Patient Dosimetry (IVD)

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Patient Dosimetry (IVD)

What is Patient Dosimetry (IVD)

- **Dosimeter(s) placed on or in the patient during the course of one treatment for the purpose of confirming the accuracy of treatment delivery.**
- **may be measuring dose from one field (distinct entrance, midplane, and/or exit doses)**
- **may be measuring dose from all fields (complex combination of contributions from entrance, exit, scatter)**
- **Intracavitary patient dosimetry will not be included in this talk, but detectors are available from most IVD vendors**
- **Note: EPID-based patient dosimetry covered in a separate continuing education course**

Why do patient dosimetry

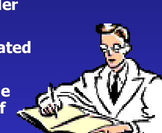
- **Confirm the accuracy of the entire dose planning and delivery system**
- **Identify significant errors early in the course of therapy so they can be corrected**
  - **Calculation**
  - **Communication**
  - **Setup**
  - **Delivery system**
- **Component of a good QA program (TG-40)**
- **Reimbursable**
- **Risk Management**

Errors Detectable by IVD

- **Wrong wedge**
- **Wrong setup (SSD, field size)**
- **Error in mu calculation**
- **Wrong energy / modality**
- **Wrong block / compensator / MLC shape**
- **Wrong daily dose**
- **Machine calibration drift**
- **Graticule tray left in during treatment**

Reimbursement

- **CPT code 77331 "Special Dosimetry"**
- **Measurement of radiation dose at a given point using devices such as TLD, solid state diode probes, special dosimetry probes, other dosimetry probes, or film dosimetry.**
- **Documentation requires a physician order for the procedure.**
- **Report must be reviewed, signed and dated by the prescribing physician.**
- **The usual frequency will be between one and six charges in total for the course of therapy.**



Radiation Oncology Coding User's Guide ASTRO/ACR 2002

When do patient dosimetry

- **At the frequency ordered by the prescribing physician**
  - **Once per field**
  - **Once per week**
  - **After some part of a single fraction**
    - **single fraction treatments, e.g. heterotopic bone**
    - **high dose fractions, e.g. TBI**

Where do patient dosimetry

- Entrance side
- Exit side
- Midplane
- Central axis
- Off-axis centered in open field
- Under shields or blocks
- Intracavitary

How do patient dosimetry

- **Ion chamber**
- **TLD**
- **Diodes**
- **MOSFETS**

Acceptance testing
Commissioning
Ongoing QA
Use and analysis

Design Characteristics of an Ideal IVD System

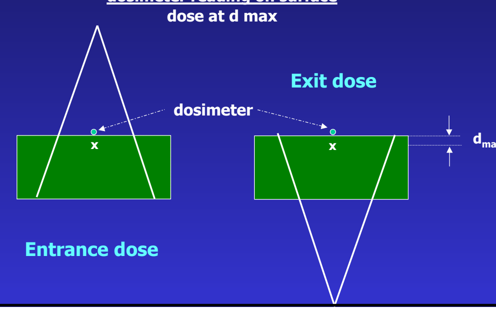
- **Accurate**
- **Tractable dependencies**
- **Safe**
- **Independent**
- **Rugged and reliable**
- **Real-time**
- **Comprehensive (x and e$^-$)**
- **Efficient to use**
- **Efficient to calibrate**
- **Efficient to QA**
- **Affordable**

Common usage

- **Dosimeter placed on the patient's skin**
- **Dose at a point of interest (typically dmax) is inferred from the measurement**

Dosimeter Calibration

$$\frac{\text{dosimeter reading on surface}}{\text{dose at d max}}$$

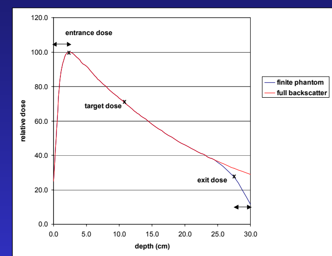


Entrance / Exit Dose

$$Dm = M \times Cal \times CF_1 \times CF_2 \times \ldots\ldots CF_n$$

Where
- M = detector reading
- Cal = cGy/rdg under reference conditions
- CF_i = correction factors for detector under clinical conditions

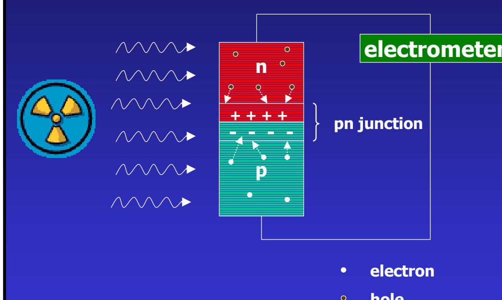
Typical Depth Dose Curve



MEM's Technology Ratings

Design Trait	TLD	Ion Chmbr	Diode	MOSFET
Accurate	+	+	+	+
Safe	+	-	+	+
Independent	+	+	+	+
Rugged and reliable	+	-	+	+
Real-time	-	+	+	+
Comprehensive	+	-	+	+
Efficient to use	-	+	+	+
Efficient to calibrate	-	+	+	+
Efficient to QA	-	+	+	+
Affordable	+	+	+	+

Silicon Diode as a Radiation Detector



Inovision / Nuclear Associates

Diode Name	Type	Beam Quality
VeriDose 30-471	n	1 – 4 MV photons
VeriDose 30-472	n	5 – 11 MV photons
VeriDose 30-473	n	12 – 17 MV photons
VeriDose 30-474	n	18 – 25 MV photons
VeriDose 30-475	n	6 – 25 MeV electrons

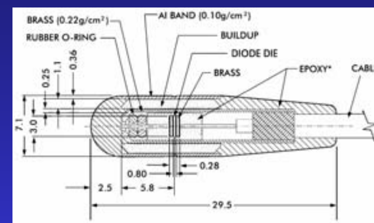
PTW Freiburg

Diode Name	Type	Beam Quality
VIVIDOS L991061	p	Co60 – 4 MV photons
VIVIDOS L991062	p	6 – 12 MV photons
VIVIDOS L991063	p	15 – 25 MV photons
VIVIDOS L991065	p	electrons

Sun Nuclear

Diode Name	Type	Beam Quality
ISORAD-3 1162000-0	P	1 – 4 MV photons
ISORAD-3 1163000-0	P	6 – 12 MV photons
ISORAD-3 1164000-0	P	15 – 25 MV photons

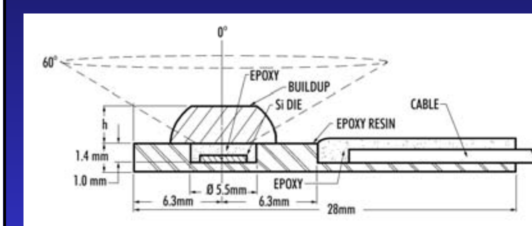
Isorad sketch



Sun Nuclear

Diode Name	Type	Beam Quality
QED 111200	p	electrons
QED 111300	p	70 kV and up surface dose with low perturbation
QED 111400	p	1 – 4 MV photons
QED 111500	p	6 – 12 MV Photons
QED 111600	p	15 – 25 MV photons

QED Sketch



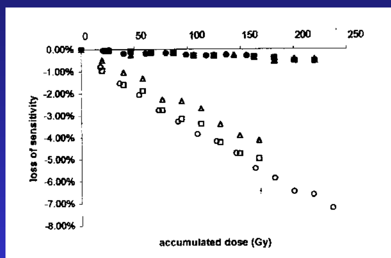
Scanditronix-Wellhofer

Diode Name	Type	Beam Quality
EDD-2	p	Electrons Photon surface dose Photon exit dose
EDD-5	p	Electrons TBI Dose outside the field
EDP-5	p	Electrons
EDP-10	p	4 – 8 MV photons
EDP-15	p	6 – 12 MV photons
EDP-20	p	10 – 20 MV photons
EDP-HL	p	16 – 25 MV photons

Diode Dependencies

- •Radiation history
- •Dose rate
- •Temperature
- •Energy
- •Diode shape

Diode Sensitivity vs Radiation History



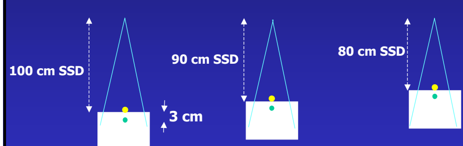
Jornet, Ribas, Eudaldo Med Phys 27 (6) 2000

SSD Dependence

- **Dose rate (cGy/per pulse)**
- **Energy (head scatter, contamination electrons)**
- **Inverse square**

SSD Dependence

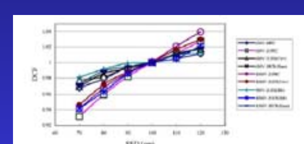
- Some or most of the correction is simply attributable to the inverse square law



$\left(\frac{100}{103}\right)^2 = 0.943$ $\left(\frac{90}{93}\right)^2 = 0.936$ $\left(\frac{80}{83}\right)^2 = 0.929$

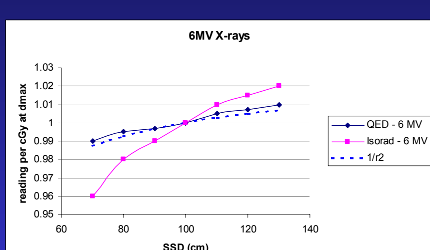
SSD Correction Factor

- Place detector on surface of solid water-equivalent phantom; measure reading per mu at different SSD's covering the clinical range
- Place ion chamber at dmax in water-equivalent phantom; measure cGy/mu at different SSD's covering the clinical range
- Determine detector reading per cGy at different SSD's, normalized to detector calibration condition.

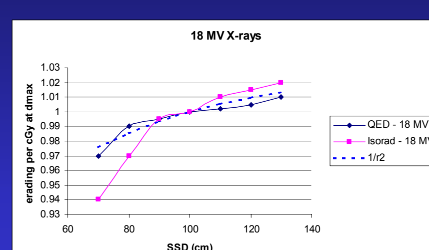


Huang, Bice, Hidalgo-Salvatierra, JACMP(4) 2 2003

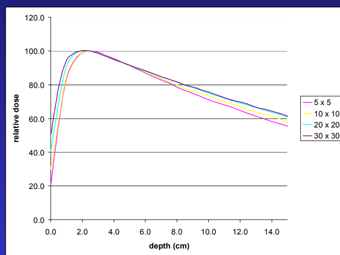
SSD Correction Factor



SSD Correction Factor

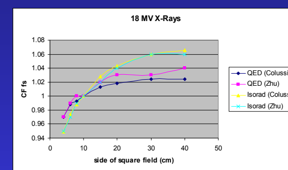


Field Size Correction Factor

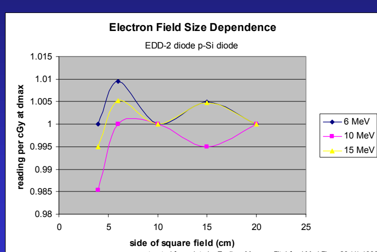


Field Size Correction Factor

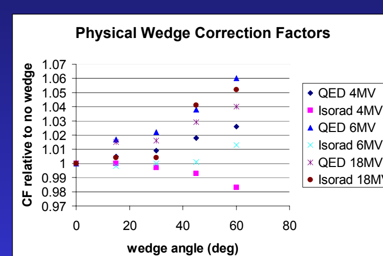
- Measure detector reading on the surface of a phantom per cGy at dmax for range of field sizes.
- Normalize to detector calibration condition.



Field Size Correction Factor

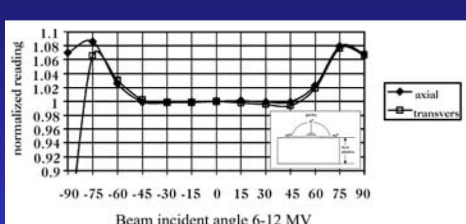


Physical Wedge Correction Factor

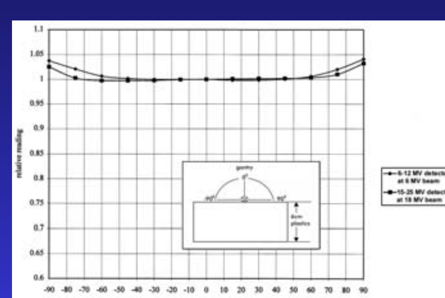


Colussi, Beddar, Kinsella, Sibata JCAMP 2 (4) 2001

Angular Correction Factor

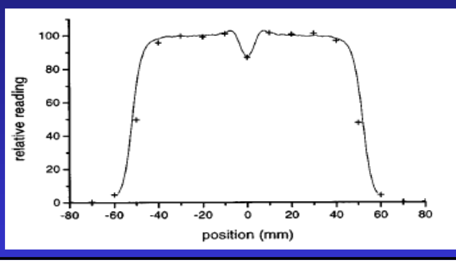


Angular Correction Factor



Dose Perturbation

Diodes (or any detector) with "buildup caps" create a lower dose region (shadow) distal to the detector



Dose Shadowing

- **The magnitude of the shadow depends on the size of the buildup cap**
- **If the diode is used during only one fraction (for multi-fraction treatments), the shadowing effect is negligible**
- **If the diode is used during every fraction, deliberate or random variation in diode positioning will reduce the overall shadowing effect**

Dose Perturbation Photons

- **Determined by thickness and material of buildup cap**
- **Varies with energy, field size, and depth**
- **If bu = buildup cap water-equiv thickness, then worst case estimate:**

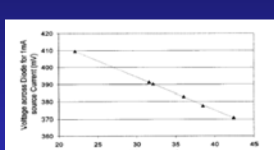
$$\text{Dose}_{\text{Pert}} = \frac{\text{TMR (d)}}{\text{TMR (d+bu)}}$$

Dose Perturbation X-Rays

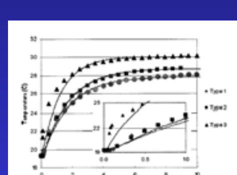
Energy (MV)	B.U. (cm)	Dose Pert @ 5 cm	Use one time per 30 fx	Use six times per 30 fx
6	1.5	5%	0.2%	1%
10	2.5	7.4%	0.2%	1.4%
15	3	6.9%	0.2%	1.3%

Note: dose perturbation effect can be very significantly larger for electrons.

Temperature Dependence



Depends on how long the detector is on the patient's skin, thermal coupling, etc.



+/- 3% per deg C

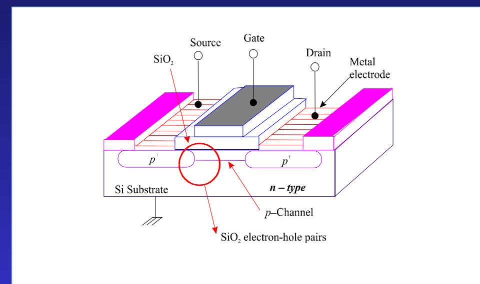
Welsh and Reinstein, Med Phys 28 (5) 2001

TEMPERATURE DEPENDENCE

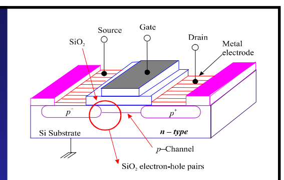
- **Various approaches to deal with diode temperature dependence**
  1. **calibrate diodes at elevated temperature**
  2. **some manufacturers (e.g. Sun Nuclear) eliminate the concern by measuring the junction temperature when reading shuts off, and automatically correcting every reading**
  3. **ignore it**

MOSFETs

THE PRINCIPLES OF MOSFET DOSIMETERS

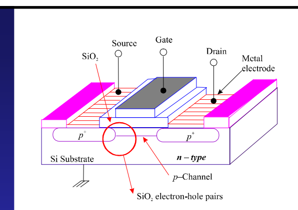


MOSFET



- A current can only pass through the MOSFET from source to drain if a negative voltage exists at the gate electrode
- In this condition, the MOSFET is "on".
- The voltage required to switch the MOSFET 'on" is called the threshold voltage, Vt.
- The MOSFET acts as a gate controlled switch, and this is how it is normally used in computer logic chips.

MOSFET

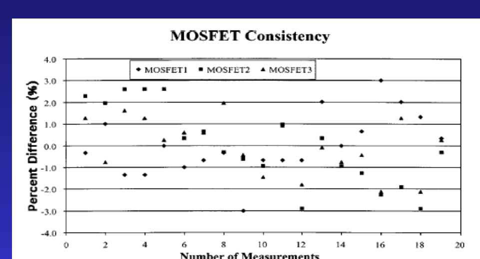


- **If ionizing radiation passes through the SiO2 layer, electron hole pairs are formed. Holes (+ charged) are trapped at the Si/SiO2 interface.**
- **Trapped charge acts to screen the Gate potential, and a higher value of Vt is required to switch the MOSFET "on".**

Practical Use of MOSFETS

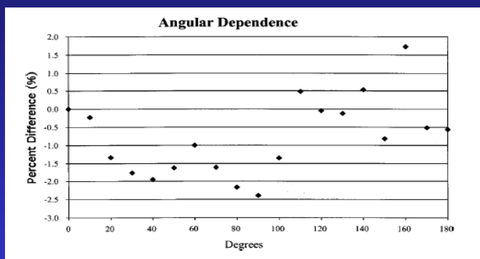
1. **V_t is measured before irradiation (by the reader).**
2. **The MOSFET is irradiated with + bias at the gate (using bias supply to drive holes into the traps and increase sensitivity).**
3. **V_t is re-measured after irradiation, and the difference between pre- and post- Vt values is proportional to the absorbed dose.**
4. **V_t changes with dose are ~ 1 – 3 mV/cGy**

MOSFET Reproducibility



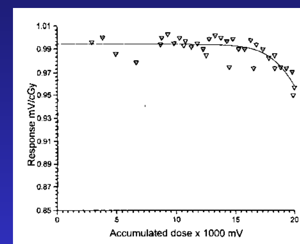
Chuang, Verhey, Xia MedPhys 29 (6) 2002

MOSFET ANGULAR DEPENDENCE



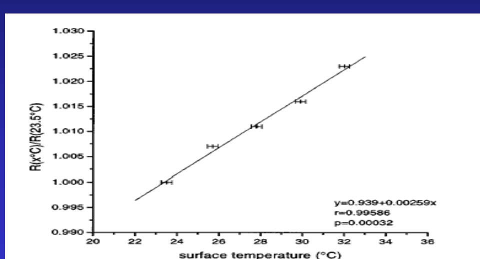
Chuang, Verhey, Xia MedPhys 29 (6) 2002

MOSFET Radiation History Dependence



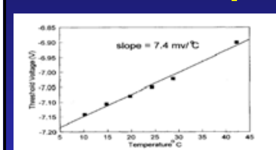
Ramani, IJROBP 37(4) 1997

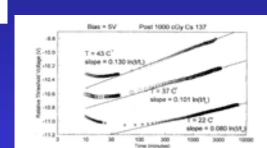
Temperature Dependence



Eveling, Morgan, Pitchford, Med Phys 26 (1) 1999

MOSFET Temperature Dependence



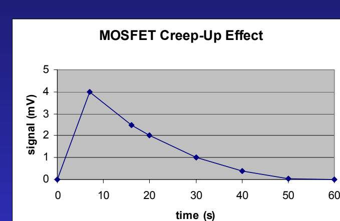


Gladstone et al. Med Phys 21 (11) 1994

Creep-Up Effect

- Threshold voltage for the MOSFET increases with consecutive readings
- Depends on the time interval between successive read cycles
- Occurs for accumulated doses > 20 Gy
- Due to charge being injected by the measuring circuit not the MOSFET
- Decays in a few minutes if left unaltered
- Can result in an 8% error at 50 cGy, 4% at 100 cGy and 2% at 200 cGy if don't allow time for decay

Creep-Up Phenomenon



Ramani, IJROBP 37 (4) 1997

MOSFETS and Buildup

MOSFETs are supplied without any buildup

- well-suited for intracavitary work
- can be used to measure surface dose
- complex relationship between dose at the surface and dose at any other point
- surface dose affected by electron and photon contamination from the primary and secondary collimators, flattener, accessories
- strong dependencies on field size, distance, location in the field, ancillary devices, etc., need to be carefully characterized
- alternatively, fabricate buildup caps

New Products

microMOSFET

- In-vivo IMRT
- Brachytherapy

Customized Dental Applicator for IMRT In-vivo Dosimetry

Practical Implementation of MOSFET Dosimetry

MOSFET inserted into mouth via catheter

Courtesy of Dr. Ramaseshan, PMH, Toronto, Canada

TBI

IORT

Commissioning a Patient Dosimetry System

- Electrical safety
- Post irradiation signal drift
- System calibration under reference conditions for each energy and modality
- Short term reproducibility
- Long term reproducibility

Commissioning a Patient Dosimetry System (cont'd)

- Measure correction factors relative to calibration conditions
  - Vary distance over range used clinically
  - Vary field size over range used clinically
  - Vary accessories (hard wedges, dynamic wedges)
  - Vary temperature over range encountered clinically
  - Vary time between readings (creep effect)
  - Vary dose rate over range used clinically
  - Vary treatment technique (IMRT, TBI, …)
- Decide which corrections are needed for your system and your clinic

Ongoing Quality Assurance

- Check calibration (under reference conditions) monthly and after any repair that could affect the dosimetry
- Check correction factors multiple times in first 6 months; if stable reduce to semi-annual or annual frequency
- Check correction factors whenever you install a new detector (of same type)
- Re-do full commissioning measurements if you change to different detector design

Train the Therapists

- Dosimeter positioning is critical to a successful and efficient program
- Plan how you will communicate between Dosimetrists and Therapists
- Invest the time to demonstrate how to position and orient the dosimeter, especially in the presence of a wedge

Ease of Use

Ease of Use

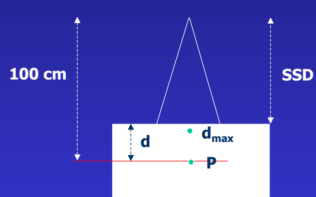
Ease of Use

Calculate the Expected Dose with Care

1. Choose your point of calculation and measurement appropriately, e.g. away from high gradient regions
2. If doing hand calculations, take the time to apply the appropriate factors, e.g. variation in OAR with depth
3. If relying on 3-D computer calculations, make sure the dose grid is fine enough
4. Some commercial software systems used for independent mu calculations also will provide a quick and accurate calculation of dmax dose above any point

Expected Dose at D_{max}

$$D(d_{max}) = D_p \frac{1}{TMR(d)} \left(\frac{100}{SSD + d_{max}} \right)^2$$



Typical Implementation

- Before first treatment, calculate the expected dose at the point of measurement
- At time of first treatment (or shortly thereafter) determine the measured dose
- At the time of first treatment (or shortly thereafter) calculate the ratio of measured dose to expected dose

$$\frac{\text{Measured dose}}{\text{Expected dose}}$$

Typical Implementation

- At the time of first treatment (or shortly thereafter), determine whether the ratio falls within the established tolerance range.

  Pass **Fail**

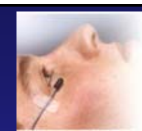
- If tolerance is exceeded, have the Technologist repeat the measurement at the next treatment fraction with someone from Physics present.
- If tolerance is still exceeded, physics investigation is launched immediately.

Tolerance Levels

- Entrance Dose
  - 5% is readily achievable using any available technology and a modicum of care
- Exit Dose
  - Looser tolerance may be needed if measuring at a point distal to significant heterogeneities, e.g. thorax-mediastinum

Remember:
reduction of the repeat rate benefits the patients, the Therapists, the Physicists, and the facility!

Conclusion



- With today's technology, patient dosimetry can be carried out very accurately and efficiently, with a very modest investment of physics time.
- The resource expense is definitely outweighed by the value of IVD to the patient and to the practitioners.

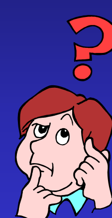
Thanks for your attention!

Don't forget to keep your eyes open for the Report of TG 62

"Diode In Vivo Dosimetry for Patients Receiving External beam radiation Therapy"

Ellen Yorke, MSKCC, Chairman

Questions



Patient Dosimetry References

Mary Ellen Masterson-McGary

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A. Saini, T. C. Zhu, “Dosimetric characteristics of p-type QED diode detectors used for in vivo dosimetry,” Med. Phys., Vol. 25, No. 7, p. A177 (1998).

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