C. Schmidt, T. Stahl, E. Mergel

Current problems in the field of radiation protection technique –

Use of Active Personal Dosimeters (APD) in pulsed radiation fields

Outline

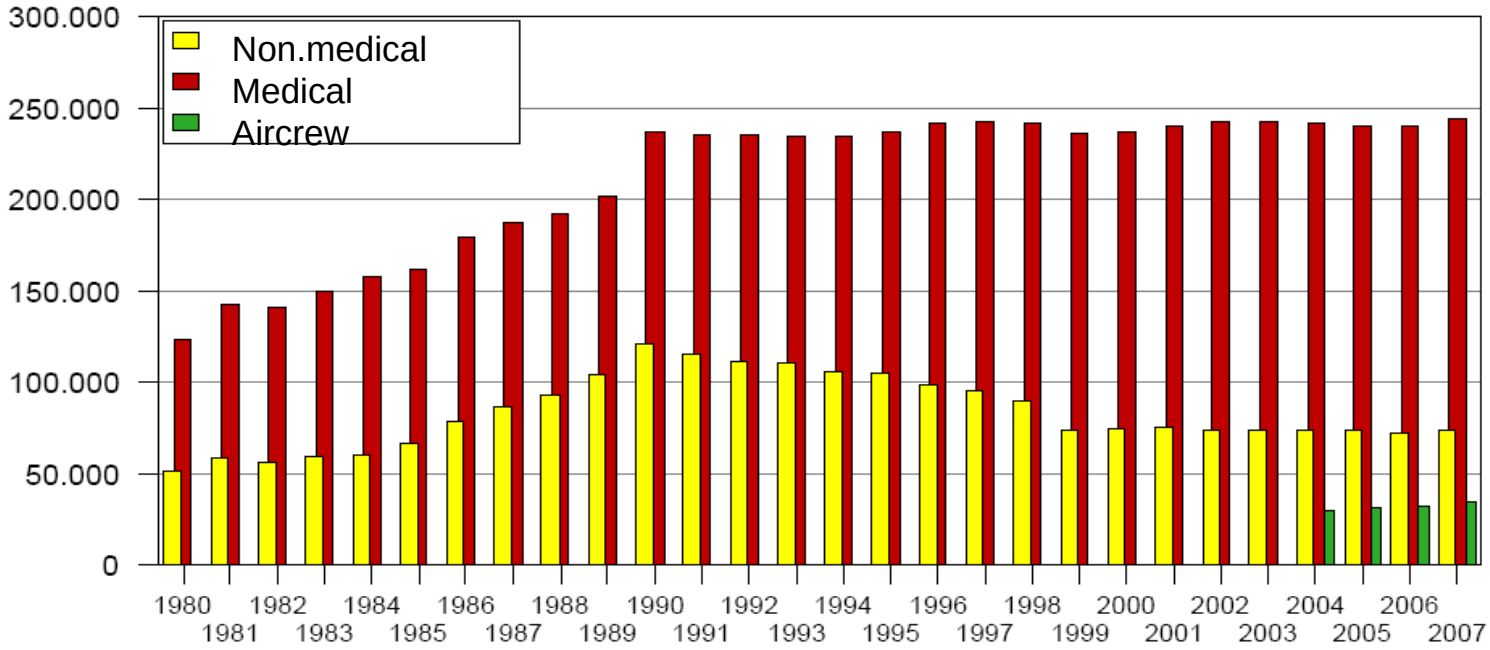
- Introduction
- Dosimeter types
- Pulsed radiation
- Limitations of APDs
- Legal requirements in Germany
- Examples of recent investigations
- Summary and outlook

Introduction (1)

- In the last decades, applications using ionizing radiation have increased significantly in
  - Industry
  - Medicine
  - Research
- New conditions and new techniques require regular updates and adjustments of the legal regulations
- Recent topics of radiation protection techniques
  - Quality control of X-ray diagnostics and radiotherapy
  - Dosimetry

Introduction (2)

- About 317 000 persons are classified as occupational exposed in Germany
  - 244 000 persons in the medical sector (77%)



[BfS 2007]

Dosimeter types (1)

- Passive dosimeters
  - Film badge
  - Thermoluminescence dosimeter
  - Glass dosimeter
  - Pen dosimeter
- Active dosimeters
  - PIN-diode
  - Geiger-Müller-counter
  - Ionization chamber

[IAEA]

Dosimeter types (2)

Quality characteristics of dosimeters

- Passive dosimeters
  - Long readout-cycles
  - Integrate the dose over the measurement time
  - Dose determination independent of dose rate and short pulse length
- Active dosimeters
  - Direct reading
  - Easy to determine local dose rate maxima
  - Audible alarms for dose rate and dose level
  - Effective tool for optimization and for on-line confirmation of dose constrains
  - Response limited with respect to high dose rates and very short pulse length

Pulsed radiation - Applications

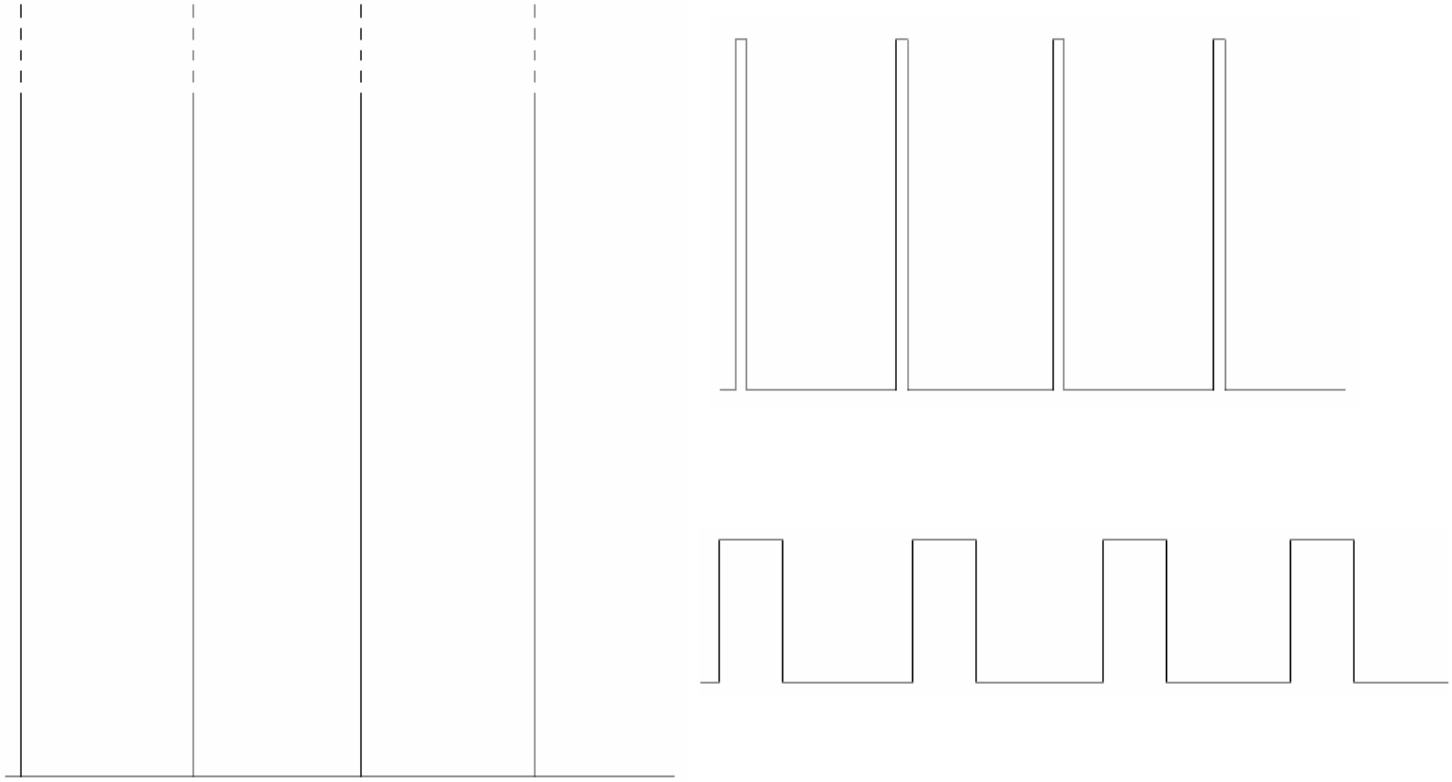
- Radiography in the industry
  - Material testing purposes
  - Scanners for goods (e.g. at customs)
- Several medical applications
  - X-ray diagnostics in human and veterinary medicine
  - Interventional radiology
  - Angiography, cardiology
  - Radiation therapy (accelerators)
- Research
  - Accelerators

Pulsed radiation - Characteristics (1)

Types of pulses

- Single pulse
  - X-ray radioscopy
  - Pulse length: a few ms up to a few seconds (e.g. abdomen adult: ~50 ms)
- Pulse series
  - Interventional radiology a few ms, 10 - 30 Hz
  - Angiography 3 - 200 ms, 1 - 12.5 Hz
  - Cardiology 3 - 20 ms, 6 - 50 Hz
  - Radiotherapy a few µs, up to 500 Hz

Pulsed radiation - Characteristics (2)



- The accumulated dose is the same in the 3 examples
- Dose rate increases with shorter pulses

Pulsed radiation - Characteristics (3)

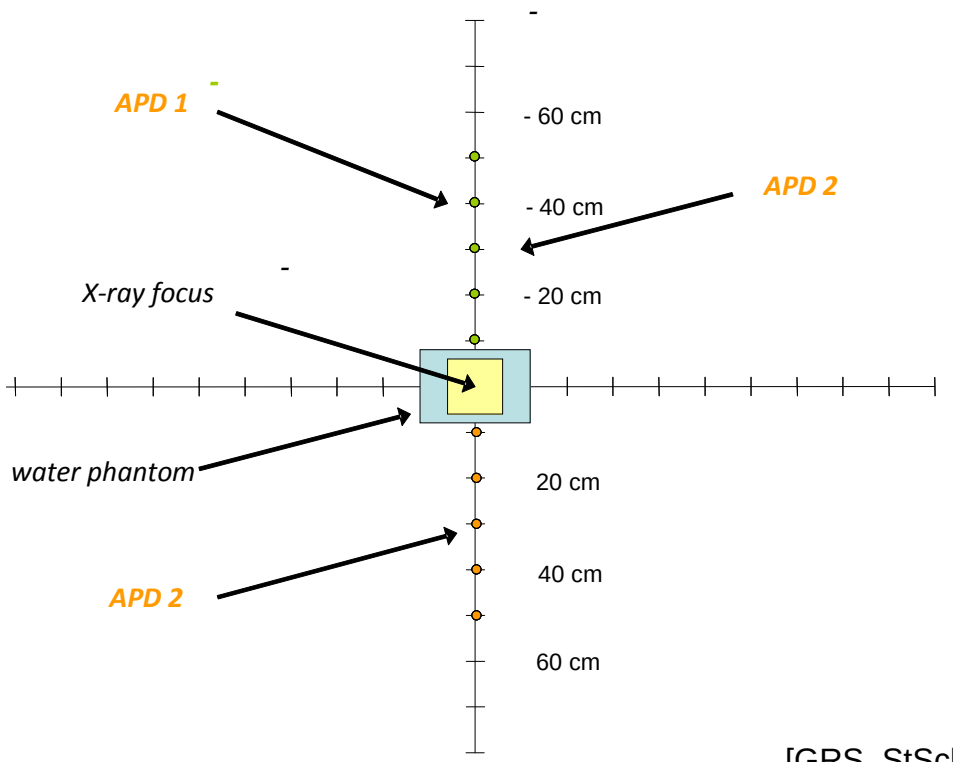
Application	Generation principle	Pulse length [s]	Dose rate in 1m distance [Sv/h]	Dose per pulse [µSv]
Scanner for persons and goods	Chopped from an X-ray tube	10^{-3}	1	0,1
Material testing	X-ray flash tube	10^{-10}	10^{5} - 10^{7}	1 - 100
Human and veterinary medicine	Rotating anode	10^{-3} - 10^{1}	100	100
Human medicine (therapy)	Electron accelerator	10^{-6}	10^{5}	10^{3}
Research	Laser plasma	< 10^{-12}	10^{6}	10^{-4}

[O. Hupe, PTB]

- Dosimeters have to work properly in wide range of dose rate as well as of dose per pulse

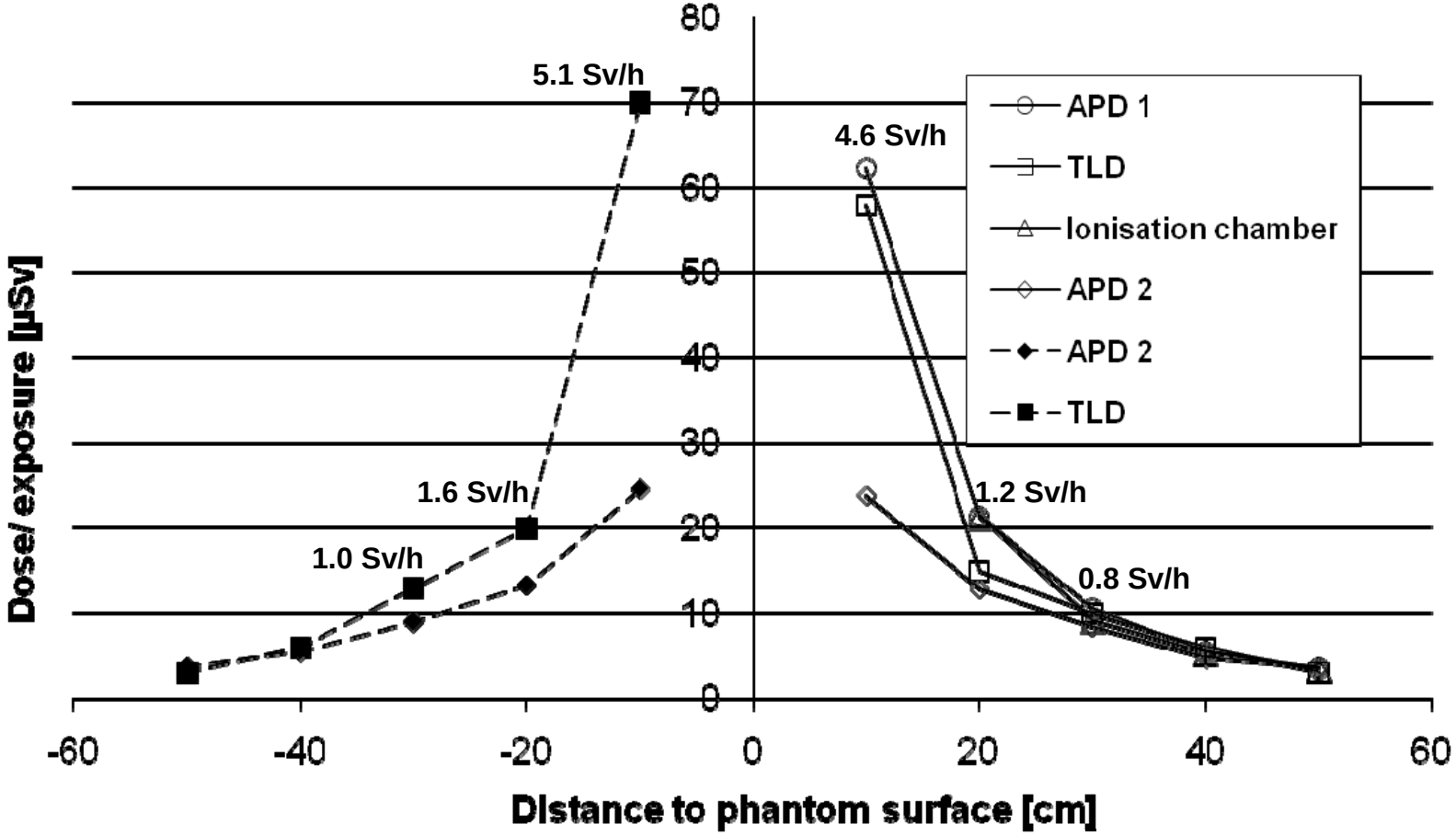
Limitations of APDs (1)

- Measurement of dose in scattered field (GRS project: Occupational exposure of medical staff in veterinary medicine)
- Measurement conditions: water phantom, energy 66 kV, exposure time 45 ms



[GRS, StSch 4477]

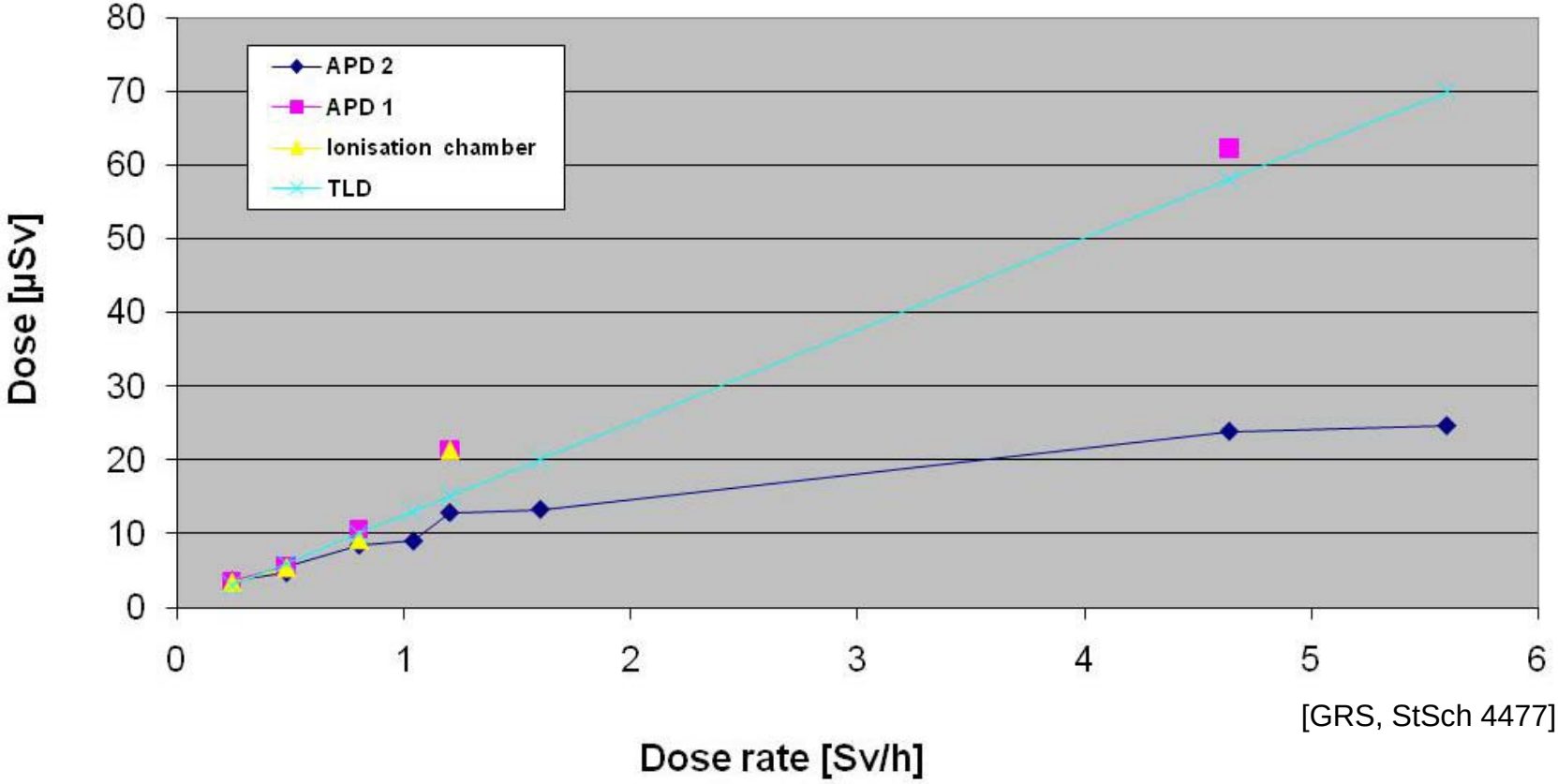
Limitations of APDs (2)
Measured dose rates in the scattered field



[GRS, StSch 4477]

- Dose rates higher than 1 Sv/h may also occur in the scattered field

Limitations of APDs (3)
Measured dose vs. dose rate



[GRS, StSch 4477]

- APDs may show deviations of the determined dose above a dose rate higher than 1 Sv/h

Legal requirements in Germany (1)
Aspects for legal dosimetry using APDs

- At work spaces of occupational radiation exposed personnel in the medical sector mainly pulsed radiation fields occur
  - Often low doses but high dose rates in the primary field
  - The dose rate in the scattered field could also be higher than 1 Sv/h
- For legal assessment of the individual dose
  - The determination of the individual dose have to be reliable
  - The dosimeter has to determine the dose properly also in the case of an accident with a dose rate higher than 1 Sv/h
  - Low doses with a high dose rate have to be detected

Legal requirements in Germany (2)
Dose determination at any time

- According to the German Radiation Protection Ordinance and X-ray Ordinance, the individual dose has to be determined at any time
  - On request of a supervised person, a dosimeter shall be placed at his disposal by means of which the individual dose may be determined at any time
  - Pregnant women: the occupational radiation exposure shall be determined and communicated to her per working week
  - Supporting persons (i.e. persons who e.g. help fixing an animal during X-ray diagnostics): measures shall be taken to restrict the radiation exposure
  - Persons under the age of 18

Legal requirements in Germany (3)
Current status in Germany

- APDs are not allowed for legal assessments in pulsed radiation fields
  - Since Nov. 08, the monitoring of the individual dose have to be fulfilled by other dosimeter types or access to radiation fields has to be prevented
    (in particular pregnant women and persons under age of 18)
- National standards currently consider only continuous radiation fields
  - Type tests need to cover pulsed fields
  - PTB is constructing a test facility
- Detailed investigations are initiated

Recent investigations (1)
Joined IAEA and EURADOS project

Intercomparison of Personal Dose Equivalent Measurements by Active Personal Dosimeters (IAEA-TECDOC-1564)

- Response of 13 different APDs in two pulsed fields measured
- Measurement conditions: energy 60 kV and 120 kV (mean energy about 30 and 50 keV), dose rate ~ 1,5 Sv/h, pulse length 1600 ms
- Only three devices show satisfactory results for both fields (six devices for the 120 kV field)

Recent investigations (2)
Working Group 9 of the CONRAD project

Intercomparision of Active Personal Dosemeters in Interventional Radiology (Clairand et al. 2009)

- Five ADPs are tested
- Measurement conditions: only one pulse at a time, 100 kV, pulse width 100 ms

Table 3. Response of APDs in terms of $H_p(10, 0°)$.

Mode	Reference $H_p(10)$	DMC 2000XB	EPD Mk2.3	DIS1	DIS100	EDMIII	PM 1621A
Continuous	210 μSv	1.14	0.79	0.70	0.59	0.95	1.09
Pulsed	112 μSv	1.25	0.85	0.80	0.63	1.17	0.01

[doi:10.1093/rpd/ncn083]

- Four are sensitive to the pulsed radiation
- Three fulfill IEC standards in terms of energy response

Recent investigations (3)
Physikalisch-Technische Bundesanstalt (PTB)

Deficiencies of Active Electronic Radiation Protection Dosemeters in Pulsed Fields (Ankerhold et al. 2009)

	Dosemeter type	Measuring quantity	Phantom	Measured mean dose per pulse	Response
Field 1	Diagnostic X-ray unit, single pulse, $T_{pulse} \approx 40$ ms, $\dot{H}_{pulse} \approx 3.9$ mSv s^{-1}				
	Reference	$H_p(10)$	ISO slab	156 µSv	1.00
	Passive	$H_p(10)$	ISO slab	121 µSv	0.78
	Active A	$H_p(10)$	ISO slab	8 µSv	0.05
	Active B	$H^*(10)$	Free in air	1.4 µSv	0.01[a]
	Active C	H_X	Free in air	80 µSv	0.51[a]
	Active D	$H^*(10)$	Free in air	2.35 µSv	0.02[a]
Field 2	X-ray flash unit, 99 pulses, $T_{pulse} \approx 50$ ns, $\dot{H}_{pulse} \approx 36$ Sv s^{-1}, $f_{repeat} = 29$ Hz				
	Reference	$H_p(10)$	ISO slab	1.55 µSv	1.00
	Passive	$H_p(10)$	ISO slab	1.14 µSv	0.74
	Active A	$H_p(10)$	ISO slab	0 µSv	0.00
	Active B	$H^*(10)$	Free in air	0.2 nSv	0.00[a]
	Active C	H_X	Free in air	1.39 µSv	0.90[a]
	Active D	$H^*(10)$	Free in air	0.14 µSv	0.09[a]

[doi:10.1093/rpd/ncp099]

- 2 different fields, 4 APDs (all APDs of different detection type: GM-counter, Ionization chamber, PIN-diode and scintillator)
- All tested APDs show detection deficiencies, consequently the dose and photon energy are in the APD specifications

Summary and outlook

- APDs may show detection deficiencies above 1 Sv/h
- Legal assessment of dose with APDs is not allowed in pulsed radiation fields in Germany
- Additional, detailed investigations are necessary
  - Work-place fields have to be characterized
  - ORAMED project started 2008
    (further measurements within medical facilities)
  - Test facility at PTB under construction
- National and international standards considering pulsed radiation needs to be defined

Thank you for your attention