Measurement of Dose to Implanted Cardiac Devices in Radiotherapy Patients

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- Members of AAPM TG203

Dose Estimation to Cardiac Devices

Out-of-field/peripherial doses

↓

Head Scatter + Head Leakage + Internal Scatter

10 to 20 cm → internal (patient) scatter dominates
collimator and head scatter contribute

≈ 30 cm → internal scatter and head leakage approximately equal, collimator scatter decreases

> 30 cm → head leakage dominates

Out-of-Field/Peripherial Doses

- **Calculations**
- **Lookup tables/graphs**
- **Measurements**
  - In-Vivo Dosimeter Characteristics
    - Real time
    - Passive

Accuracy of out-of-field dose calculations

RPC Study out-of-field dose

Rebecca M Howell[1,3], Sarah B Scarboro[1,2], S F Kry[1,2] and Derek Z Yaldo[1,2]
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- Rando Phantom –Slices 20 to 25
- Mantle Field –AP/PA
- 6 MV – 30 Gy delivered to isocenter
- Measure the dose out-of-field

TPS vs. Measurements

Table 1. Mean measured doses ($\mu_{meas} \pm \sigma$) and mean TPS-calculated doses ($\mu_{calc} \pm \sigma$) for all TLD data for each phantom slice and for all phantom slices. The standard deviation (σ) is reported as one standard deviation of the mean. This value is dominated by the spread of doses across each phantom slice as compared to an additional standard uncertainty in each TLD measurement of $\leqslant$3% .

Phantom slice	Distance from field edge (cm)	Count	μ_{calc}, cGy/Gy$_{Rx}$ (σ)		μ_{meas}, cGy/Gy$_{RX}$ (σ)		Mean TPS underestimation of measured dose (σ)	
21	3.75	56	3.08	(0.61)	4.24	(0.45)	28%	(17%)
22	6.25	59	2.02	(0.43)	3.01	(0.24)	32%	(12%)
23	8.75	62	1.16	(0.32)	2.09	(0.14)	44%	(15%)
24	11.25	61	0.66	(0.33)	1.49	(0.13)	55%	(23%)
All slices	N/A	238	1.7	(1.01)	2.65	(1.05)	40%	(20%)

cGy/Gy$_{Rx}$: cGy per prescribed Gy.

Rebecca M Howell[1,3], Sarah B Scarboro[1,2], S F Kry[1,2] and Derek Z Yaldo[1,2]

TPS Calculations for out-of-field doses are NOT accurate

- Range of 3.8 → 11.2 cm from the field edge the TPS underestimates the dose by <40% ± 20%>
- As distance from field edge increases, the TPS increasingly underestimates the dose
- D(TPS) varies with depth, whereas D(meas) shows little variation with depth

Dose Calc: Photon out-of-filed dose

ELSEVIER

RADIOTHERAPY & ONCOLOGY
JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

Peridose, a

Abstract

A software program, P
calculation is based on pu
wedges and shielding blo
Elsevier Science Ireland

Keywords: Peripheral dose;

The calculation steps are summarized in the following equations:

$$\text{Peripheral dose (PD)} = PD\% \times f_{\text{MV}} \times f_{\text{thickn}} \times f_{\text{depth}} \times (f_{\text{couch}}) \times f_{\text{elong}} \text{ (step 1 to 6)}$$

$$\text{PD with wedge} = \text{PD} \times f_{\text{wedge}} \text{ (step7)}$$

$$\text{extra scatter wedge} = (f_{\text{wedge}} - 1) \times \text{PD}$$

$$\text{Coll. rel. rad.(CRR)} = \text{PD} \times f_{\text{CRR}} \text{ (step8)}$$

$$\text{PD with block} = \text{PD}$$

$$\text{scatter block} = (1 - f_{\text{block}} \times (1 - f_{\text{CRR}})) \times PD \text{ (step 9)}$$

$$\text{CRR} = \text{CRR} \times f_{\text{att}} \text{ (step 10)}$$

In these equations the parameters and correction factors are defined as follows:

$PD\%$ = peripheral dose in % of dose at d_{max}
f_{MV} = correction for photon energy
$f_{\text{thickn.}}$ = correction for patient thickness along beam axis
f_{depth} = correction for depth of PD point
f_{couch} = (optional) correction for couch attenuation
f_{elong} = correction for field elongation
f_{wedge} = correction if wedge is used
f_{CRR} = fraction of PD contributed by collimator related radiation
f_{block} = correction if shielding blocks are used
f_{att} = attenuation correction of CRR for depth of PD point

2.2. Tangential beams

The program also offers the option to calculate the PD for

3.1. Constraints and limitations

When using the program the user has to realize that certain constraints have to be considered. The PD percentages which form the basis for the calculations, are related to the dose at d_{max}. This is easy for SSD treatments, but for isocentric techniques the user has to calculate the dose at d_{max} from the dose at isocentre. For non-coplanar, non-orthogonal beams, the program should be used with caution and careful output data interpretation. An example of such a technique would be the application of an anterior oblique vertex field for the treatment of a pituitary or some other brain tumor.

PERIDOSE REPORT

```
Date:    Tuesday, August 8, 2000, at 08:35 AM
Patient: John Doe

Total Peripheral Dose:                    19.9 cGy
Uncertainty:                              12.0 cGy

Total Leakage and External Scatter:       15.7 cGy

Total Number of Beams:                    2

Contribution of Beam number 1:(Left anterior oblique)
            Peripheral Dose:                       7.5 cGy
            Leakage and External Scatter:          5.9 cGy

Contribution of Beam number 2:(Right lateral)
            Peripheral Dose:                       12.4 cGy
            Leakage and External Scatter:          9.8 cGy
```

Fig. 2. Print of the results of the 2-beam calculation for which the input is shown in Fig. 1.

Peripheral Doses in Photon Beams

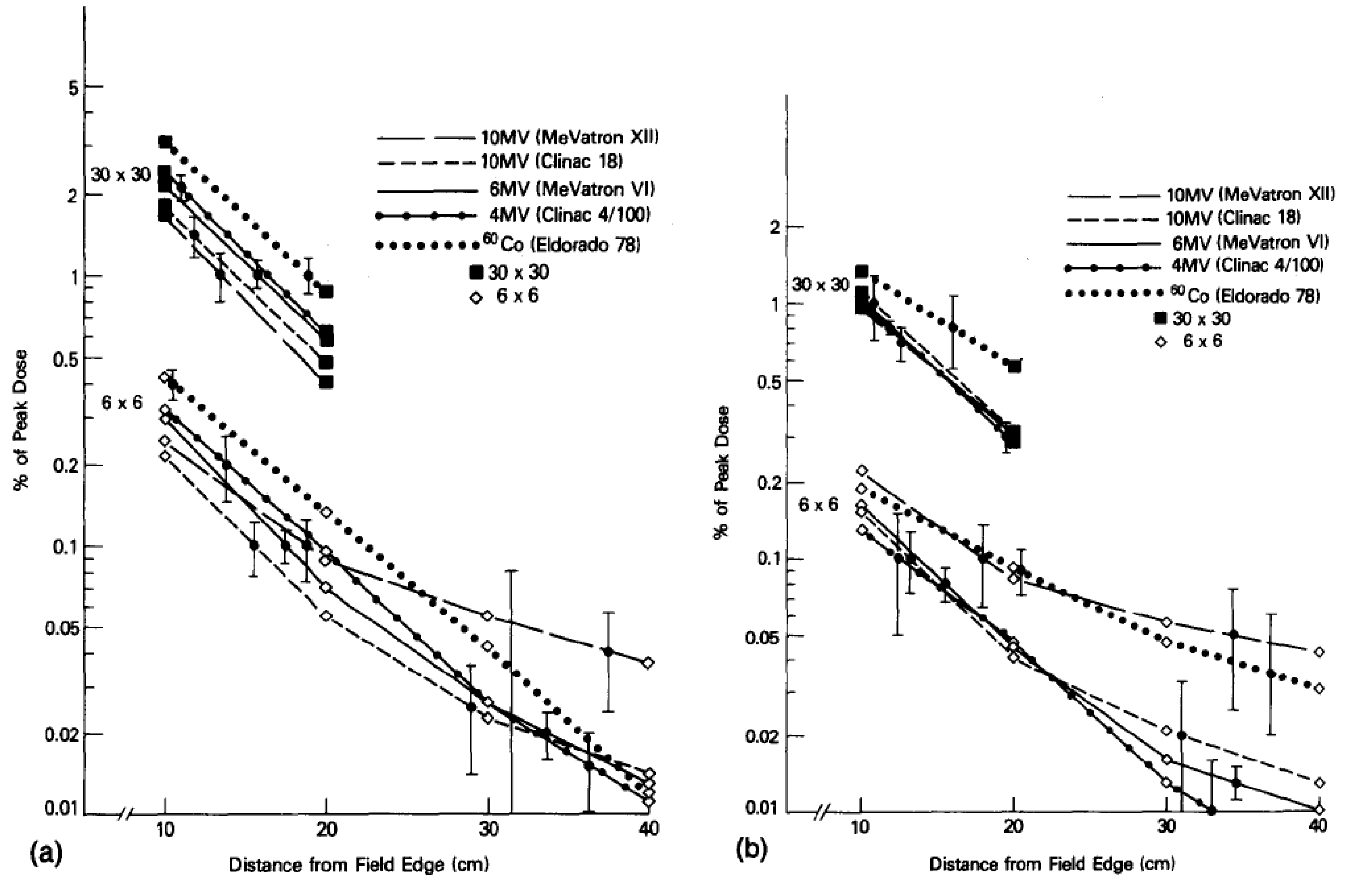

FIG. 7. Scatter component of the PD. (a) Data for 30×30 and 6×6 fields at 10-cm depth. (b) Same at depth = d_{max}. Error bars are indicative of spread between different methods of determination. See the text.

[a] Mevatron XII.

Dose Estimation: Photon out-of-filed dose

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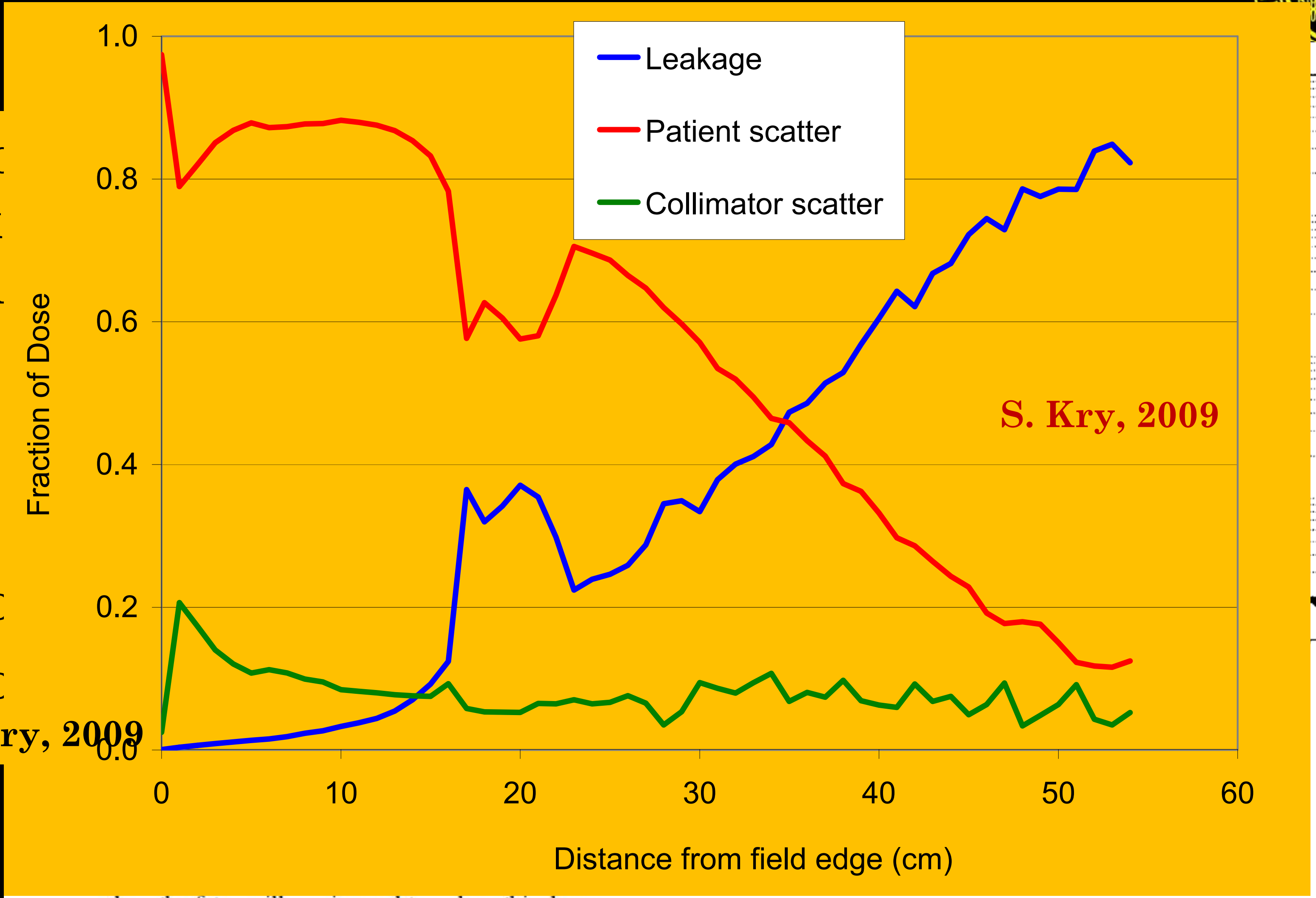
- Co

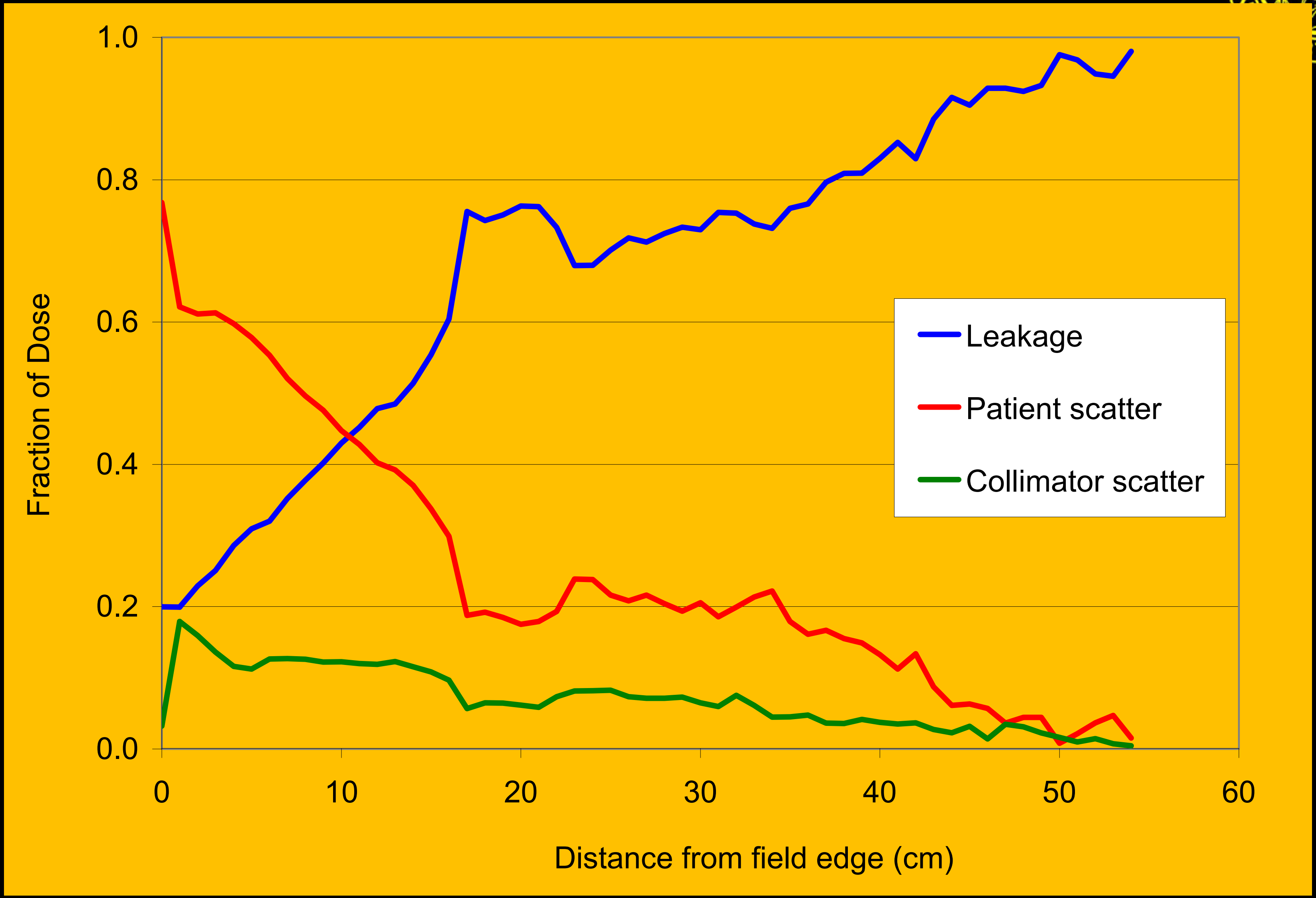
S. Kry, 2009



dose the fetus will receive and to reduce this dose v
presented for a variety of photon beams, including
MV. Designs for simple and inexpensive to more c
ment are described. Clinical examples show that p
the fetus by 50%. In addition, a review of the biological aspects of irradiation enables estimates of
the risks of lethality, growth retardation, mental retardation, malformation, sterility, cancer induc-

FIG. 21. Total absorbed dose in phantom from 6-MV photons for field sizes of 5×5, 10×10, 15×15, and 25×25 cm^2 at 10-cm depth, normalized to 100% on the central axis at depth of maximum dose.

What about IMRT?



S. Kry, 2009

What about SBRT and filter-free beams?

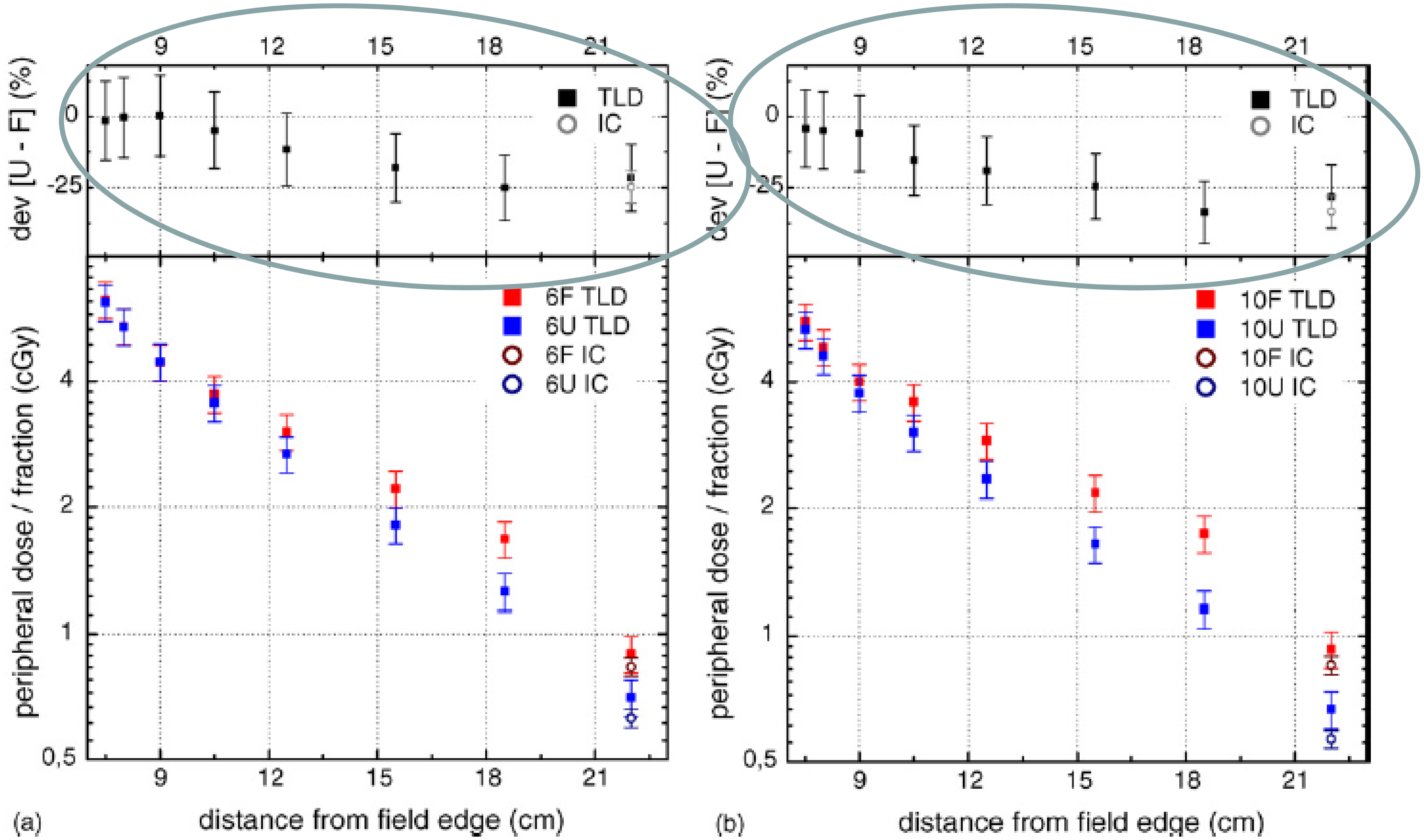
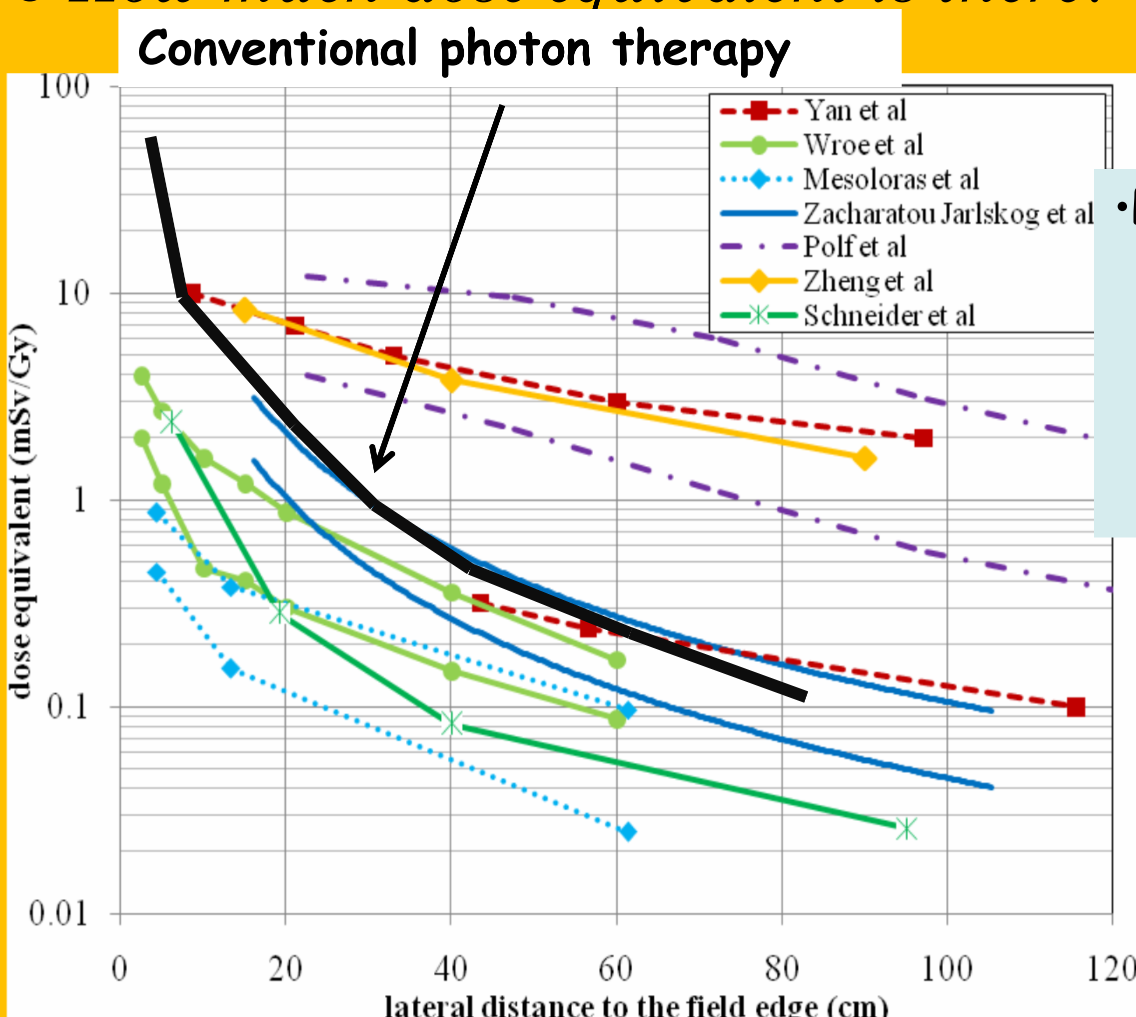


Figure 5. Results of peripheral dose measurements (in the isocentric plane) as a function of the distance from the field edge for the lung SBRT plans with a) 6 and b) 10 MV flattened and unflattened beams. The relative percentage reduction in peripheral dose (dev [U - F]) achieved by using FFF beams when compared to FF beams is indicated in gray in the top part of the figure.

may benefit by decreased exposure of normal tissue to scattered dose outside the field.

Dose estimation: Proton out-of-field dose

- *How much dose equivalent is there?*



Xu, 2008, Phys Med Biol

Variations in beam

- Photons:
  - More dose near treatment field
  - Comparable dose beyond 10-20 cm from field edge

Size and material of phantom, manufacturer of accelerator

Challenges in Dosimetry
  Lack of high energy response

Unique machines

Courtesy of S. Kry

Out-of-Field Dose Measurements

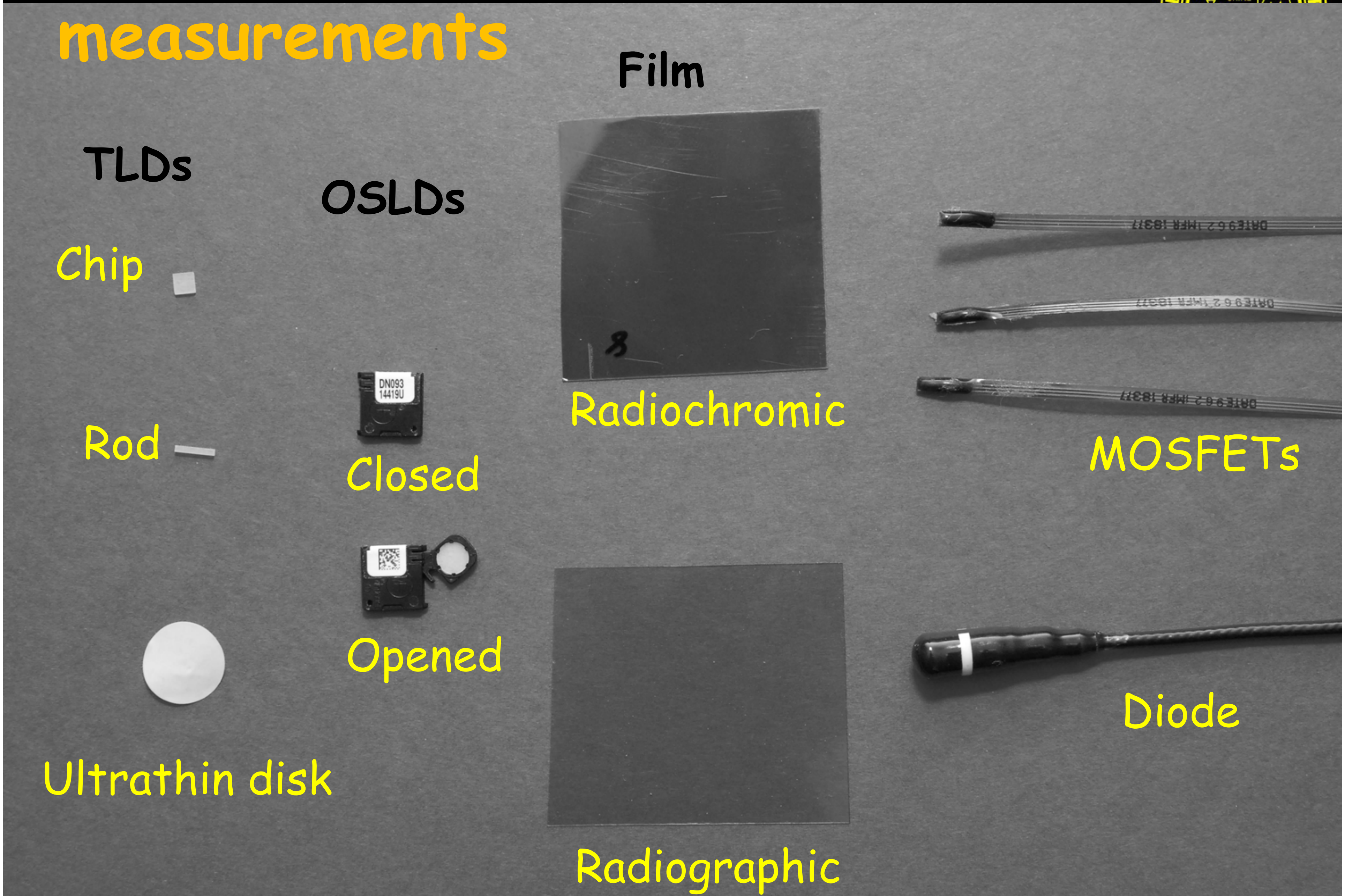
Requirements:

- Sensitivity
- Energy Dependence
- Size

↓

TLDs / OSLDs / Diodes

Detectors used for patient measurements



Examples of measured dose to Cardiac Devices

Treatment Site	Dose(Gy) Fraction	Energy MV	Technique	%Dose
Head & Neck	1.5	6	IMRT	3
Head & Neck	1.5	6	IMRT	5
Esophagus	2.0	6 & 18	3DCRT	4
Pelvis	1.8	15	3DCRT	0.8

Real Time
In Vivo Dosimeter:
Diodes and MOSFET

Diodes

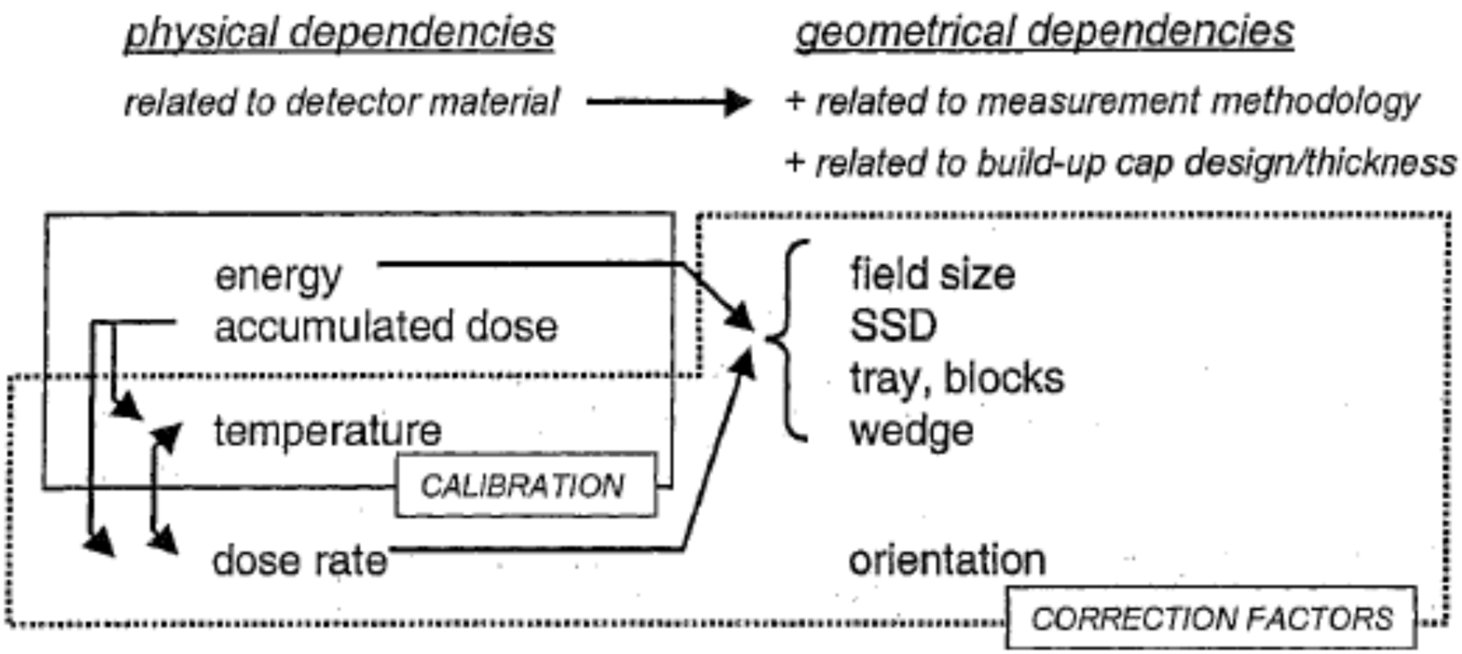
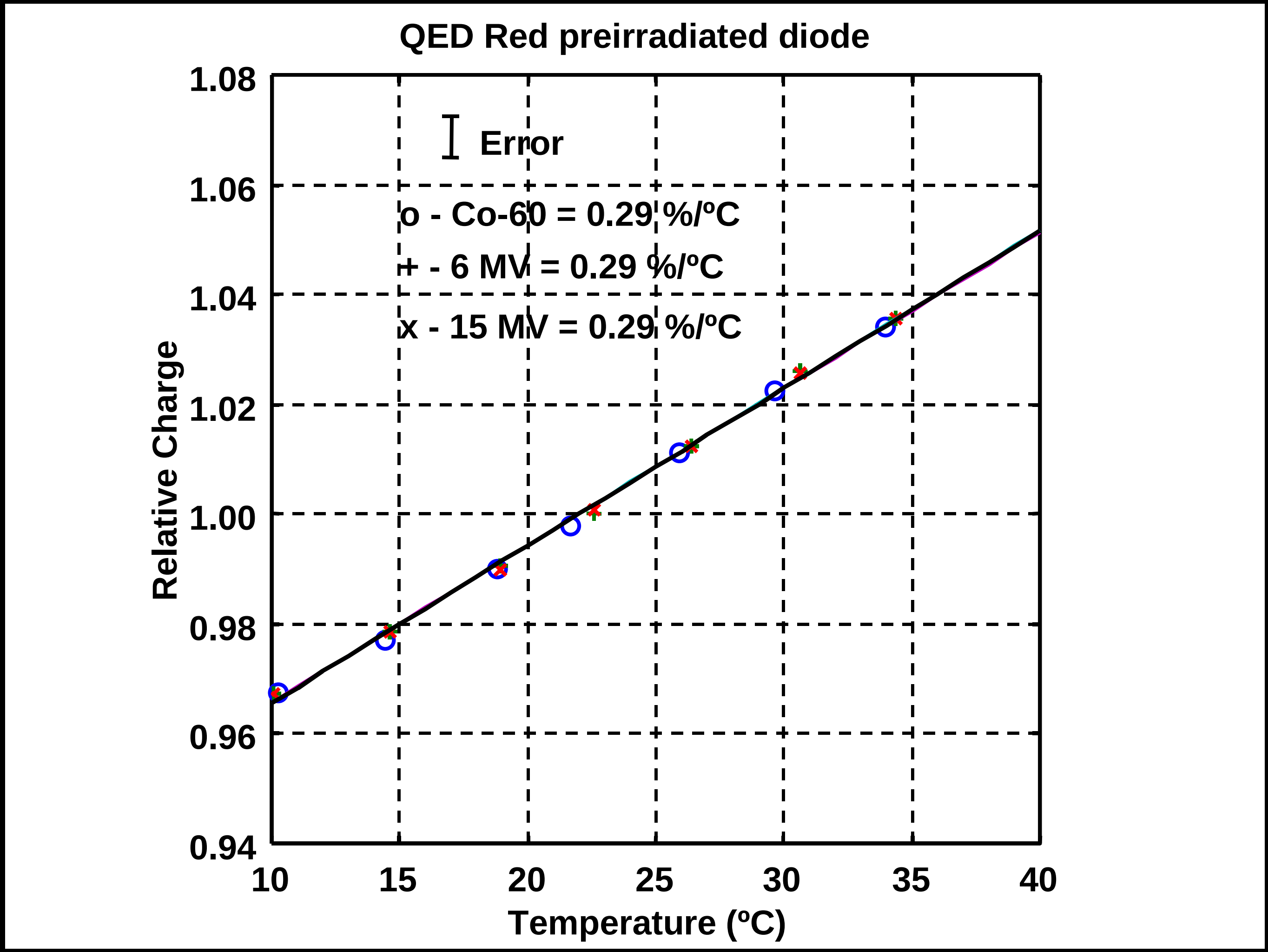


Figure 1.2 Schematic summary of the factors (physical as well as geometrical) influencing the diode signal. Arrows indicate dependencies of one factor on another. The different influences are taken into account in calibration and correction factors (see Section 1.2).

Temperature coeff ≈ 0.3%/^{o}C



(Saini and Zhu, 2002)

Temperature function of time

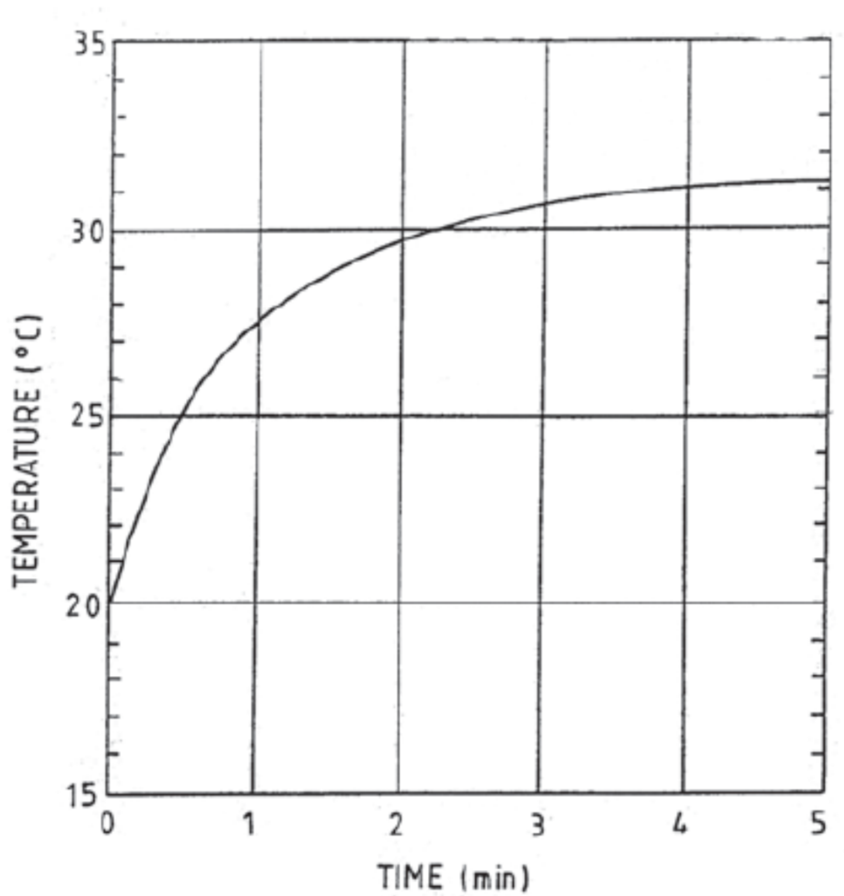
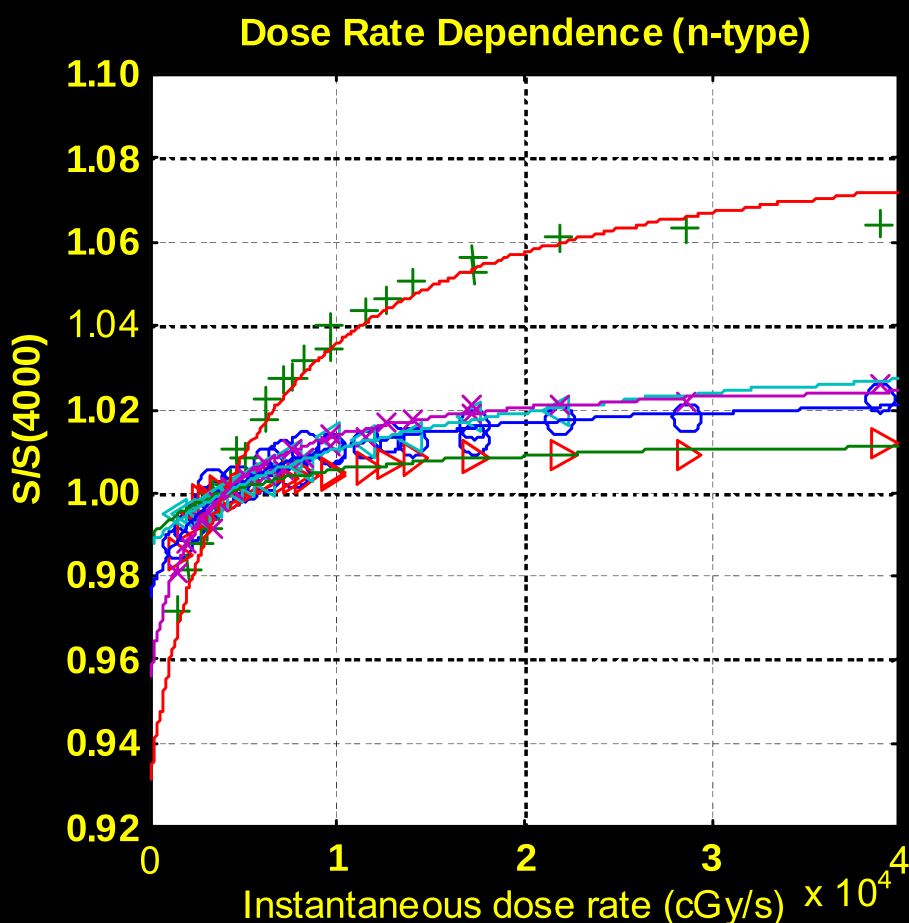


Figure III.6: Variation of diode temperature as a function of time after taping on the patient (After Grusell and Rikner, 1986).

Dose Rate Dependence



o-Isorad Gold#1 + - Isorad Red (n-type), ▹ - Isorad-3 Gold, ◃ - Veridose Green x - QED Red (n-type)

◊ - EDP103G , x- EDP203G , * - Isorad-p Red, Δ - QED Red (p-type), ∇- QED Blue

(Saini and Zhu, 2004)

Sensitivity Loss with Dose

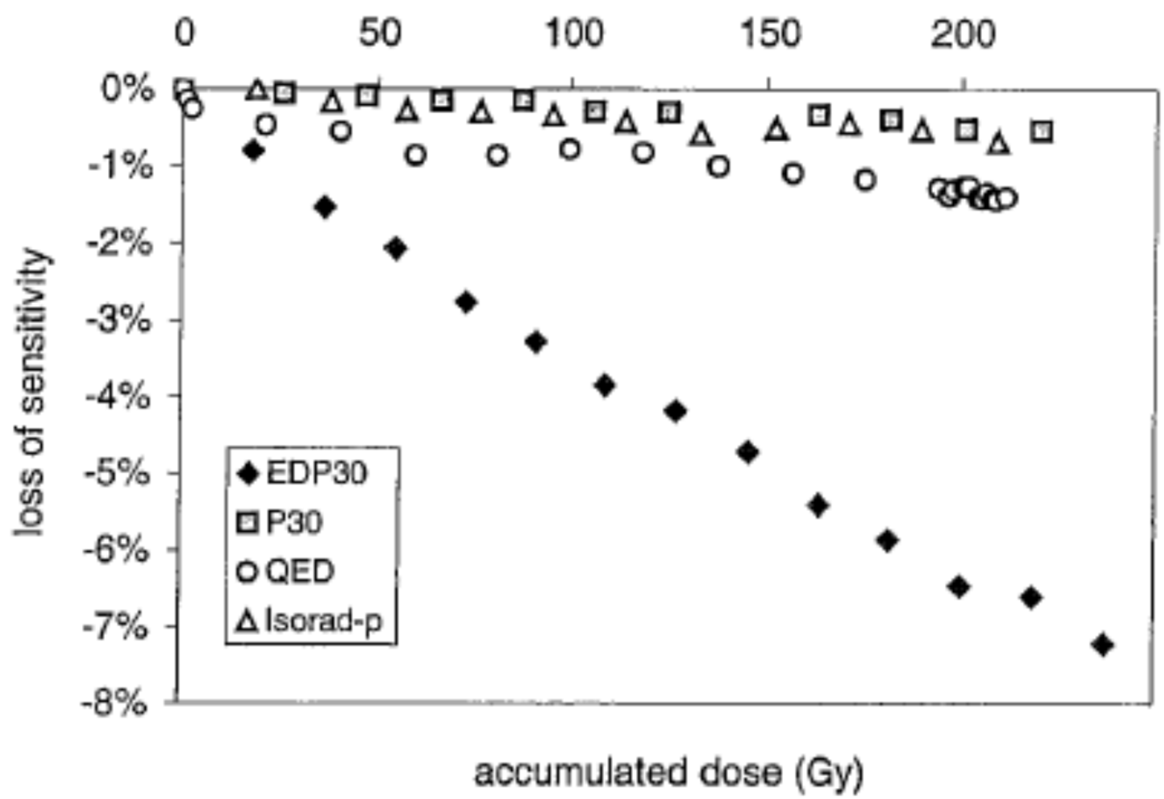
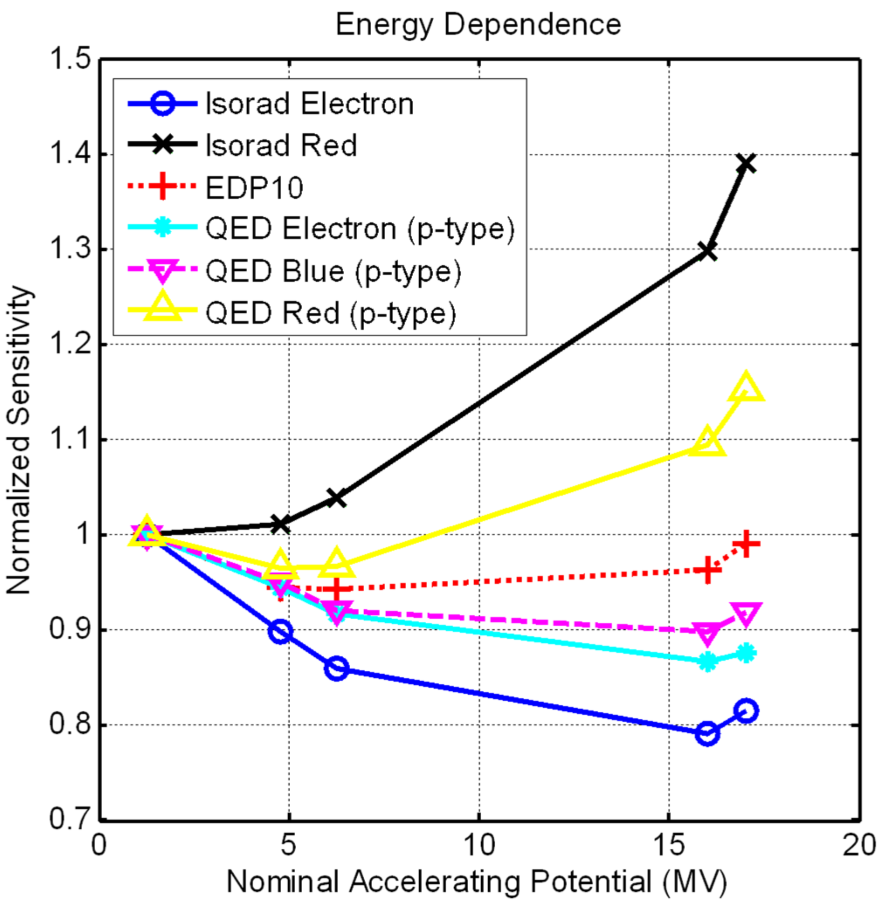
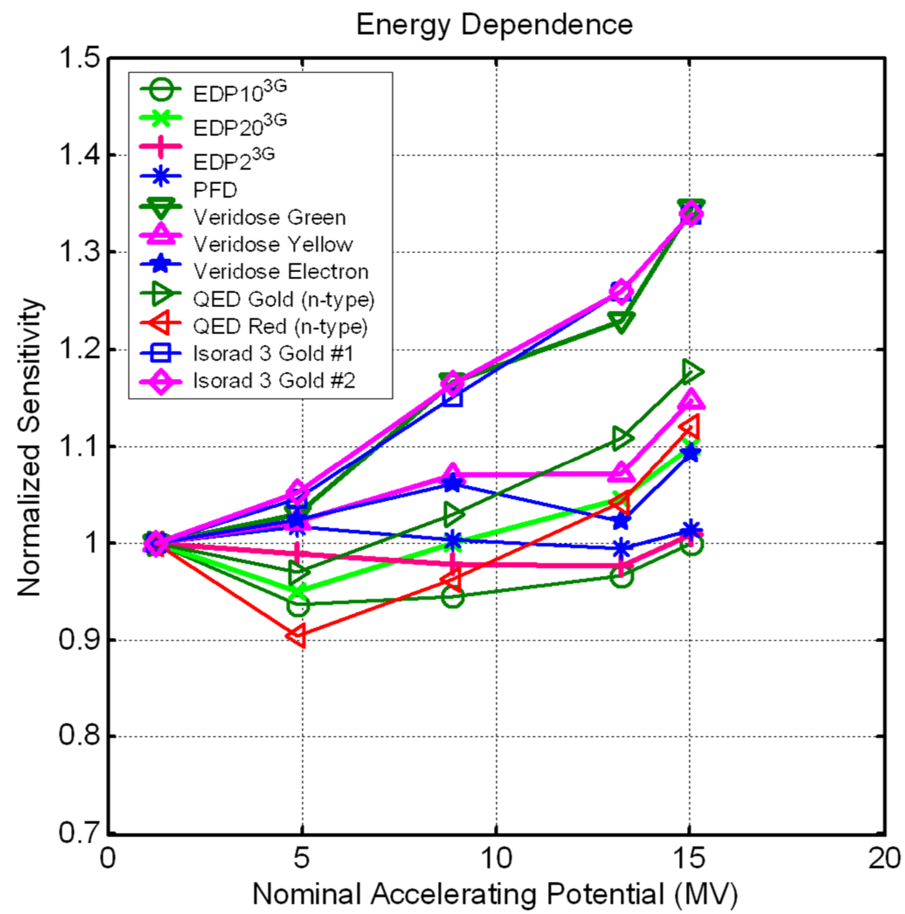


Figure 5.13 Sensitivity loss with accumulated dose for EDP-30, P30, QED and Isorad-p diodes

Energy Dependence for MV Photon Beams





 (Saini and Zhu, 2007)

Directional Dependence

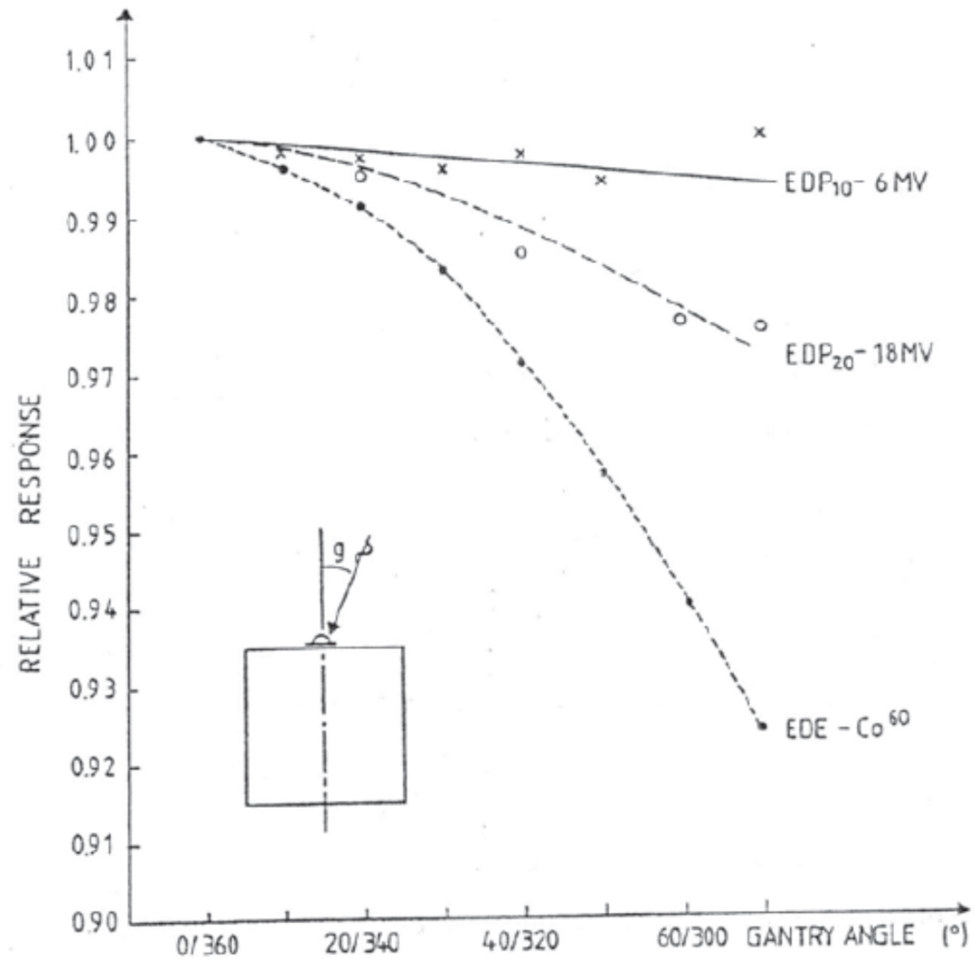
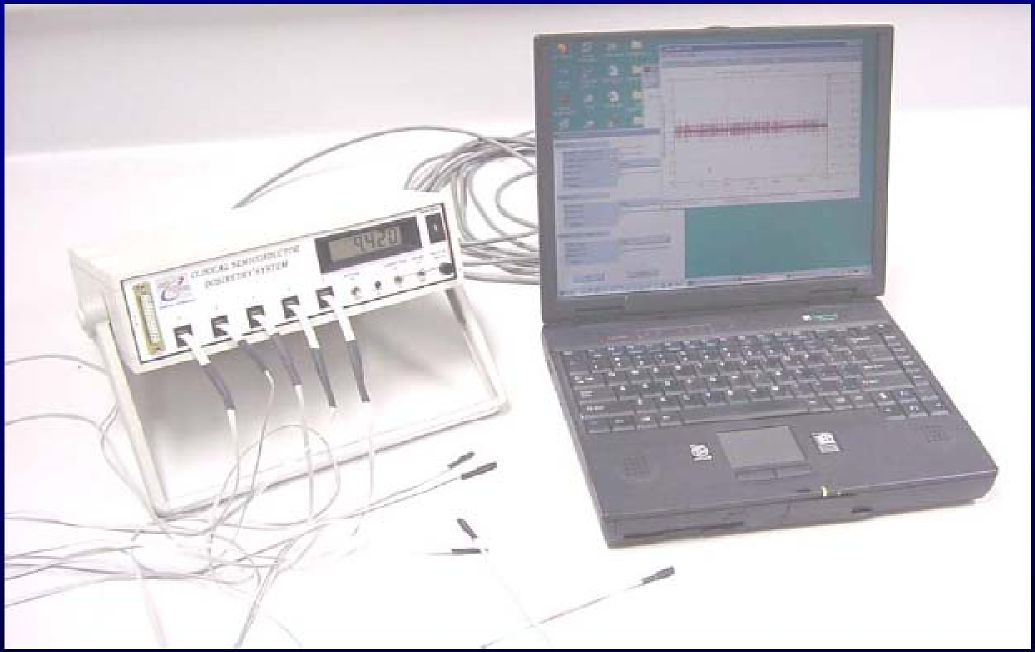


Figure III.8: Relative response of 3 different diodes, used at different photon energies (without additional build-up cap), as a function of the angle g between the symmetry axis of the diode and the beam axis. For the 3 diodes investigated the sensitivity decreases as a function of the angle (After Van Dam et al, 1994).

Diode as an in-vivo dosimeter

- Advantages:
  - Higher relative sensitivity
  - Quick response – (1 – 10 μs)
  - Good mechanical stability
  - No external bias needed
  - Small size
  - Smaller energy dependence of mass collision stopping power ratios (between silicon and water compared to air and water)
- Disadvantages:
  - Dependence on temperature, dose rate, energy dependence, angle
  - Require an electrical connection during irradiation

CMRP MOSFET Dosimetry System



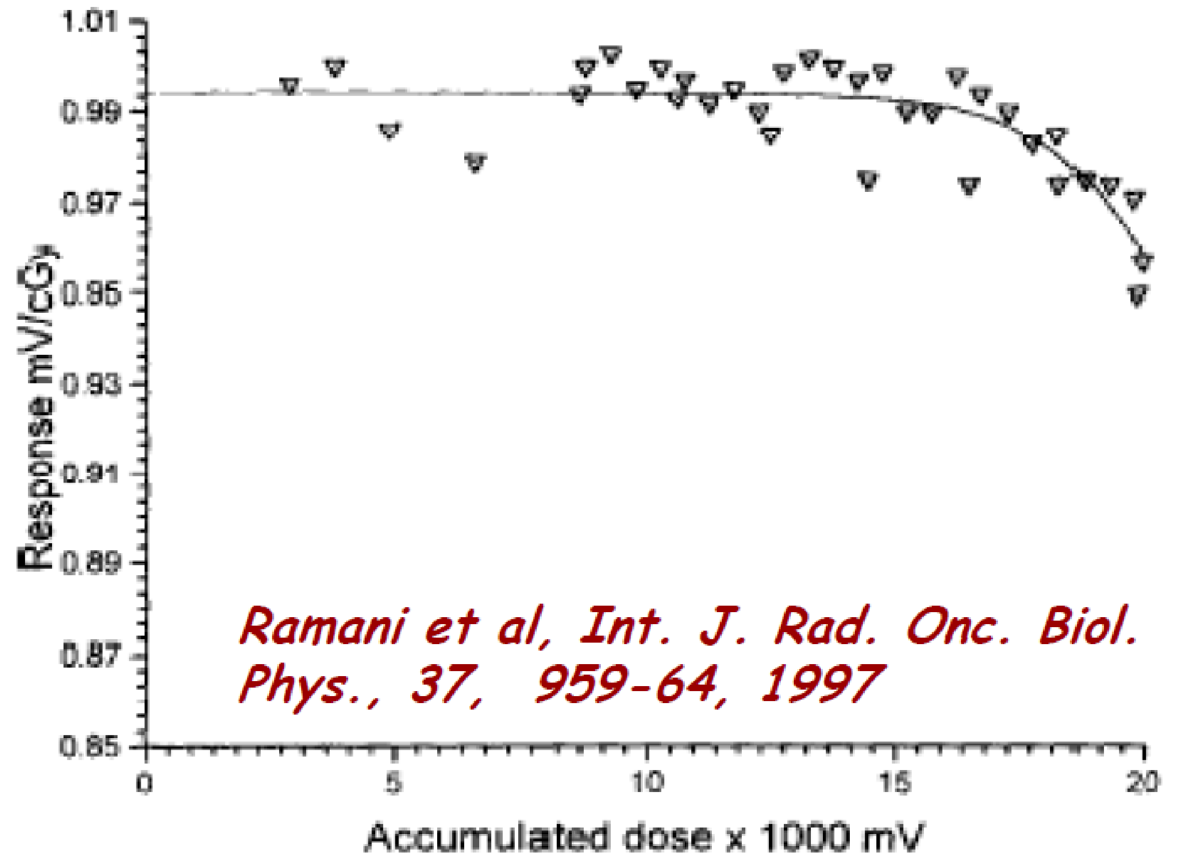
MOSkin detectors, thickness 0.07 mm, see Table 29-III

MOSFET Clinical Dosimetry System:

designed and distributed by CMRP

Courtesy of Anatoly Rosenfeld

Effect of accumulated dose



Ramani et al, Int. J. Rad. Onc. Biol. Phys., 37, 959-64, 1997

MOSFET detectors
Advantages *vs.* disadvantages

Advantages

- Very small active volume
- Dual-MOSFET-dual bias system eliminates most correction factors
- Instantaneous readouts (on-line dosimetry)
- Permanent dose storage (Can be read multiple times)
- Waterproof
- Efficient in use

Disadvantages

- Finite lifetime(~100 Gy)
- Energy dependence
- Temperature dependence for single-MOSFET-detector
- Sensitivity change with accumulated dose for unbiased MOSFETs

Passive In Vivo Dosimeters:

Luminescent In Vivo Dosimeters TLDs and OSLDs TG-191

Recommendations on the clinical use of luminescent detectors

microStar
NITROGEN OUTLET
lenovo
R60e
InLight
Loader
LED
ON
Indicator
LANDAUER®
Measuring
Position
Dial
H/P
DRK
CAL
LED
E4
E3
E2
E1
Power
ON
Indicator
microStar

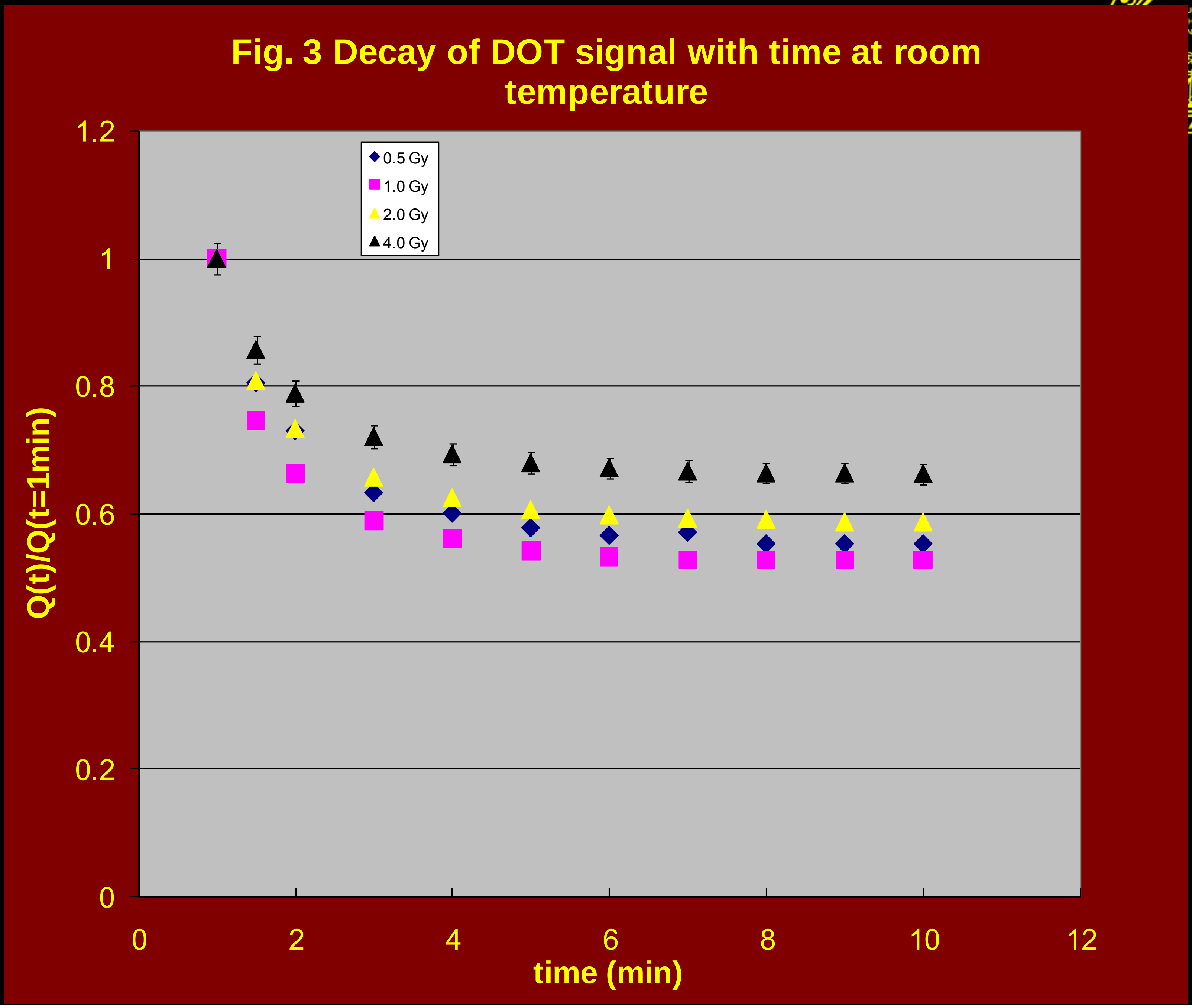
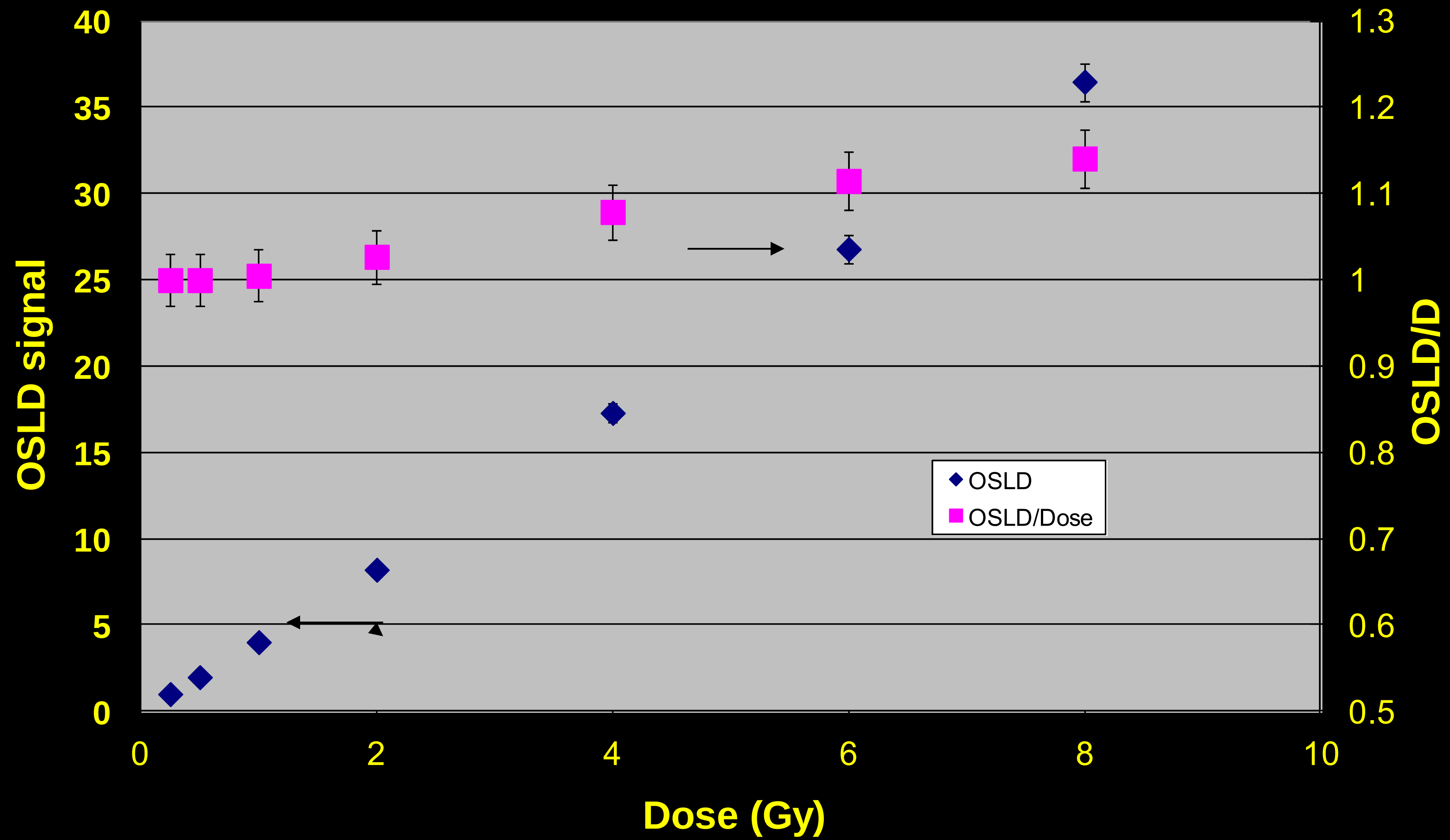
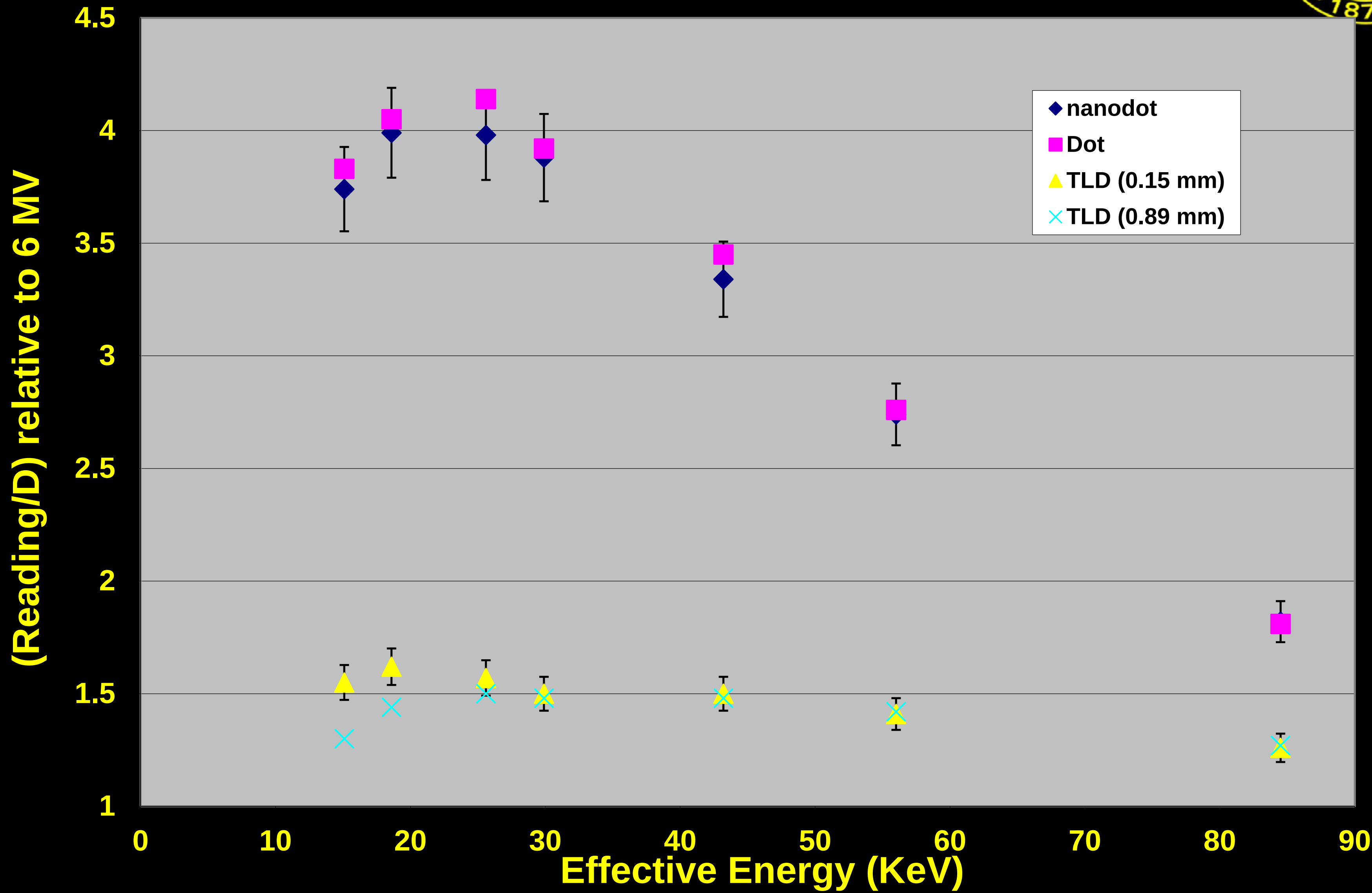


Fig. 3 Decay of DOT signal with time at room temperature
0.5 Gy
1.0 Gy
2.0 Gy
4.0 Gy
Q(t)/Q(t=1min)
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
time (min)

OSLD and OSLD/Dose as a function of dose normalized to their readings at 0.25 Gy Similar response for TLDs



Energy dependence of OSL and TLD dosimeters



Energy response of TLD and OSLD detectors normalized to their response at 6 MV

Modality	Energy MV	Equivalent Energy MeV	$(TLD/D)^{Q}_{6MV}$	$(OSLD/D)^{Q}_{6MV}$
photons	0.250	0.110	1.28	1.71
photons		1.25	1.02	1.04
photons	6	2.4	1.00	1.00
photons	18	5.7	0.99	0.99
electrons		6	0.98	0.99
electrons		9	0.99	0.99
electrons		12	0.99	0.98
electrons		16	0.99	0.98
electrons		20	0.99	0.98
protons		100	1.08	0.95
protons		180	1.06	0.95
protons		250	1.08	0.96

$\sigma \approx \pm 5.5\%$, and $\pm 3.8\%$ within 1 SD for kilovoltage and megavoltage irradiations, respectively

Advantages of TLDs

- Wide useful dose range mrad→10^2 cGy(linearity)
- Dose-rate independence 0 → 1000 cGy/s
- Angular independence
- Reusability
- Readout convenience
- Economy
- Availability of different types and sizes
- Automation compatibility
- Accuracy and precision

Disadvantages of TLDs

- Lack of uniformity
- No immediate read-out
- Fading
- Light sensitivity
- Memory of radiation and thermal history
- Reader instability
- Loss of reading

Advantages of OSLDs

- Easier read-out procedure
- Re-read the detector
- Easier individual identification
- Optical bleaching easier than thermal annealing to remove radiation effects
- Angular independence
- Accuracy and precision

Disadvantages of OSLDs

- Encapsulated in light tight plastic housing
- Optical bleaching cannot clear all the radiation effects → increased background signal
- Sensitivity changes with accumulated doses > 20 Gy

Comparison of Out-of-Field dose measurements with different detectors

Detectors centered 10 cm from field edge of 10x10 cm^2 at a depth of 1.5 cm with no correction except for calibration
6 MV, 600 MUs, SSD=100 cm

Property	Ion Chamber 0.1 cc	TLD-100 .035x.035 x.089 cm^3	OSLD	Surface Diode	Table
Dose (cGy)	5.8	5.6	5.6	5.0	5.4
σ(1 SD)	±0.1	±0.2	±0.2	±0.1	---
D(det)/D(Ion)	1.0	0.97	0.97	0.86	0.93

Summary

- Measurement useful to document dose to the device and compare to TPS calculation
- TLDs, OSLDs and diodes are appropriate detectors for these measurements
- Ignore detector CFs → provide an upper dose value
- TPS calcs are not accurate to estimate the dose to cardiac devices outside the field edge

Thank You

CU Anschutz Medical Campus