IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Assessment of Occupational Exposure due to External Radiation Sources

Active personal dosimeters

Active personal dosimeters

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Purpose of active personal dosimeters

Passive dosimeters have limitations

- Lack of direct dose display
- No alarm or indication of high dose rate or dose
- Limited sensitivity
- Need for significant laboratory investment

Active Personal dosimeters (APD): advantages

- Active dosimeter:
  - Immediate read-out possible
    - More feedback to worker
    - Better use and care for dosimeters by workers
    - Will in general help in decreasing doses
  - Alarm function possible
  - 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

APDs also have limitations

- dosimeter cost
- Potential lack of security of data storage
- Mass and size of dosimeter
- Battery type and life span
- Possibly poor low energy photon energy dependence
- Poor beta radiation response
- Sensitivity to electromagnetic fields (older models)
- Possibly saturation at high dose rates

For what purpose are they used?

- Supplementary dosimeters of the direct reading type
  - For controlling individual exposure on a day to day basis
  - During a particular task
  - Can be useful for optimisation
- Can be recommended for specific purposes
  - Short term radiation control of workers' exposures, or during a particular task
  - For situations where the radiation field could increase unexpectedly and significantly (say, by a factor of ten)
  - For operations of short duration in high radiation fields
- Maintains alertness to possible accidental exposures
- Useful for education and training
- Sometimes used for visitors and outside workers, pregnant staff

Active personal dosimeters (APD)

- Mostly passive for legal dose of record, while APD is used as ALARA or alarm dosimeter

- Possibly also for record keeping purposes (the dosimeter of record)
- Same procedures for approval by the regulatory body should apply
  - Adequate energy range, sensitivity, linearity and precision, reliable
  - Sufficient quality control measures and periodic calibration procedures
  - dosimeters and procedures must be accredited
  - Must be maintained by approved dosimetry service

Standards for APD’s

Standards for APD’s

- Type test requirements:
  - IEC 61526: “Radiation protection instrumentation - Measurement of personal dose equivalents Hp(10) and Hp(0,07) for X, gamma, neutron and beta radiations - Direct reading personal dose equivalent meters “
  - Use reference radiation qualities according to ISO 4037-1
- Testing of dosimeters for pulsed radiation fields can be done in accordance with the IEC 63050 standard with reference radiation according ISO/TS 18090-1
- When an APD is used as an official dosimeter, testing for protection against data manipulation and software security (both the read-out software and the dosimeter firmware) must be done
  - Requirements for this can be found in WELMEC Guide 7.2 (WELMEC, 2019).

Where are APD used?

Different types of users

- APD common practice in nuclear installations
- More and more popular in smaller companies and hospitals
  - Risk of misuse and lack of QA and QC
  - Differences in use of results
    - Sometimes just alarm dosimeter
    - Sometimes check of passive dosimeter

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 calibrations done
  - Use as alarm dosimeter or for tests
  - Less knowledge on radiation characteristics

Types of APD’s

Detection mechanisms for APDs

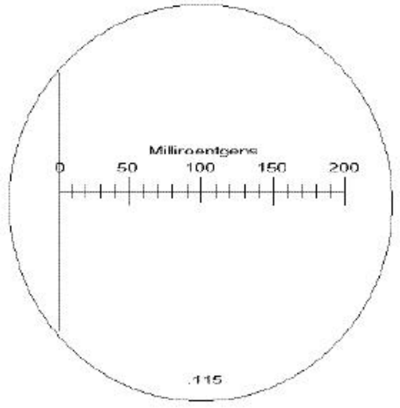
- Charged fiber (electroscope) pocket dosimeters
- Electronic dosimeters
  - Silicon diodes
  - Geiger-Müller counters

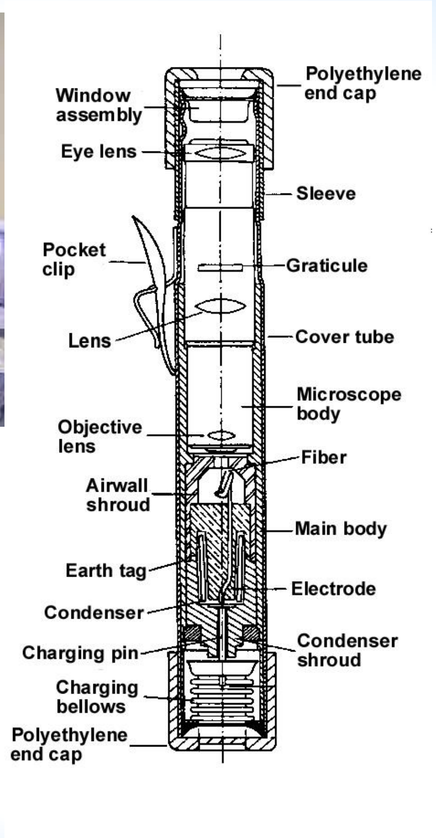
Pocket dosimeters

- Based on ionization of gases in a small chamber
- Direct-reading devices with and without built-in charger: pocket electrometers
- Should have appropriate wall materials and thicknesses for adequate response to electrons, photons or neutrons
- Single dosimeters will have a limited dose range
- Care should be taken against erroneous readings due to electrical leakage
- A high degree of accuracy is not important, but reliability is

- Hardly used anymore….

Direct reading pocket dosimeter





Active personal dosimeters

- Many types of active personal dosimeters are commercially available (>50)
  - Some on Geiger-Müller detection methods
  - Most with semiconductor detection methods (diodes)
- GM devices mainly for photons >30 keV
- GM devices not suited for pulsed fields
- Diode based APDs can have several diodes for simultaneous measurement of $H_p(10)$ and $H_p(0.07)$ for photons and betas
- All possible formats available
  - Even in form of credit cards, watches,….
- Large variation in specifications and quality

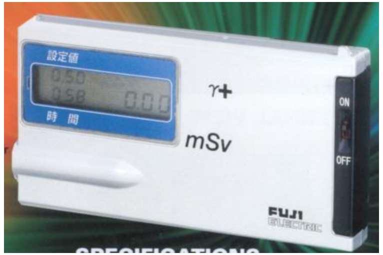
Some selected commercial APDs

Raysafe i3

Rados RAD60

Polimaster PM1721

Mirion DMC3000



Fuji dosimeter

ThermoFischer TruDose

Tracerco PED+

General APD characteristics

Catalogue of APD’s

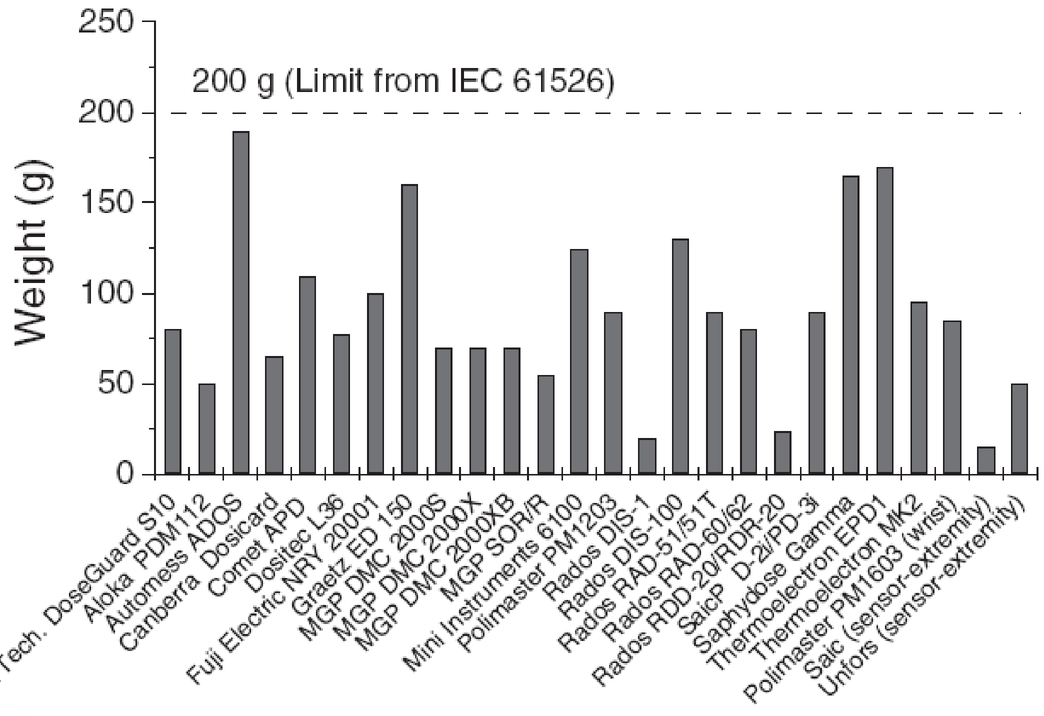
- Many types of APD’s are commercially available
- How to choose the best one for your application?
- As exercise, EURADOS has made a selection of 31 dosimeters from 16 manufacturers
- Three types
  - Photon dosimeters with Geiger-Muller tube
    - Automess, Graetz, Mini Instruments, Polimaster, SAIC
  - Photon or beta-photon dosimeters with one or more silicon detectors
    - AEA Technology, Aloka, Canberra Dosicard, Comet, Dositec, Fuji Electric, MGP, Saphymo, Rados, Thermo Electron
- Information gathered:
  - Radiological performance, physical characteristics, environmental performance, mechanical performance, dose recording procedure, type test

Comparing APD's with standards

Charateristic	IEC 61526 requirement*	Typical values for APD
Size	< 250 cm^3	100 cm^3 (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)

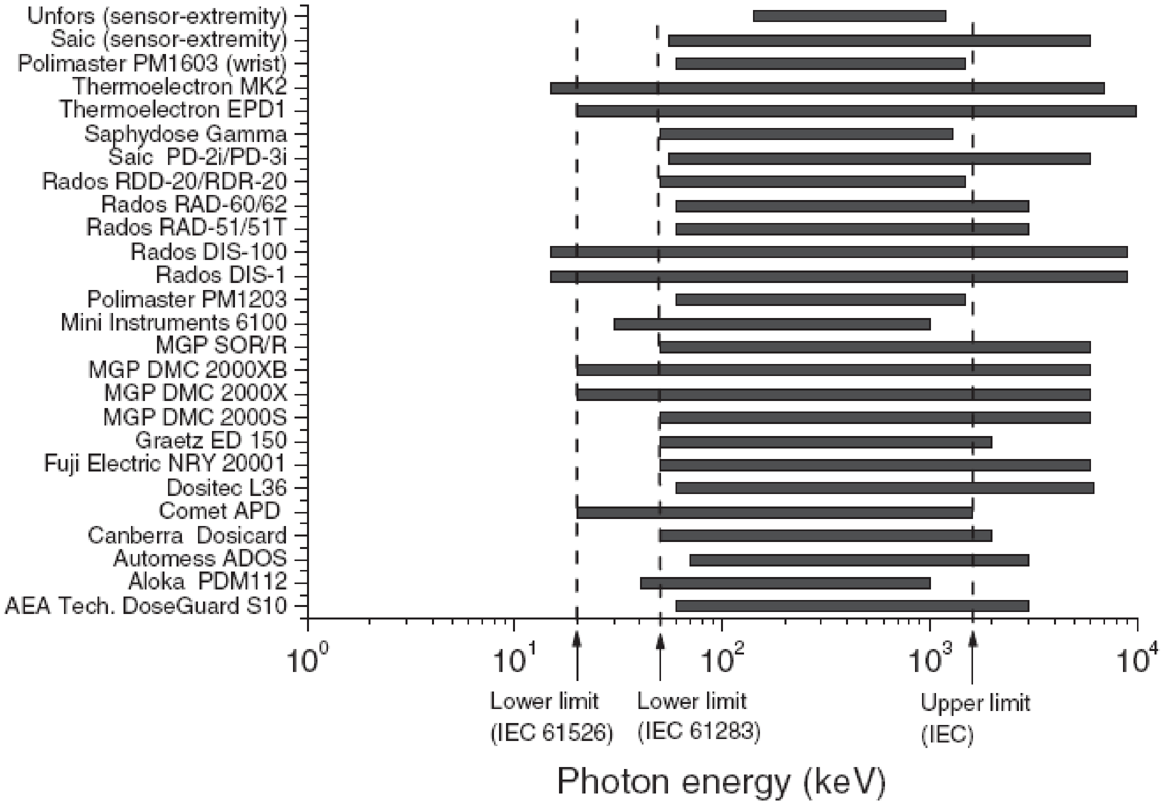
*: this exercise was done with the 1998 version of IEC 61526

Weight

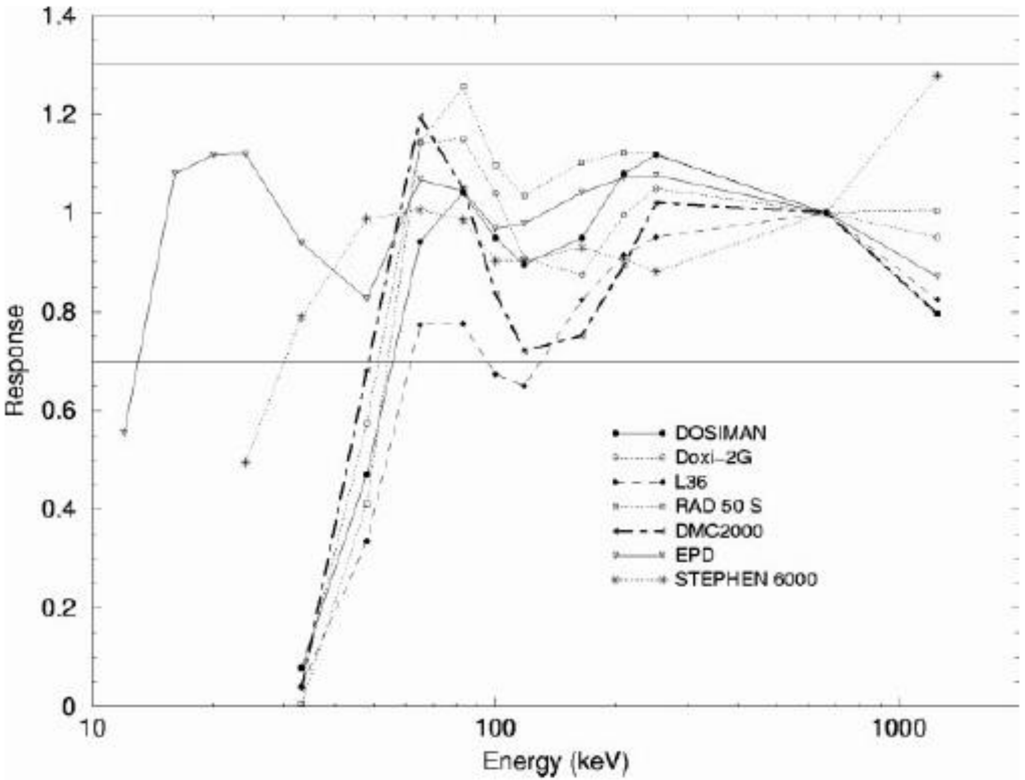


200 g (Limit from IEC 61526)
Weight (g)
250
200
150
100
50
0
AEA Tech. DoseGuard S10
Aloka PDM112
Automess ADOS
Canberra Dosicard
Comet APD
Dositec L36
Fuji Electric NRY 20001
Graetz ED 150
MGP DMC 2000S
MGP DMC 2000X
MGP DMC 2000XB
MGP SOR/R
Mini Instruments 6100
Polimaster PM1203
Rados DIS-1
Rados 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)

Energy range according to manufacturer



Energy range according to manufacturer

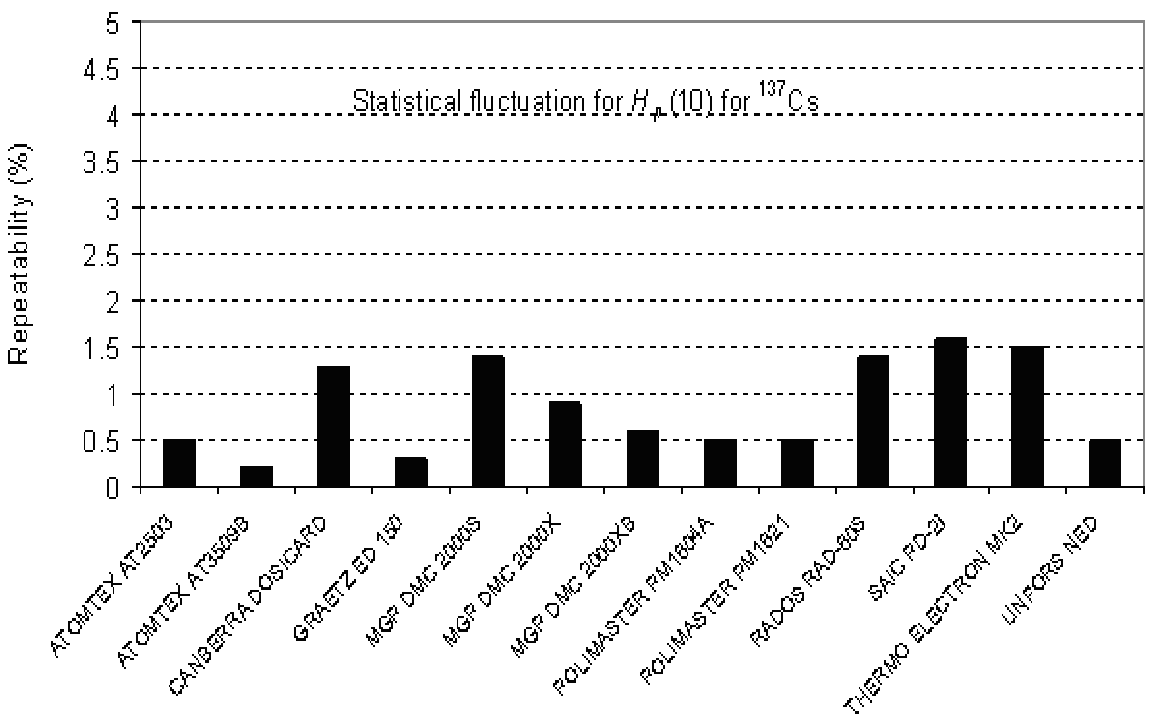


IAEA/EURADOS intercomparison of APD

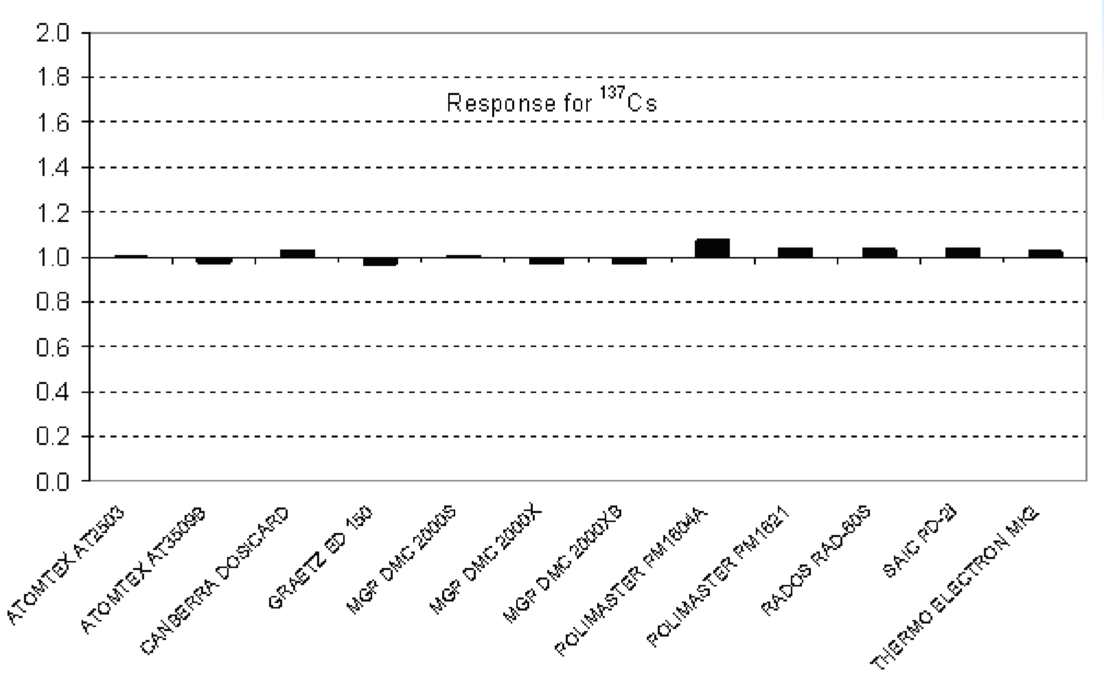
- Scope
  - Assess capabilities of APD to measure Hp(d) in photon and beta radiation fields
    - Compared to IEC 61526 standard
  - To help member states achieving accurate knowledge on APD’s
  - To provide guidelines for improvements to manufacturers
- 13 different models, 9 suppliers
- Results: IAEA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

IAEA/EURADOS intercomparison of APD

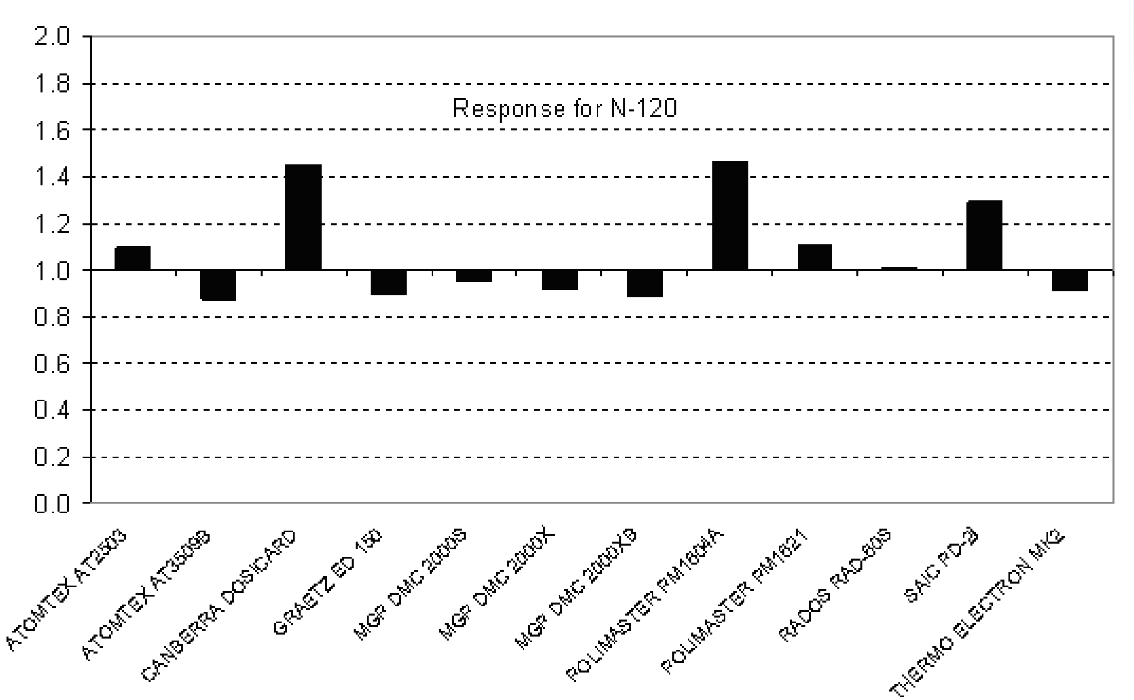
Statistical fluctuations: very good



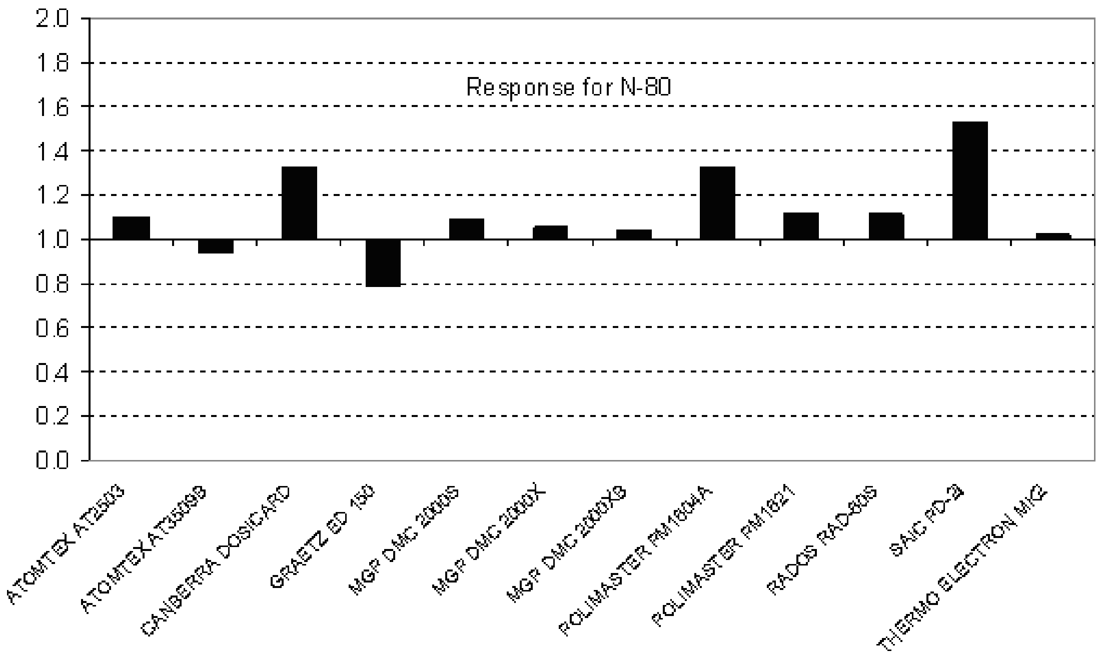
Results: Cs-137: very good



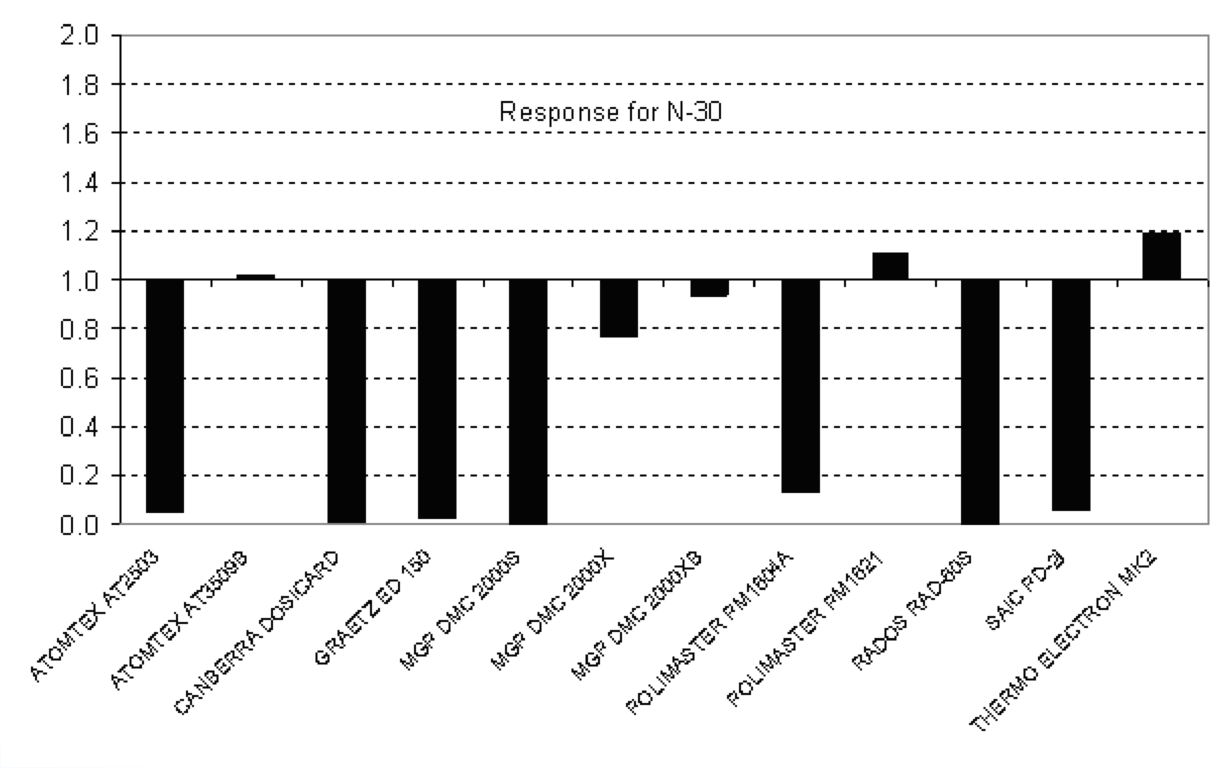
Results narrow series spectrum N-120: acceptable



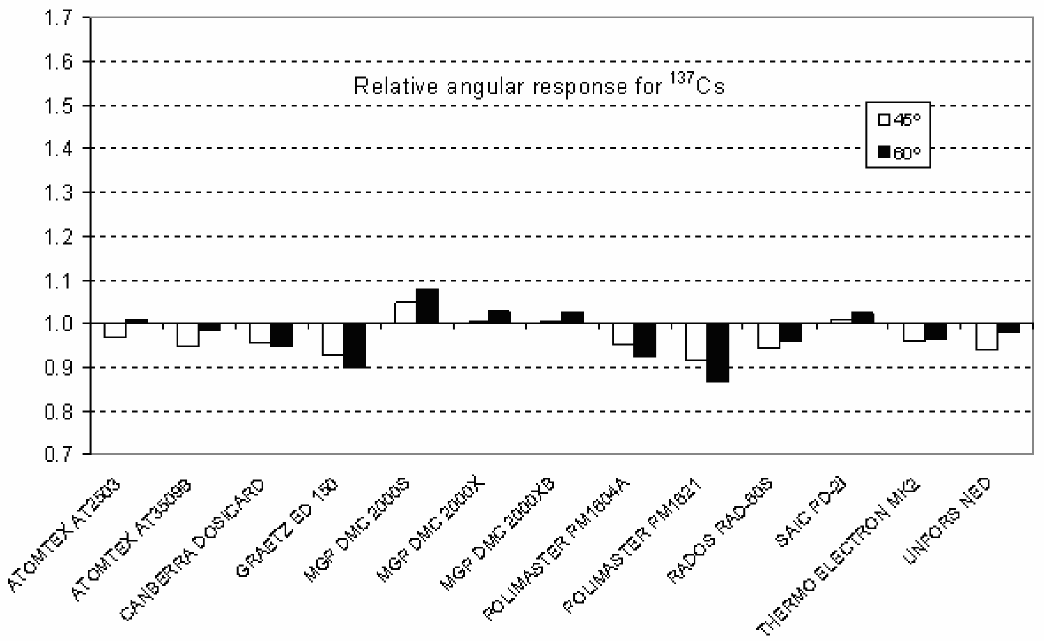
Results narrow series spectrum N-80: acceptable



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



Angular response: no problem



Specific APD aspects for hospital use

Survey in European hospitals 2018

- 79 answers from 19 European countries
- How many APDs are used in your hospital?

N° of APD	N° of hospitals/institutions
0	24
1-5	14
6-10	11
11-15	4
16-20	7
20-50	7
51-100	5
>100	2

- More than 2/3rd of the hospitals have APDs available

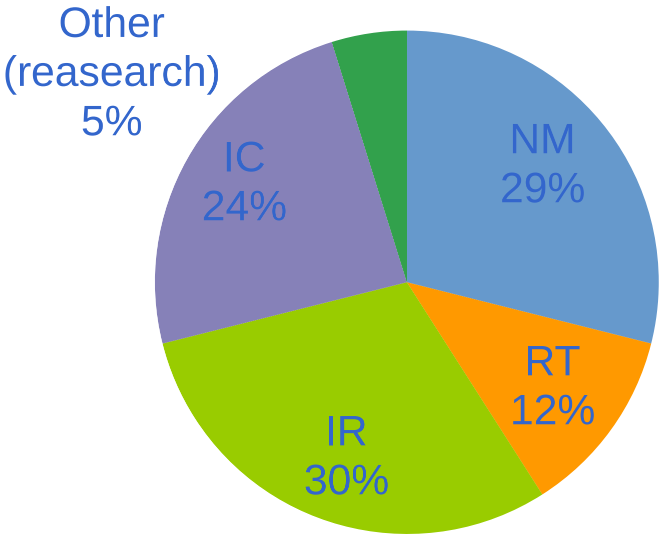
Which types of APDs?

Manufacturer	Models	Number of hospitals	Type of detector
Mirion	DMC 2000, DMC 2000 X, DMC 2000 XB, DMC 3000, DMC 2000 S	22	Silicon diode
Mirion	RAD 50S, RAD 51S, RAD 52S, RAD 62S, RAD 60S, RAD 60 R	14	Silicon diode
Thermo Scientific	MK2, EPD-G, N2	14	Silicon diode
RaySafe	I2 DOSEAWARE, EDD30, NED	8	Silicon diode
Polimaster	PM 1610, PM1621	3	Geiger Muller tube
IBA	DOSE GUARD S10	2	Silicon diode
Tracero	PED Blue	2	Geiger Muller tube

- Some use GM tubes
- Some not suited for low energies….
- And a whole list of other devices….

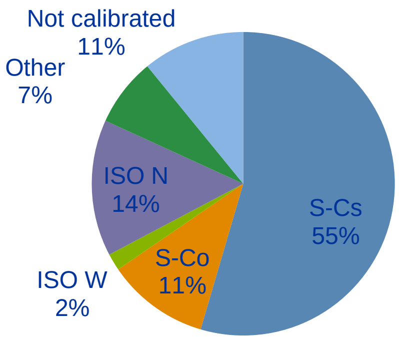
In which department are they used?

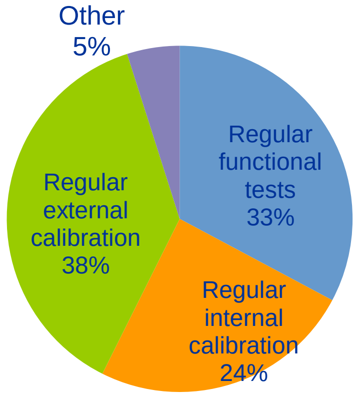
- Half are used in interventional procedures
- One third in nuclear medicine



Are the APDs regularly calibrated?

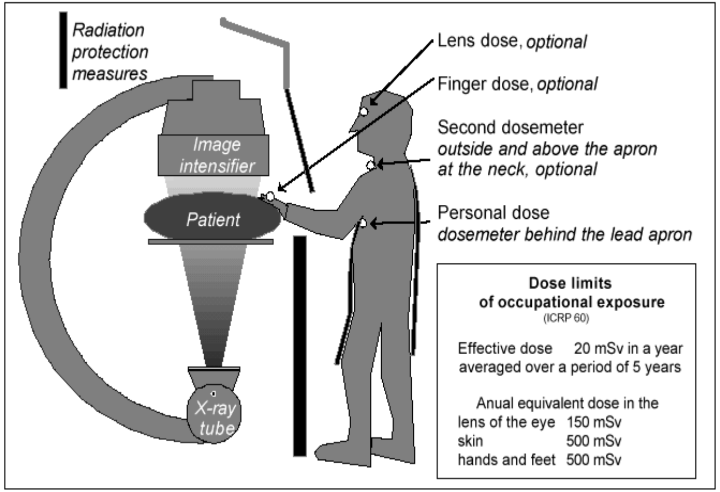
- Only 60% are regularly calibrated, only 1/3rd externally
- Mostly using Cs-137, only few are calibrated with X-rays.





Occupational exposure staff in interventional procedures

- Among highest doses for occupationally exposed professionals
  - Whole body doses (effective dose)
  - Eye lens doses
  - Extremity doses
  - Others… (brain, leg, heart,…)
- Many dosimeters needed (in theory) because of highly inhomogeneous field
  - Above and below lead apron
  - Eye lens
  - Ring

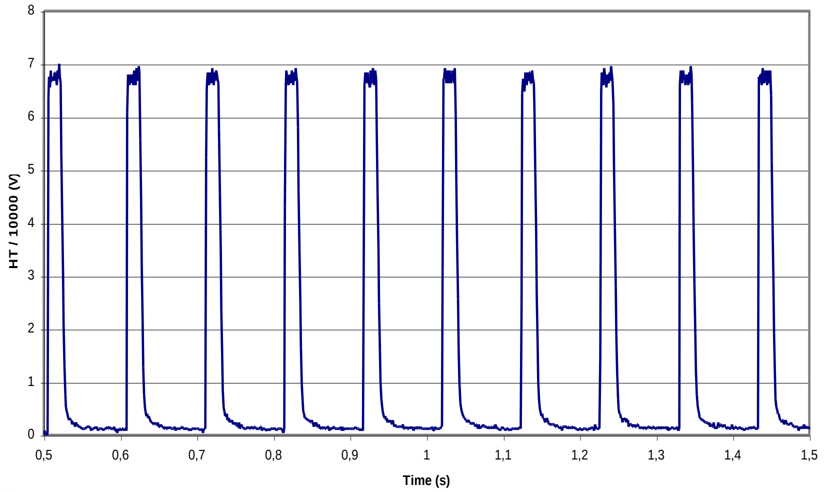


Specific exposure conditions in interventional procedures

Parameter	Range
High voltage	60-150 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 – 150 keV

Interventional procedures: use of pulsed radiation

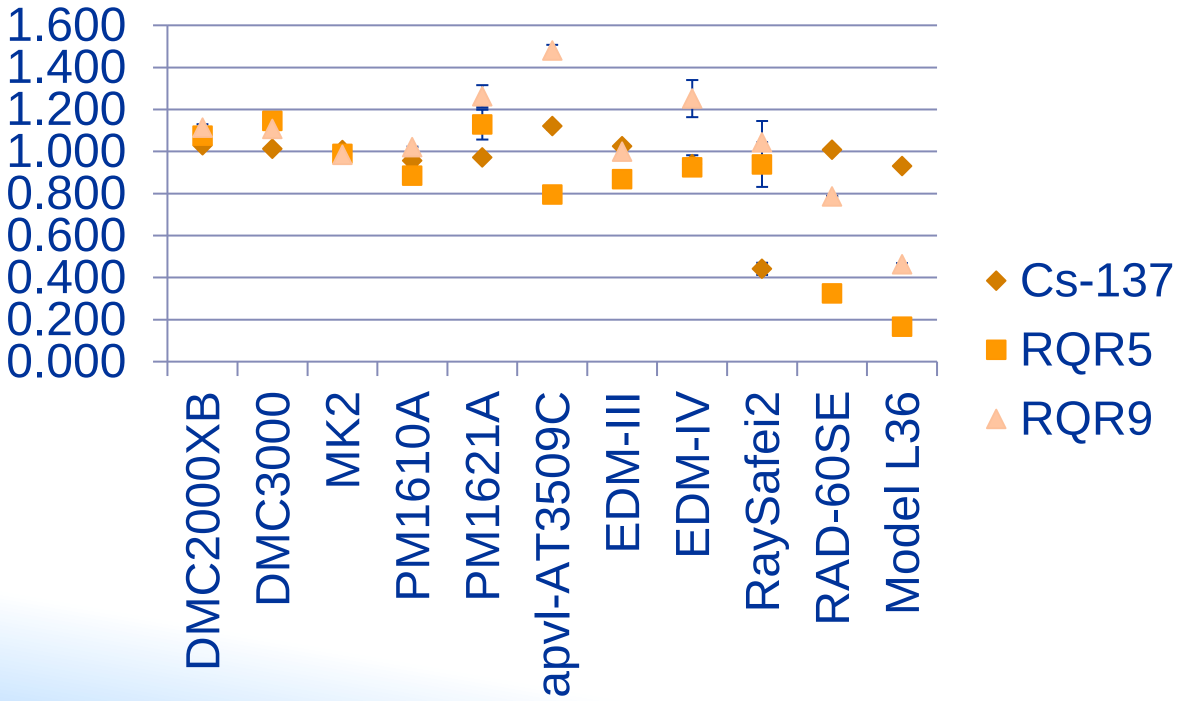
- Important parameters:
  - Pulse frequency
  - Pulse width
  - Instantaneous dose rate



EURADOS WG12 testing of APDs (2017)

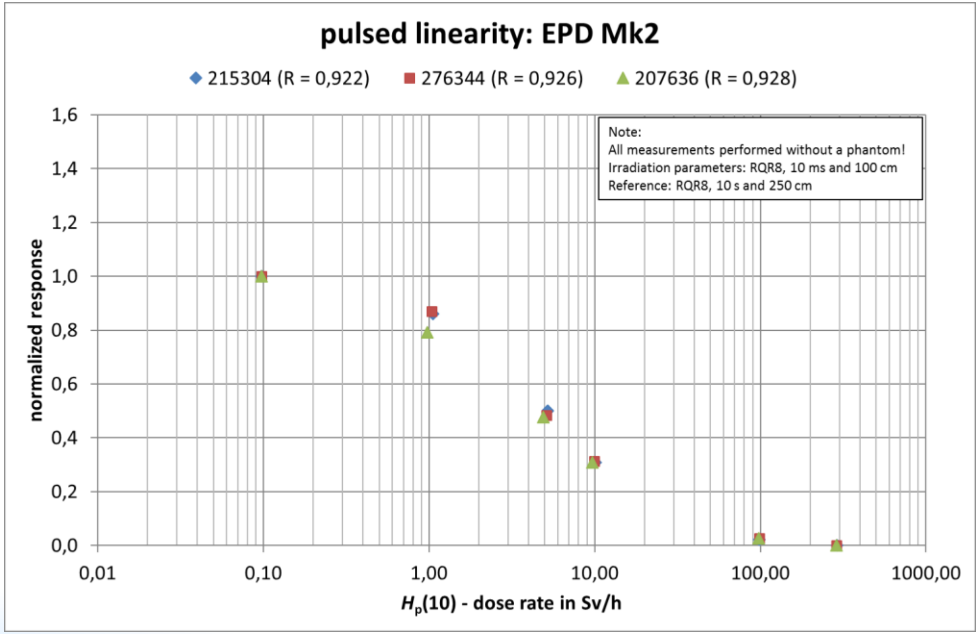
Tests in continuous fields

- Some devices show bad response for low energies
- Raysafe is designed only for low energies



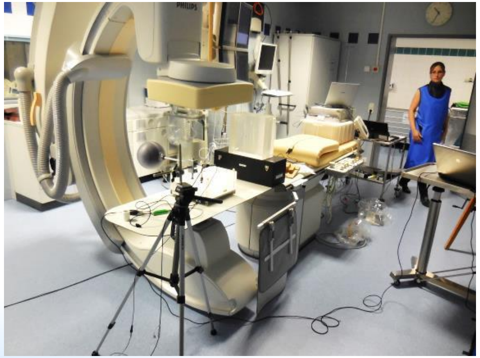
Tests in pulsed fields: example of Thermo: EPD Mk2

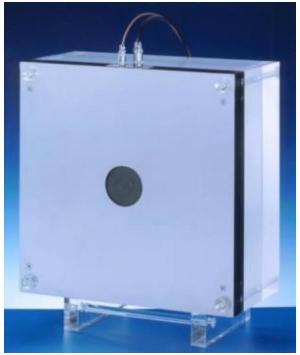
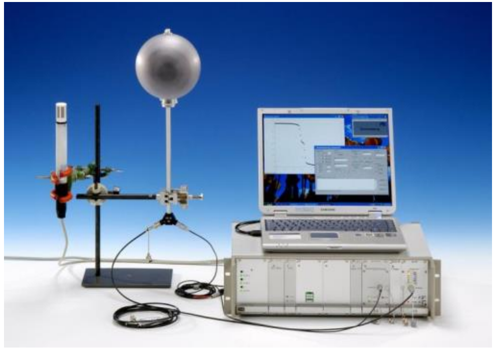
- Instantaneous dose rate is critical parameter for pulsed field response
- All APDs show a decreasing trend with increasing instantaneous dose rate
- Some types decrease faster than others



Tests in real hospital fields

- Two different X-ray units: Alura Philips, Arcadis Siemens
- Reference instruments: H*(10) and $H_p(10)$ chamber
- Three types of APDs: Thermo Mk2, Mirion DMC3000, Raysafe i2
- Different set-ups: tube below table, tube above table, direct beam
- HV=84 kV, HVL=4,8 mm Al, t_{pulse} =48 ms

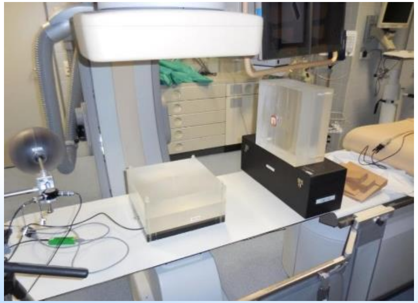


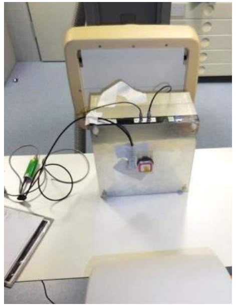



Tests in real hospital fields

- Decreasing response with increasing instantaneous dose rate
- Difference between 3 types of APD
- Very low response in direct beam: dangerous situation!

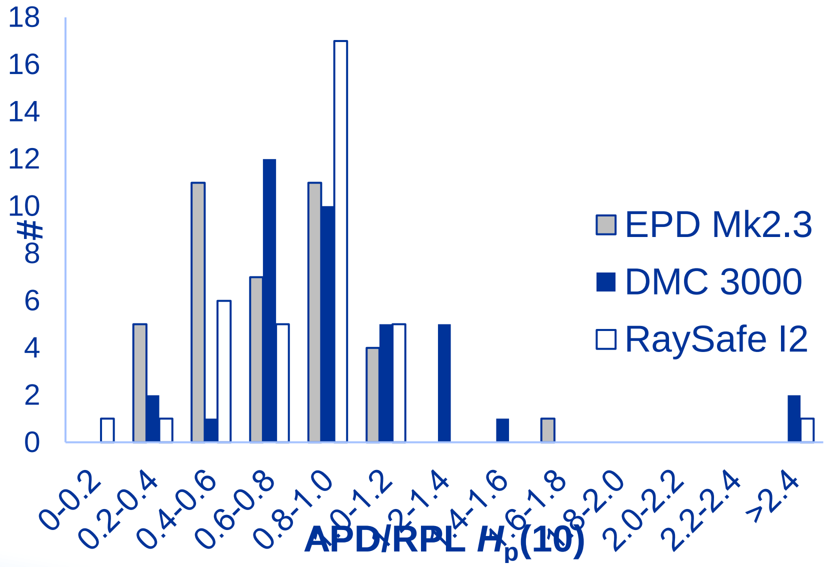
Relative response $H_p(10)$	Reference inst. dose rate [Sv/h]	Mk2	DMC3000	Raysafe i2
Tube below	0.2	0.92	1.13	0.7
Tube above	0.4	0.79	1.05	0.6
Direct beam	72	0.05	0.17	0.03





Measurements on operators in IC/IR

- Operators wearing both passive (RPL) and active dosimeter during routine work
- Fixed geometry, larger data set per APD
- Still large spread in results
- Average APD results is lower than RPL
- APD/RPL=
  - EPD: 0,7 (0,3-1,7)
  - DMC: 1,0 (0,3-2,9)
  - Raysafe: 0,9 (0,5-3,1)
- Differences in
  - Energy response
  - Pb apron response
  - Angular response
  - Pulsed fields response



Conclusions for APDs in interventional procedures

- Increasing use in hospitals
- Clear attention needs to be made for the energy range of the APDs
  - Especially for low energies: <60 keV (scattered radiation)
- APDs have problems with pulsed fields:
  - Will have large influence in direct beam
  - Should have overload alarm…
- Large differences with passive dosimeters
  - Different reasons, a.o. positioning of dosimeter on worker
  - Still large uncertainties

Conclusion: take away messages

- APD’s have reached a state-of-the-art: ready to be used as DOR
  - Clear advantages (ALARA, Alarm, higher sensitivity)
  - Technical characteristics and reliability are sufficient
- Also for APD:
  - approval needed by regulator
  - QA/QC and calibration is needed
- BUT!
  - Attention for suitable approval procedures: not always possible in-house
  - More expensive
- Careful in choice of which APD to use and where to use them
- Hospitals
  - Check for low energy, pulsed radiation, beta response