Practical Aspects of Cyberknife Small Beam Dosimetry

Sonja Dieterich, PhD and Lei Wang, PhD
Stanford University Hospital

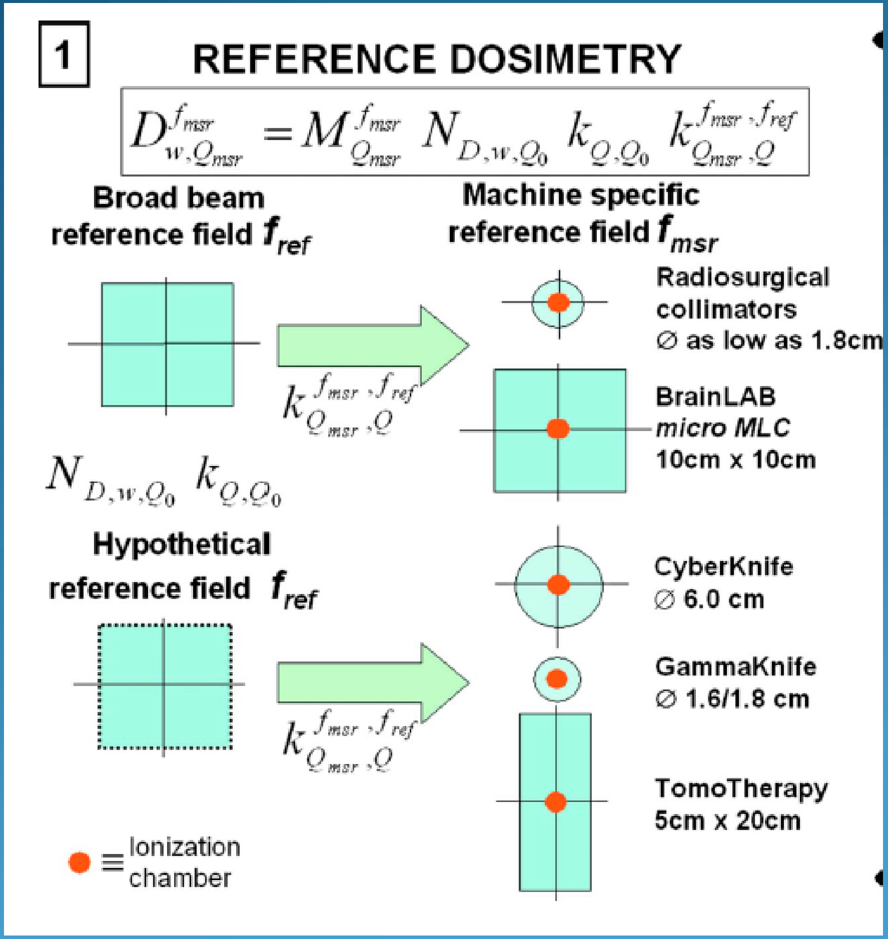
Conflict of Interest

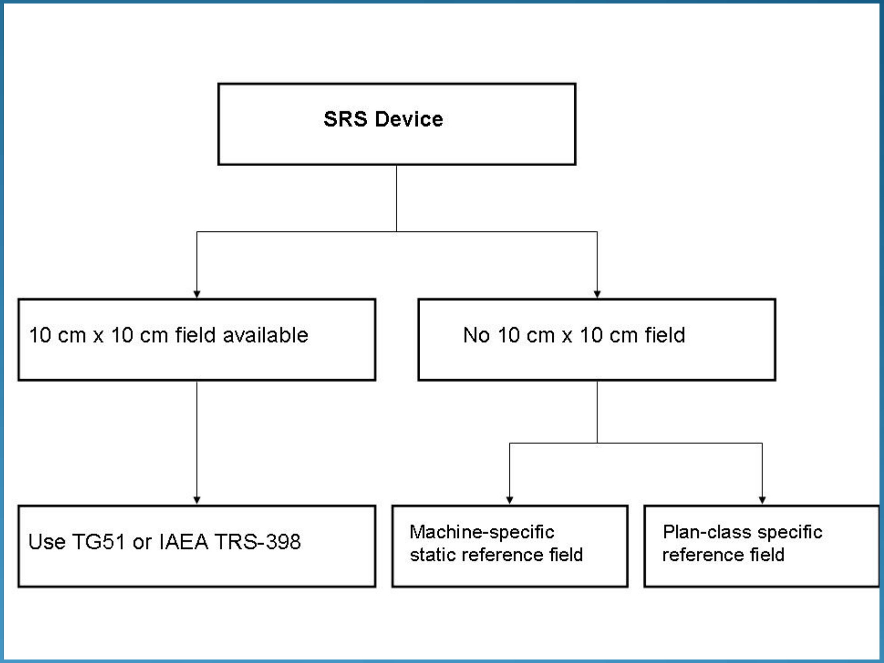
Sonja Dieterich has a consulting agreement with Cyberheart, Inc.

Outline

- Reference dosimetry
  - TG-51
  - Detectors
  - Independent output check
- Relative Dosimetry
  - Output Factors
  - OARs
- Practical Comments on taking dosimetry data
  - Tools needed
  - Time required
  - Order of measurement

The IAEA concept



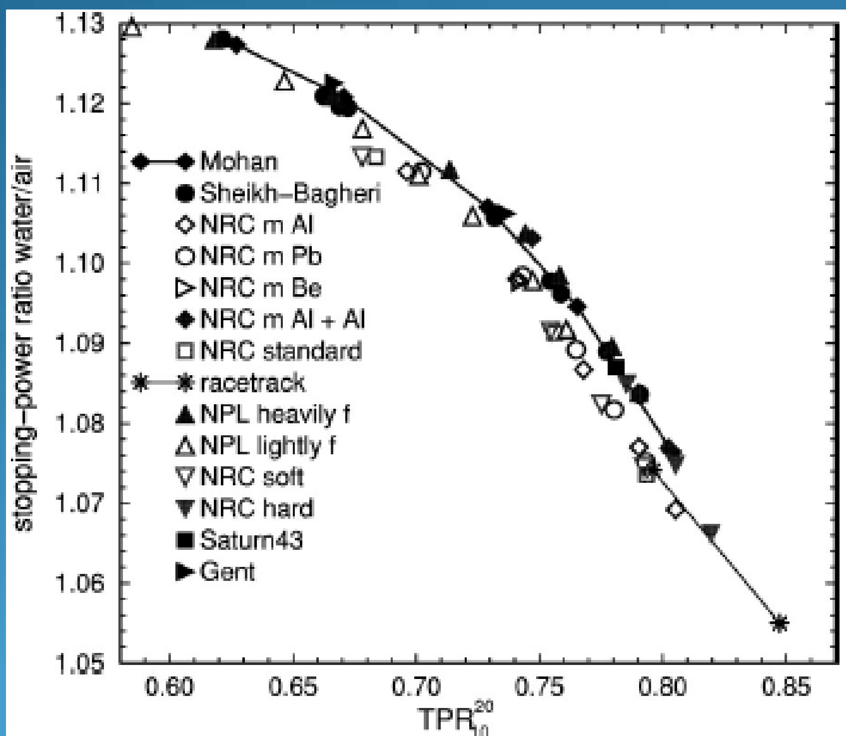


- CyberKnife: machine-specific static reference field
- 60 mm collimator, 80 cm SAD

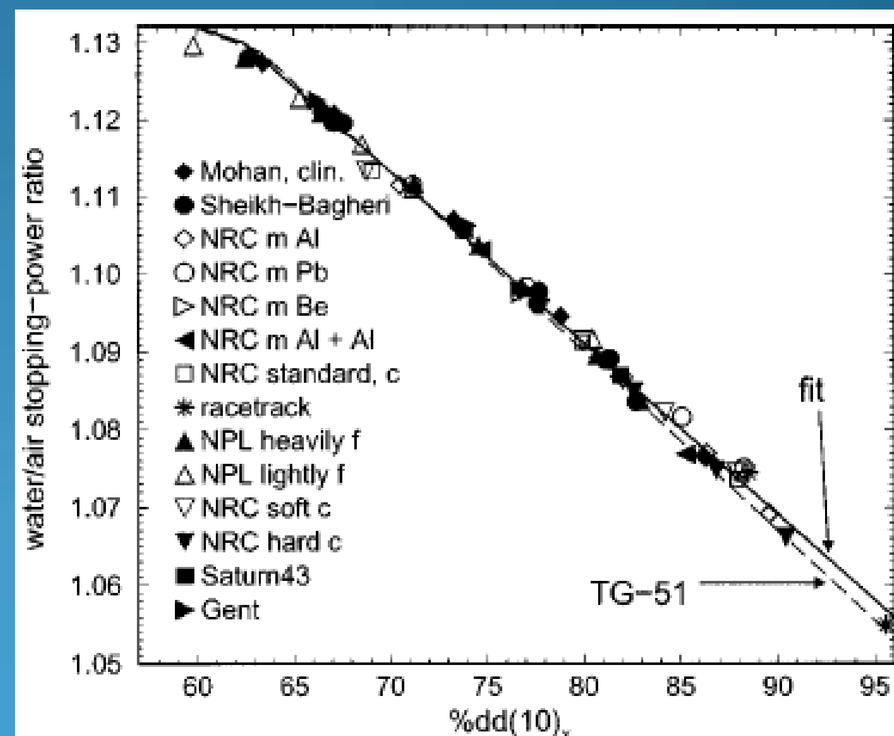
Alfonso et al, Med Phys (2008), 5179

TG-51 for flattening filter only? No!

TPR^{20}_{10}



TG51 is using $\%dd(10)_x$



Kalach & Rogers, Med Phys 30 (2003) 1546

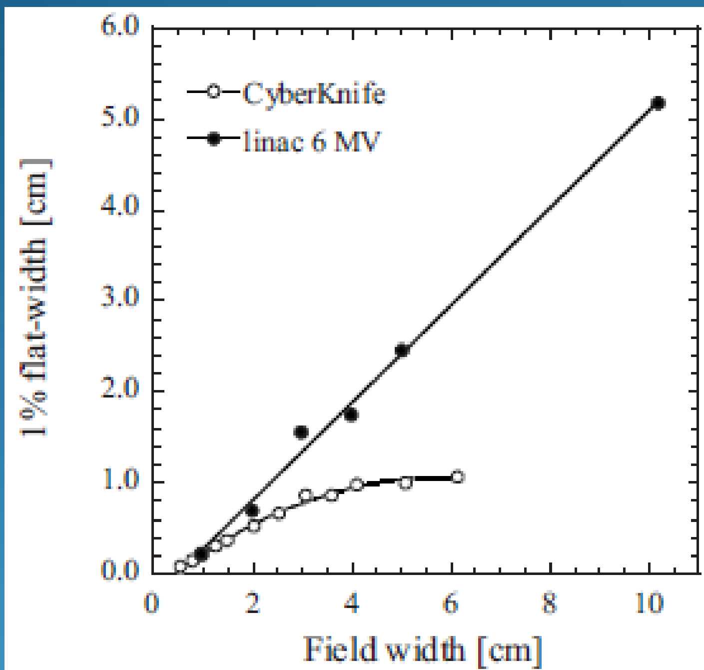
TG-51: Measuring %dd(10)$_x$

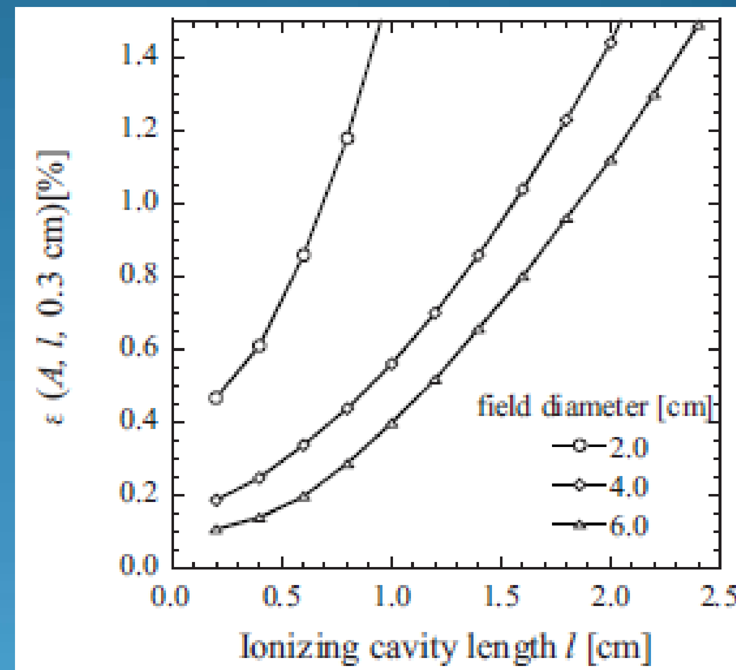
$\%dd(10)_x$: the photon component of the photon beam percentage depth-dose at 10 cm depth in a 10×10 cm^2 field on the surface of a water phantom at an SSD of 100 cm (see Sec. VIII B).

- CK: 60 mm spherical collimator at 80 cm SAD
- Measure at 10 cm depth, 100 cm SSD, 60 mm collimator
- Calculate equivalent square
- Interpolate to 80 cm SAD using the BJR data

STANFORD
SCHOOL OF MEDICINE
Stanford University Medical Center

TG-51: Chamber selection



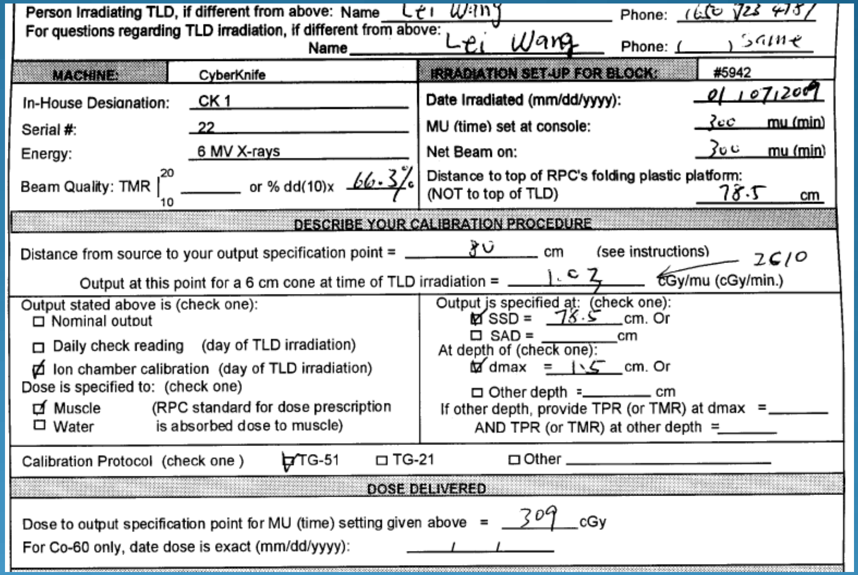


Kawachi et al, Med Phys (2008) 4591

- Dose flatness insufficient for Farmer-type chamber
- Cavity length should be 1 cm or shorter
- Option: cross calibrate a short chamber with Farmer-type chamber

Independent Output Check

- Absolutely necessary before treating a patient!
- Same institute: cross-calibrate (TLD)
- Stand-alone site: TLD service



Person Irradiating TLD, if different from above: Name Lei Wang Phone: (650) 723 4187
For questions regarding TLD irradiation, if different from above: Name Lei Wang Phone: ( ) same

MACHINE:	CyberKnife	IRRADIATION SET-UP FOR BLOCK:	#5942
In-House Designation:	CK 1	Date Irradiated (mm/dd/yyyy):	01/07/2009
Serial #:	22	MU (time) set at console:	300 mu (min)
Energy:	6 MV X-rays	Net Beam on:	300 mu (min)
Beam Quality: TMR 20/10 ____ or % dd(10)x	66.3%	Distance to top of RPC's folding plastic platform: (NOT to top of TLD)	78.5 cm

DESCRIBE YOUR CALIBRATION PROCEDURE

Distance from source to your output specification point = 80 cm (see instructions) 26/0

Output at this point for a 6 cm cone at time of TLD irradiation = 1.03 cGy/mu (cGy/min.)

Output stated above is (check one):
- ☐ Nominal output
- ☐ Daily check reading (day of TLD irradiation)
- ☑ Ion chamber calibration (day of TLD irradiation)

Dose is specified to: (check one)
- ☑ Muscle (RPC standard for dose prescription
- ☐ Water is absorbed dose to muscle)

Output is specified at: (check one):
- ☑ SSD = 78.5 cm. Or
- ☐ SAD = ____ cm

At depth of (check one):
- ☑ dmax = 1.5 cm. Or
- ☐ Other depth = ____ cm

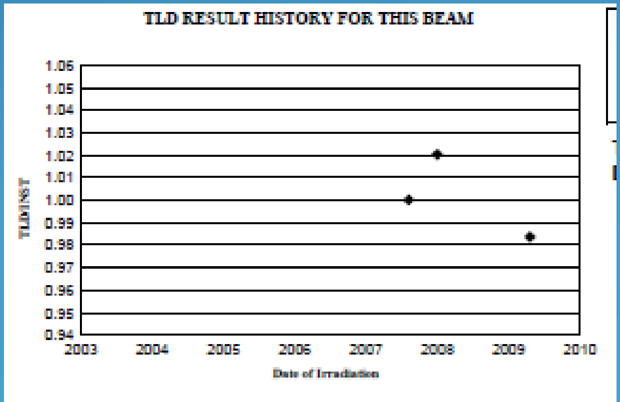
If other depth, provide TPR (or TMR) at dmax = ____
AND TPR (or TMR) at other depth = ____

Calibration Protocol (check one) ☑ TG-51 ☐ TG-21 ☐ Other ____

DOSE DELIVERED

Dose to output specification point for MU (time) setting given above = 309 cGy

For Co-60 only, date dose is exact (mm/dd/yyyy): __/__/____



Outline

- Reference dosimetry
  - TG-51
  - Chambers
  - Independent output check
- Relative Dosimetry
  - Output Factors
  - OARs
- Practical Comments on taking Beam Data
  - Tools needed
  - Time required
  - Order of measurement

Goal: OF Uncertainty < 3%

- Francescon, Cora, Cavedon, Med Phys (2008) 504
- OF (= $s_{c,p}$) for 3 smallest cones:
  - 2 microchambers, **PTW60012 diode**, diamond detector
  - Measurements
  - Monte Carlo simulation

  } Consistency Check
- Dependency of OF on FWHM of electron beam
- MC correction factors for detector response

OF as Function of Electron-Beam FWHM

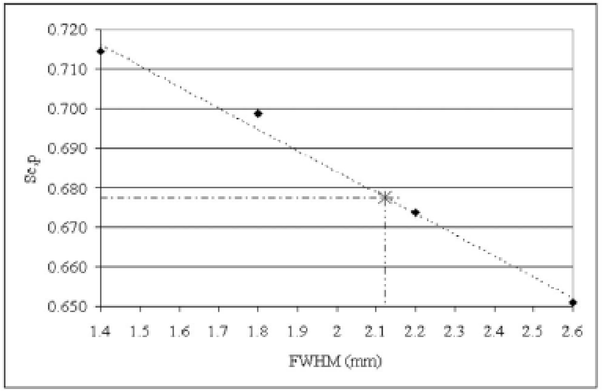


FIG. 5. True Monte Carlo $s_{c,p}$ as a function of the FWHM: the estimated $s^{*}_{c,p}$ allows the FWHM of the electron beam to be estimated for the Cyberknife system under investigation.

TABLE IV. Measured and MC-simulated $s_{c,p}$, for the four detectors and for the 5, 7.5, and 10 mm collimators, for the various FWHM of the Gaussian spatial distribution of the electron source.

		FWHM 1.4 mm	FWHM 1.8 mm	FWHM 2.2 mm	FWHM 2.6 mm
Coll 5 mm	Measured $s_{c,p}$	Simulated $s_{c,p}$	Simulated $s_{c,p}$	Simulated $s_{c,p}$	Simulated $s_{c,p}$
A16	0.614	0.669	0.643	0.611	0.585
PinPoint	0.613	0.661	0.636	0.607	0.582
Diode	0.710	0.757	0.732	0.704	0.679
Diamond	0.613	0.677	0.639	0.609	0.580
Coll 7.5 mm					
A16	0.801	0.809	0.808	0.799	0.792
PinPoint	0.798	0.805	0.802	0.795	0.789
Diode	0.852	0.757	0.850	0.843	0.842
Diamond	0.815	0.833	0.818	0.813	0.803
Coll 10 mm					
A16	0.859	0.874	0.870	0.860	0.857
PinPoint	0.858	0.867	0.865	0.860	0.857
Diode	0.895	0.909	0.896	0.890	0.886
Diamond	0.871	0.889	0.876	0.872	0.866

Point source assumption starts breaking down for 5 mm collimator!

OF Correction Factor F_{corr}

- No lateral electron equilibrium
- Detector response : F_{corr} = OF (MC) / OF (measured)
- Combine detector correction with FWHM correction to get $s^*_{c,p}$

TABLE III. Estimated values of F^*_{corr} and $s^*_{c,p}$ for the 5, 7.5,, and 10 mm collimators, for the four detectors.

	5 mm		7.5 mm		10 mm	
	F^*_{corr}	$s^*_{c,p}$	F^*_{corr}	$s^*_{c,p}$	F^*_{corr}	$s^*_{c,p}$
A16	1.098	0.675	1.021	0.818	1.010	0.867
PinPoint	1.107	0.679	1.027	0.819	1.014	0.870
Diode	0.957	0.679	0.966	0.823	0.978	0.875
Diamond	1.104	0.677	1.006	0.820	1.000	0.871
Mean $s_{c,p}$		0.677		0.820		0.871
$\pm 2\sigma$		±0.004		±0.008		±0.008

OF Corrections: Results

TABLE V. Raw measurements and estimated values of $s_{c,p}$ for the 5, 7.5, and 10 mm collimators.

	5 mm		7.5 mm		10 mm	
	Raw $s_{c,p}$	$s^*_{c,p}$	Raw $s_{c,p}$	$s^*_{c,p}$		
A16	0.615	0.675	0.801	0.818		
PinPoint	0.613	0.679	0.798	0.819		
Diode	0.710	0.679	0.852	0.823		
Diamond	0.613	0.677	0.815	0.820		
Mean $s_{c,p}$	0.638	0.677	0.817	0.820		
$\pm 2\sigma$	0.096	0.004	0.050	0.004		

- Vicenza study results in low uncertainty of OFs if all corrections apply
- Pantelis Med Phys (2008) 2312 BANG gel measurement <u>strong indication</u> for OF correction factor

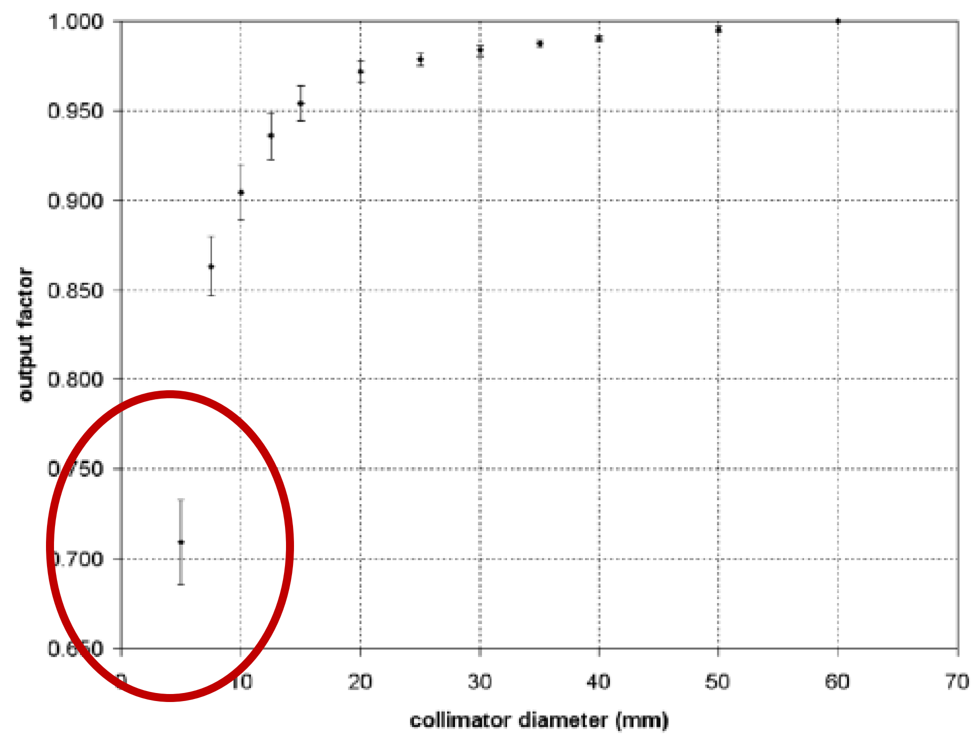
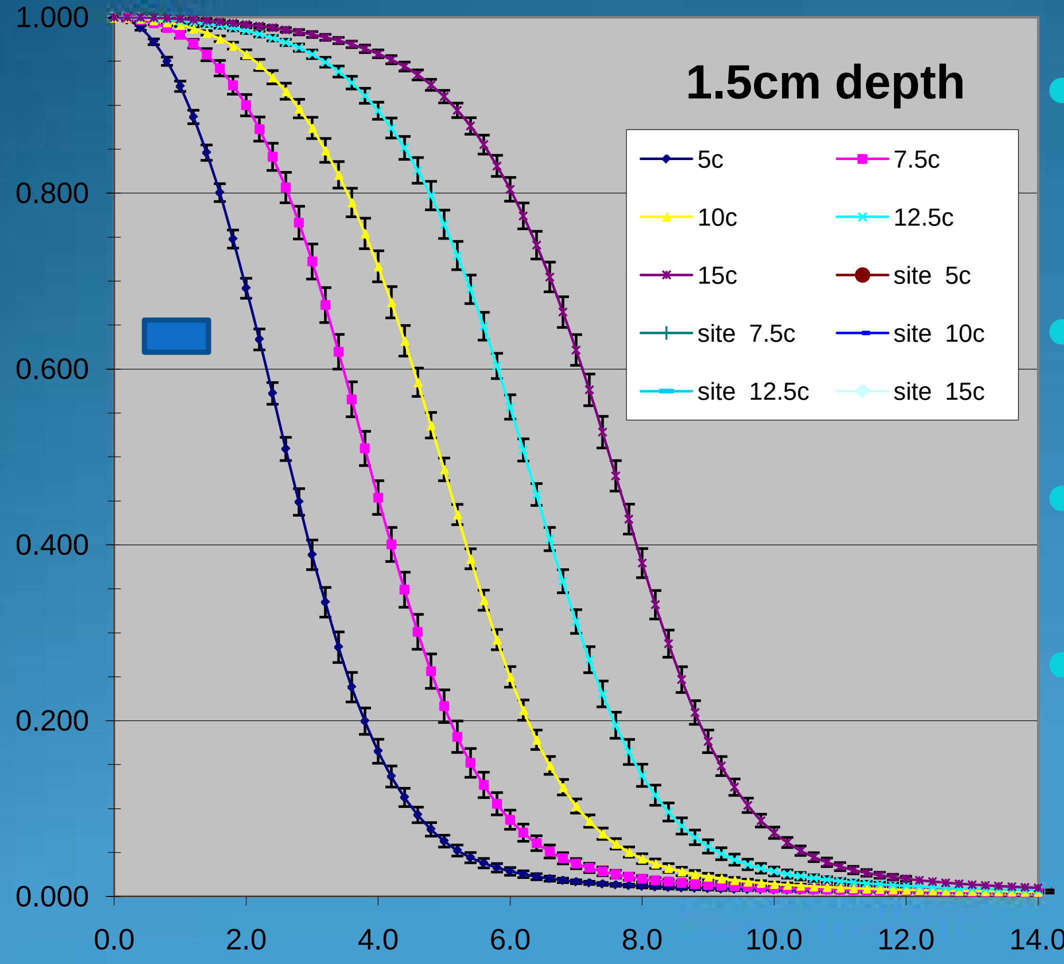


Figure 20-2. Example of rapidly decreasing output factor with decreasing field size from CyberKnife® data. Composite data from several centers, measured by means of diode detectors and normalized to the 60 mm collimator output factor.

OF corrections: What now?

- Convince me to change the 5 mm OF **for my machines**:
  - # of published papers agreeing on factor?
  - Doing my own, independent simulation? (Time, resources)
  - CyberKnife-wide consensus? ("Lets all decide on a number")
- **IF** we change, how do we account for it in medical literature (e.g. trigeminal neuralgia)?
  - OF is usually not mentioned in physicians' papers
  - Potential for errors in retrospective analyses
- We will have to discuss soon!

OAR Width vs. Detector Size



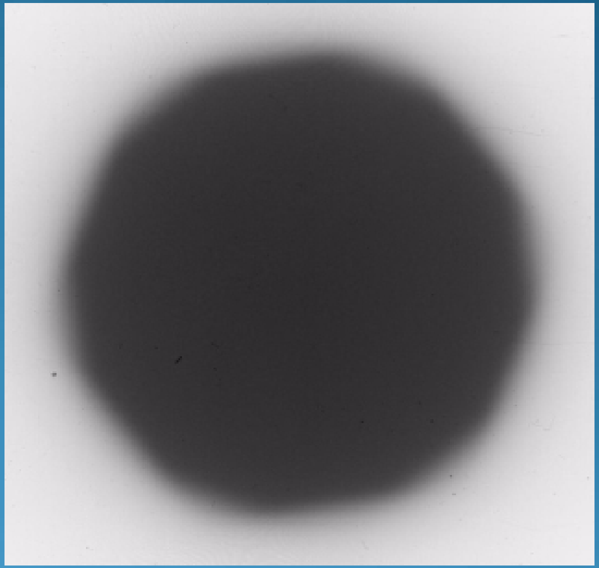
- Width of PTW60012 diode compared to small collimator OARs
- Use film as alternative? Other issues …
- Do we need to de-convolve?
- No published literature (yet)

Outline

- Reference dosimetry
  - TG 51
  - Detectors
  - Independent output check
- Relative Dosimetry
  - Output Factors
  - OARs
- Practical Comments on taking Beam Data
  - Tools needed
  - Time required
  - Order of measurement

Tools needed

- Water phantom:
  - 3D tank with CAX correction
  - Be able to program star-pattern for IRIS
- Detectors:
  - (Farmer chamber)
  - Chamber with length < 1 cm
  - Diode & Reference Diode
    - PTW60012 (current standard)
    - Sun Nuclear Edge detector (hear lots of good things about it)
    - Other diodes
- Other Detectors (Bang gels, Diamond detectors, film …)



How much time is required?

	1 Fixed Collimator	1 IRIS collimator	Total/nozzle (hours)	Total (hours)
OF (3 SADs)	10 min	10 min	2	4
TPR*	1.5 – 2 hrs	1.5 – 2 hrs	18 - 24	36 - 48
OCR*	1.5 – 2 hrs	1.5 – 2 hrs	18 - 24	36 -48
MC data acqu.	N/A	N/A	1	2
TG 51	0.5-1	N/A	0.5 - 1	0.5 - 1
Total	3.5 - 5	3-4	40 - 51	78.5 - 103

- No automated tool to move robot ☹
- Time depends on position of robot teach pendant (outside room vs. inside room for each depth change)
- NOT Accuray recommended to watch by camera only …

Order of Measurement

1. OF first!
   - Most difficult
   - Check inverse square law first (diodes go bad …)
2. TPR, PDD, OCR
   - Fixed collimators first, then IRIS
   - TPRs for all cones
   - Then PDD for annual/quick reference!
   - OCRs for each cone
3. Process fixed cone data (ready to go live!)
4. Then process IRIS during the day, fixed cone MC during night
5. Last comes IRIS MC
6. Most efficient way to treatment!

Conclusion

- We have learned how to do TG 51 for CK
- The smallest cones remain a challenge, but …
- … we have several published papers on OF now
- Follow the literature
- Evaluate new detectors for suitability
- Definitely need more efficient beam data taking tools