Small field dosimetry in radiotherapy from a standpoint of basic research

Guerda Massillon-JL

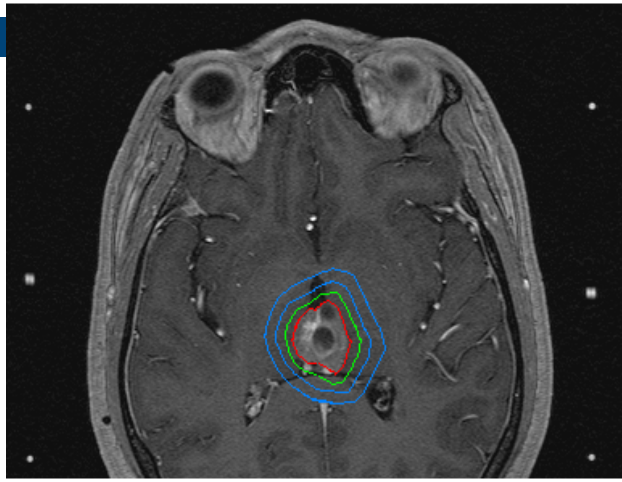
massillon@fisica.unam.mx

Instituto de Física,

Universidad Nacional Autónoma de México, México

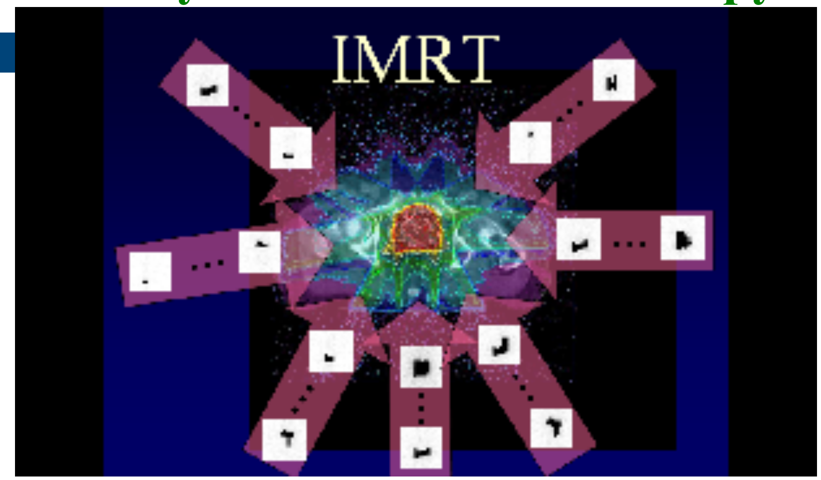
Small fields in radiotherapy

Stereotactic radiosurgery (SRS)



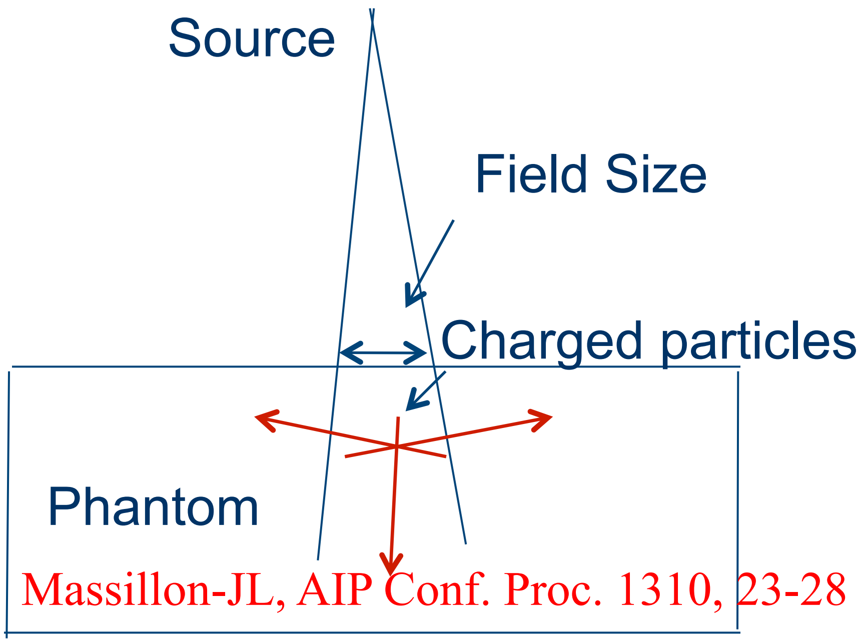
SRS : fields of 4 mm -60 mm diameter

Intensity Modulated radiotherapy



IMRT beam-lets of 2x2 to 6x6 mm^2

Sánchez-Doblado, 2010



Massillon-JL, AIP Conf. Proc. 1310, 23-28 (2010)

Radiation fields with a size smaller than the lateral range of charged particles

The physical processes?

Small fields in radiotherapy

- Variation of the electron fluence in the lateral direction of the radiation field

- Very short range of the electrons generated

$\Downarrow$

High ionization density problem

Which is the situation?

Great variations of the absorbed dose in the lateral direction of the radiation field due to the short range of the electrons

⇓

Difficulty to make accurate dose measurements

⇓

Very high-resolution, water equivalent and very small size dosimeters are needed

High ionization density Dosimetry?

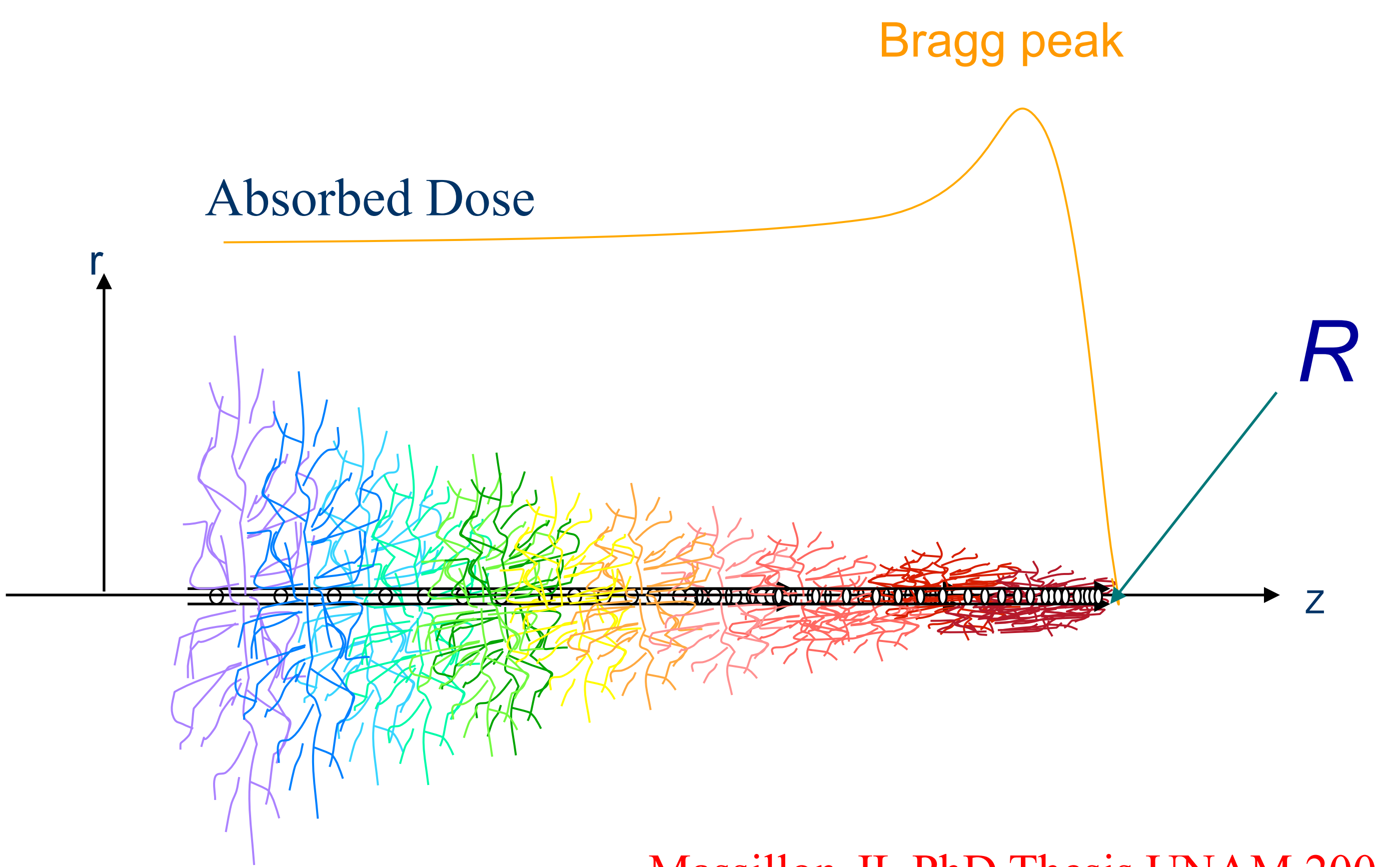
Study, through a dosimeter response, the high pattern of energy deposited in the matter by ions or electrons at a very short distance from their main tracks

$\Downarrow$

Understanding of

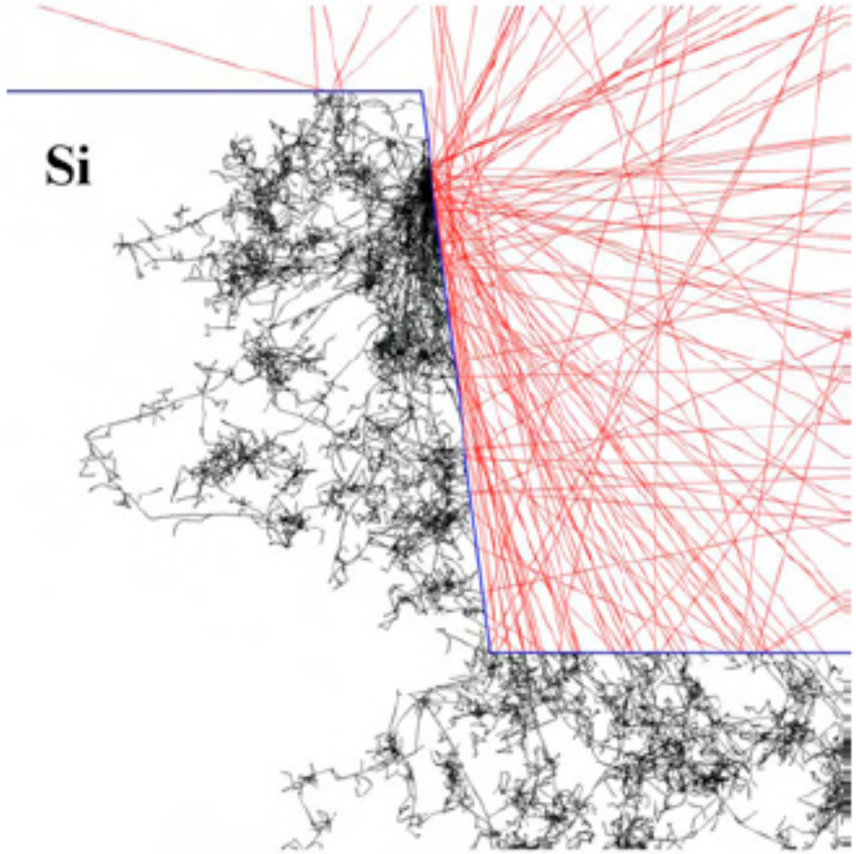
Dosimeter response versus linear energy transfer, LET

Ion interactions



Massillon-JL PhD Thesis UNAM 2006

Electron interactions



(b)

Villarrubia and Ding, *J. Micro/Nanolith.* 2009

Dosimetry: The challenge

One quantity, two definitions:

1) Product of the electron fluence (cm^{-2}) generated and the LET or restricted mass stopping power averaged over the electron energy spectrum ($MeVcm^2/g$)

2) $\frac{dE}{dm}$ = Ratio of the energy deposited (J) and the irradiated mass (kg)

=

Absorbed dose (Gy)

Dosimetry: The challenge

Two Questions?:

1) How do we know the electron fluence (cm^{-2}) and the LET or restricted mass stopping power?
2) How do we know the irradiated mass?

↓

Absorbed dose (Gy)?

How energy is transfered to the matter?

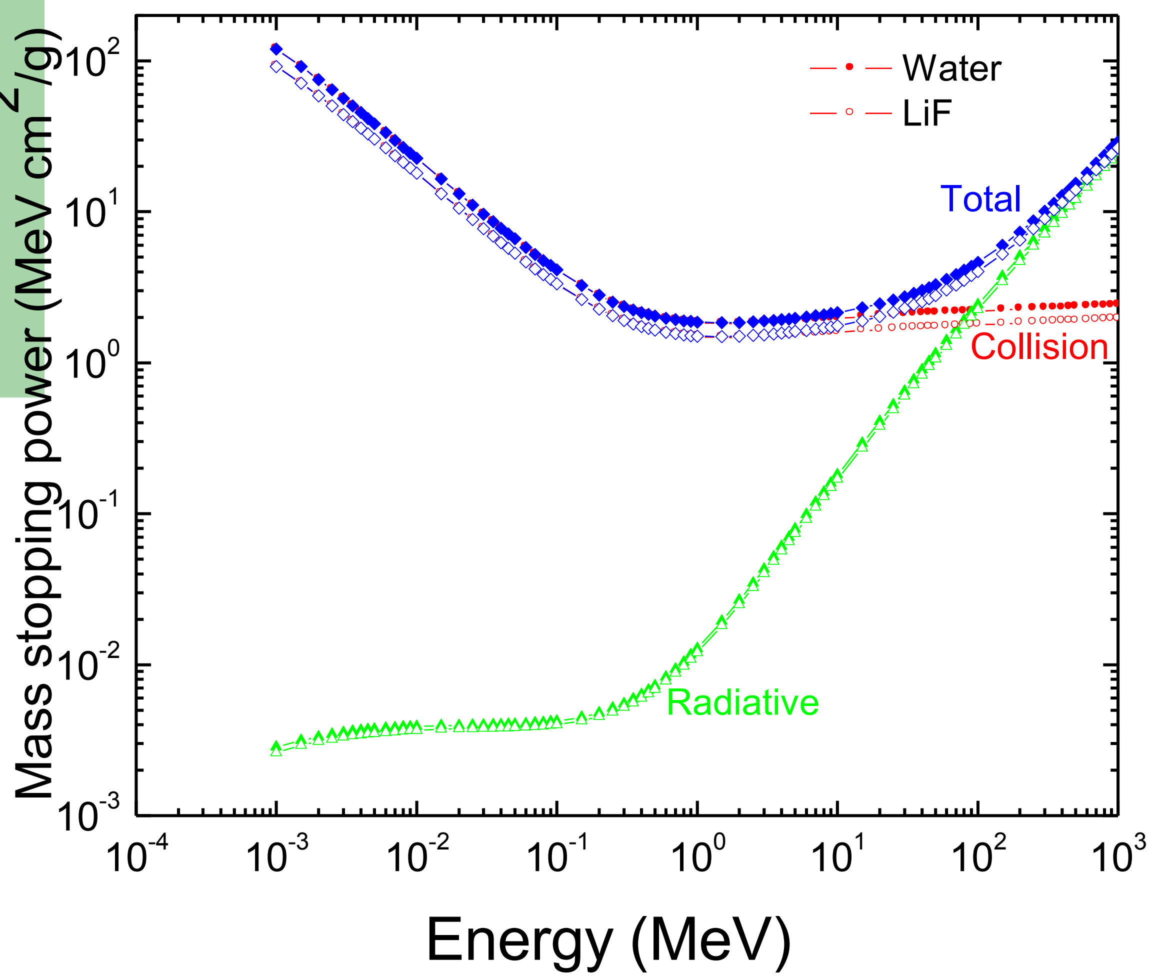
Bethe Aproximation and the classical limit

$$\left(\frac{dT}{\rho\, dx}\right)_c = k\left[\ln\left(\frac{\tau^2(\tau+2)}{2(I/m_0c^2)^2}\right) + F^{\pm}(\tau) - \delta - \frac{2C}{Z}\right]$$

$$k \equiv \frac{2Cm_0c^2z^2}{\beta^2} = 0.1535\frac{Zz^2}{A\beta^2}\frac{MeV}{g/cm^2} \qquad C \equiv \pi(N_AZ/A)r_0^2$$

$$F^-(\tau) \equiv 1-\beta^2+\frac{\tau^2/8-(2\tau+1)\ln(2)}{(\tau+1)^2} \qquad \tau = T/m_oc^2$$

Electron interactions



The ionization potential concept, *I*, is valid only for electron with energies higher than the binding energy of the deepest inner shell of an atom

⇓

Bethe approximation does not hold in the low-energy region.

Interaction of charged particles with energy below 1 keV?

Existing Monte Carlo codes

- EGSnrc, Canada (Bethe approximation)
- Penelope, España (Dielectric Function: 100 keV-100 eV)
- Geant4, CERN (~ Penelope)
- MCNP, Los Alamos National Laboratory, EUA (Bethe Approximation)
- NOREC, Oak Ridge Laboratory (Track Structure Theory in water), used of Hartree-Fock Wave Functions of H and O atoms for energy below 1 keV

Which should be the response?

Development of Research projects relative to Low-energy radiation is fundamental to improve our knowledge about the physical processes of the radiation interaction with matter at the atomic level

In the mid-time, should we leave the patient alone?

NO!

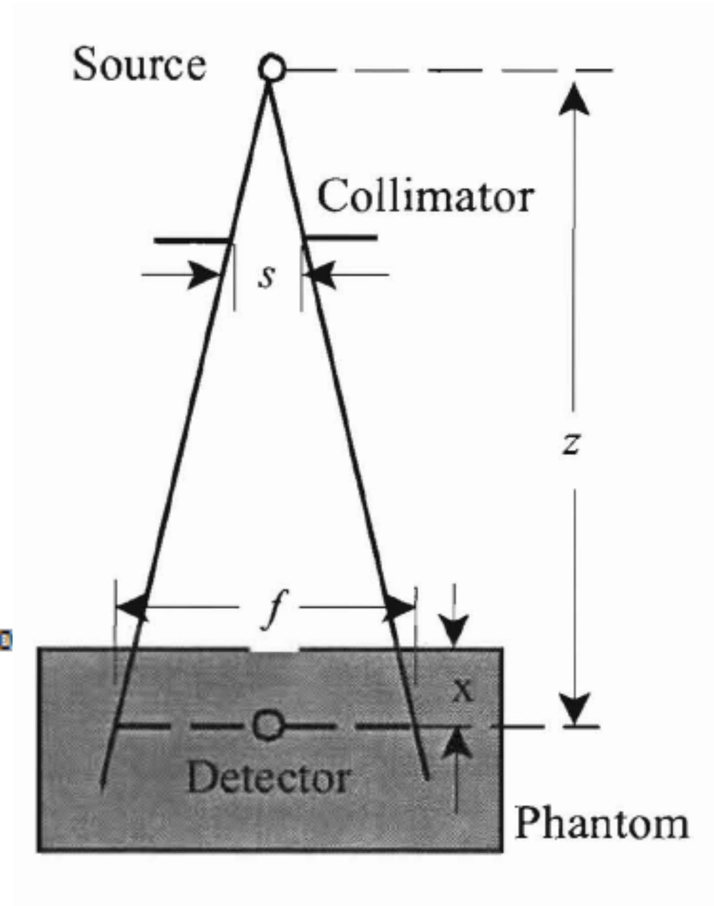
Which is the situation?

Reference Dosimetry

- Absolute calibration
- Field size of 10 cm x 10 cm
- Beam quality factor under reference conditions

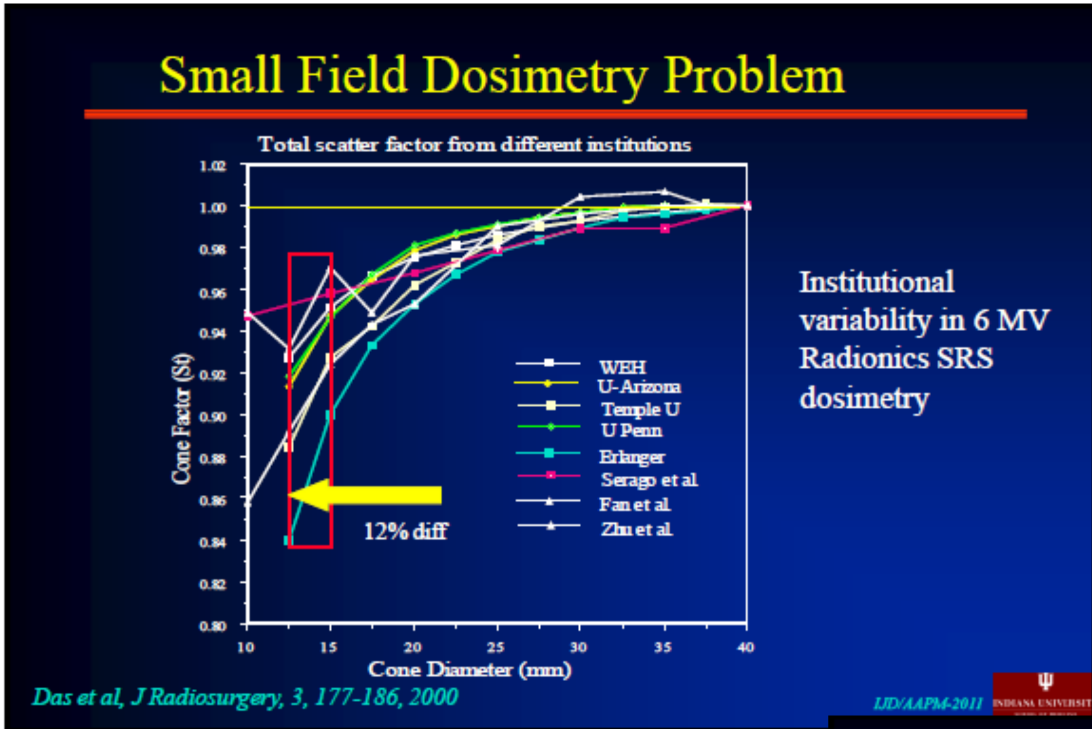
⇓

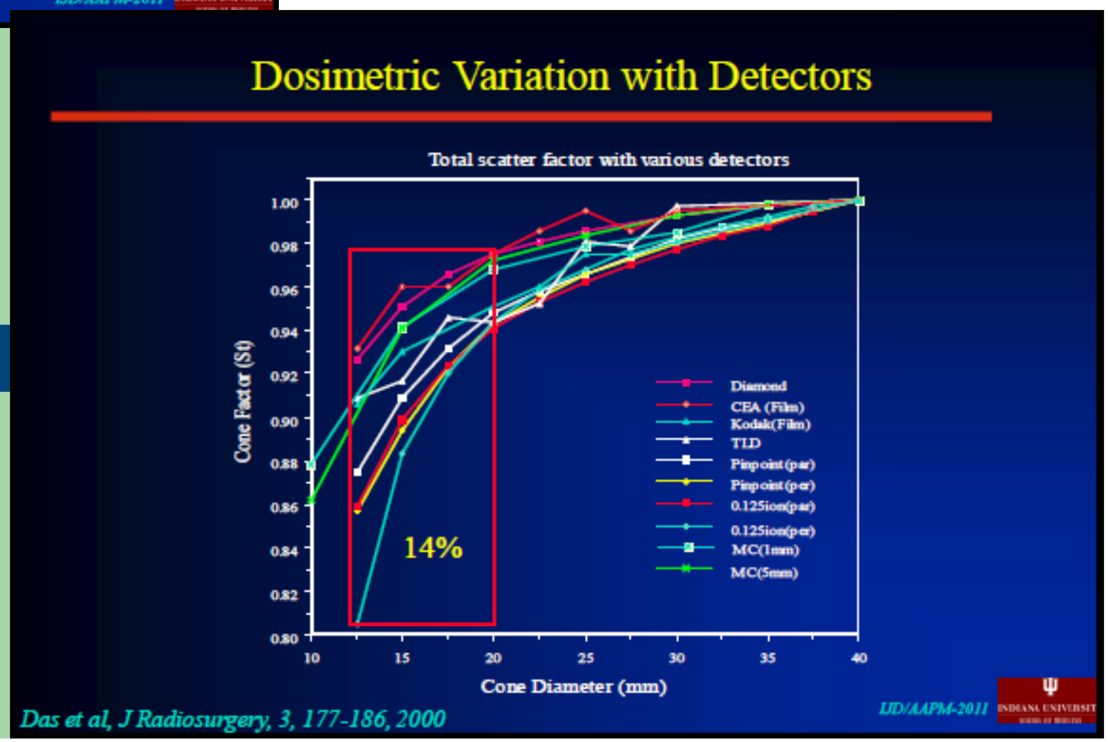
$$D_{w,Q} = (\bar{M}_{Q\ (corregida)}\ k_{pol}\ k_s) N_{D,w,Q_0}\ k_{Q,Q_0}$$



All ionization chambers are calibrated under these or similar conditions

IAEA TRS-398


Small Field Dosimetry Problem
Total scatter factor from different institutions
Cone Factor (St)
Cone Diameter (mm)
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
10
15
20
25
30
35
40
WEH
U-Arizona
Temple U
U Penn
Erlanger
Serago et al
Fan et al
Zhu et al
12% diff
Institutional variability in 6 MV Radionics SRS dosimetry
Das et al, J Radiosurgery, 3, 177-186, 2000
IJD/AAPM-2011


Dosimetric Variation with Detectors
Total scatter factor with various detectors
Cone Factor (St)
Cone Diameter (mm)
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
10
15
20
25
30
35
40
Diamond
CEA (Film)
Kodak(Film)
TLD
Pinpoint(par)
Pinpoint(per)
0.125ion(par)
0.125ion(per)
MC(1mm)
MC(5mm)
14%
Das et al, J Radiosurgery, 3, 177-186, 2000
IJD/AAPM-2011

Possible Solutions

AAPM/IAEA 2008:

New formalism for the dosimetry of small and composite fields with the intention to extend recommendations given in conventional Code of Practices for clinical reference dosimetry based on absorbed dose to water. **Alfonso *et al.* Med. Phys. 35, (2008)**

AT NIST 2008:

A special very small field of 1 cm^2 ^{60}Co gamma beam has been characterized with Radiochromic film and TLDs within an uncertainty of 3–4% for gel calibrations.

Massillon-JL *et al.*, *Med. Phys.* 35 2920 (2008)

⇓

Relevant to ongoing efforts in the medical community to develop protocols for small field dosimetry.

Massillon-JL *et al.* Appl. Radiat Isotopes, (2010)

NIST/Univ of Pittsburgh MC.

It is important to identify and evaluate new dosimeters that are suitable for measurements of absolute dose in small and non-standard fields.

Novotny *et al.* Med. Phys. 36, 2009

Why films are not accepted as reference?

- LOW UNCERTAINTIES? NO
- High spatial resolution? Yes
- Dose rate independent? Yes
- Energy dependent? Yes and NO
- Tissue equivalent? Yes and NO

How to reduce uncertainties in Films?

- ✓ Knowing the minimum limit of absorbed dose
- ✓ Evaluating uncertainties vs photon energy
- ✓ Determining the degree of energy dependence vs spatial resolution, color channel and absorbed dose

Massillon-JL *and* Zúñiga-Meneses, Phys. Med. Biol. **55** 2010
I D Munoz-Molina, B. Sc. thesis UNAM 2012
Massillon-Jl et *al.* Physica Medica 2015 i*n revision*
Massillon-JL *et al.* IJMPCERO 2012

Stereotactic radiosurgery:

Gamma Knife and Modified linear acelerator

Absorbed dose to water rate determined in the 10 x 10 cm^2 reference fields

Detectors	^{60}Co gamma rays		6 MV X-rays	
	$x\ 10^{-3}\ Gys^{-1}$	IC_1/other	$x\ 10^{-3}\ Gys^{-1}$	IC_1/other
$^{a}IC_1$	11.292 ± 0.141	1.000	9.733 ± 0.131	1.000
$^{b}IC_2$	11.297 ± 0.184	0.9995		
Alanine	11.220 ± 0.083	1.0065		
$^{c}IC_3$			9.625 ± 0.135	1.0112

Massillon-JL et al. PlosOne 2013

Reference absorbed dose to water rate computed in the modified accelerator for SRS

		Collimator diameters (mm)				
		7.5	10	15	25	35
imeter	Size	(mGy MU^{-1})	(mGy MU^{-1})	(mGyMU^{-1})	(mGyMU^{-1})	(mGyMU^{-1})
-V2-55	~240[a]	7.14 ± 0.10	7.43 ± 0.10	8.13 ± 0.10	8.60 ± 0.11	8.79 ± 0.11
D-100	3.1×3.1×0.89[b]		7.44 ± 0.20	8.16 ± 0.14	8.53 ± 0.21	8.73 ± 0.19
anine	4.9[c] x 3.0[d]			7.87 ± 0.09		8.7 ± 0.1
CD		6.4	7.08	7.89	8.35	8.55

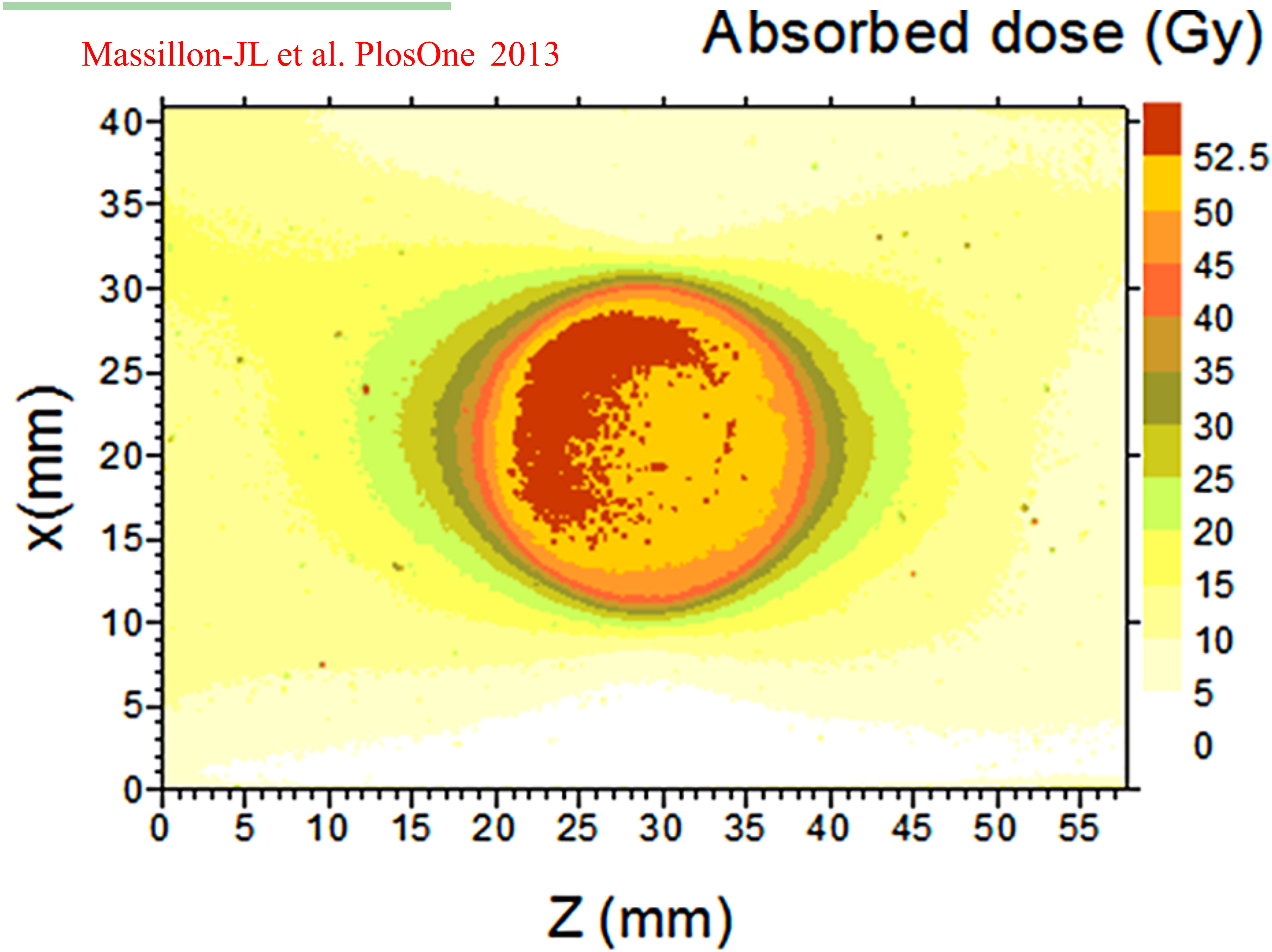
Massillon-JL et al. PlosOne 2013

Reference absorbed dose to water rate computed in the Leksell Gamma Knife® unit

		Collimator diameters (mm)			
		4	8	14	18
Dosimeter	Size	(mGy s^{-1})	(mGy s^{-1})	(mGy s^{-1})	(mGy s^{-1})
MD-V2-55	~240[a]	20.18 ± 0.30	22.23 ± 0.34	22.92 ± 0.35	23.31 ± 0.36
TLD-100	3.1×3.1×0.89[b]	19.34 ± 0.27	21.86 ± 0.72	22.28 ± 0.52	23.06 ± 0.73
Alanine	4.9[c] x 3.0[d]		21.09 ± 0.32	21.47 ± 0.24	21.89 ± 0.22
CD		18.94	20.83	21.48	21.82

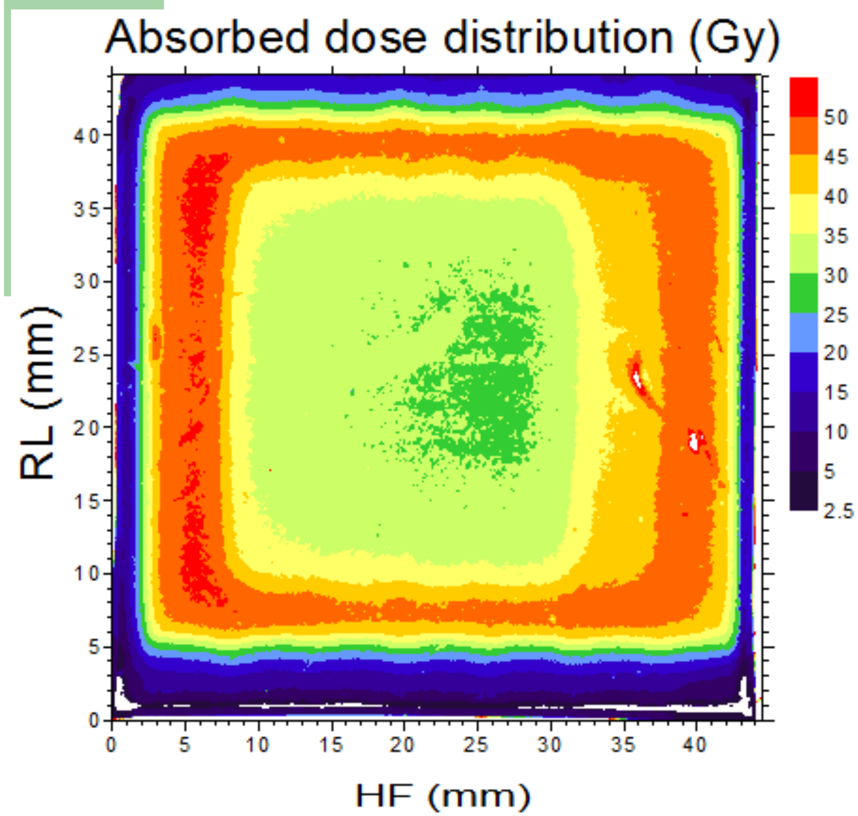
Massillon-JL et al. PlosOne 2013

Massillon-JL et al. PlosOne 2013

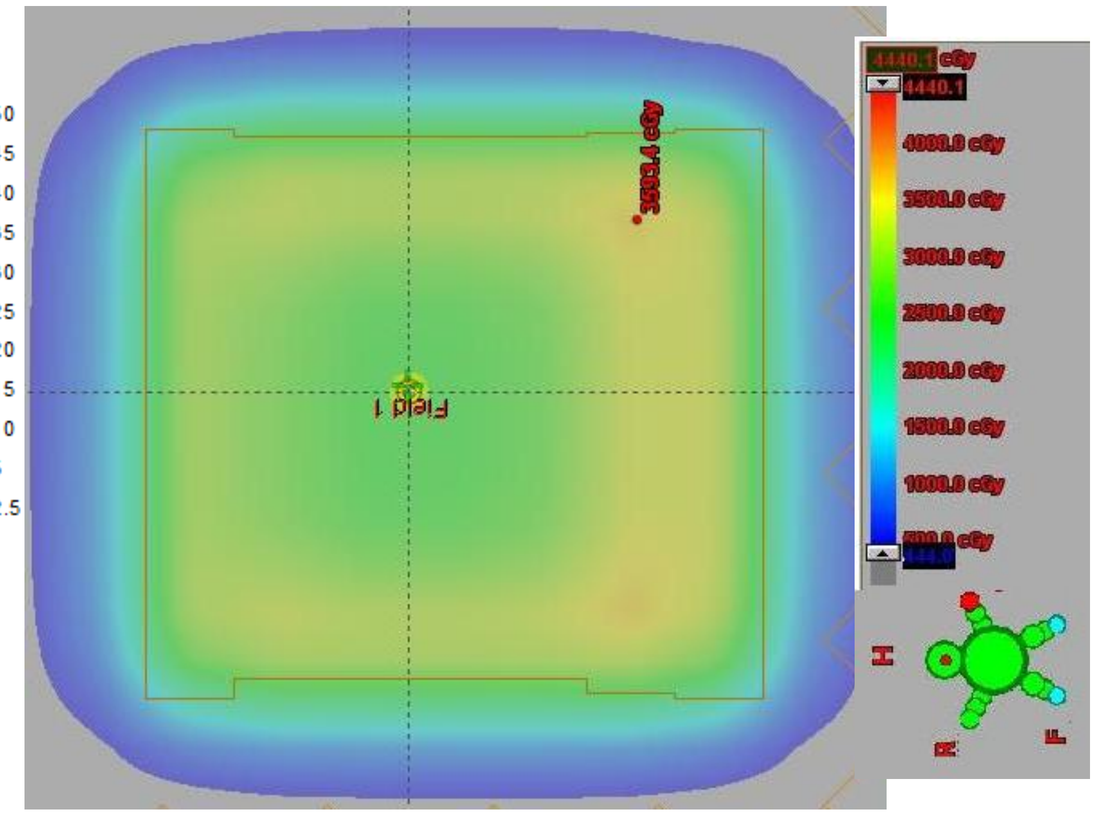


Results: IMRT-Dynamic MLC

Gafchromic MD-V2-55



Planning system

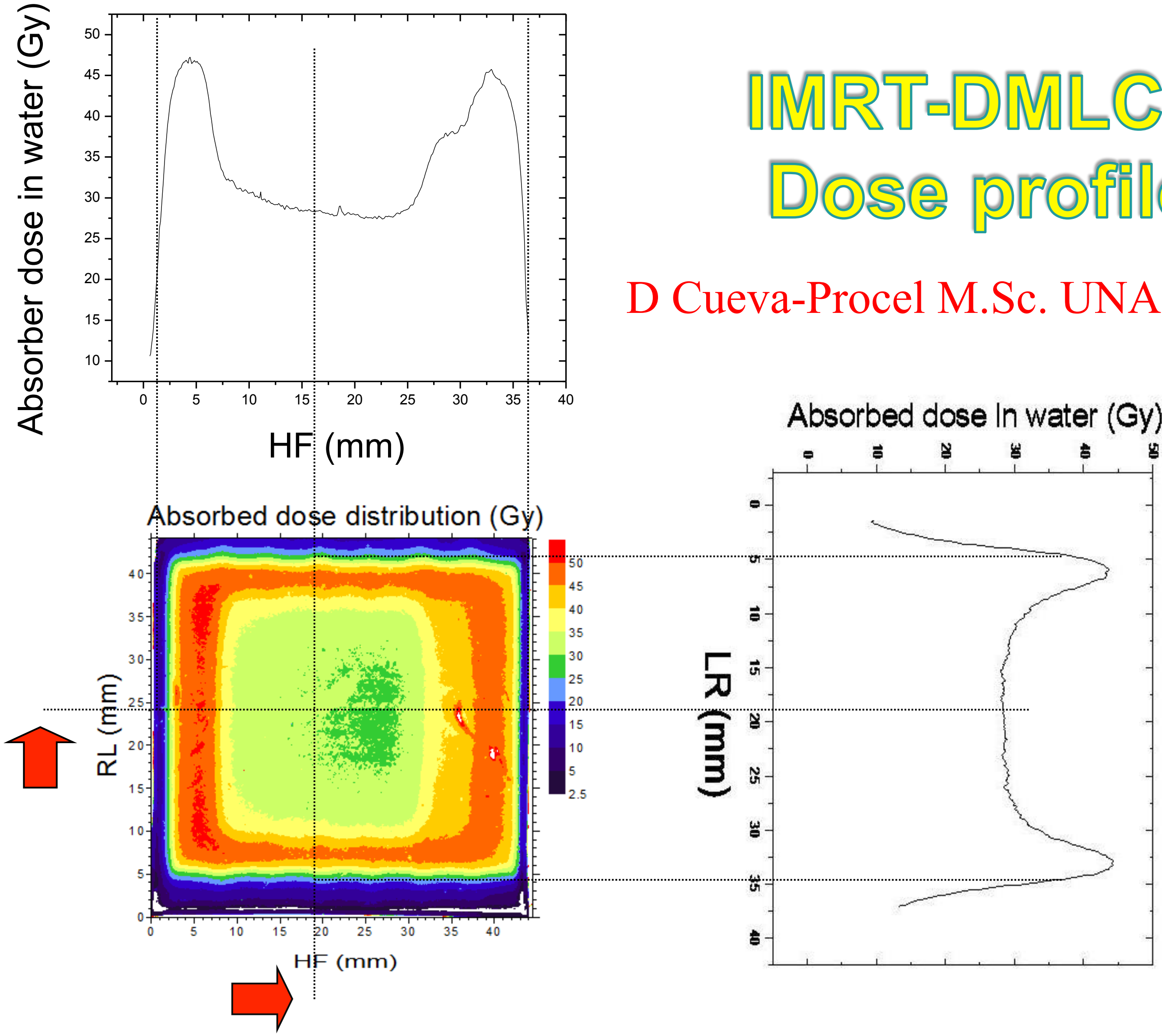


D Cueva-Procel M.Sc. UNAM 2011

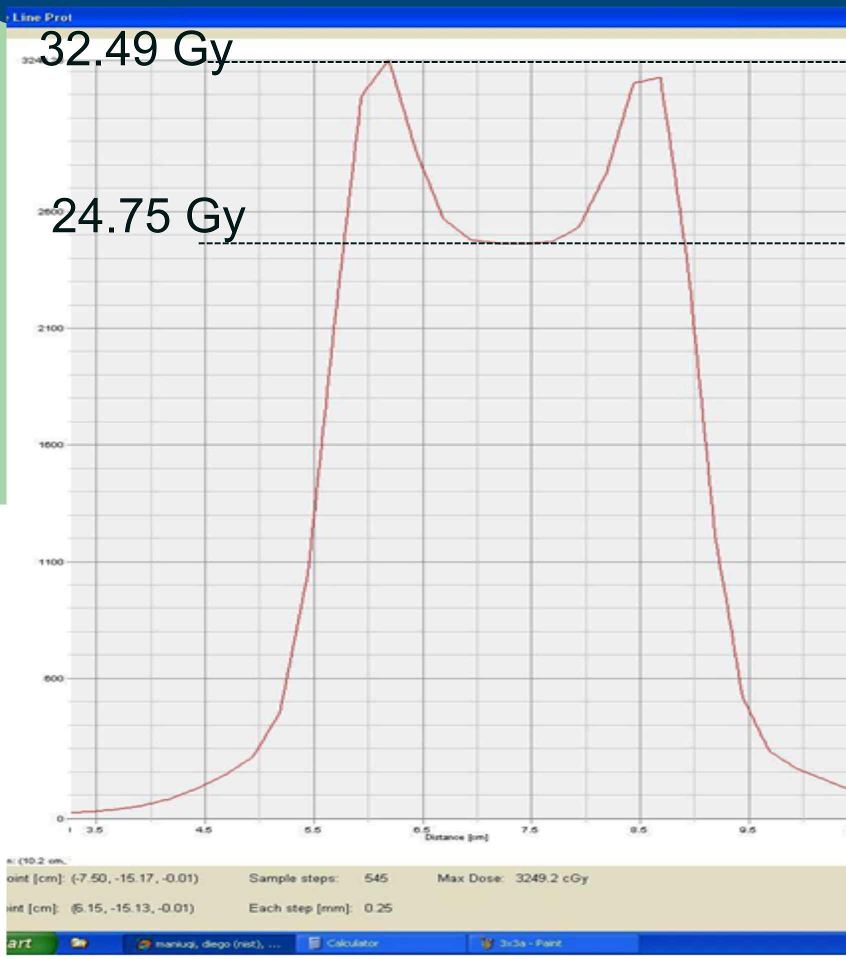
Results: IMRT-Dynamic MLC

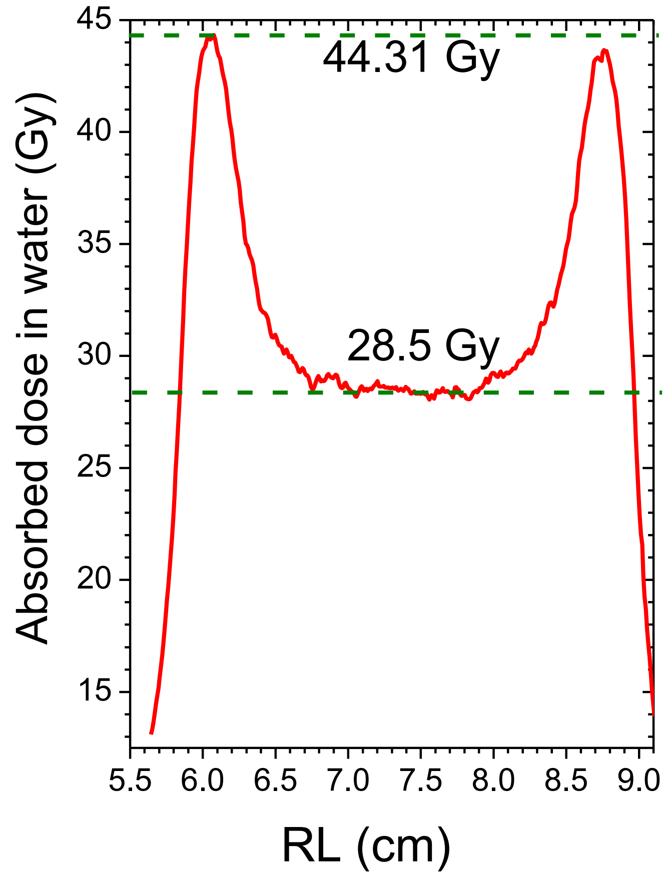
IMRT-DMLC: Dose profiles

D Cueva-Procel M.Sc. UNAM 2011



IMRT-DMLC: System planning vs Film





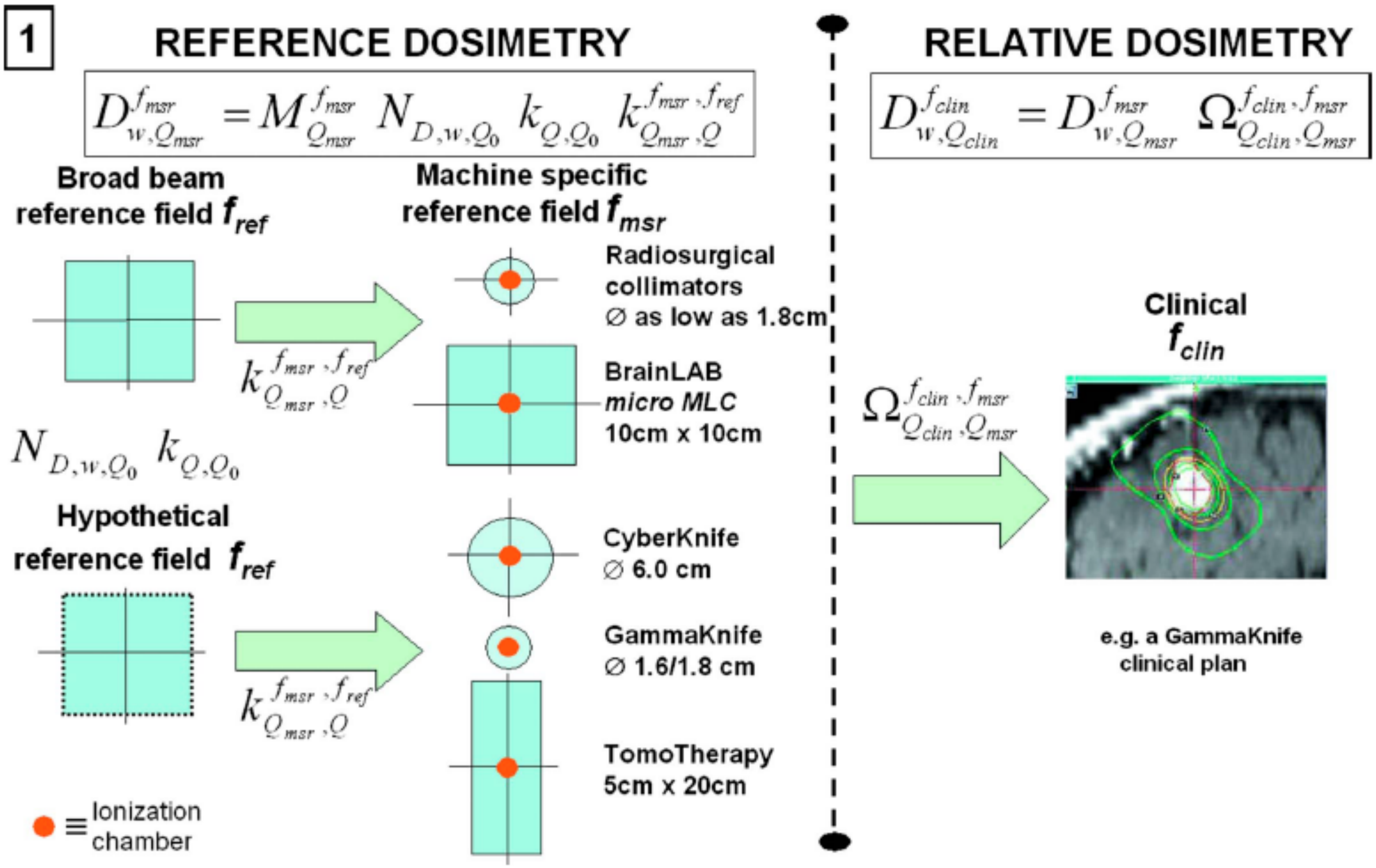
D Cueva-Procel M.Sc. UNAM 2011

Difference: minimum: 15% ; maximum: 36%

Stereotactic radiosurgery:

Cyberknife unit

IAEA/AAPM?



$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} N_{D,w,Q_0} k_{Q,Q_0} k_{Q_{msr},Q}^{f_{msr},f_{ref}}$$

$$D_{w,Q_{clin}}^{f_{clin}} = D_{w,Q_{msr}}^{f_{msr}} \Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$$

FIG. 2. Schematic overview of the dosimetry of small static fields with reference to a machine-specific reference field according to the formalism presented in this paper.

Alfonso *et al.* Med. Phys. 35, (2008)

Absorbed dose to water rate in a 10 x 10 cm^2 reference field at 100 cm SDD, 10 cm depth

IC	Where calibrated	Dose Rate [cGy/MU]	Diff [%]
IC-A12	NIST	0.785 ± 0.004	NA
IC-2258	IBA	0.787 ± 0.010	0.16
IC-580	ININ	0.804 ± 0.010	2.24

Aragon-Martinez *et al.* AIP Conf. Proc. 1626, 55-60 (2014)

Absorbed dose to water rate in 10 x 10 cm^2 and 5.4 cm x 5.4 cm fields at 80 cm SDD, 10 cm depth

IC	10 cm x 10 cm Dose Rate [cGy/MU]	10 cm x 10 cm Diff. [%]	5.4 cm x 5.4 cm Dose Rate [cGy/MU]	5.4 cm x 5.4 cm Diff. [%]
IC-A12	1.262 ± 0.006	NA	1.023 ± 0.005	NA
IC-2258	1.278 ± 0.014	1.27	1.037 ± 0.011	1.37
IC-580	1.311 ± 0.013	3.88	1.059 ± 0.011	3.52

Aragon-Martinez *et al.* AIP Conf. Proc. 1626, 55-60 (2014)

Acknowledgments

Collaborators

- Ronaldo Minniti, NIST, USA
- Michael G. Mitch, NIST, USA
- Chris Soares, NIST, USA
- Porfirio Diaz-Aguirre, HSJ, MX
- Arnulfo Gomez-Munoz, HO, CMN, Siglo XXI

Students

- Diego Cueva Procel, M. Sc. UNAM, MX
- Ivan Munoz-Molina, B. Sc. UNAM, MX
- Nestor Aragon-Martinez, M.Sc. UNAM. MX
- Lucero Zuniga-Meneses, B. Sc. UNAM, MX

Grants

UNAM, PAPIIT-IN105813, Conacyt, Mexico 127409