2020 JULY 12–16 VIRTUAL EASTERN TIME [GMT-4]
JOINT AAPM | COMP MEETING
Improving Health QUALITY. Increasing Global IMPACT.

Dose Assessment Considerations

SAM THERAPY EDUCATIONAL COURSE:
Task Group 203; Implanted Cardiac Devices

Dimitris Mihailidis, PhD.,FAAPM, FACMP
University of Pennsylvania
Perelman Center for Advanced Medicine

Penn Medicine

RADIATION ONCOLOGY
PENN MEDICINE

Contents of the presentation

- Introduction
- CIED sensitivities on radiation dose and radiation modality (Literature coverage)
- Dose assessment
  - Where and how to estimate dose to the CIED
  - Out-of-field doses and CIEDs
  - Calculation and measurement of dose on the CIED
    - Issues to be aware of
    - Proposed methods and limitations
- Short presentation of data from clinical examples
- List of recommendations
- Conclusions

Management of radiotherapy patients with implanted cardiac pacemakers and defibrillators: A Report of the AAPM TG-203†

Moyed Miften[a),‡]
Task Group 203, Department of Radiation Oncology, University of Colorado School of Medicine, Aurora, CO 80045, USA

Dimitris Mihailidis[a),‡]
Task Group 203, University of Pennsylvania Perelman Center for Advanced Medicine, Philadelphia, PA 19104, USA

Stephen F. Kry
Department of Radiation Physics, UT MD Anderson Cancer Center, Houston, TX 77030, USA

Chester Reft
Department of Radiation Oncology, University of Chicago, Chicago, IL 60637, USA

Carlos Esquivel
Department of Radiation Oncology, UT Health Sciences Center, San Antonio, TX 78229, USA

Jonathan Farr
Division of Radiological Sciences, St. Jude Children's Research Hospital, Memphis, TN 38105, USA

David Followill
Department of Radiation Physics, UT MD Anderson Cancer Center, Houston, TX 77030, USA

Coen Hurkmans
Department of Radiotherapy, Catharina Hospital, Eindhoven, the Netherlands

Arthur Liu
Department of Radiation Oncology, University of Colorado School of Medicine, Aurora, CO 80045, USA

Olivier Gayou
Department of Radiation Oncology, Allegheny General Hospital, Pittsburg, PA 15212, USA

Michael Gossman
Department of Radiation Oncology, Tri-State Regional Cancer Center, Ashland, KY 41101, USA

Mahadevappa Mahesh
Department of Radiology, Johns Hopkins University School of Medicine, Baltimore, MD 21287, USA

Richard Popple
Department of Radiation Oncology, University of Alabama, Birmingham, AL 35249, USA

Joann Prisciandaro
Department of Radiation Oncology, University of Michigan, Ann Arbor, MI 48109, USA

Jeffrey Wilkinson
Consultant, Medtronic Inc., Mounds View, MN55112, USA

(Received 4 April 2019; revised 16 July 2019; accepted for publication 28 August 2019; published 1 November 2019)

Managing radiotherapy patients with implanted cardiac devices (implantable cardiac pacemakers and implantable cardioverter-defibrillators) has been a great practical and procedural challenge in radiation oncology practice. Since the publication of the AAPM TG-34 in 1994, large bodies of literature and case reports have been published about different kinds of radiation effects on modern technology implantable cardiac devices and patient management before, during, and after radiotherapy. This task group report provides the framework that analyzes the potential failure modes of these devices and lays out the methodology for patient management in a comprehensive and concise way, in every step of the entire radiotherapy process. © *2019 American Association of Physicists in Medicine* [https://doi.org/10.1002/mp.13838]

Key words: cardiac implantable electronic devices (CIED), device malfunction, implantable cardiac pacemakers (ICP), implantable cardioverter-defibrillators (ICD), patient management, radiation damage

†The report was endorsed by the European Society for Radiotherapy and Oncology (ESTRO)-Advisory Committee on Radiation Oncology Practice (ACROP).

Intention:

1) Provide an up-to-dated comprehensive guidance,
2) Provide initial mechanism of communication between professionals in the RT and cardiac rhythm management.
3) Approach the issue through patient management instead of device management.
4) Provide guidance for development of institutional policies based on available resourses.

December 2019

INSTITUTE OF PHYSICS PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. 47 (2002) 2879–2893 PII: S0031-9155(02)32606-X

Dose rate study-2002

Influence of high-energy photon beam irradiation on pacemaker operation

J Mouton[1], R Haug[2], A Bridier[3], B Dodinot[4] and F Eschwege[5]

[1] Commissariat à l'Energie Atomique, BP 12 F 91680 Bruyères-le-Châtel, France
[2] DEE, UMR 8578 CNRS–Univ. Paris-sud–SUPELEC, Plateau du Moulon F 91190 Gif-sur-Yvette, France
[3] Service de Physique, Institut Gustave ROUSSY, rue Camille Desmoulins F 94805, Villejuif, France
[4] Centre de Stimulation Cardiaque, CHU de Brabois, F 54500, Vandœuvre-lès-Nancy, France
[5] Département de Radiothérapie, Institut Gustave ROUSSY, rue Camille Desmoulins, F 94805, Villejuif, France

Received 11 January 2002, in final form 10 April 2002
Published 24 July 2002
Online at stacks.iop.org/PMB/47/2879

In conclusion, warnings given by manufacturers about the maximum tolerable cumulative radiation doses for safe operation of irradiated pacemakers (5 Gy), even reduced to 2 Gy, are not reliable. The spread of cumulative doses inducing failures is very large since our observations show an important failure at 0.15 Gy, while ten pacemakers withstood more than 140 Gy of cumulative dose. The safe operation of pacemakers under irradiation depends mainly on type and model. It depends also on dose rate. From our observations, for the safe operation of pacemakers, a recommendation of a maximum dose rate of 0.2 Gy min^{-1} rejecting direct irradiation of the pacemaker at a standard dose rate for tumour treatment (2 Gy min^{-1}) is made.

Main points:

- 6% of directly irradiated devices failed at <5Gy.
- 32% failed at <50Gy.
- 8% failed at 1-2 Gy.
- Impossible to isolate EMI to other radiation effects.
- Cumulative dose risk is not stochastic, variability in sensitivity is device dependent.
- Cumulative dose threshold settings are challenging.

Cumulative dose-Risk

- Hurkmans 2005, Hurkmans 2005, Uiterwaal 2006, Mollerus 2014
  - Just 6 MV beams.
- Gomez 2013 and Grant 2015
  - Mixed cumulative dose and high photon energies

	Failed by 5 Gy	Failed by 50 Gy
ICPs	0/19 (0%)	2/19 (11%)
ICDs	3/30 (10%)	10/19 (53%)
Total	3/49 (**6%**)	12/38 (**32%**)

High doses often lead to device failure – relatively severe risk

Malfunction risk associated with clinical procedures

- Imaging for treatment planning (CT mostly).
- Imaging for Image Guidance (CT, Rad., EMI)
- RT treatment delivery (photons, protons, neutrons, particles, other)
- Use of high energy photons, E>10 MV?
- Dose rate
- IMRT, SBRT, VMAT, FFF beams
- HDR, breast, MammoSite®
- Other…

Out-of-Field Photon Beams

Out of Field-Peripheral Doses

Head Scatter (HS)

+

Head Leakage (HL)

+

Internal (patient) Scatter (IS)

>30cm:HL Dominates

≈30cm: HS<HL=IS

10-20 cm: IS Dominates, HS>HL

Out-of-Field Doses: Options

- **Estimation**
  - Lookup tables/graphs
- **Calculations**
- **Measurements**
  - In-Vivo Dosimeter
  - Phantom measurements

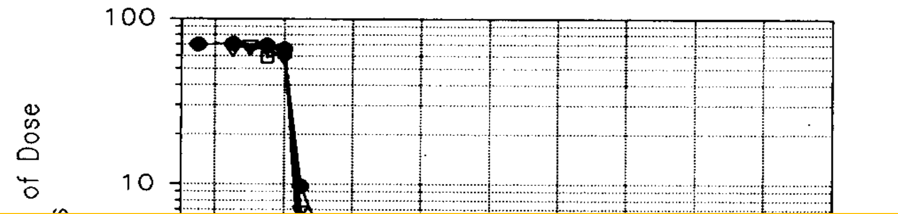
Dose Estimation: *Photon out-of-field dose*

Fetal dose from radiotherapy with photon beam
Radiation Therapy Committee Task Group No. 3

- Dose decreases ~ exponentially away from edge of field
- ↑ with field size
- Const. with energy
- Const. with depth

(Received 2 June 1994; accepted for publication 20 October 1994)

Approximately 4000 women per year in the United States require ra
This report presents data and techniques that allow the medical phys
dose the fetus will receive and to reduce this dose with appropriate sl
presented for a variety of photon beams, including cobalt-60 gamma
MV. Designs for simple and inexpensive to more complex and exper
ment are described. Clinical examples show that proper shielding ca
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-



Wedges

Physical wedges → increase out of field dose by 2-4 times (Sherazi et al, 1985, Int J Radiat Oncol Biol Phys)

Dynamic or universal wedges → no increase (Li et al, 1997, Int J Radiat Oncol Biol Phys)

MLC

Secondary MLC → no impact on out-of-field dose (Mutic et al, 2002, J Appl Clin Med Phys)

Tertiary MLC is extra shielding → decrease out of field dose by 30-50% (Stern, 1999, Med Phys)

ONCOLOGY
PENN MEDICINE

Doses out-of-field: TG158 (2017)

AAPM TG 158: Measurement and calculation of doses outside the treated volume from external-beam radiation therapy

Stephen F. Kry[a)]
Department of Radiation Physics, MD Anderson Cancer Center, Houston, TX 77054, USA

Bryan Bednarz
Department of Medical Physics, University of Wisconsin, Madison, WI 53705, USA

Rebecca M. Howell
Department of Radiation Physics, MD Anderson Cancer Center, Houston, TX 77054, USA

Larry Dauer
Departments of Medical Physics/Radiology, Memorial Sloan-Kettering Cancer Center, New York, NY 10065, USA

David Followill
Department of Radiation Physics, MD Anderson Cancer Center, Houston, TX 77054, USA

Eric Klein
Department of Radiation Oncology, Washington University, Saint Louis, MO 63110, USA

Harald Paganetti
Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, MA 02114, USA

Brian Wang
Department of Radiation Oncology, University of Louisville, Louisville, KY 40202, USA

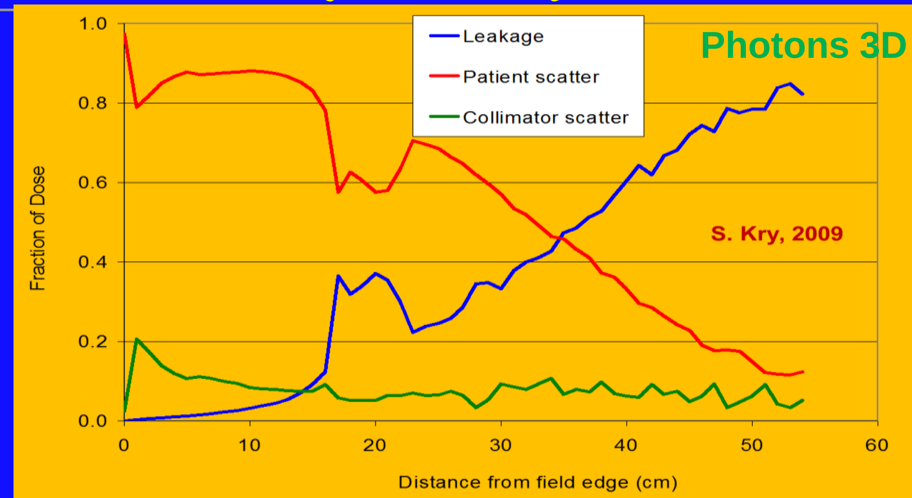
Cheng-Shie Wuu
Department of Radiation Oncology, Columbia University, New York, NY 10032, USA

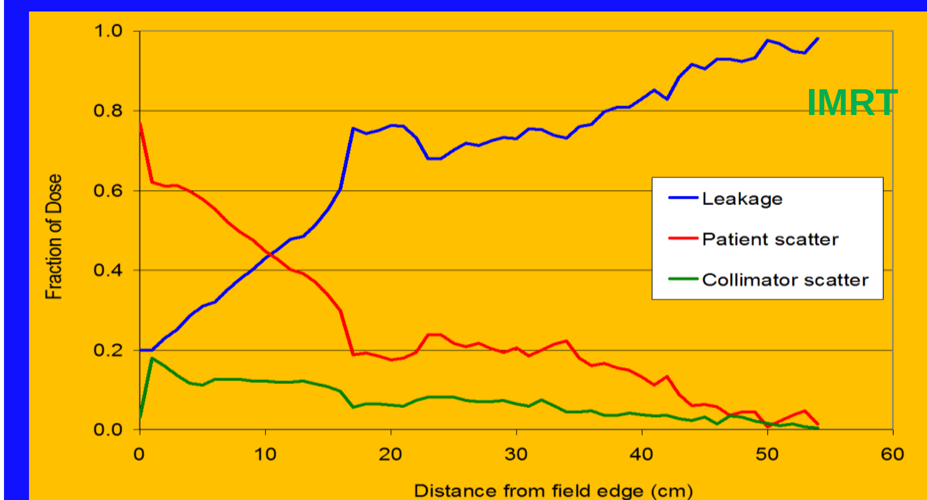
X. George Xu
Department of Mechanical, Aerospace, and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

(Received 28 September 2016; revised 17 May 2017; accepted for publication 25 May 2017; published 20 August 2017)

The introduction of advanced techniques and technology in radiotherapy has greatly improved our ability to deliver highly conformal tumor doses while minimizing the dose to adjacent organs at risk. Despite these tremendous improvements, there remains a general concern about doses to normal tissues that are not the target of the radiation treatment; any "nontarget" radiation should be minimized as it offers no therapeutic benefit. As patients live longer after treatment, there is increased opportunity for late effects including second cancers and cardiac toxicity to manifest. Complicating the management of these issues, there are unique challenges with measuring, calculating, reducing, and reporting nontarget doses that many medical physicists may have limited experience with. Treatment planning systems become dramatically inaccurate outside the treatment field, necessitating a measurement or some other means of assessing the dose. However, measurements are challenging because outside the treatment field, the radiation energy spectrum, dose rate, and general shape of the dose distribution (particularly the percent depth dose) are very different and often require special consideration. Neutron dosimetry is also particularly challenging, and common errors in methodology can easily manifest as errors of several orders of magnitude. Task Group 158 was, therefore, formed to provide guidance for physicists in terms of assessing and managing nontarget doses. In particular, the report: (a) highlights major concerns with nontarget radiation; (b) provides a rough estimate of doses associated with different treatment approaches in clinical practice; (c) discusses the uses of dosimeters for measuring photon, electron, and neutron doses; (d) discusses the use of calculation techniques for dosimetric evaluations; (e) highlights techniques that may be considered for reducing nontarget doses; (f) discusses dose reporting; and (g) makes recommendations for both clinical and research practice. *© 2017 American Association of Physicists in Medicine* [https://doi.org/10.1002/mp.12462]

Key words: late effects, neutrons, nontarget radiation, out-of-field dose





S. Kry, 2009

What about SBRT and filter-free beams?

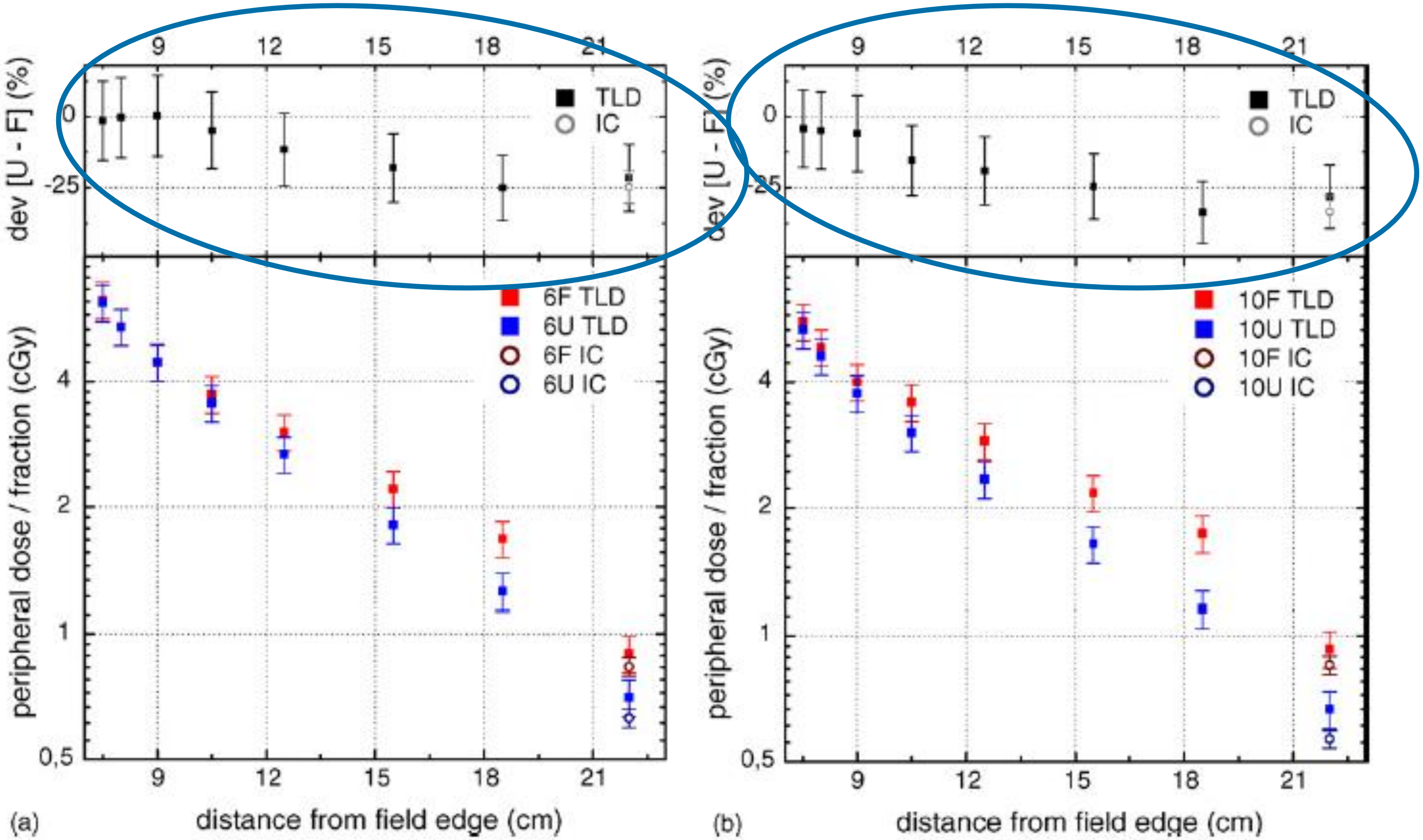


Figure 5. Results of peripheral dose measurements (in the isocentric plane) as a function of the distance from the field edge for the lung SBRT plans with a) 6 and b) 10 MV flattened and unflattened beams. The relative percentage reduction in peripheral dose (dev [U - F]) achieved by using FFF beams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

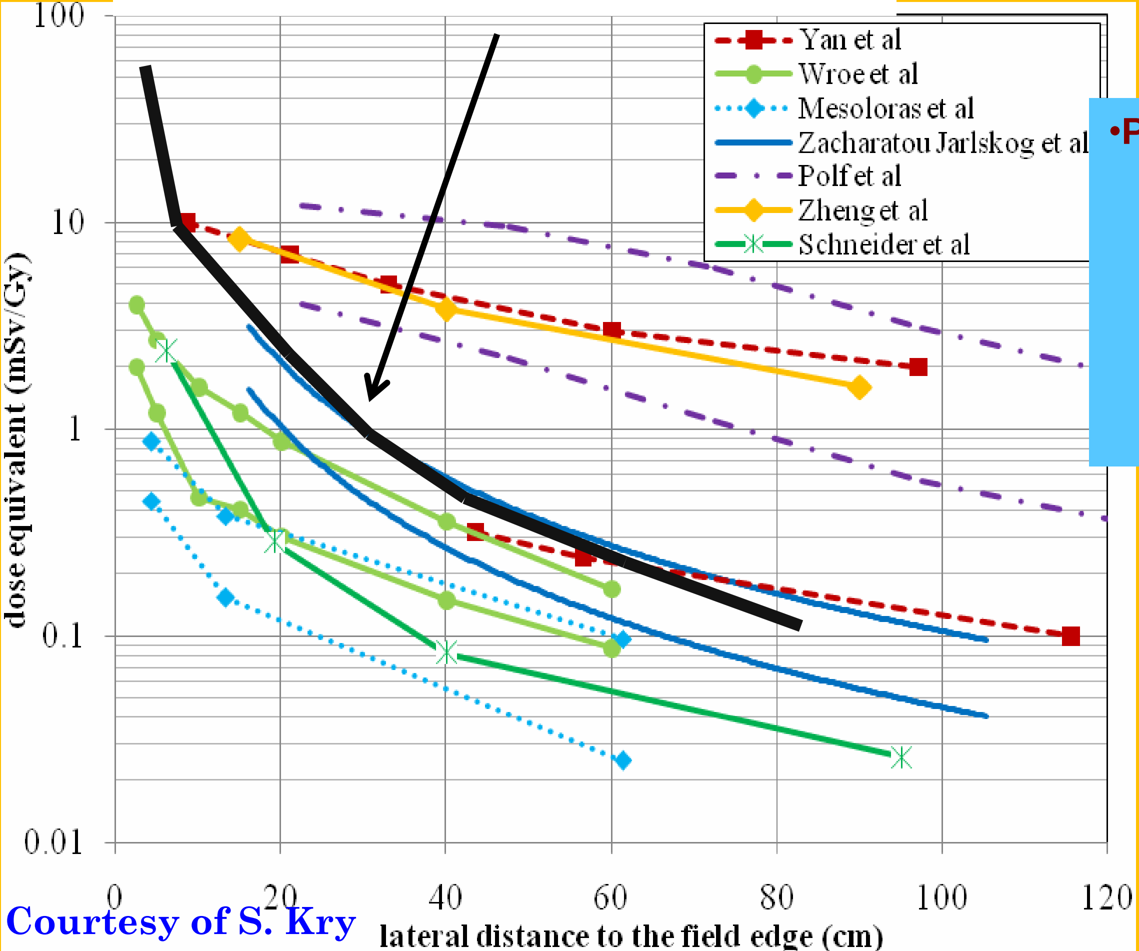
scattered dose outside the field.

Dose Estimation: Proton out-of-field dose

- *How much dose equivalent is there?*

TG-158

Conventional photon therapy



Courtesy of S. Kry

Variations in beam parameters

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

Challenges in Dosimetry
Lack of high energy response

Unique machines

Xu, 2008, Phys Med Biol

Dose Calculation: *Photon* out-of-field dose

ELSEVIER

Peridose, a so

Rec

Abstract

A software program, Peri
calculation is based on publi
wedges and shielding blocks
Elsevier Science Ireland Ltd

Keywords: Peripheral dose; Fet

The calculation steps are summarized in the following equations:

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

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

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

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

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

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

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

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.

Treatment planning-dose estimation

- Contour the cardiac device (if possible: leads, body, electrodes).
- Select appropriate treatment technique: modality, energy, beam angles, etc.
- Maximize distance of device from beam(s) borders-only scattered radiation to the device.
- Utilize independent collimators, dynamic wedging, MLCs, etc – to reduce dose to device.

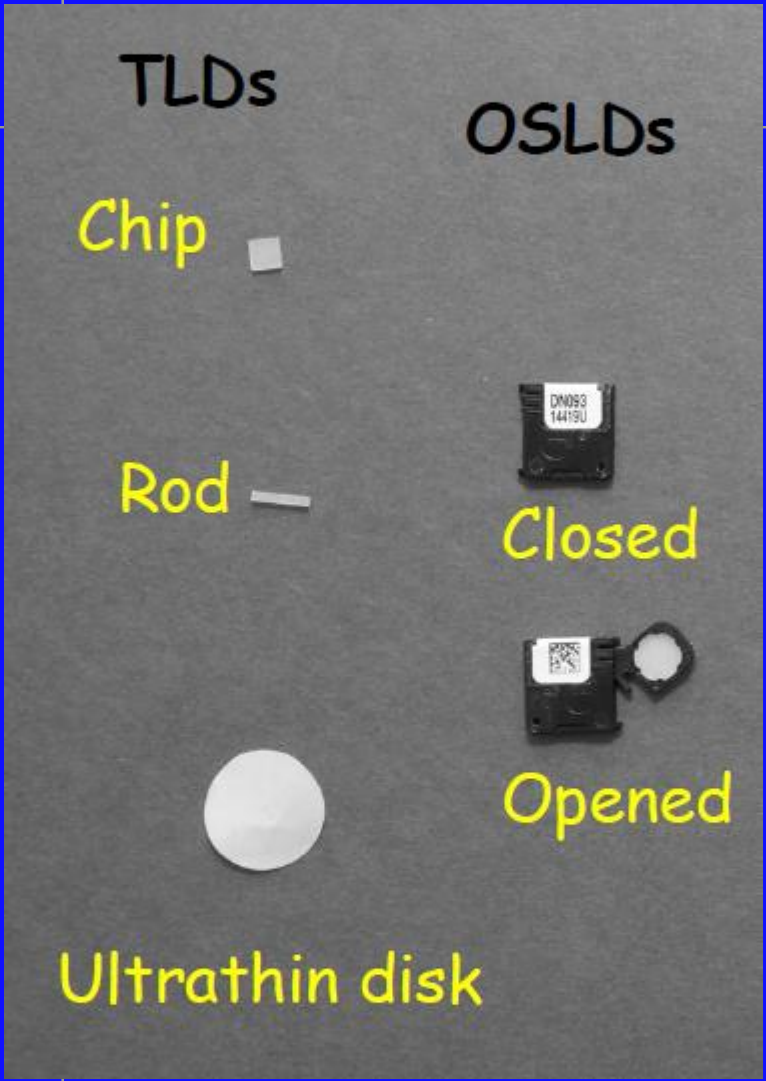
Device dose assessment/TPS-calculations

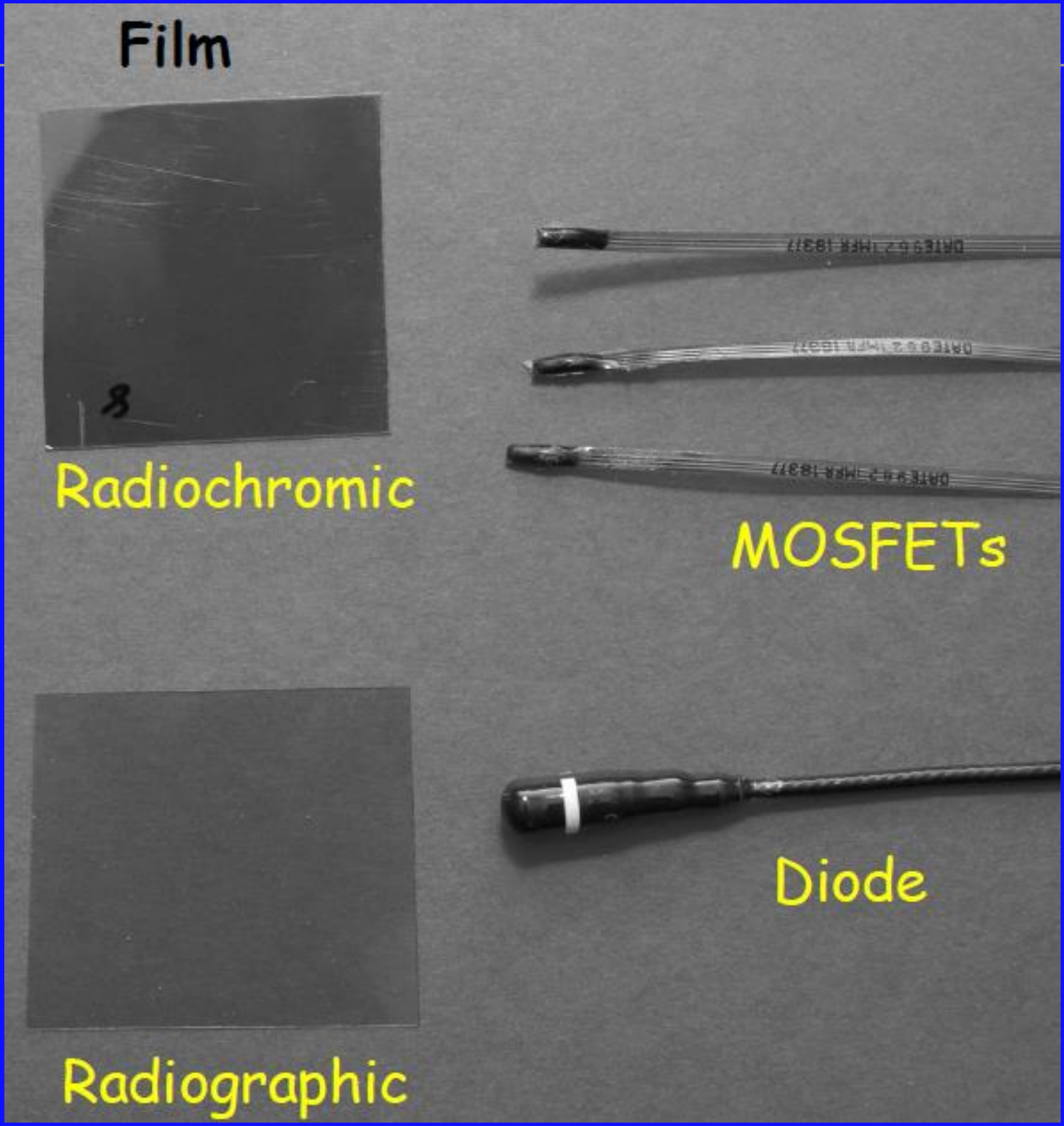
- **Use the TPS calculated dose**
  - Dose calculation won't be highly accurate because it will not capture the low-energy of the scattered radiation interacting with the high-Z of the CIED
  - Don't worry about this issue (e.g., by over-riding the HU of the device). Just calculate dose normally in the TPS to the CIED contour.
    - Can still over-ride e.g., missing tissue
- **The TPS is only suitable for assessing dose to the device within 3 cm of the treatment field (below the 5% isodose line)**
- **Further out, the dose estimates are wrong, typically underestimating dose by 50%, with increasing error as the distance increases.**
- **Don't use the TPS beyond 3 cm/5% isodose.**

Slide courtesy of S. Kry

Device dose assessment-Measurement

- **Energy**:
  - Out-of-Field energy spectrum of a 6MV averages 200-400 keV.
  - Overresponse of dosimeters
  - Need flat energy response or well-known correction factor.
  - Calibration at ~1cm depth, >5cm from field border in reference to a 10x10 at beam calibration conditions.
- **Depth**:
  - Avoid surface measurement-use 0.5-1 cm bolus in practice.
- **Detectors**:
  - Use appropriate detector for in-vivo
    - Refer to TG-203
    - New guidance TG-191

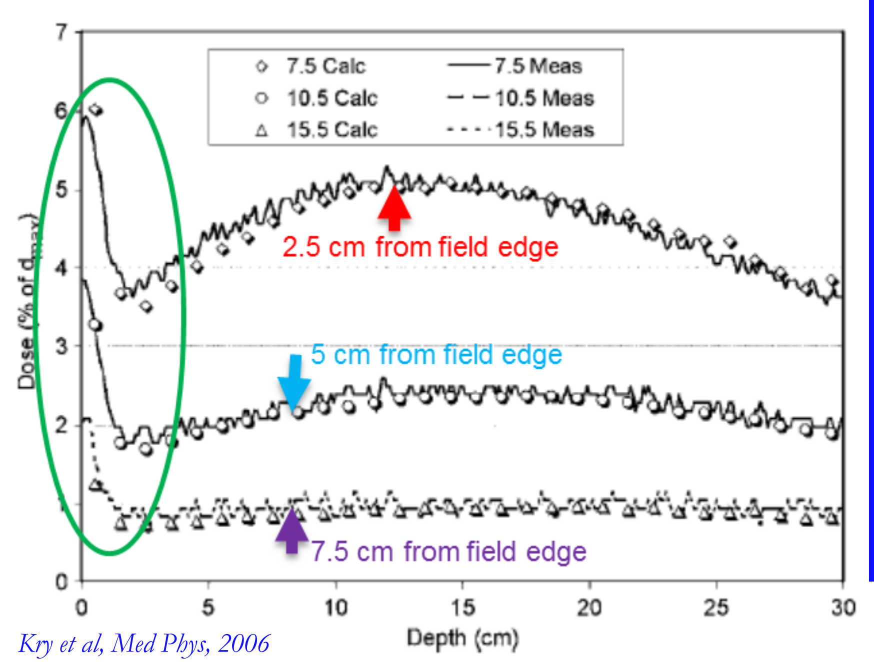

TLDs
OSLDs
Chip
Rod
Closed
Opened
Ultrathin disk


Film
Radiochromic
MOSFETs
Radiographic
Diode

Device dose assessment-in vivo

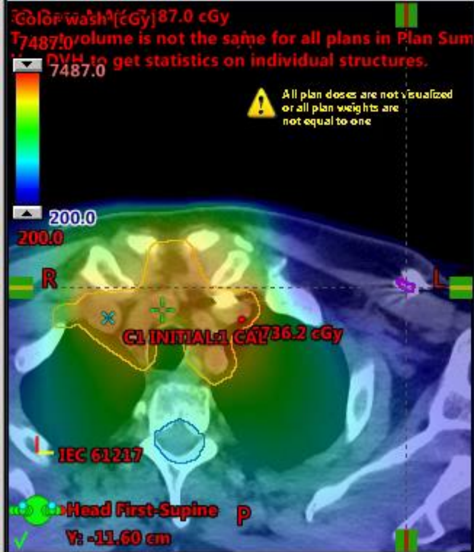
- 3-10 cm from field edge
- Measure the dose to the device
    - Select an appropriate dosimeter, consider necessary corrections
    - Put bolus over detector
- Most measurement errors/shortcuts will lead to overestimate of dose
    - Acceptable as long as patient is placed in appropriate risk category

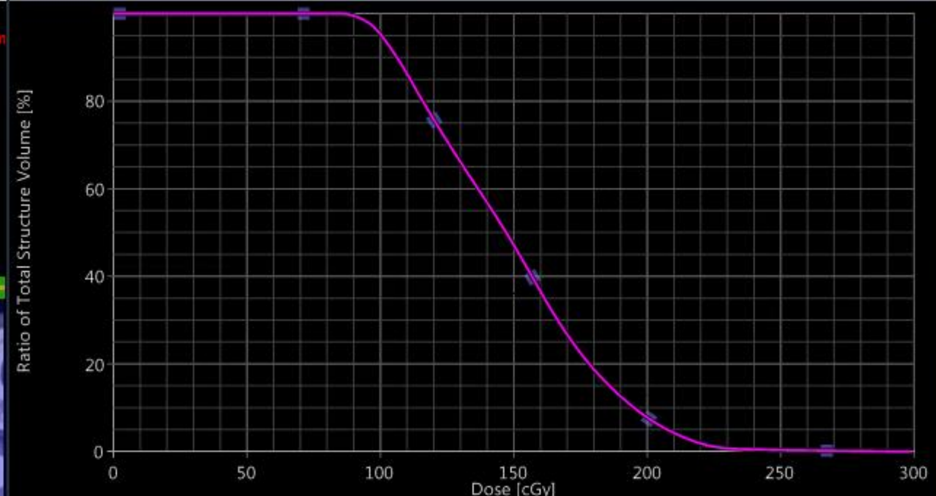
- There is elevated dose at the surface (by a factor of >2)
- CIEDs are typically located 1-3 cm below skin
- To get reasonable dose measurement, cover device in bolus (~1cm)



Kry et al, Med Phys, 2006

Slide courtesy of S. Kry

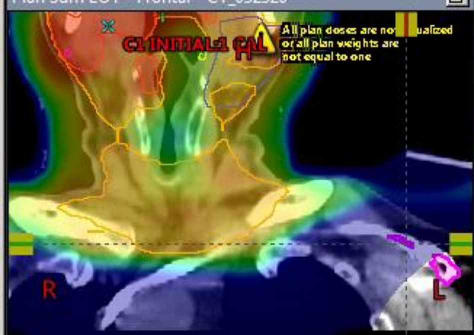


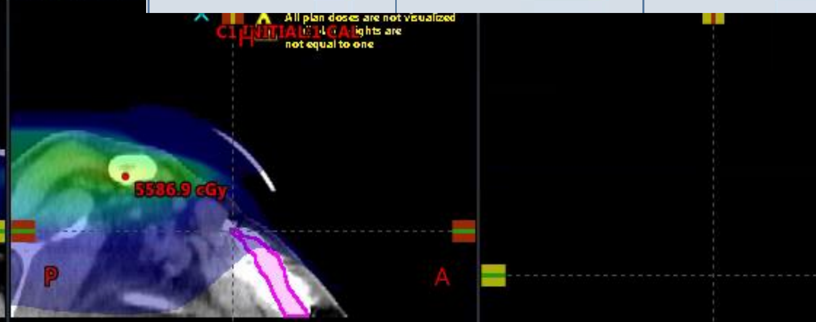


Min Dose [cGy]	Max Dose [cGy]	Mean Dose [cGy]
85.1	300.0	148.7

Plan Sum EOT - Frontal - CT_032320

Plan Sum EOT - S





Target:	PTV_7000	PTV_6300	PTV_5600	PTV_5950
Dose per Fraction (cGy):	200	180	160	170
Number of Fractions:	35	35	35	35
Fractions per day:	1 (one)	1 (one)	1 (one)	1 (one)
Number of Fields per Day	All fields	All fields	All fields	All fields
Total Dose (cGy):	7000	6300	5600	5950
Cumm. Dose (cGy):	7000	6300	5600	5950
Plan Type/Method:	IMRT/VMAT Ph	IMRT/VMAT Ph	IMRT/VMAT Ph	IMRT/VMAT Ph
Energy:	6 MV Drop Down	6 MV Drop Down	6 MV Drop Down	6 MV Drop Down

Structure	Limit	Vol [%]	[cGy]	Priority
(d)PACEMAKER+05	upper	0.0	150.0	200
(d)PACEMAKER+05	upper		150.0	150
(D)pacemaker+20	upper	0.0	500.0	200
(D)pacemaker+20	upper		500.0	150

Device Information: Biotronik, model# Setrox S 53

Plan	OSLD Reading (cGy)	Average Reading (cGy)	No. Fractions	Expected Total Dose at Device (cGy)	Eclipse Max Dose to Device (cGy)
INITIAL	4.06	4.18	28	146.44	266.14
	4.29				
INITIAL:1	4.49	4.20	7		
	3.91				

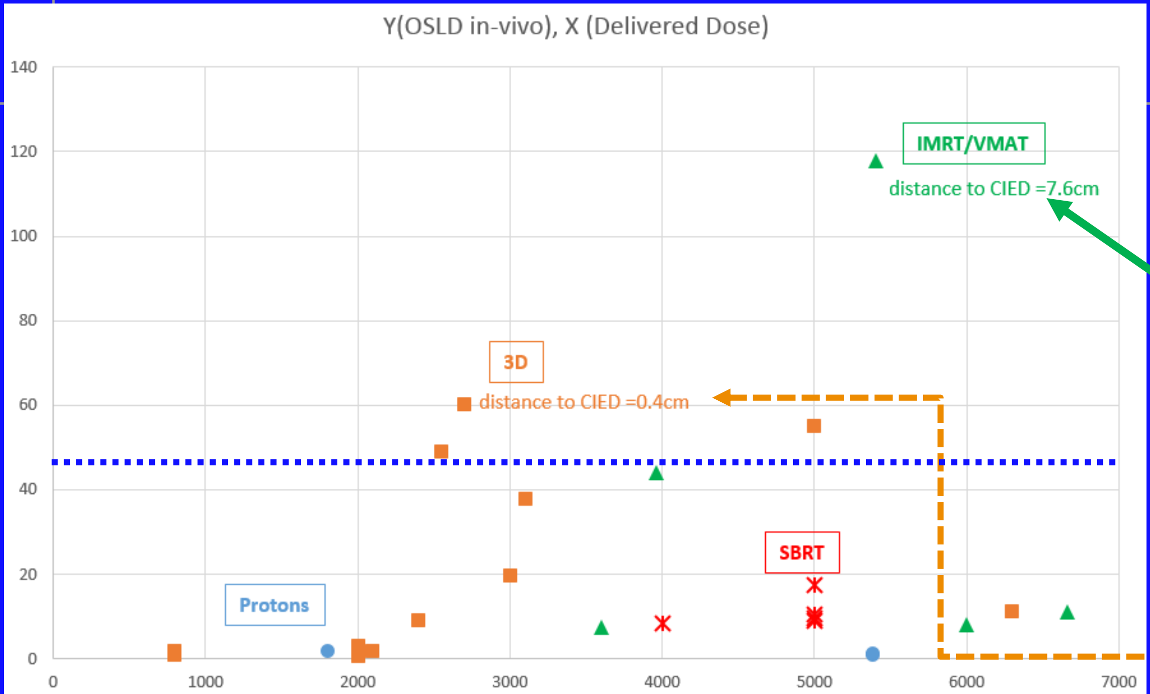
Comments: Two optically stimulated luminescent dosimeters (OSLDs) were placed over the patient's device and under 1.5 cm bolus. Imaging dose was included in the measurement.

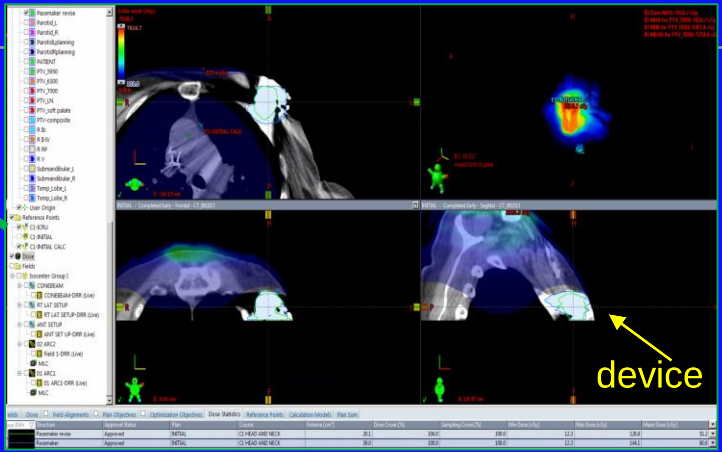
Penn Medicine

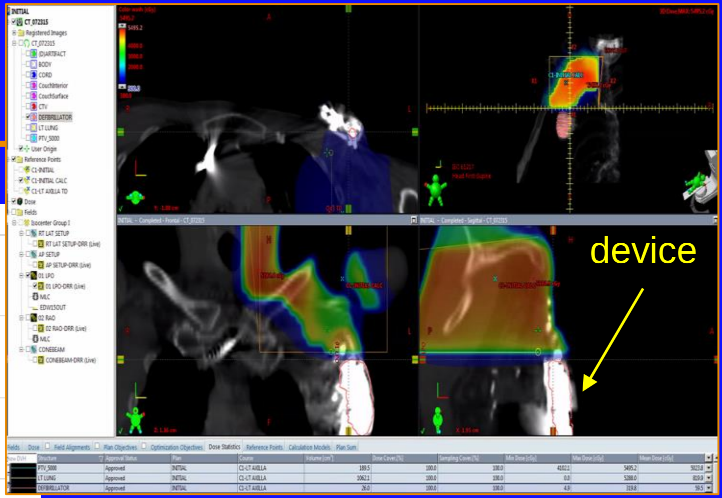
Device dose assessment

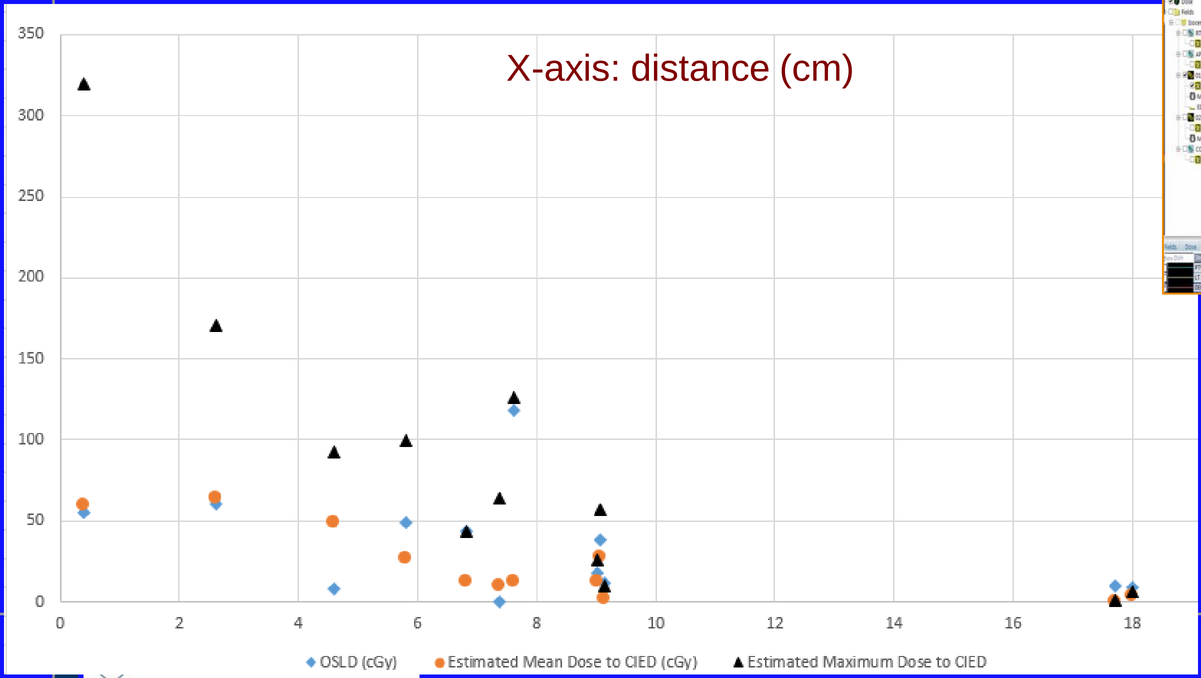
- Beyond 10 cm from the field edge:
- Dose almost certain to be less than 2 Gy
  - Use clinical judgement. If there are vertex fields pointed straight at the device it may still warrant a measurement.
- Don't generally need to worry about the dose at this distance (>10cm)
- No further assessment necessary

Slide courtesy of S. Kry









Mihailidis et al., private communication

RADIATION ONCOLOGY
PENN MEDICINE

Additional dose assessments

- **Imaging and Image Guidance**
  - CT simulation: Transient effects
  - IG during RT: Refer to TG-75 and TG-180 for dose assessment
    - Imaging dose can vary from tenths of cGy to >10cGy per fraction depending on what kind of imaging is used (need for image parameter optimization)

- **Brachytherapy**
  - Mostly for breast brachytherapy, dose can reach >100cGy at 10cm from a breast applicator.

TABLE II. Estimated maximal dose (D_d) to the device for typical distances from a spherical breast applicator's surface. (Table reproduced from Kim et al.[98]).

Balloon Vol. (cc)	35	50	70	90	110	125
Balloon Diam. (cm)	4.06	4.58	5.12	5.56	5.94	6.20
1 Gy	15.6	16.9	18.2	19.3	20.2	20.8
2 Gy	10.5	11.3	12.1	12.8	13.4	13.8
3 Gy	8.2	8.8	9.4	10.0	10.4	10.7
4 Gy	6.8	7.3	7.8	8.2	8.6	8.9
5 Gy	5.9	6.3	6.7	7.1	7.4	7.6

Estimated dose to the device at distance, d from a spherical applicator is given by: $D_d = D_P \cdot \left(\frac{R_{balloon}+1}{R_{balloon}+d}\right)^2$, where D_P is 3.4 Gy at 1 cm from applicator surface and $R_{balloon}$ is the balloon radius (cm).

Penn Medicine

RADIATION ONCOLOGY PENN MEDICINE

Recommendations-Summary

- CT imaging using limited couch movement or no couch motion should be avoided to prevent long (>3s) periods of direct irradiation of the device.
- Lower dose-rates are preferred (higher are not prohibitive).
- The generator for the device should be kept at least 5cm from the collimated field edge if possible, including imaging fields
- Appropriate beam angles should be selected increase the distance between the field edge and the CIED.
- Perform in-vivo dosimetry for the first fraction (at the minimum) if the device is <10 cm from treatment area.
- The TPS can be used in lieu of a measurement if the device is within 3 cm (laterally) of the field edge (50% isodose line).

THANK YOU