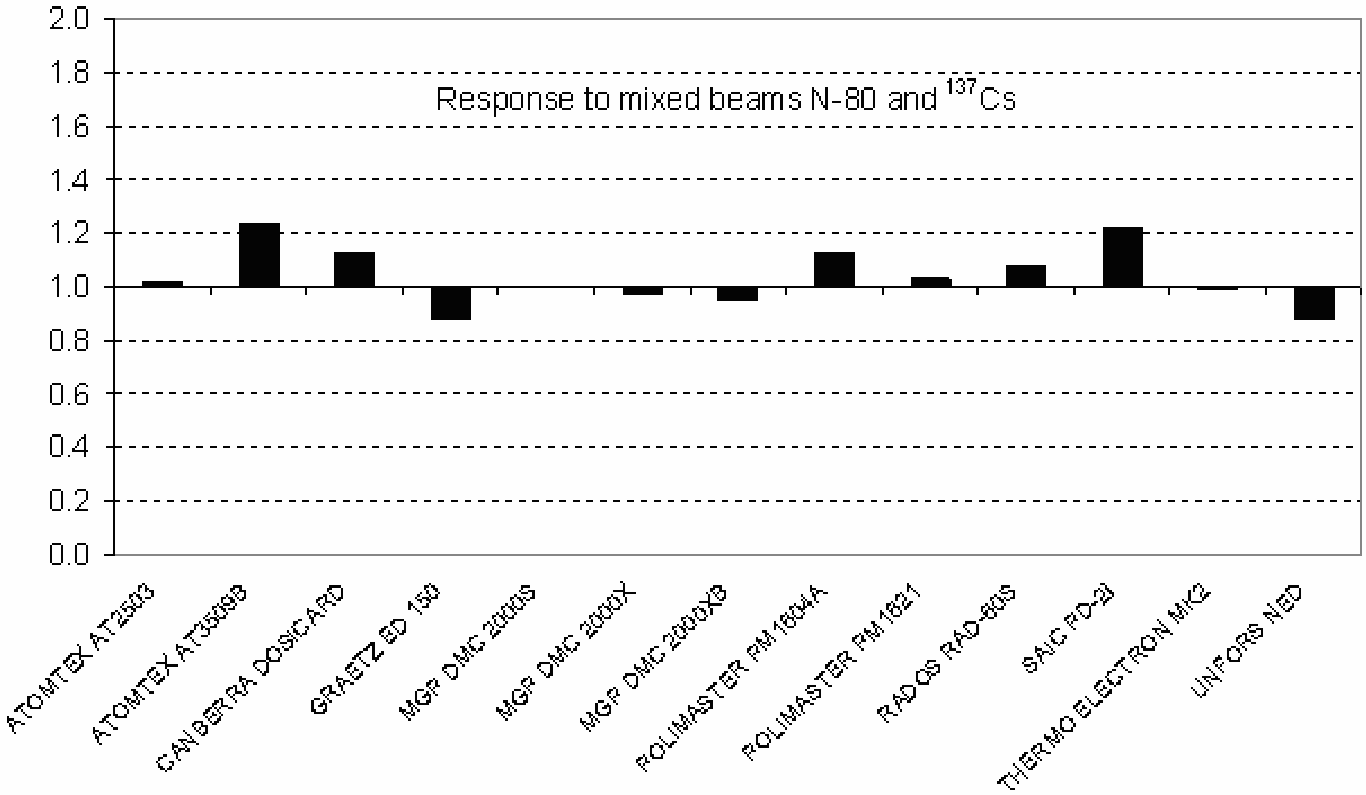
Statistical fluctuations



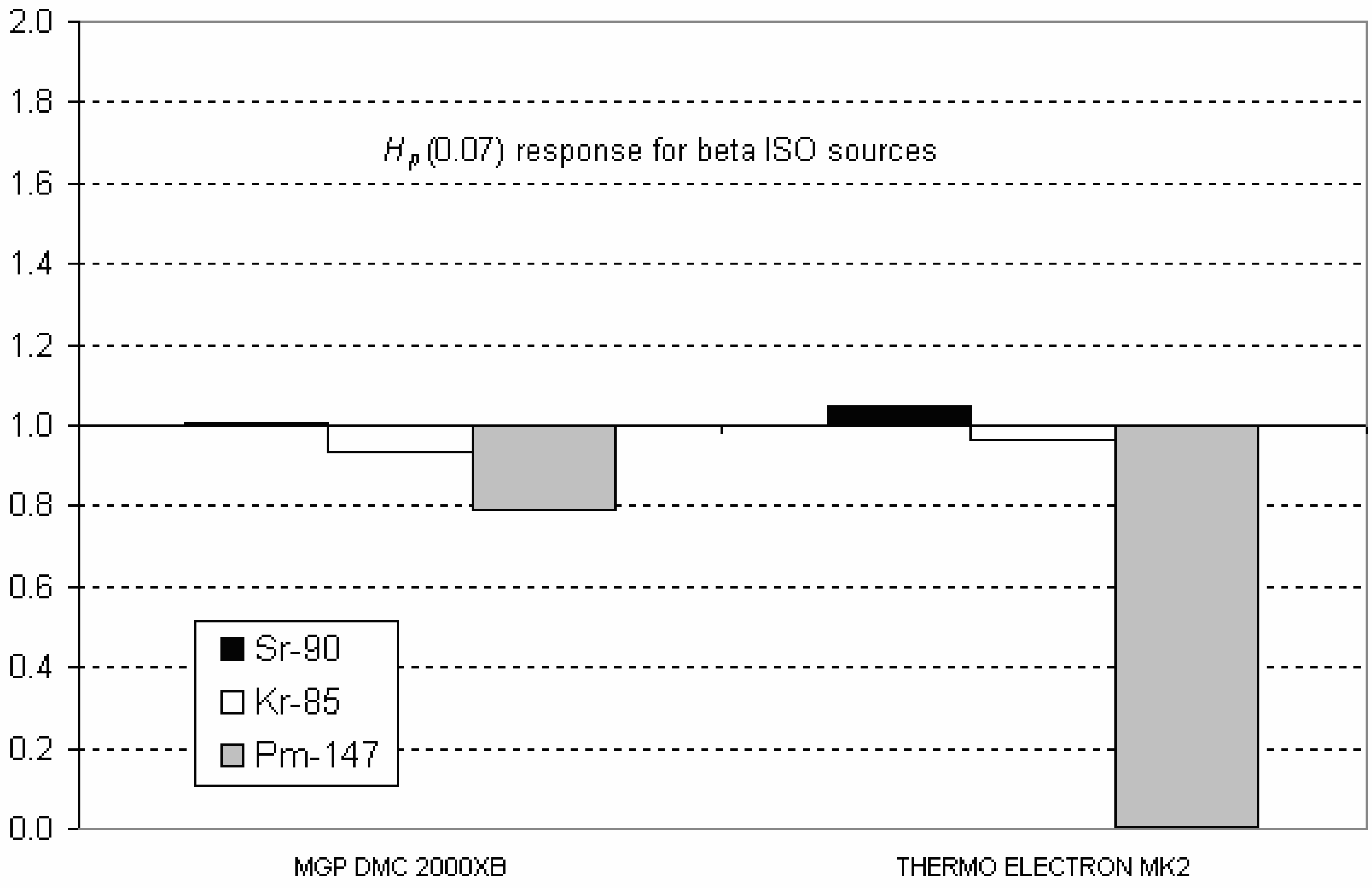
Dose equivalent rate: no problem



Mixed field: no problem



Beta fields: sometimes outside specified range



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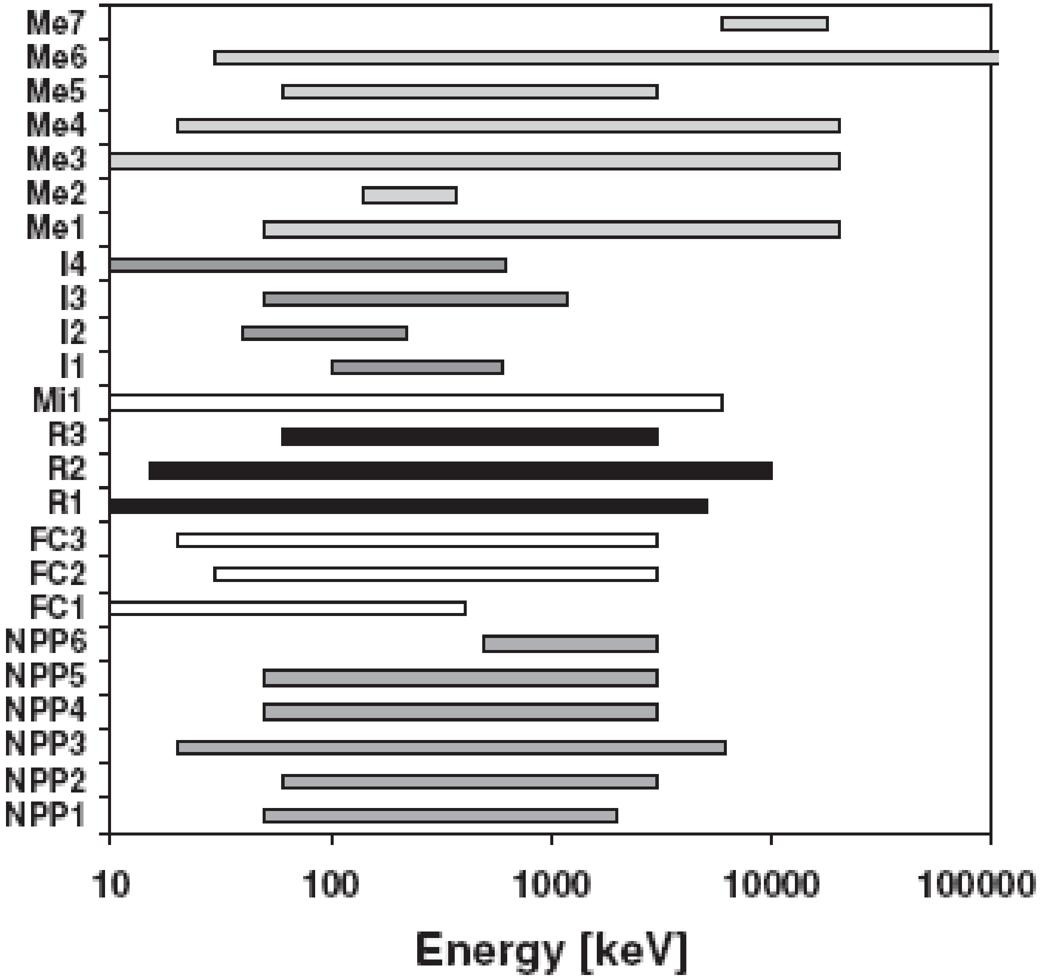
Conclusions intercomparison

- General dosimetric performance:
  - Within limits of standard
- But !!
  - **Not all dosemeters designed for all fields**
  - Caution in
    - *Beta fields*
    - *Low energy X-rays*
    - *Pulsed fields*
  - Three types satisfactory for all fields
    - *MGP DMC2000XB, MGP DMC2000X, Thermo EPD Mk2*

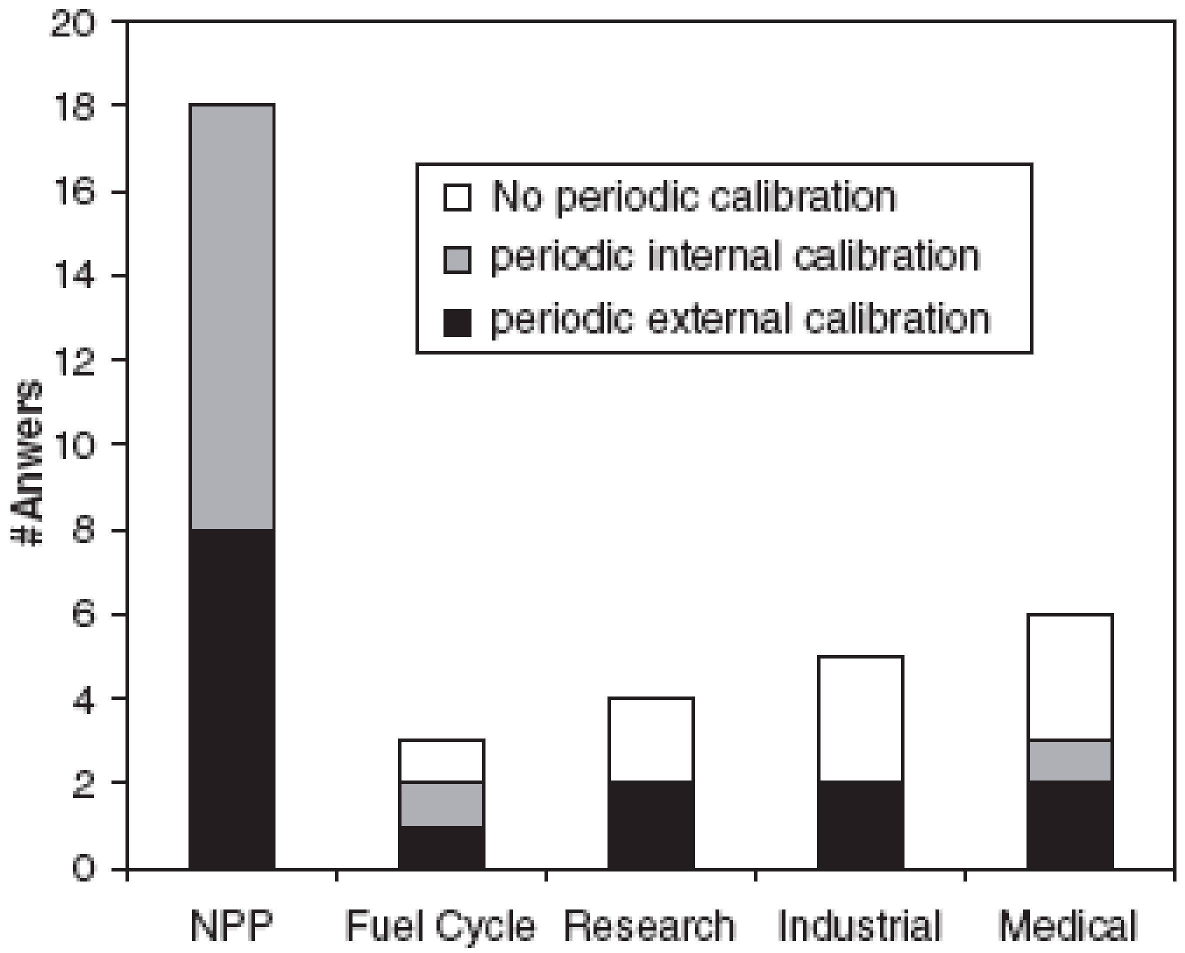
End-user questionaire

- APD use common practise in nuclear installations
- More and more popular in smaller companies and hospitals
  - Risk of mis-use and lack of QA and QC
  - Differences in use of results
    - Sometimes just alarm dosemeter
    - Sometimes check of passive dosemeter
- Questionaire to end-users
  - 39 answers from B-FIN-GER-SLN-SPA-UK
  - Grouped in categories: NPP-FC-Industry-Research-Medical

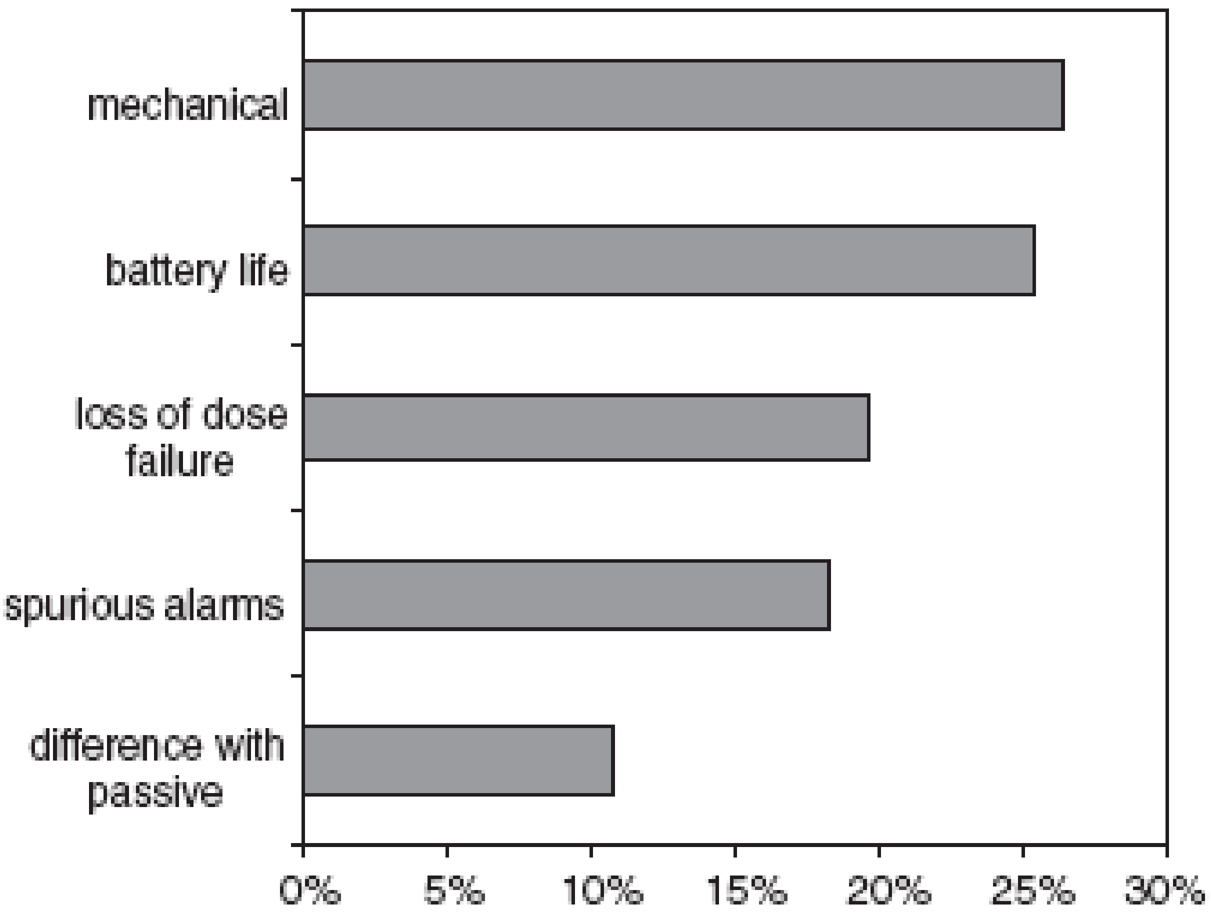
What radiation fields in your facility?



Calibration of your APD's



Major problems



Conclusion: difference in approach

- Nuclear Power plants:
  - Large number of APD's
  - Systematic calibration
  - Systematic comparison with passive devices
    - Differences reported between 3 and 8%

- Industry and medical fields
  - Small number of APD's
  - Much less calibration
  - Use as alarm dosemeter or for tests
  - Less knowledge on radiation characteristics

APD or passive dosemeters for legal dose record????

- Passive: TLD-OSL-RPL-film
- Active:
  - Used for 20 years now
  - Recent types are ‘wonders’ of technology
  - Very specific advantages
- Using only APD’s would be cost-effective
  - Are they reliable enough?
  - Are technically good enough?

Legal requirements

- 96/29 Euratom Directive
  - No specific requirement for type of dosemeter
  - Must estimate effective dose and skin dose
- Most countries require passive dosemeter for dose record
  - Only UK and Switserland: specific approvals for APD systems
  - Projects in Germany: possible within law
- Mostly APD's obliged for high dose workplaces

APD reliability

- Little experience as legal dose of record (DOR)
- EPD used in BNFL (NPP) for many years as DOR
  - Specific approval, much QC for data transfer and management (regular calibration)
  - Result:
    - Computer system reliable and robust
    - Initial problems with RF interference
    - Mk2: only 0.06% of results lost (physical loss, not readable,..)
- !! In NPP strict follow up
  - Numbers may be higher for other industries

Passive systems reliability

- EURADOS questionaire
  - % lost dosemeters results
    - between 0% and 20% reported
    - Median: 1%
  - Uncorrect wearing
  - Washing machine
  - Loss during processing
- If dosemeter is lost: more data lost !!!
- Most systems have many years experience and are well known

Passive systems technical assessment

- Energy/angular dependence: well known
- Mechanical very robust
- Very small
- Lower detection limit: low enough
- Cheap

Conclusion

- APD's have reached a state-of-the-art: ready to be used as DOR
- Data transfer and reliability are sufficient
- Technical characteristics are sufficient or better than passive
  - Care needs to be taken for specific fields
- Authorities are starting to accept APD as DOR
- Still:
  - Attention for suitable approval procedures: not always possible in-house
  - More expensive
  - Two dosemeter types has advantages or is sometimes obligatory
  - Small and easy passive dosemeter can be sufficient
- Many users will stay with passive systems, even if APD's will be approved through dosemeter services

FP6: CONRAD Radiation protection of medical staff

The working group covered three specific area's within the CONRAD project:

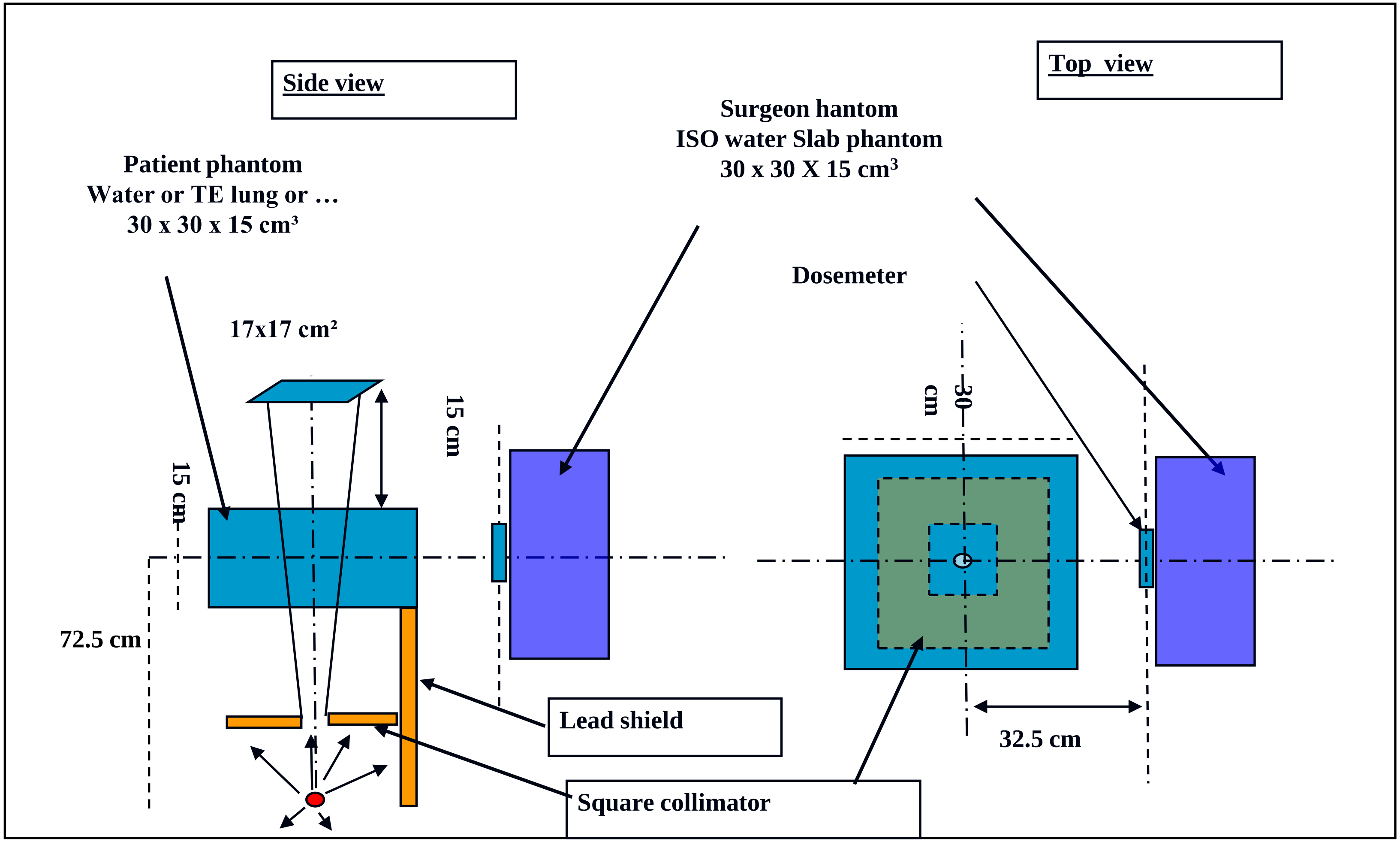
- Extremity dosimetry for medical staff in nuclear medicine and interventional radiology
- The practice of double dosimetry for staff wearing a lead apron
- The use of active personal dosemeters in interventional radiology

Active personal dosemeters

- Active personal dosemeters (APD)
  - usefull tools to apply the ALARA principle, also for interventional radiology (IR) workers
  - should be able to respond to low-energy [10-100 keV] and pulsed radiation with relatively high instantanious dose rates
  - With the current APD technology is not always the case
- Test the APD characteristics specifically for the IR fields
  - Test of 5 types of APDs
  - Single pulse beam
  - specific clinical configuration
  - Monte Carlo calculations to determine the energy spectra

- The single pulse beam could be measured by 4 out of 5 dosemeters
- High instantanious dose rate could be a problem

Intercomparison set-up



FP7: The ORAMED project:

Optimization of Radiation Protection for Medical Staff

ORAMED: FP7 (02/2008-02/2011)

1 . **SCK•CEN**: Belgian Nuclear Research Centre, Belgium
F. Vanhavere, L. Struelens, S. Krim
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G. Gualdrini, P. Ferrari, F. Mariotti
4 . **IRSN:** Institut de Radioprotection et de Sûreté Nucléaire, France
I. Clairand, L. Donadille, C. Itié, J. Debroas
5 . **IRA**: Institut Universitaire de Radiophysique Appliquée, Switzerland
M. Sans, N. Ruiz, J.Mezzo, M. Tosic
6 . **UPC**: Universitat Politècnica de Catalunya, Spain
M. Ginjaume, A. Carnicer, X. Ortega
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J.M.Bordy, J. Daures, M. Desnozière
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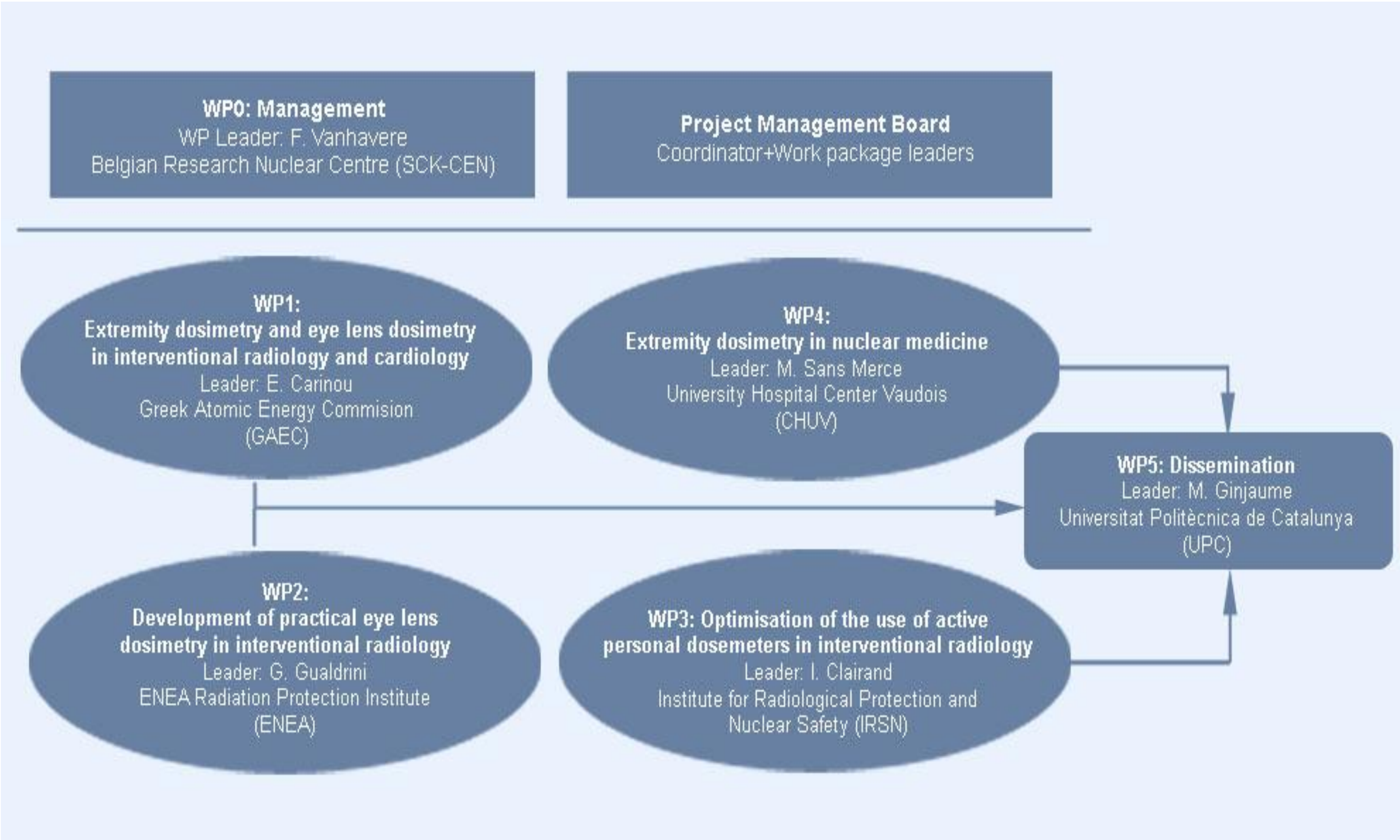
10 . **BfS:** Federal Office of Radiation Protection, Germany
A. Rimpler, I. Barth
11 . **Radcard**, Poland
S. Wach, P. Kocjan, P. Bilski, P. Olko
12 . **MGP** Intruments (MGPi), France
P. Martin, JL. Barrère

Organization of ORAMED:
5 work packages



WP3: objectives

- To study the **real radiation field characteristics** encountered in interventional radiology in terms of energy, angular distribution, dose rate and pulse characteristics
- To measure under **laboratory conditions**, **the angular and dose rate response of selected APDs**.
- To study **the effect of the frequency and duration of pulses** on the APD response by testing dosemeters **in real conditions** on site in different hospitals and under **laboratory conditions**
- To prepare **guidelines** related to the use of APDs in interventional radiology, to define corrections that will eventually be applied
- To **propose technical solutions** to improve the response of APDs in collaboration with MGPi

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:

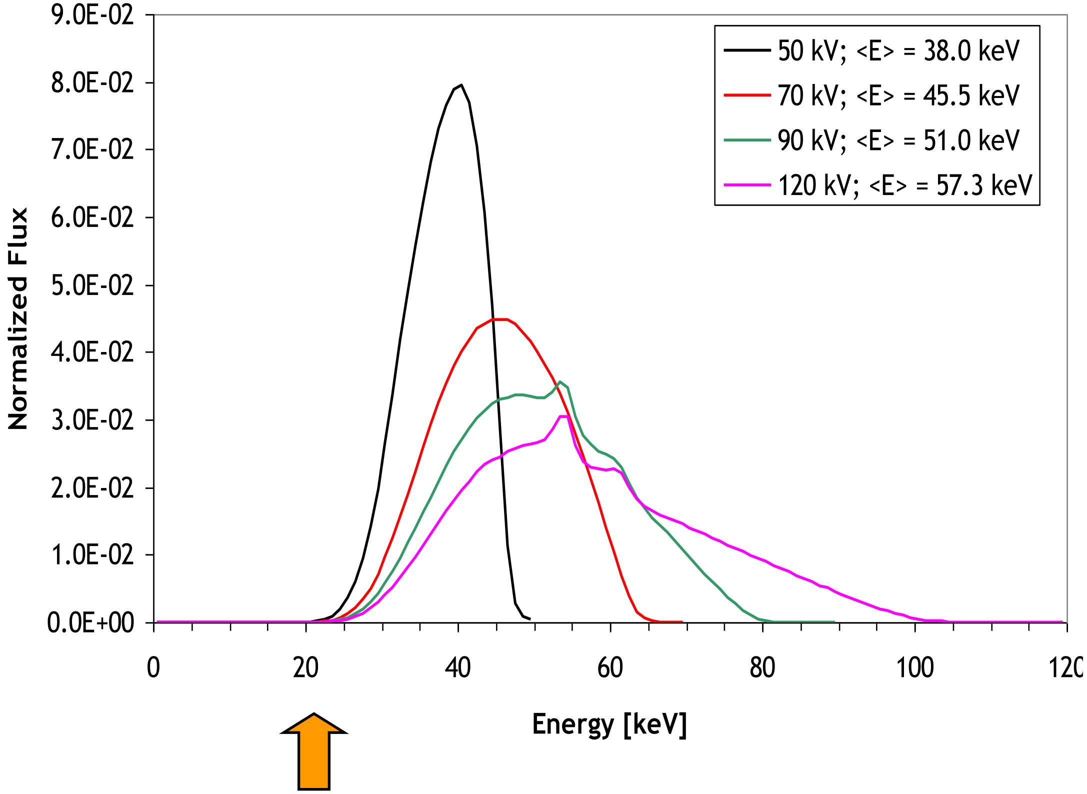
- low-energy photons (20-100 keV)
- pulsed radiation with relatively high instantaneous dose rates.

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

Typical Fields 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

Scattered spectra



20 keV

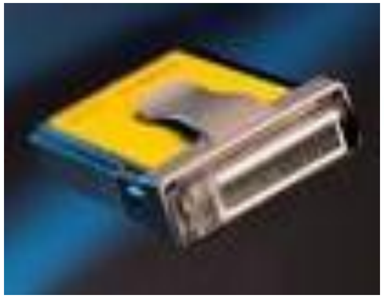
Scattered spectra at the operator position considering a filtration of 4.5 mmAl + 0.9 mmCu

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

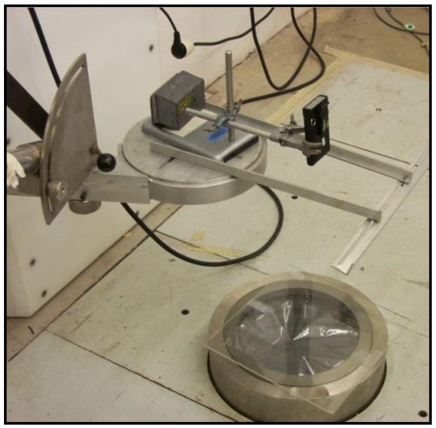
Philips
DoseAware

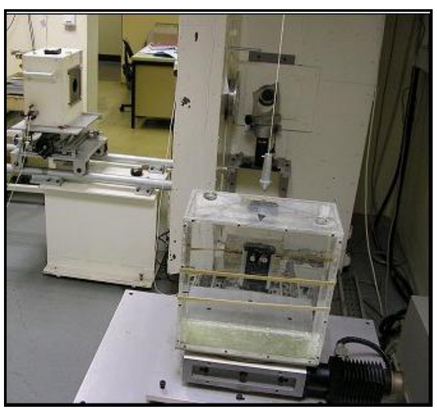
Selection of APDs

APD	Energy range		Dose equivalent rate range		Dose equivalent 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 Thermo	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
DoseAware Philips	33 keV	118 keV	10 μSv.h^{-1}	50 mSv.h^{-1}	1 μSv	10 Sv	Silicon diode

Test performed with continuous X-ray beams in Laboratory conditions

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





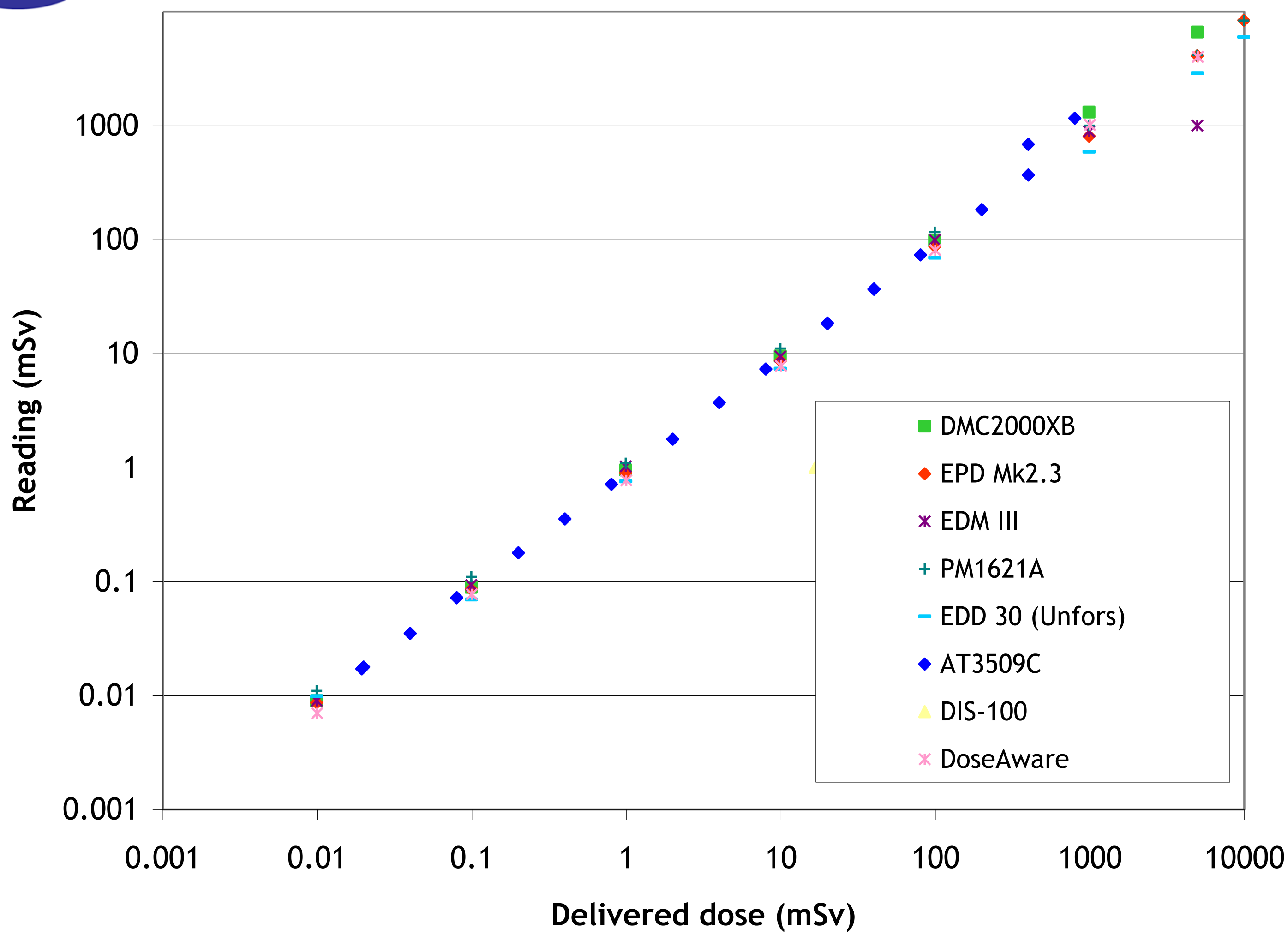
Dose response : S-Co, N-150 for DoseAware
Dose rate response from 0 to 10 $Gy.h^{-1}$: S-Co for all APDs, H-100 for EDD30, N-150 for DoseAware
Energy response: N-15, N-20, N-25, N-30, N-40, N-60, N-80, N-100, N-120, S-Cs and S-Co, from N-30 to N-300 for DoseAware
Angular response at +/- 60 : N-25, N-30, 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)

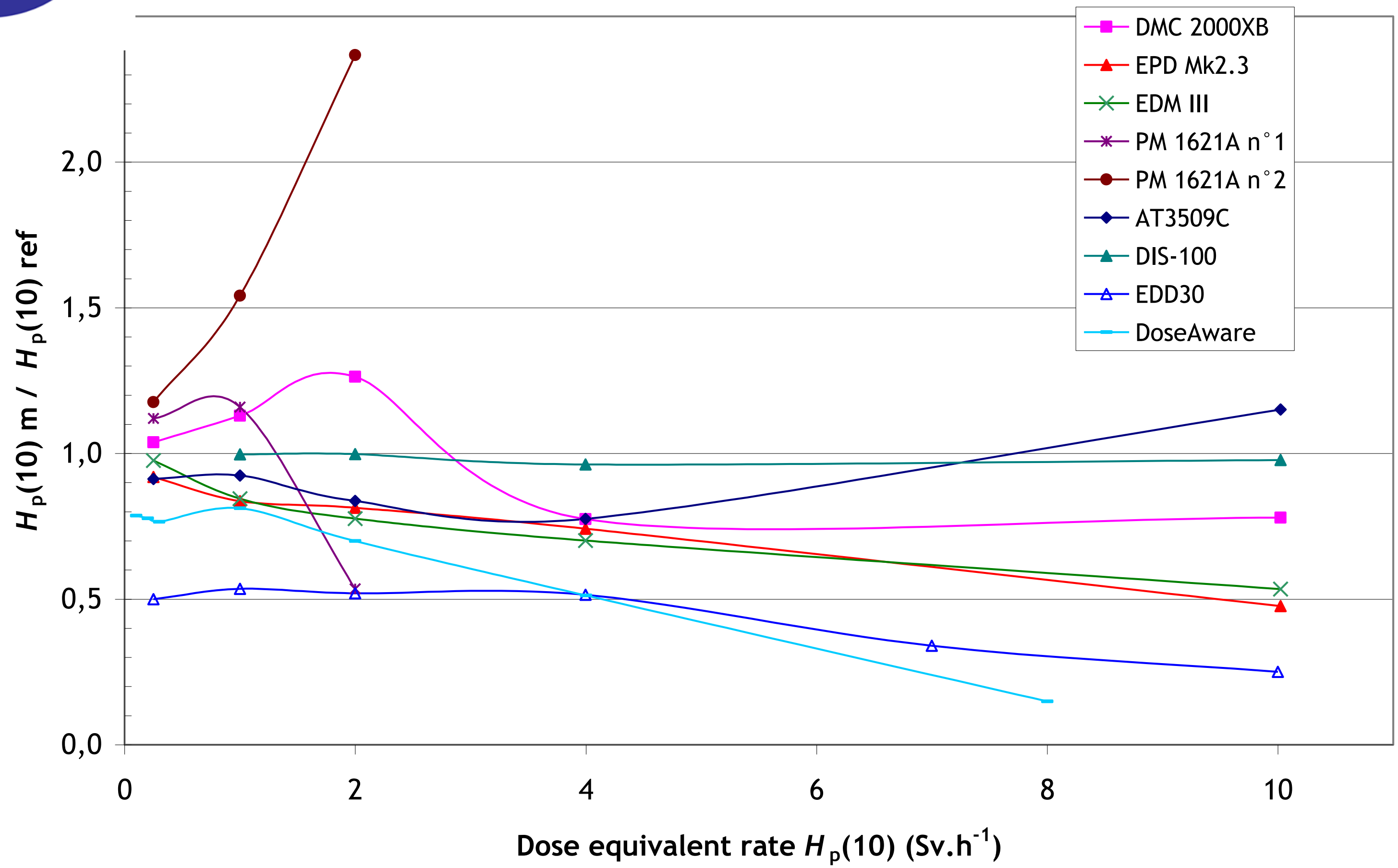
International Electrotechnical Commission. Radiation protection instrumentation. measurement of personal dose equivalent Hp(10) and Hp(0.07) for X, gamma, neutron and beta radiation: **direct reading personal dose** equivalent and/or dose equivalent rate dosemeters (2010 – 07) IEC 61526 Geneva: IEC

Dose Response



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

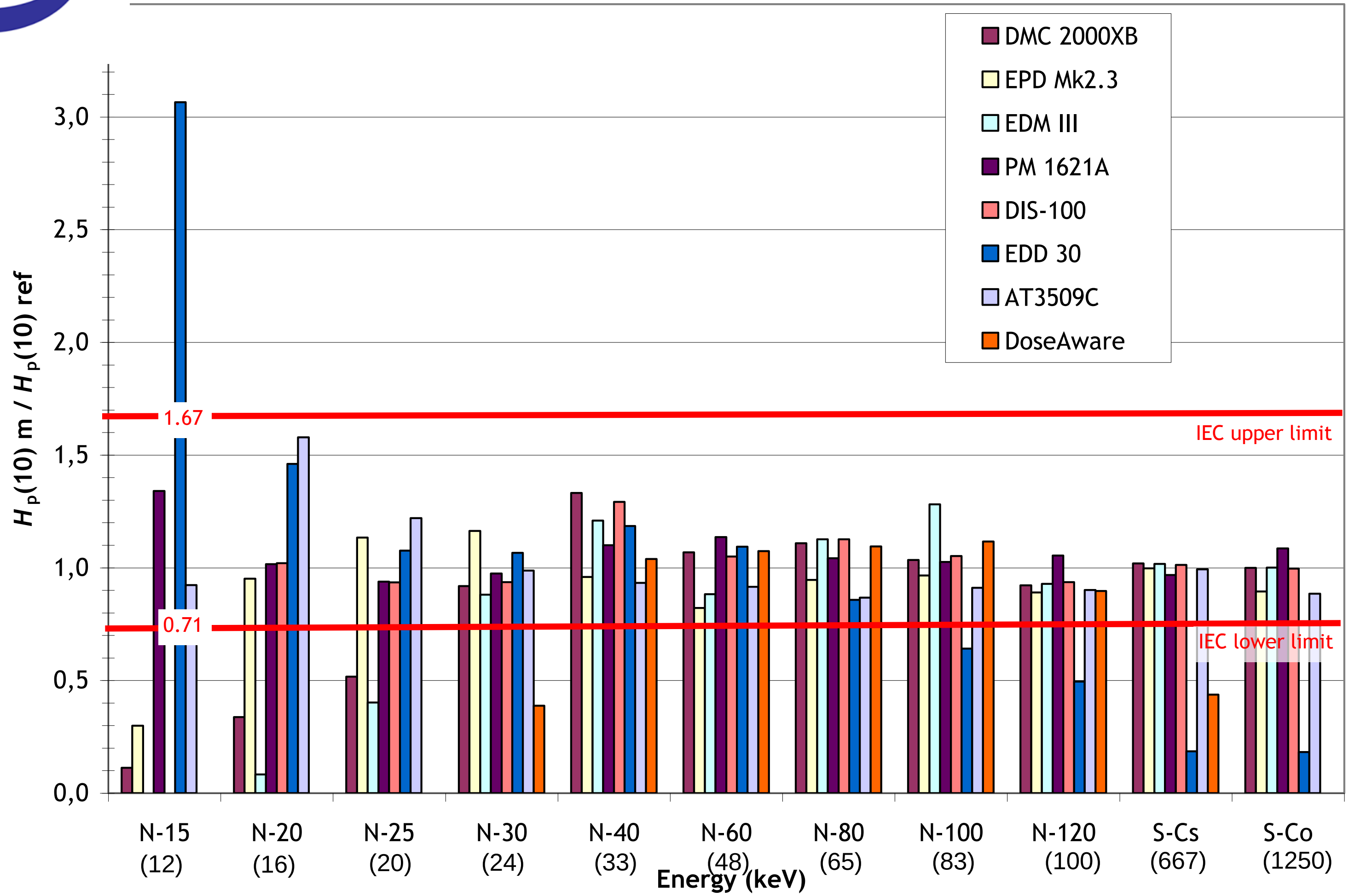
Dose Rate Response



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}
- EDD30 which saturates for dose rates above 2 Sv.h^{-1}.
- DoseAware which saturates for dose rates above 4 Sv.h^{-1}.

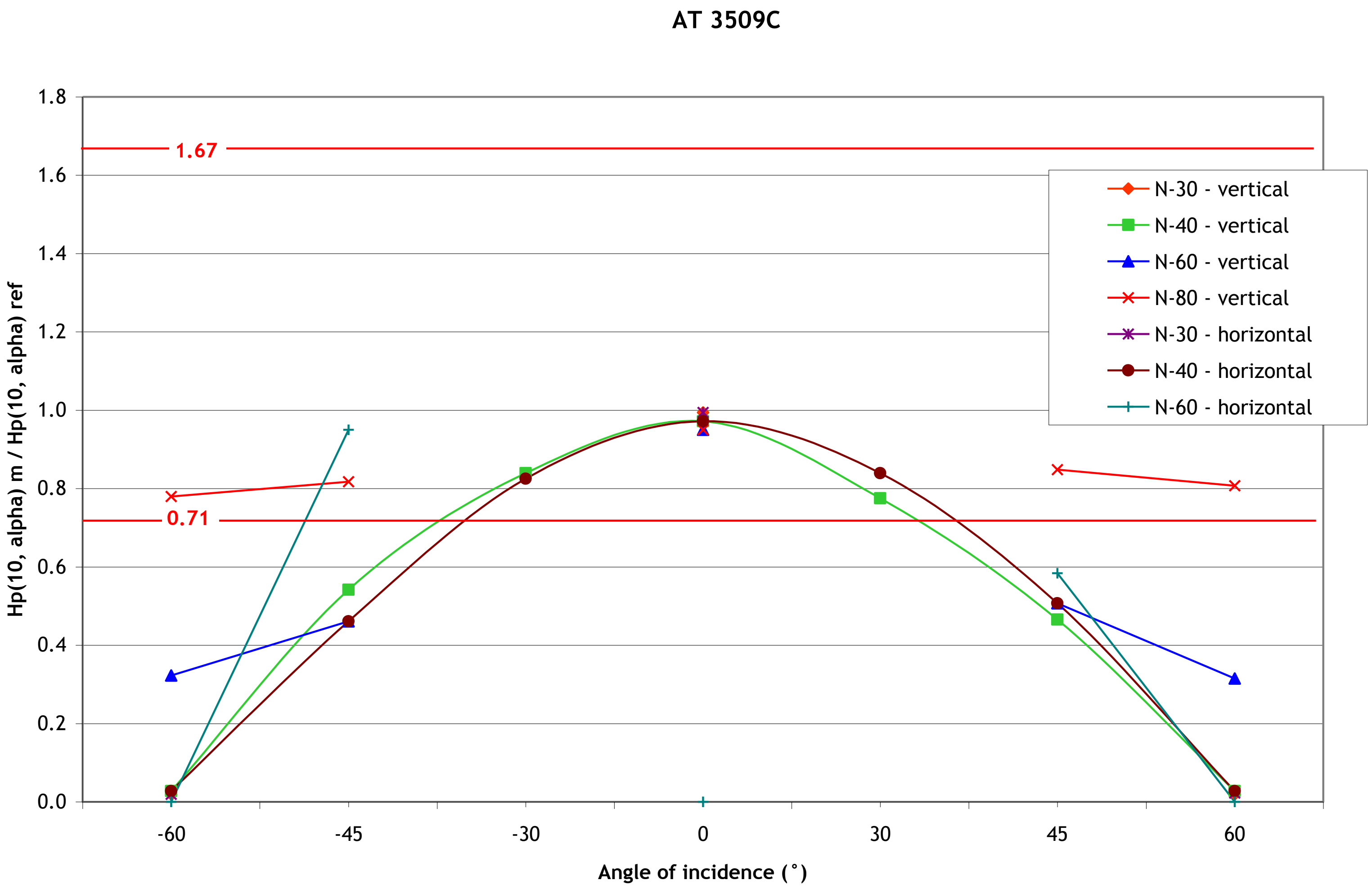
Energy Response



The energy response is within the interval [0.71 – 1.67] from ^{137}Cs energy down to 24 keV for all APDs except EDD30 and DoseAware. These results are consistent with the fact these APDs are calibrated at low energy.

Angular Response

Atomtex
AT3509C



Conclusions on tests with continuous X-ray beams

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

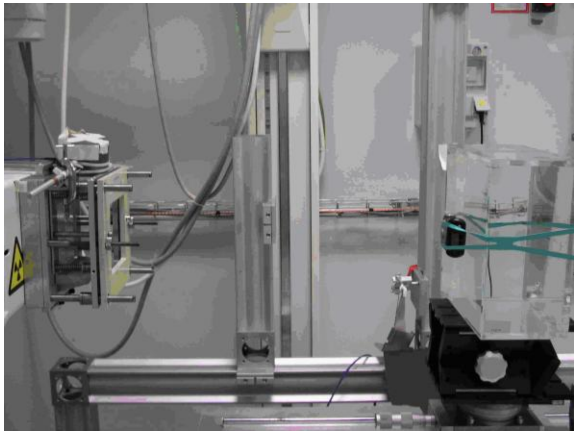
Most APDs can stand high dose rates up to 10 $Sv.h^{-1}$, except:

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



- X-ray generator: GEHC PHASIX 80
- High Voltage: 70 kVp,
- Total filtration: 4.5 mm Al + 0.2 mm Cu,
- Half Value Layer: 5.17 mm Al.

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

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

Tests performed with pulsed X-ray beams in laboratory conditions

<u>APD response with dose equivalent rate variation</u> :

Pulse duration: 20 ms

Pulse frequency: 10 pulse 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)

<u>APD response with pulse frequency variation</u> :

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,

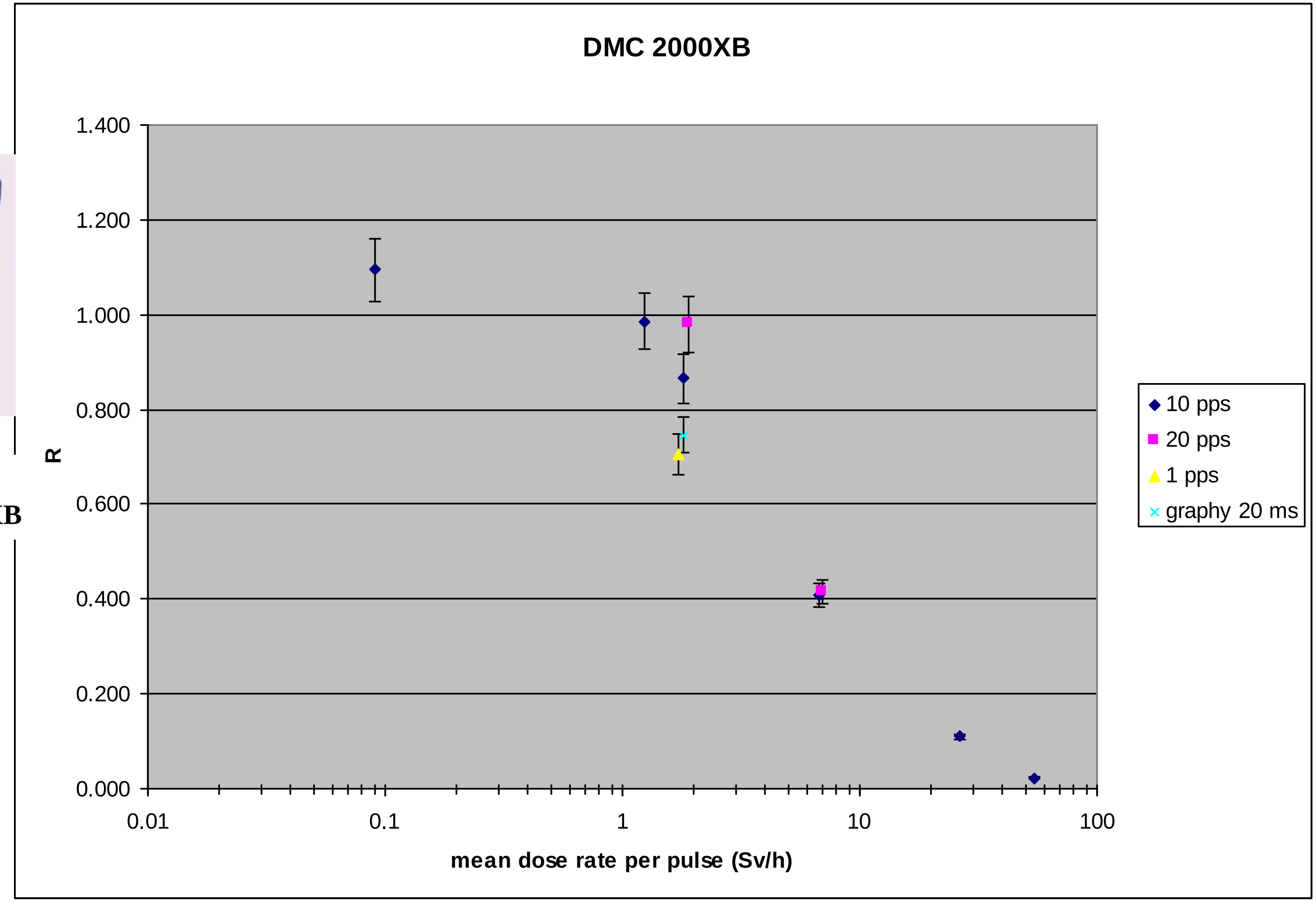
Pulse frequency variation: 1 pps, 10 pps and 20 pps (1 pps and 10 pps for DoseAware)

<u>APD response with pulse width variation</u> :

Pulse width variation: 20, 50, 100 and 1000 ms at 1.8 $Sv.h^{-1}$ (DoseAware not tested in this configuration)

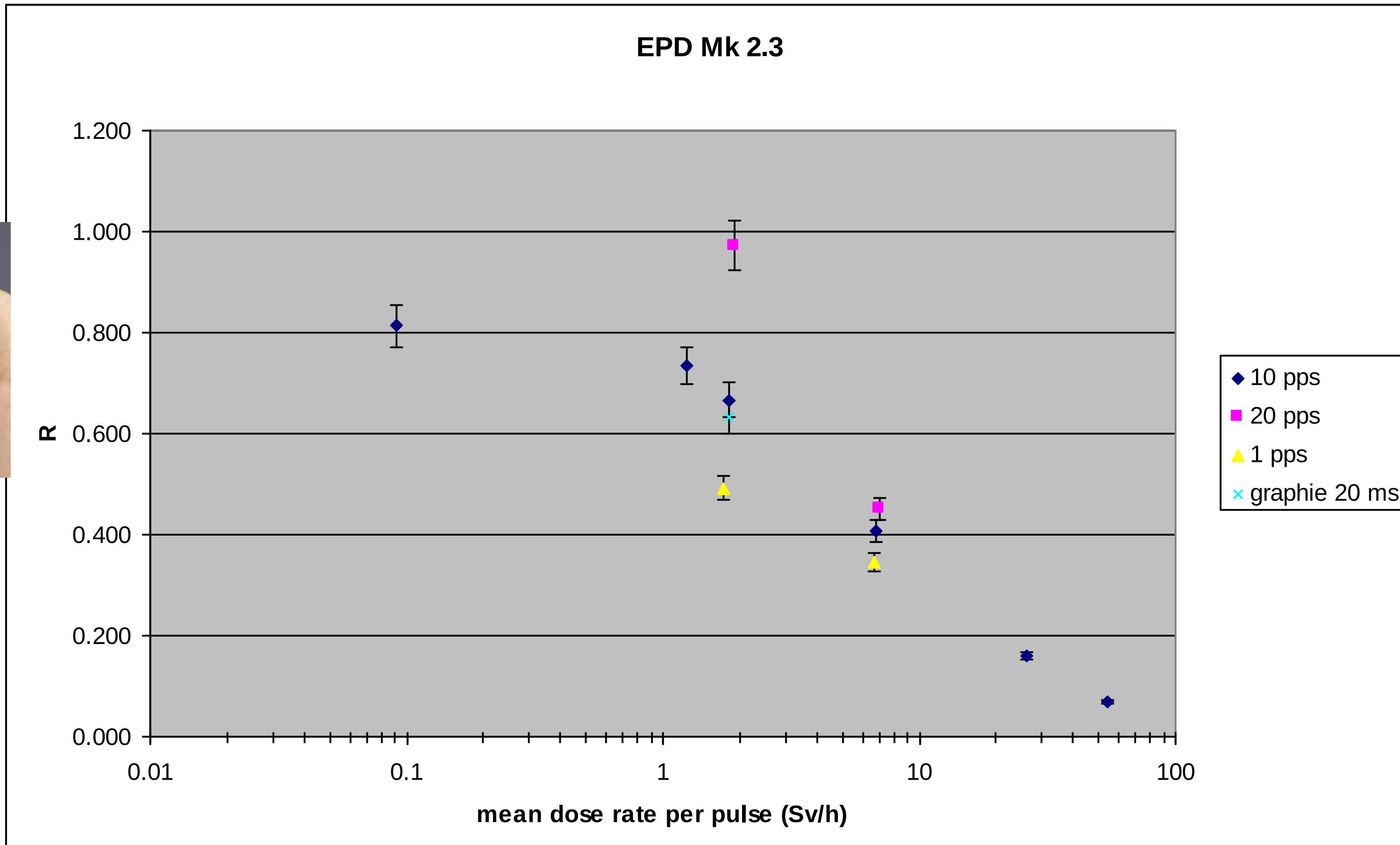
Effect of dose rate

MGPi DMC2000XB

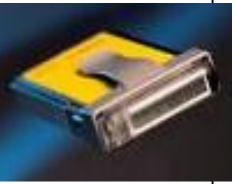


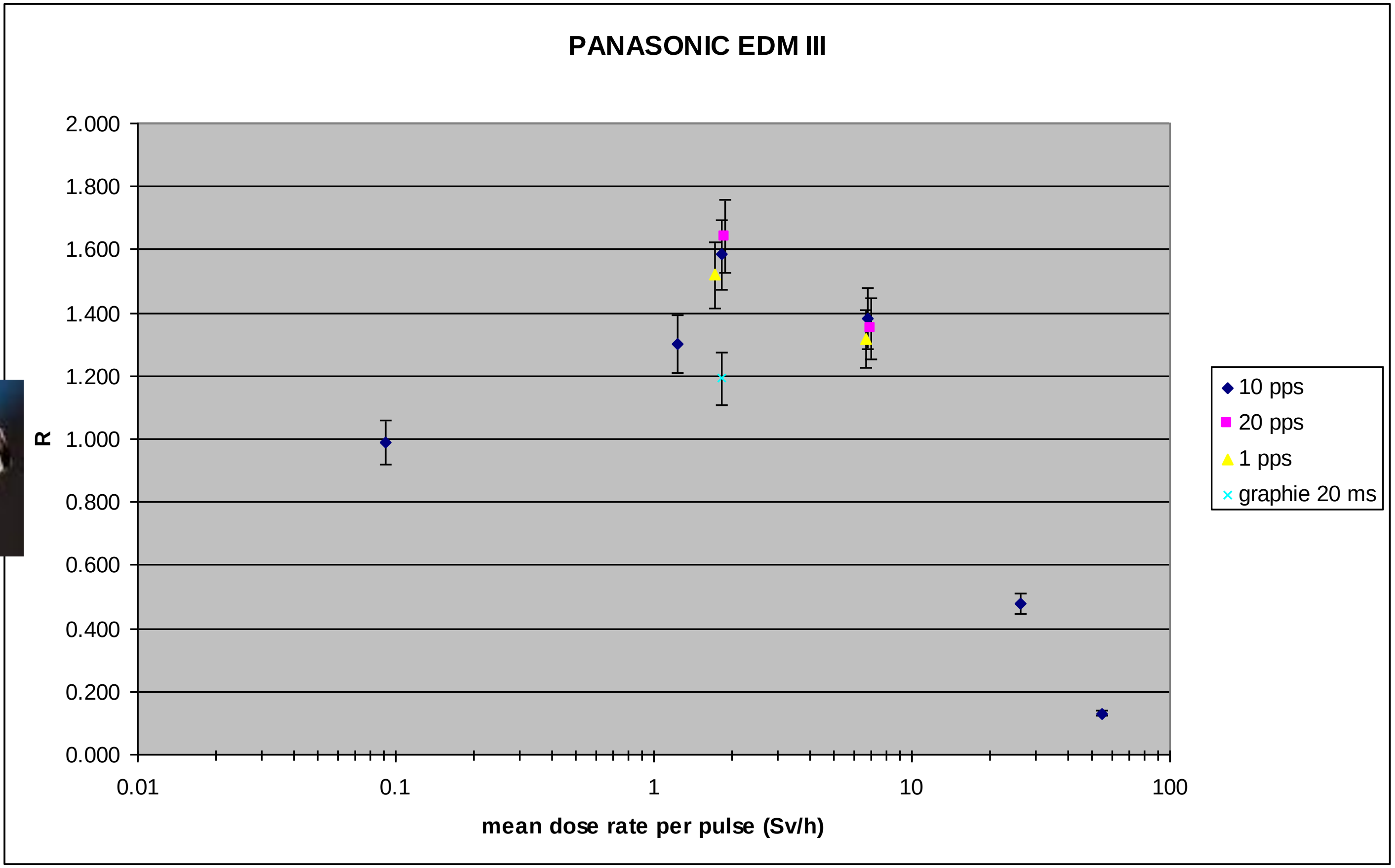
Effect of dose rate

Siemens EPD Mk2.3



Effect of dose rate





Dosilab EDM III

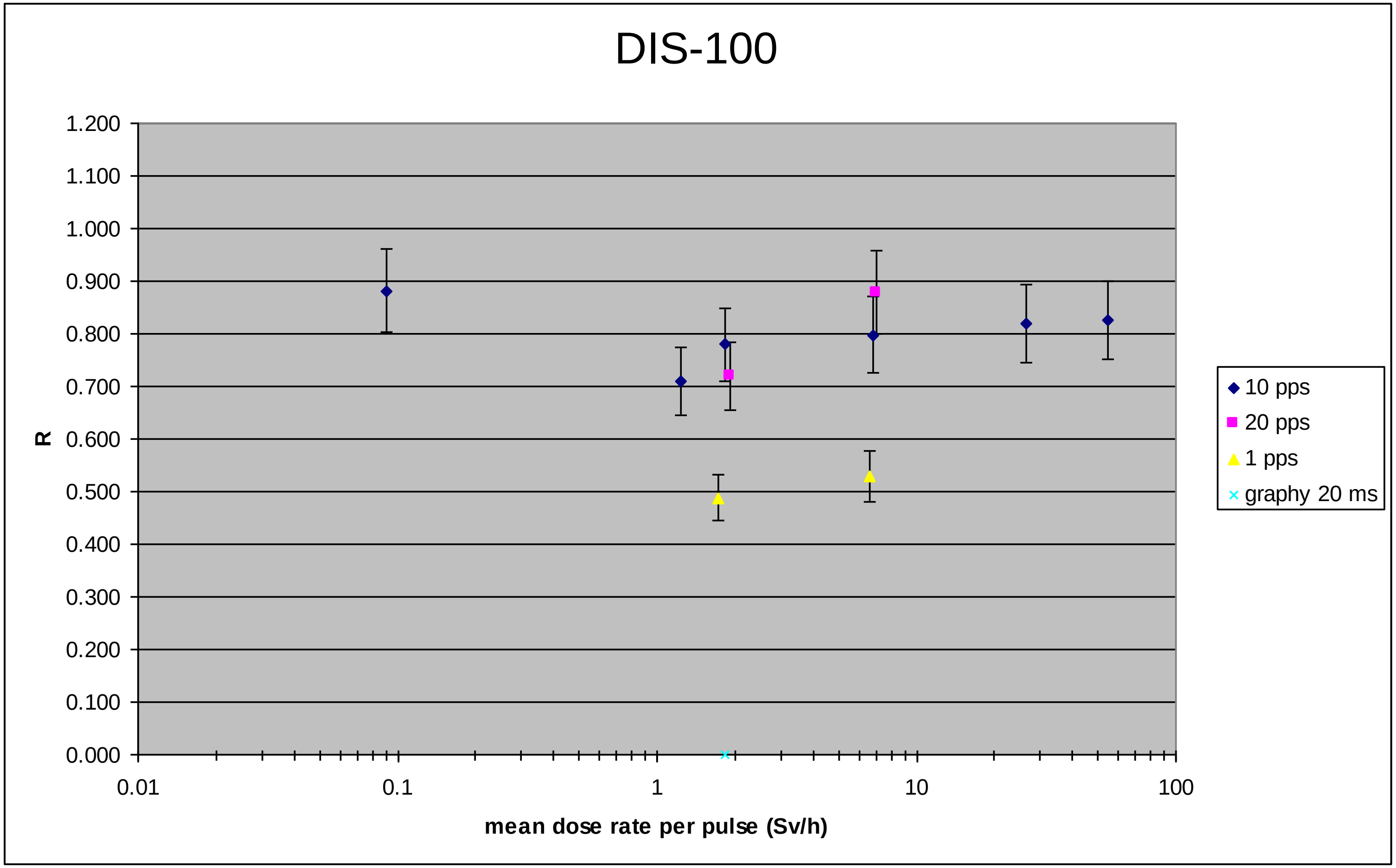
Effect of dose rate

NO SIGNAL IN PULSED MODE

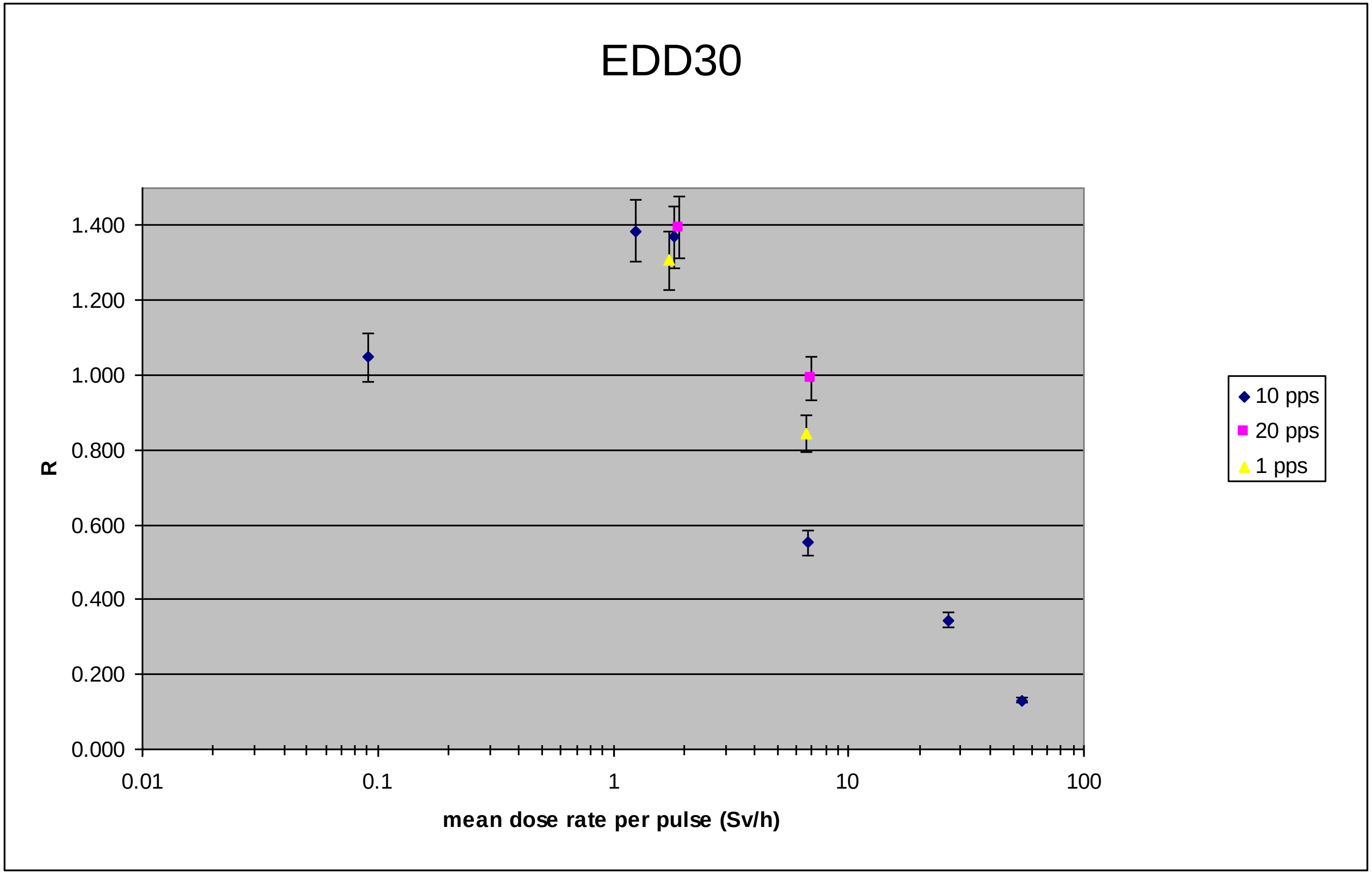
Polimaster
PM1621A

Effect of dose rate

Rados DIS-100



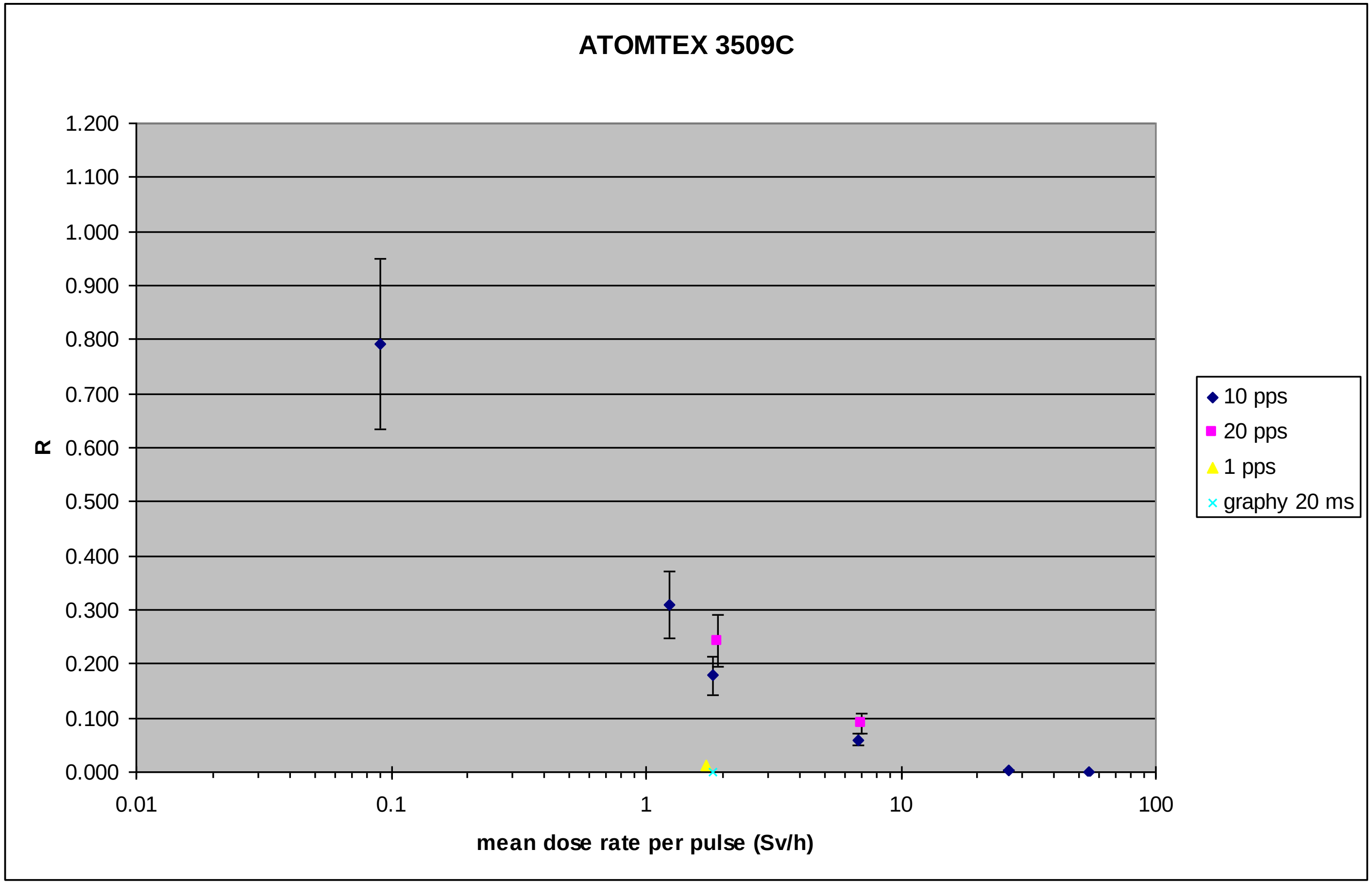
Effect of dose rate



Unfors
EDD 30

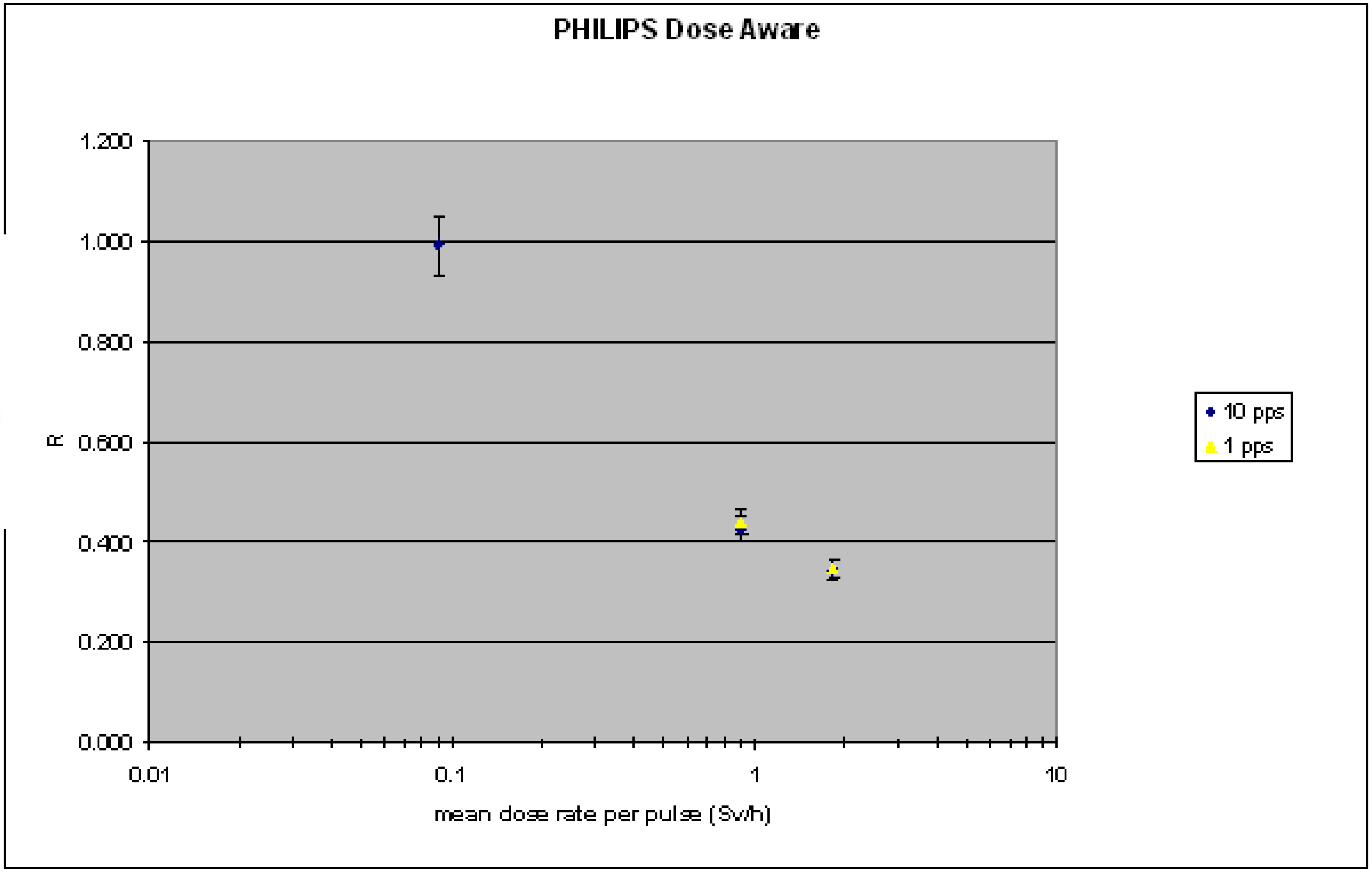
Effect of dose rate

Atomtex
AT3509C



Effect of dose rate

Philips
DoseAware



Effect of dose rate

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

APD	DMC 2000XB	EPD MK2.3	ED M III	PM1621 A	DIS-100	EDD 30	AT3509C	Dose Aware
Dose rate ($Sv.h^{-1}$) for APD response divided by 2	5	7	20	NO SIGNAL	Response within +/- 30% for all dose rates up to 55 $Sv.h^{-1}$	10	3.5	0.8





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)





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 $Sv.h^{-1}$

Conclusions on tests with pulsed X-ray 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.

- DMC 2000XB, EPD Mk2.3, EDMIII, EDD30, AT3509C and DoseAware contain all a silicon detector, the differences of their response is probably due to the time response of the electronics.

- The results are better the more the beam resembles a continuous beam

- Lower respons for higher instantaneous dose rate

- The DIS has a “hybrid” technology between silicon and ionisation chamber which presents correct results.

TESTS IN HOSPITALS

1. Tests on phantoms
   - Use of hospital X-ray system
   - Phantoms to represent patient and doctor

   OBJECTIVE: study the behavior of APDs in realistic conditions with <u>the possibility to select specific field parameters</u>

2. Tests on operators
   - Use of interventional X-ray systems
   - APDs worn by operators during routine practice

   OBJECTIVE: obtain an overview of differences between active and passive dosimetry in routine practice <u>without an accurate knowledge of field parameters</u>

TESTS ON PHANTOMS - CONCLUSIONS

APDs tested in scattered fields (no direct beams)

For several realistic setups with different kVp and pulse width, compared to the TL dosemeter as reference:

- Response of all APDs is roughly within +/- 30%
- DMC 2000XB and EDD30: slightly higher than TLD
- EPD Mk2.3 and DIS-100: slightly lower than TLD
- EDMIII gives higher responses within +/- 50%
- PM1621A did not respond

Problems encountered in pulsed mode (lab tests) do not occur

- probably because dose rate < 1 $Sv.h^{-1}$

TESTS ON OPERATORS

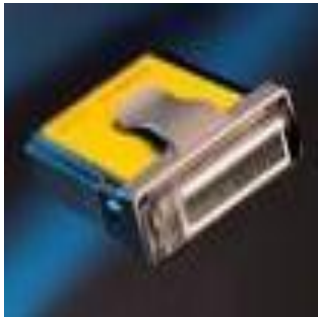
- Operators wear side by side one APD and one additional passive dosemeter **above the lead apron**
- Tests were performed in parallel in different hospitals from different European countries
- At least 300 µSv were integrated by TLD
- The same dosemeters were worn for different IR/IC procedures
  Unknown field characteristics

TESTS ON OPERATORS

- APDs tested

MGPi DMC2000XB

Siemens EPD Mk2.3



Dosilab EDM III

Rados DIS-100

Philips DoseAware

- Passive dosemeter: TLDs
  - Dose provided by TLD according to the routine measurement protocol by ORAMED partner (background removed)

- In total 95 measurements were performed in 6 hospitals

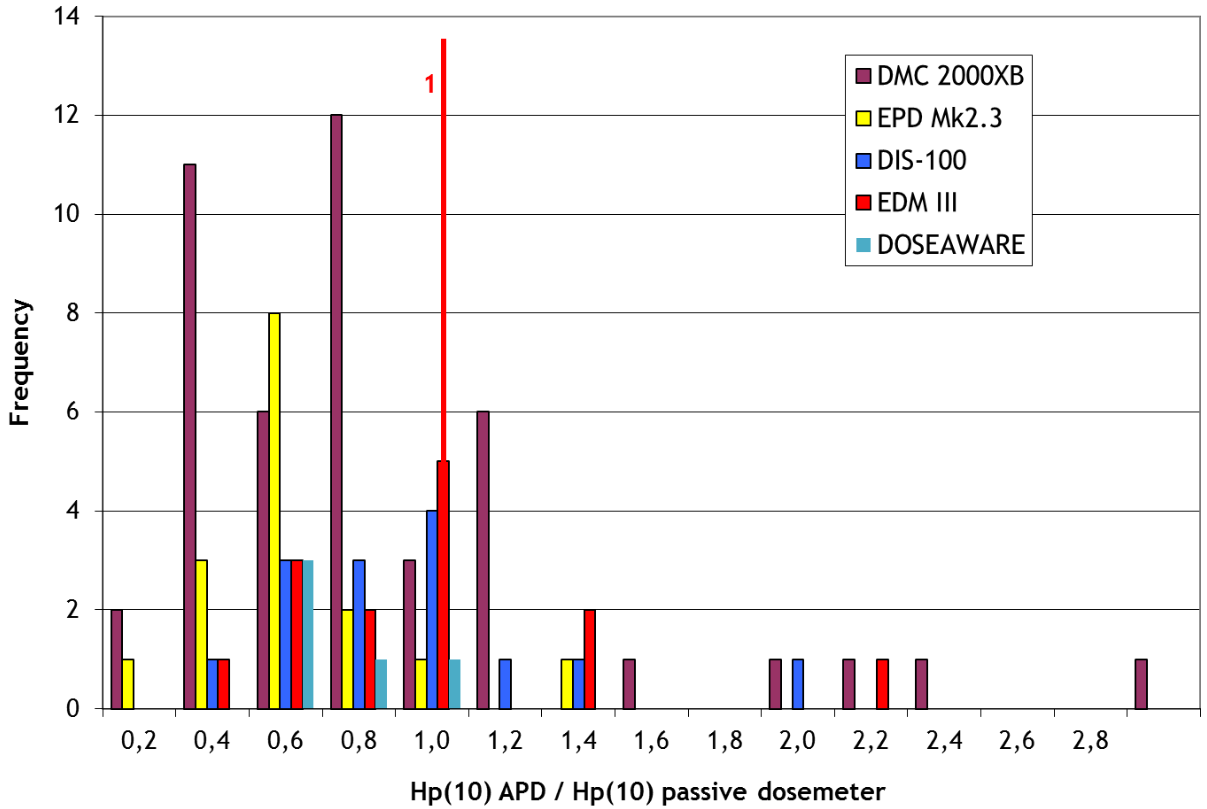
  * DMC2000XB: 45 measurements in 3 hospitals
  * EPD Mk2.3: 17 measurements in 2 hospitals
  * EDMIII: 14 measurements in 1 hospital
  * DIS-100: 14 measurements in 2 hospitals
  * DoseAware: 5 measurements in 1 hospital

TESTS ON OPERATORS - RESULTS

A **distribution of APD response** related to passive TL dosemeter

Mean
Hp(10) APD/TLD:

- DMC 2000XB: 0,77
- EPD Mk2.3: 0,69
- DIS-100: 0,86
- EDMIII: 0,88
- DoseAware: 0,61



- A large spread in the results
  (non-uniform irradiation, shielding of one dosemeter by the other)
- All dosemeters slight under-response compared to passive dosemeter

TESTS IN HOSPITALS - CONCLUSIONS

- The behavior of the APDs in the laboratories for low dose rates were confirmed with tests in real conditions in hospitals

- The behavior of the APDs is even more satisfactory in hospitals than in laboratories (effect of kVp and pulse width)
  - because they are exposed to scattered fields with dose rates < 1 $Sv.h^{-1}$

- 5 APDs were tested in daily routine practice
  - All dosemeters have a slight under-response compared to the passive dosemeter

Conclusions for ORAMED

- 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 $Sv.h^{-1}$ (except PM1621A, EDD30 and DoseAware).
- 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 rates rather than to pulse frequency.

- 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.**

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ORAMED

EURADOS

Thank you….