

# Lessons Learned from IROC Houston Audits



**IROC**<sup>™</sup>  
IMAGING AND  
RADIATION ONCOLOGY CORE  
*Global Leaders in Clinical Trial Quality Assurance*

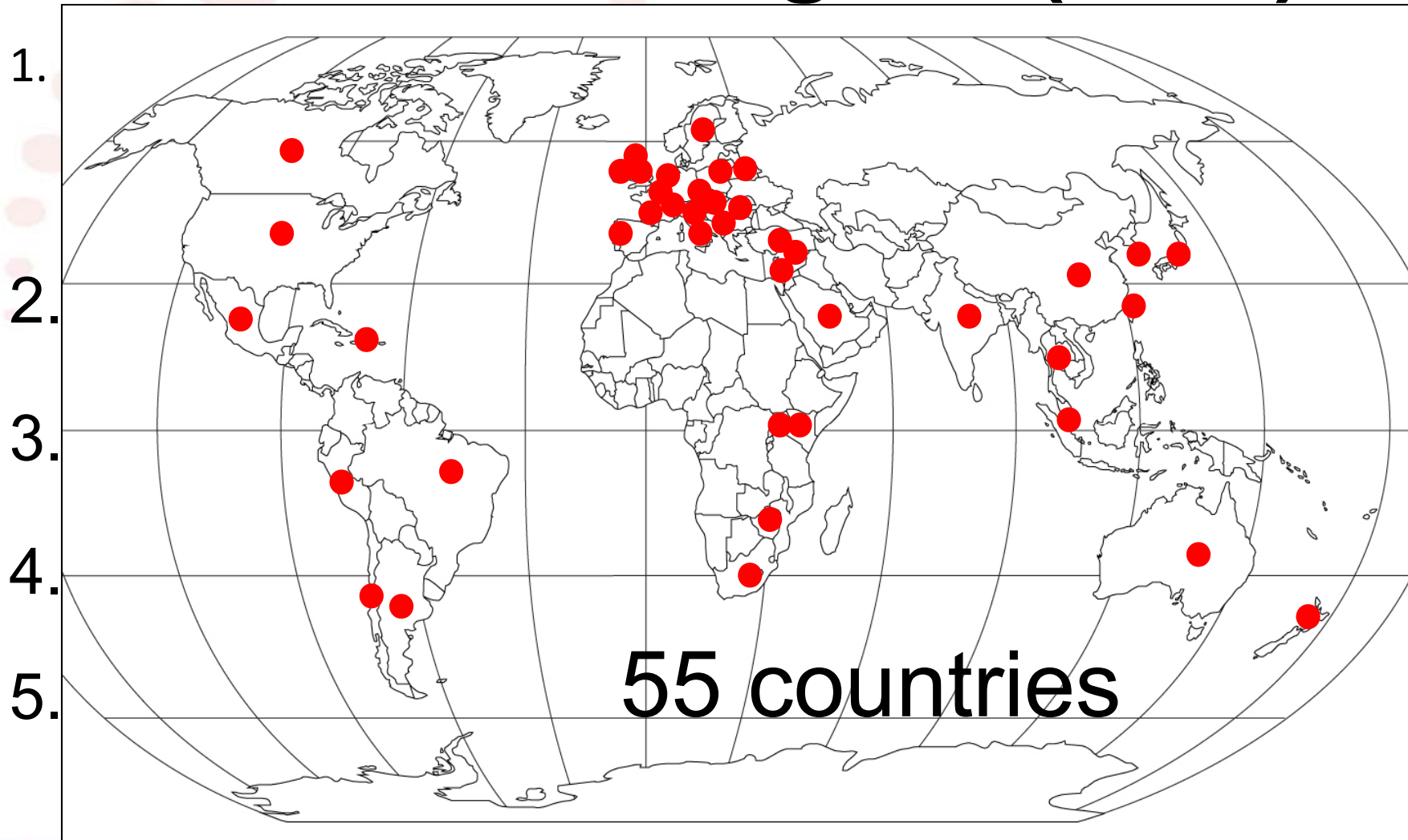
**ACR**  
AMERICAN COLLEGE OF  
RADIOLOGY

David Followill  
2016 AAPM Summer Meeting  
August 3, 2016

# Mission

1. Assure NCI and cooperative groups that institutions participating in clinical trials deliver prescribed doses that are comparable and consistent. (Minimize dose uncertainty)
2. Help institutions to make any corrections that might be needed.
3. Report findings to the community.

# IROC QA Program (2015)



# IROC-H Verification of Delivery of Tumor Dose

Reference calibration  
(NIST traceable)

Evaluated by  
IROC Dosimeters

×

Correction Factors:  
Field size & shape  
Depth of target  
Transmission factors  
Treatment time

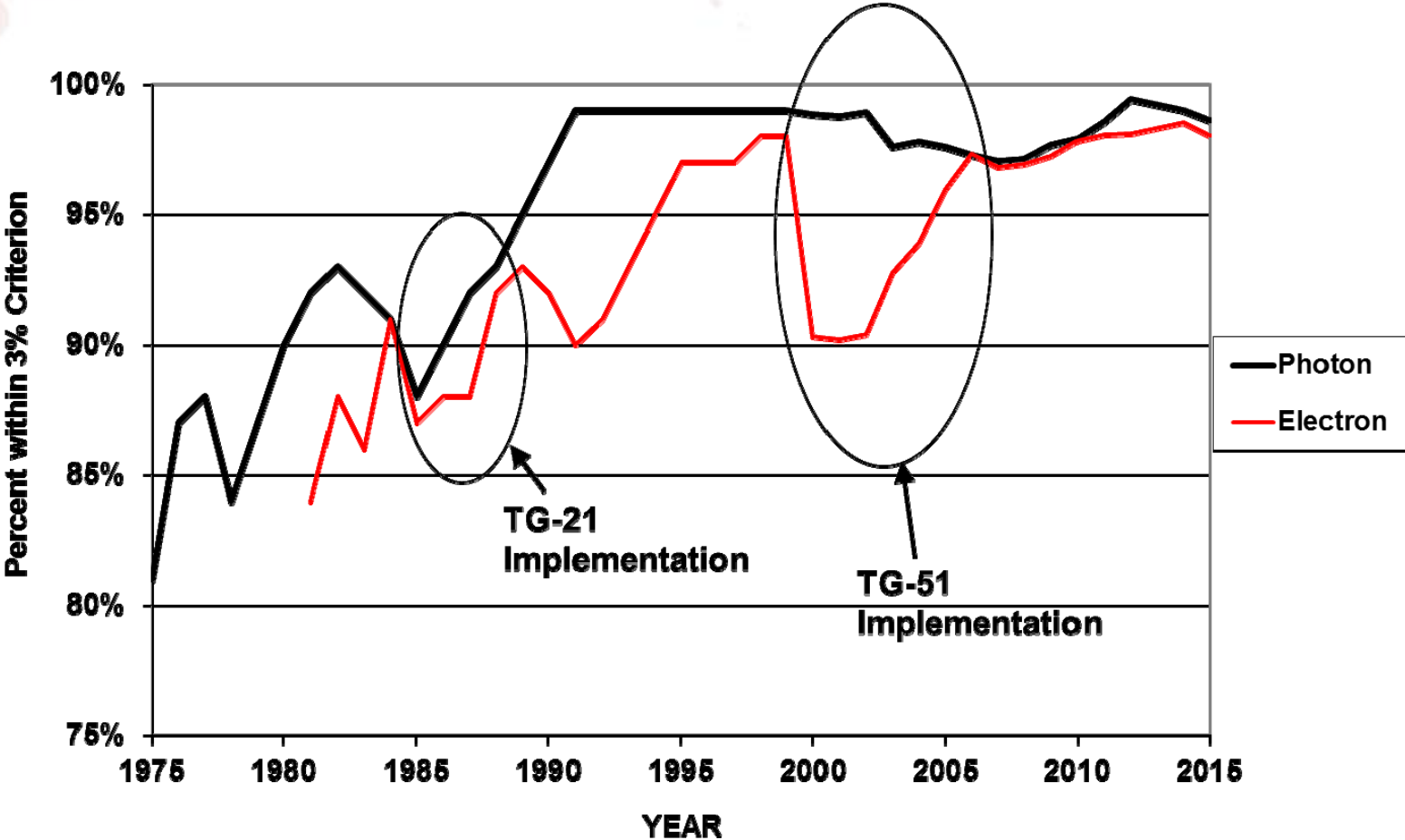
Evaluated by  
IROC visits and  
chart review

Tumor Dose

Evaluated by  
IROC phantoms

# On-Site Dosimetry Review Audit

**BEAM CALIBRATION  
IROC Houston Onsite Visits**



# TG-51 Addendum

## Addendum to the AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon beams

Malcolm McEwen<sup>a)</sup>

*National Research Council, 1200 Montreal Road, Ottawa, Ontario, Canada*

- Defines reference class chambers ( $V \geq 0.05 \text{cm}^3$ ) performance (Table III)
- Includes new chamber models
- New radial beam profile correction (FFF beams)
- Provides clarity but also reaffirms the recommendations of TG-51

# Ion Chambers - Photons

- ADCL calibrated 0.6 cm<sup>3</sup>
  - Smaller volume chambers (> 0.05 cm<sup>3</sup>) okay if traceable to another 0.6 cm<sup>3</sup> and meets requirements of Table III in addendum
  - **NO parallel plate chambers**
  - Waterproof (Go ahead and get one)
    - Most common: Exradin A12, PTW 30013
  - Non waterproof needs a 1mm PMMA sleeve that does not leak!

# Ion Chambers - Electrons

- Parallel-plate or cylindrical chambers okay
  - Cylindrical for energies > 6 MeV per protocol ( $R_{50} \geq 2.6$  cm)
  - Cylindrical = parallel plate if care in placement

	P11	PTW Roos	Welhoffer Roos	Marcus
5	1.008 (n=1)			
6	1.002 ± 0.1% (n=3)	1.000 (n=1)	0.996 ± 0.3% (n=2)	1.002 (n=1)
7	1.009 (n=1)			
8	1.006 (n=1)			
9	1.003 ± 0.1%(n=2)	0.998 (n=1)	0.996 (n=1)	1.000 (n=1)
12	1.000 ± 0.1%(n=3)	0.997 ± 0.2% (n=2)	0.996 (n=1)	1.004 ± 0.1% (n=3)
16	1.003 ± 0.2%(n=3)	0.998 ± 0.2 % (n=2)	1.001 ± 0.0% (n=2)	1.001 ± 0.2% (n=2)
20	1.000 ± 0.1%(n=4)	1.000 (n=1)	1.000 ± 0.1% (n=2)	1.000 (n=1)

- Always use a parallel plate chamber for 4 MeV beams  
Caution as to where the inside surface of the front window is located



# Ion Chambers - Electrons

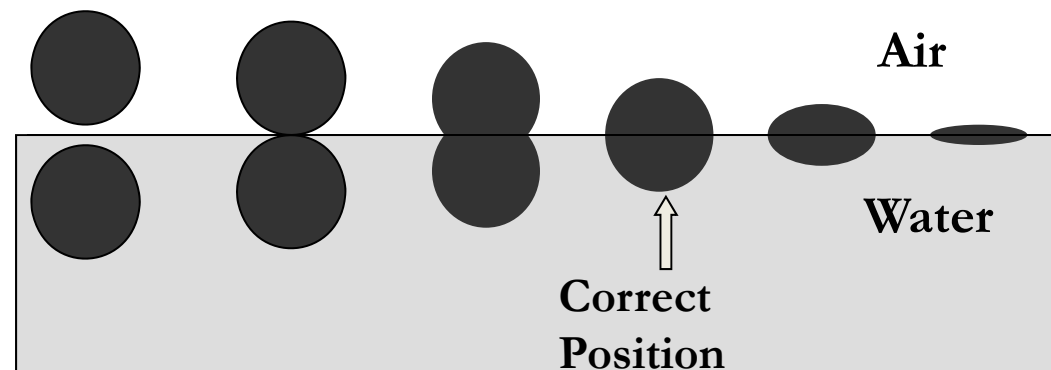
- All chambers must have an ADCL calibration coefficient **EXCEPT PARALLEL PLATE CHAMBERS**
  - AAPM recommendation is to cross calibrate parallel plate chamber with cylindrical chamber in a high energy electron beam (worksheet C *a la* TG-39)
  - ADCL  $N_{D,w}$  – **good**      TG-51  $k_{ecal}$  – **bad**
  - Use of  $(N_{D,w} \cdot k_{ecal})$  results in an error of 1-2%
  - ONE EXCEPTION – Exradin P11 seems to be okay**
  - FUTURE: TG-51 electron addendum new  $k_{ecal}$  values

# Measurement Techniques

- Accurate placement of cylindrical ion chamber at depth ( $<0.1$  mm)
  - Whether manual or electronic motor driven there must be a **starting reference point**

## Two techniques

### 1. Surface method

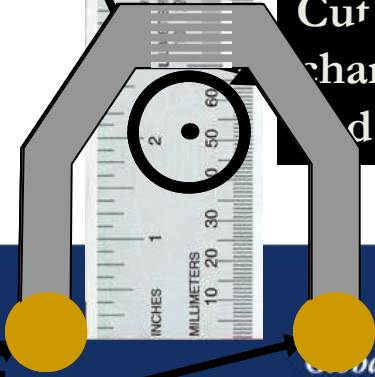
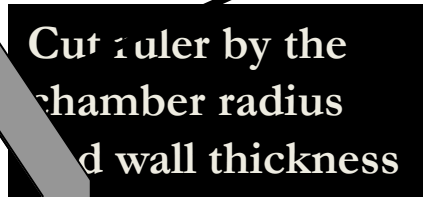


# Measurement Techniques

## 2. "Cowboy" method



- Accuracy depends on cutting ruler
- Used for reference starting point
- Periodic check of depth

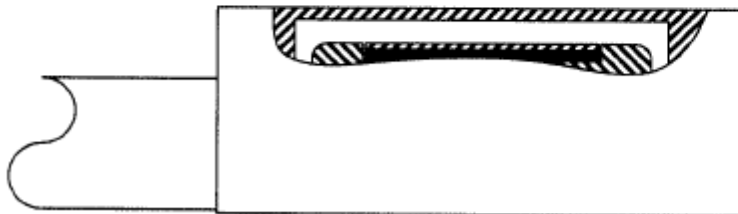


# Measurement Techniques

- Parallel plate ion chambers
  1. Flat surface makes it easy to measure depth
  2. Accurate ruler needed
  3. Must know where the inside surface of the front window is located

## Spokas Parallel Plate Chamber Model A11, P11 or T11

Collecting Volume: 0.6 cc  
Nominal Calibration Factor: 5.5 R/nC (TG-21)  
Nominal Calibration Factor: 48.3 Gy/ $\mu$ C (Air Kerma)



**Centroid of Collecting Volume:** 2.0 mm from window surface

**Collector Diameter:** 20.0 mm

**Window-Collector Gap:** 2.0 mm

**Window Thickness:** 1.0 mm

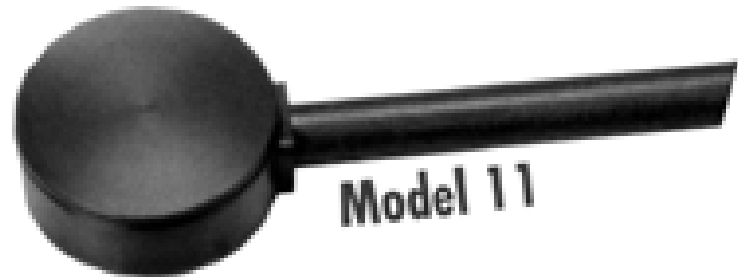
**Window, Collector and Guard Material:**

A11 – C552 Shonka air-equivalent plastic

P11 – D400 polystyrene-equivalent plastic.

T11

**Stem:** 1 cm long;  
**Waterpr**  
**Venting**  
body an  
inside tu  
**Buildup**  
chamber



# Effective Point of Measurement and Beam Quality

## Photons

10 cm

calibration depth

“point of measurement” is the center electrode of a cylindrical chamber and the front window of a parallel plate chamber

$\%dd(10)_x$

beam quality

## Electrons

$d_{ref}$

$R_{50}$

Beam quality should always be measured using the “effective point of measurement”

$0.6r_{cav}$

shift to effective point

$0.5r_{cav}$

100 cm

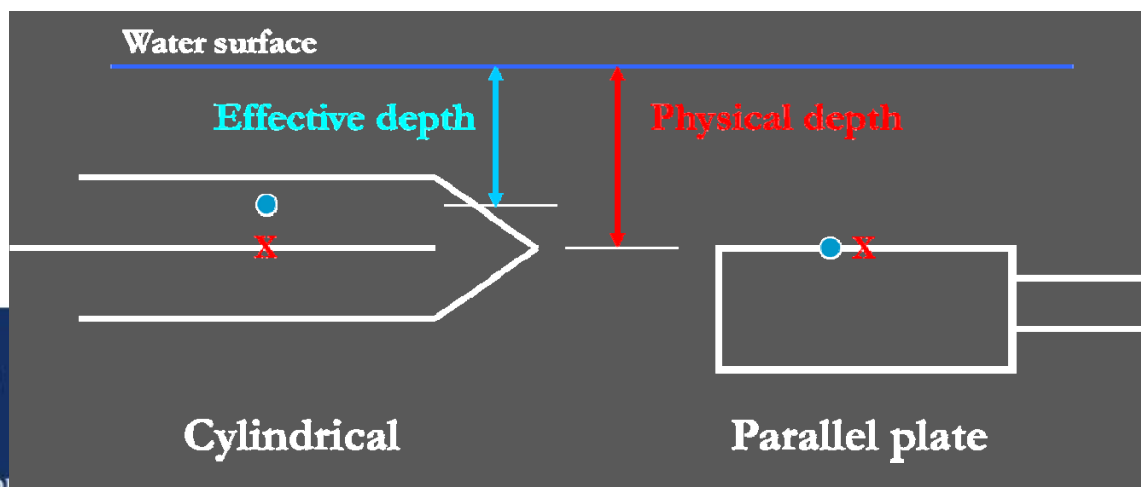
beam quality SSD

100 cm

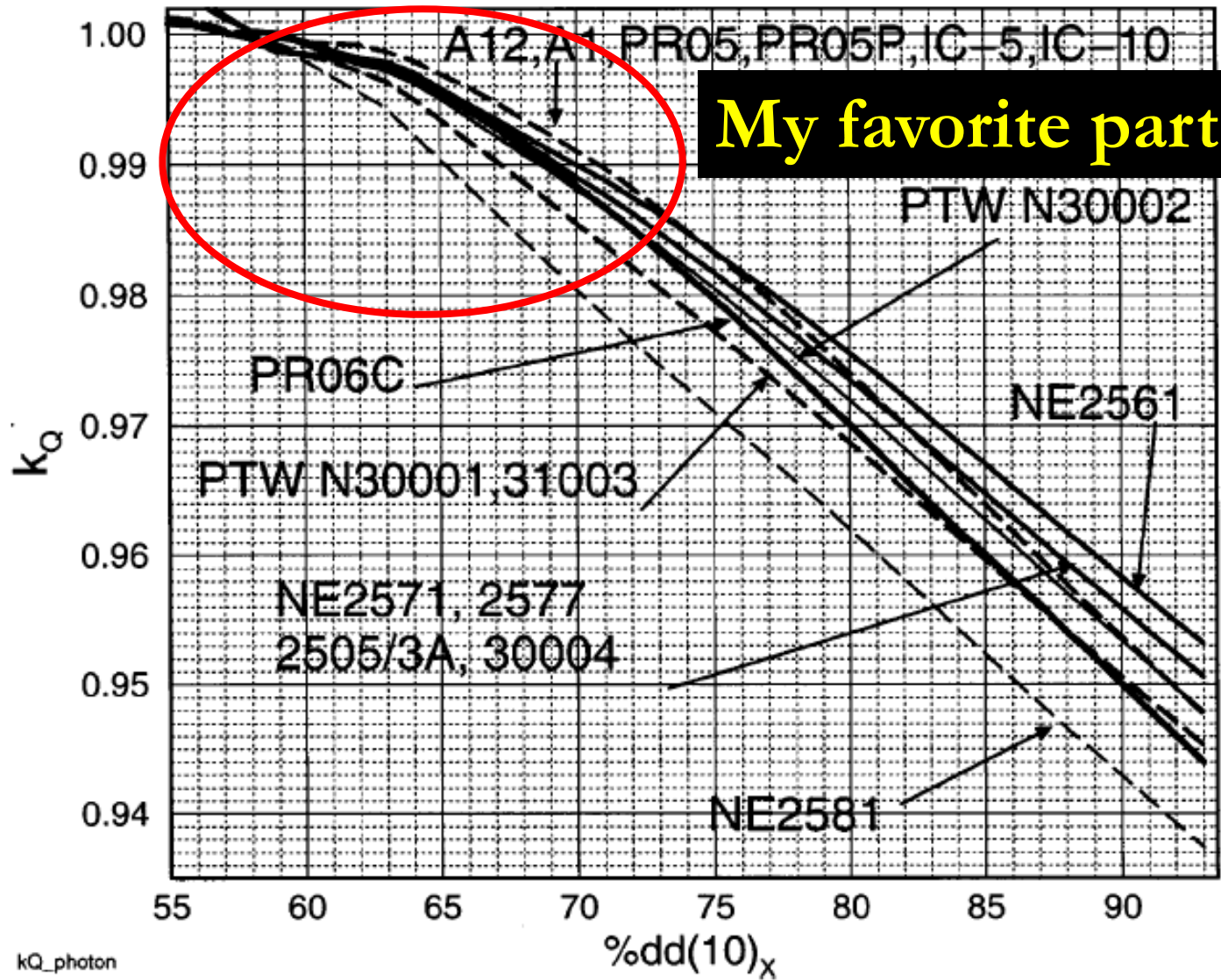
$10 \times 10 \text{ cm}^2$

field size

$\geq 10 \times 10 \text{ cm}^2$



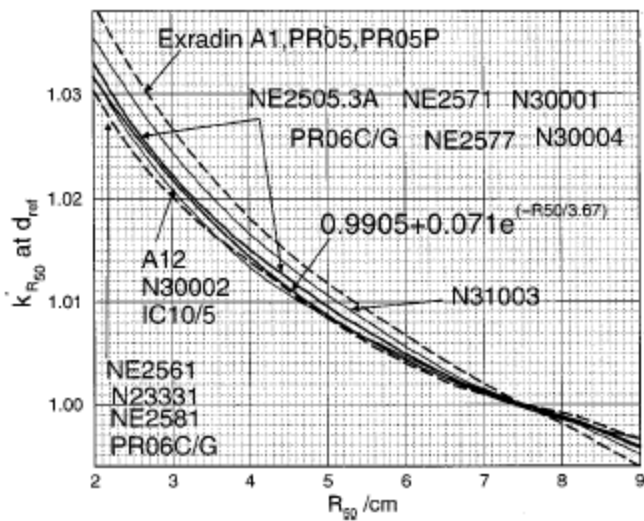
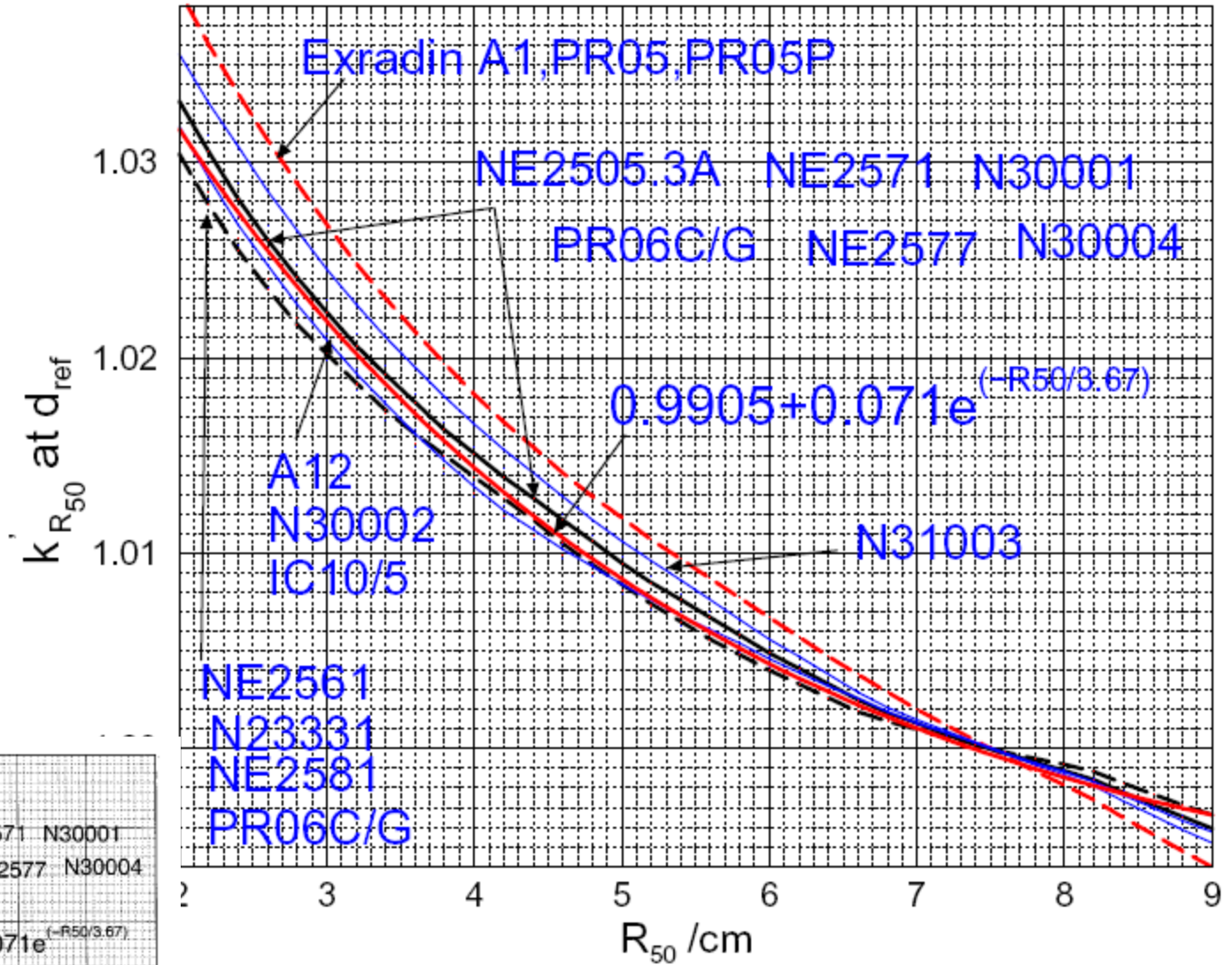
# Beam Quality Conversion Factors



ber

# Beam

- Electror
    - Only s
    - Good
- <http://v>  
papers



# Charge Measurements

$$M = P_{ion} \cdot P_{TP} \cdot P_{elec} \cdot P_{pol} \cdot M_{raw}$$

- $P_{TP}$  correction factor
  - Mercury thermometers and barometers most accurate (but they are no longer kosher)
  - Hg barometers T&G corrections needed
  - Quality aneroid or digital can be used
    - Check annually against a standard
    - Digital purchased with a calibration does not mean accurate but rather what it read at certain pressures or temperatures



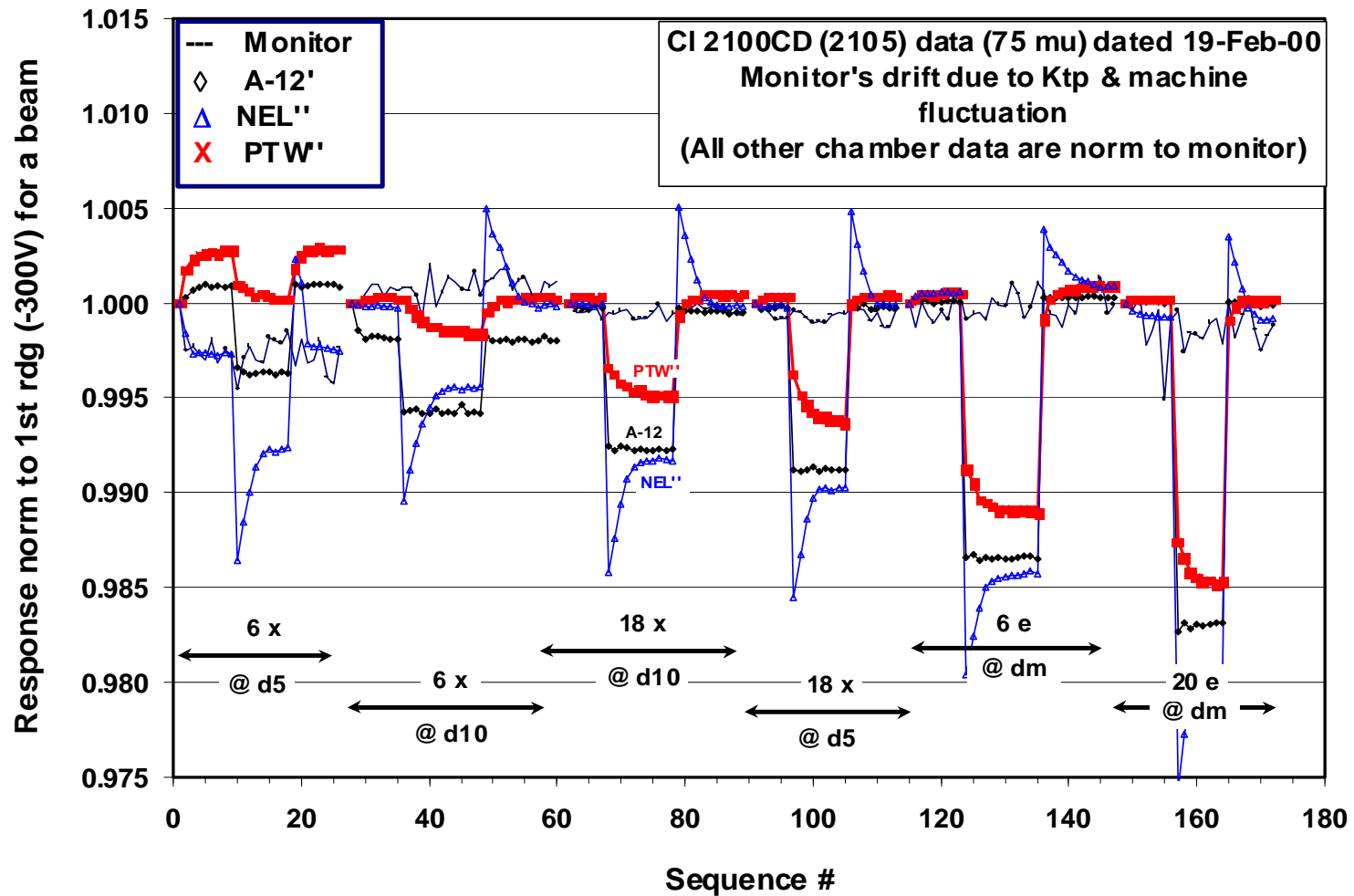
# Charge Measurements

- $P_{elec}$  correction factor
  - ADCL calibration for each scale needed
- $P_{pol}$  correction factor
  - Change polarity requires irradiation (600 to 800 cGy) to re-equilibrate chamber
  - Use of eq 9 in TG-51 requires that you preserve the sign of the reading or

$$P_{pol} = \frac{|M_{raw}^+| + |M_{raw}^-|}{2|M_{raw}|}$$

- $P_{pol}$  should be near unity for cylindrical chambers and slightly larger correction for parallel plate chambers

# Charge Measurements



# Charge Measurements

- Electron beam gradient ( $P_{gr}$ ) correction factor
  - No correction for photon beams since correction included in  $k_Q$
  - Only for cylindrical ion chambers
  - Ratio of readings at two depths

$$P_{gr} = \frac{M(d_{ref} + 0.5r_{cav})}{M_{raw}(d_{ref})}$$

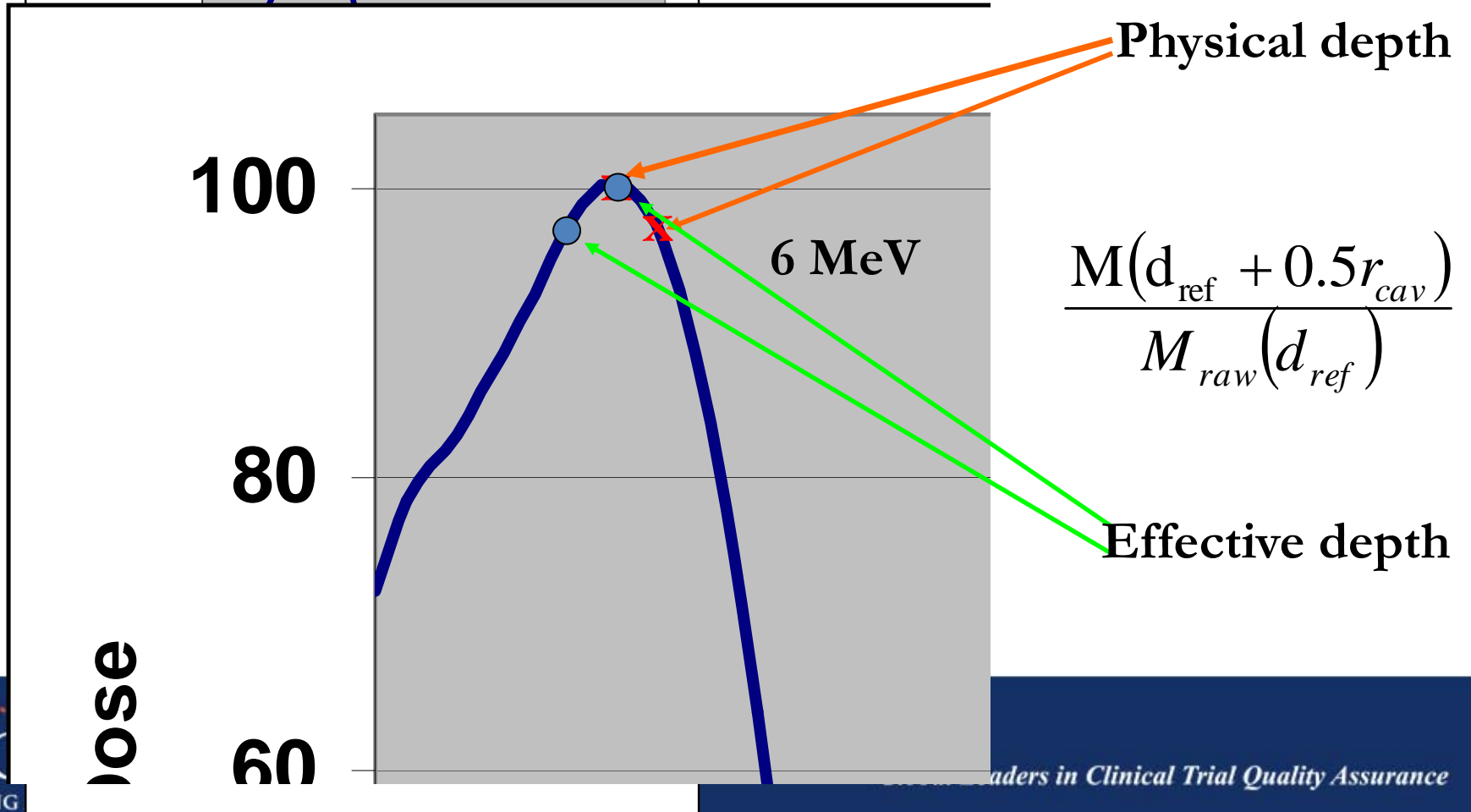
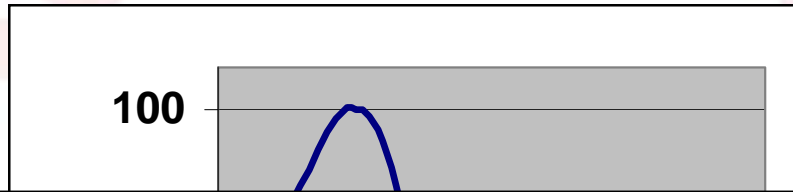
- The reading at  $d_{ref} + 0.5r_{cav}$  should have the same precision as the reading at  $d_{ref}$  since:

$$\text{Dose} = \cancel{M(d_{ref})} \cdot (\text{many factors}) \cdot \frac{M(d_{ref} + 0.5r_{cav})}{\cancel{M(d_{ref})}}$$

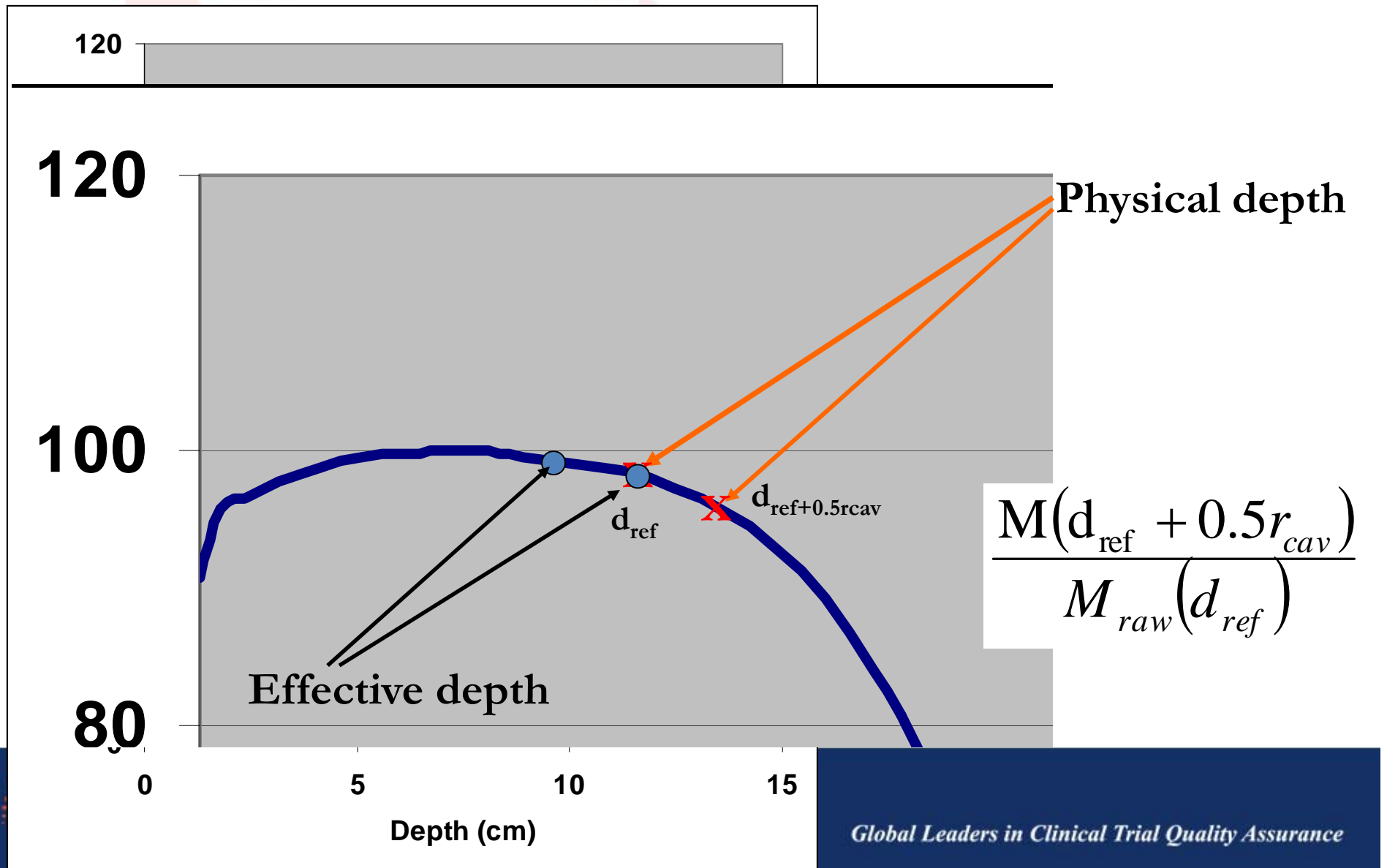
# Charge Measurements

- Electron beam gradient ( $P_{gr}$ ) correction factor
  - $E < 12$  MeV; typically  $P_{gr} > 1.000$
  - $E \geq 12$  MeV; typically  $P_{gr} \leq 1.000$
  - Why? Because for low electron energies  $d_{ref} = d_{max}$  and this places the eff. pt. of measurement in the buildup region thus a ratio of readings greater than 1.000.
  - At higher electron energies  $d_{ref}$  is greater than  $d_{max}$  and as such the eff. Pt. of measurement is on the descending portion of the depth dose curve thus a ratio of readings less than 1.000.

# Charge Measurements



# Charge Measurements



Global Leaders in Clinical Trial Quality Assurance

# Clinical Depth Dose

- Always measure using the effective point of measurement
  - Re-measurement not suggested for existing Linacs, **but TG-51 came out in 1999**. New Linacs should incorporate shift
- Always use the clinical depth dose (value TPS calculates) to make the correction from the calibration depth (10 cm) to the reference depth ( $d_{\max}$ )
  - Calibration now consistent with TPS dose calculation

# Clinical Depth Dose

- For photons – do not use the beam quality value  $\%dd(10)_x$  to take dose from 10 cm to  $d_{\max}$
- For electrons – depth dose correction for  $\geq 15/16$  MeV is significant  
**(~98.5% - 16 MeV and ~95.5% - 20 MeV)**
  - **Caution!!!** Super big problem if you use % depth ionization data (3-5% error for high energy electron beams)



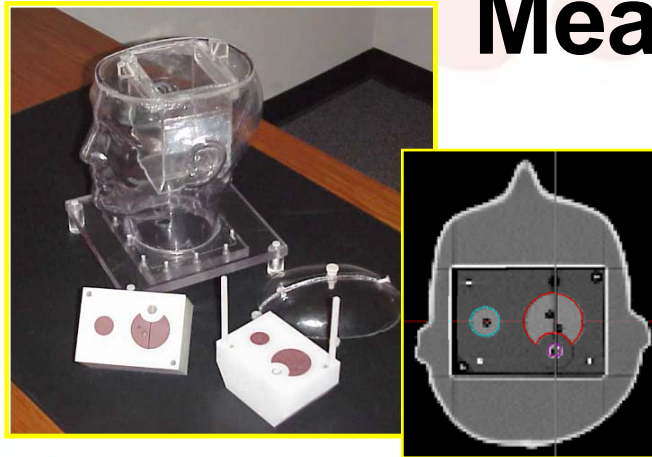
# MLC QA a la TG-142

TABLE V. Multileaf collimation (with differentiation of IMRT vs non-IMRT machines).

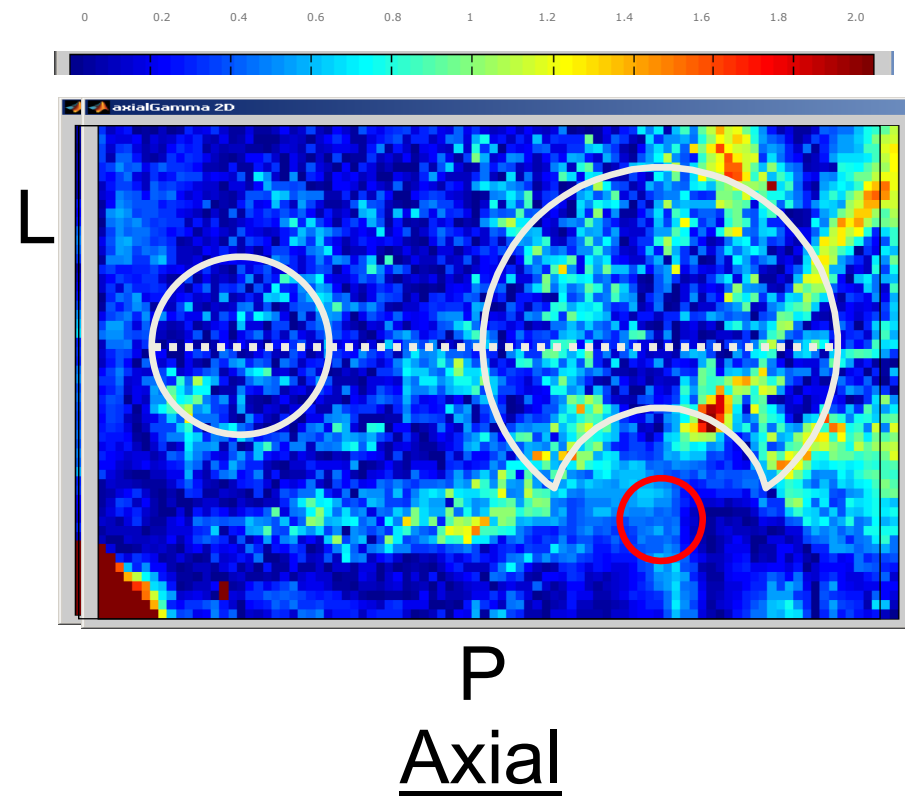
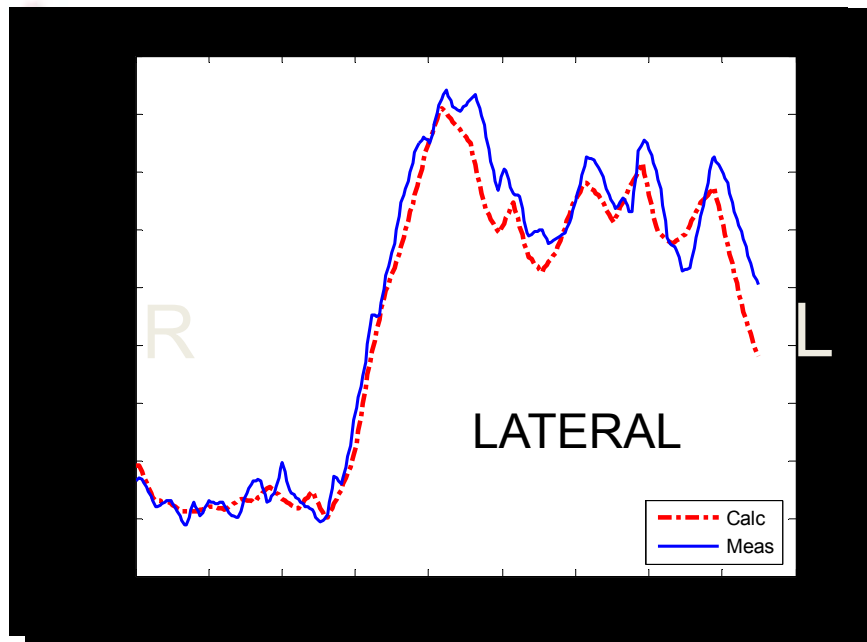
Procedure		Tolerance
	<b>Weekly (IMRT machines)</b>	
Qualitative test (i.e., matched segments, aka “picket fence”)		Visual inspection for discernable deviations such as an increase in interleaf transmission
	<b>Monthly</b>	
Setting vs radiation field for two patterns (non-IMRT)		2 mm
Backup diaphragm settings (Elekta only)		2 mm
Travel speed (IMRT)		Loss of leaf speed >0.5 cm/s
Leaf position accuracy (IMRT)		1 mm for leaf positions of an IMRT field for four cardinal gantry angles. ( <i>Picket fence</i> test may be used, test depends on clinical planning-segment size)
	<b>Annually</b>	
MLC transmission (average of leaf and interleaf transmission), all energies		±0.5% from baseline
Leaf position repeatability		±1.0 mm
MLC spoke shot		≤1.0 mm radius
Coincidence of light field and x-ray field (all energies)		±2.0 mm
Segmental IMRT (step and shoot) test		<0.35 cm max. error RMS, 95% of error counts <0.35 cm
Moving window IMRT (four cardinal gantry angles)		<0.35 cm max. error RMS, 95% of error counts <0.35 cm

**It's all about leaf position accuracy!**

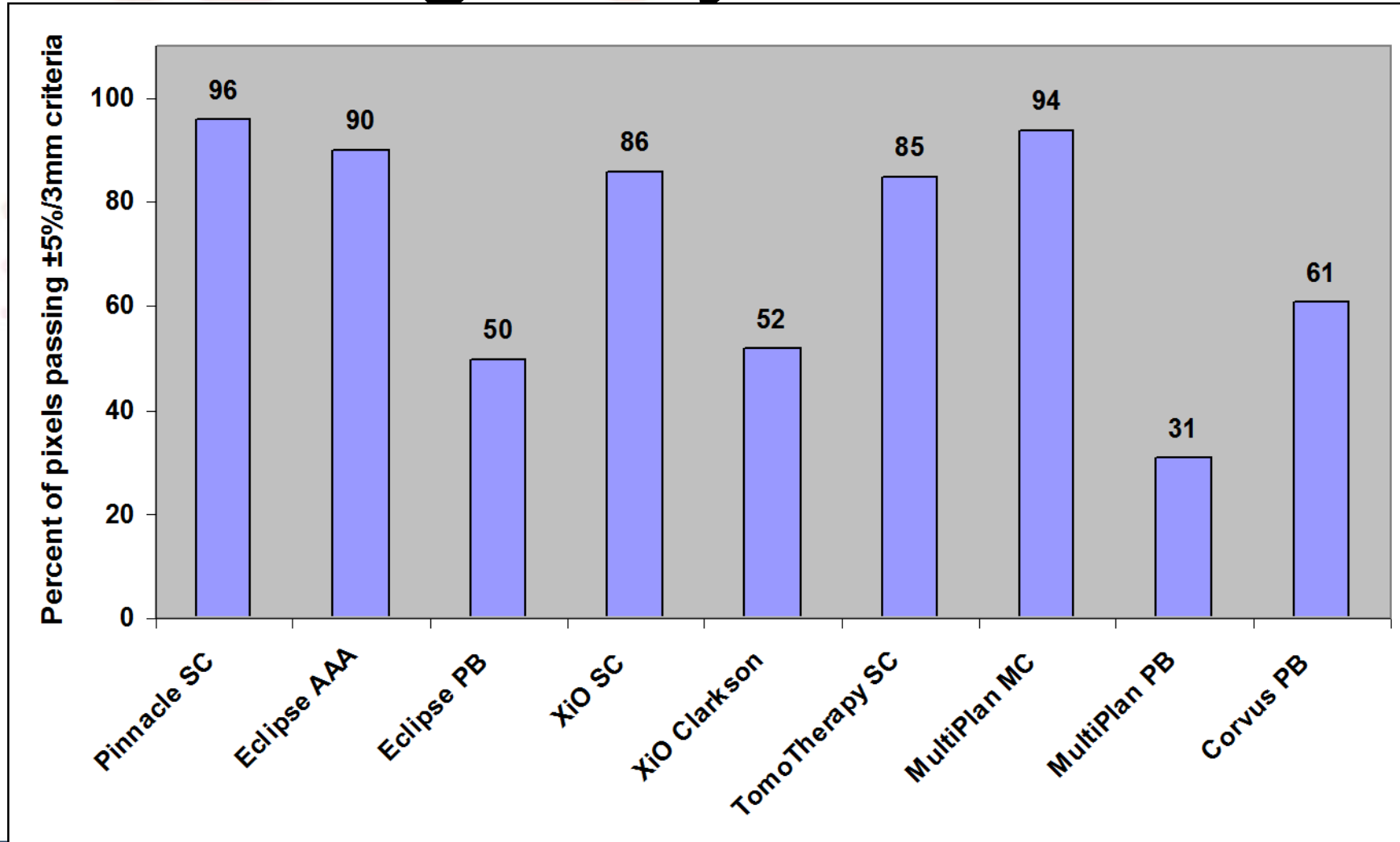
# Measurement vs. Monte Carlo



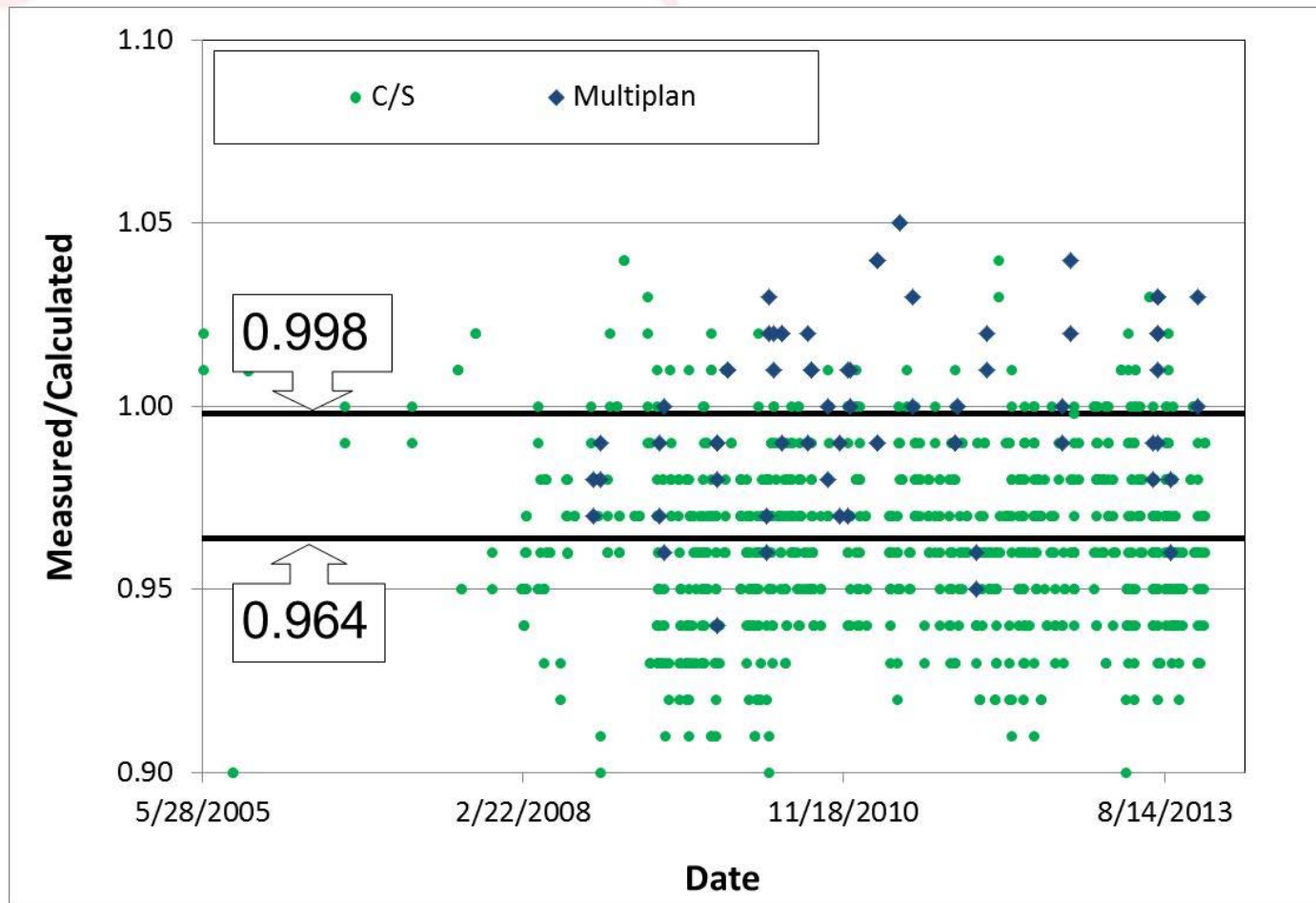
Criteria  
3%/2 mm



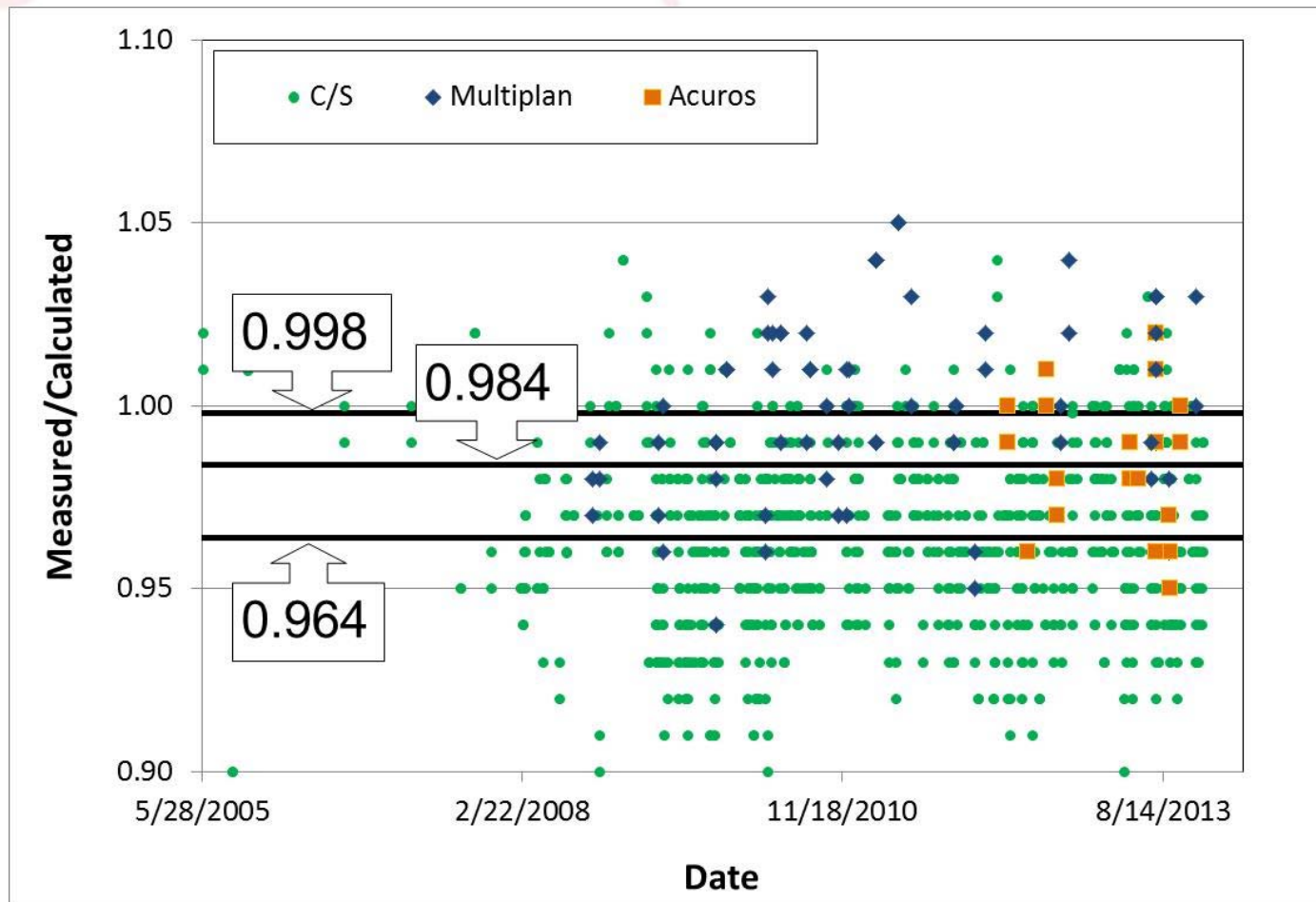
# Heterogeneity Corrections



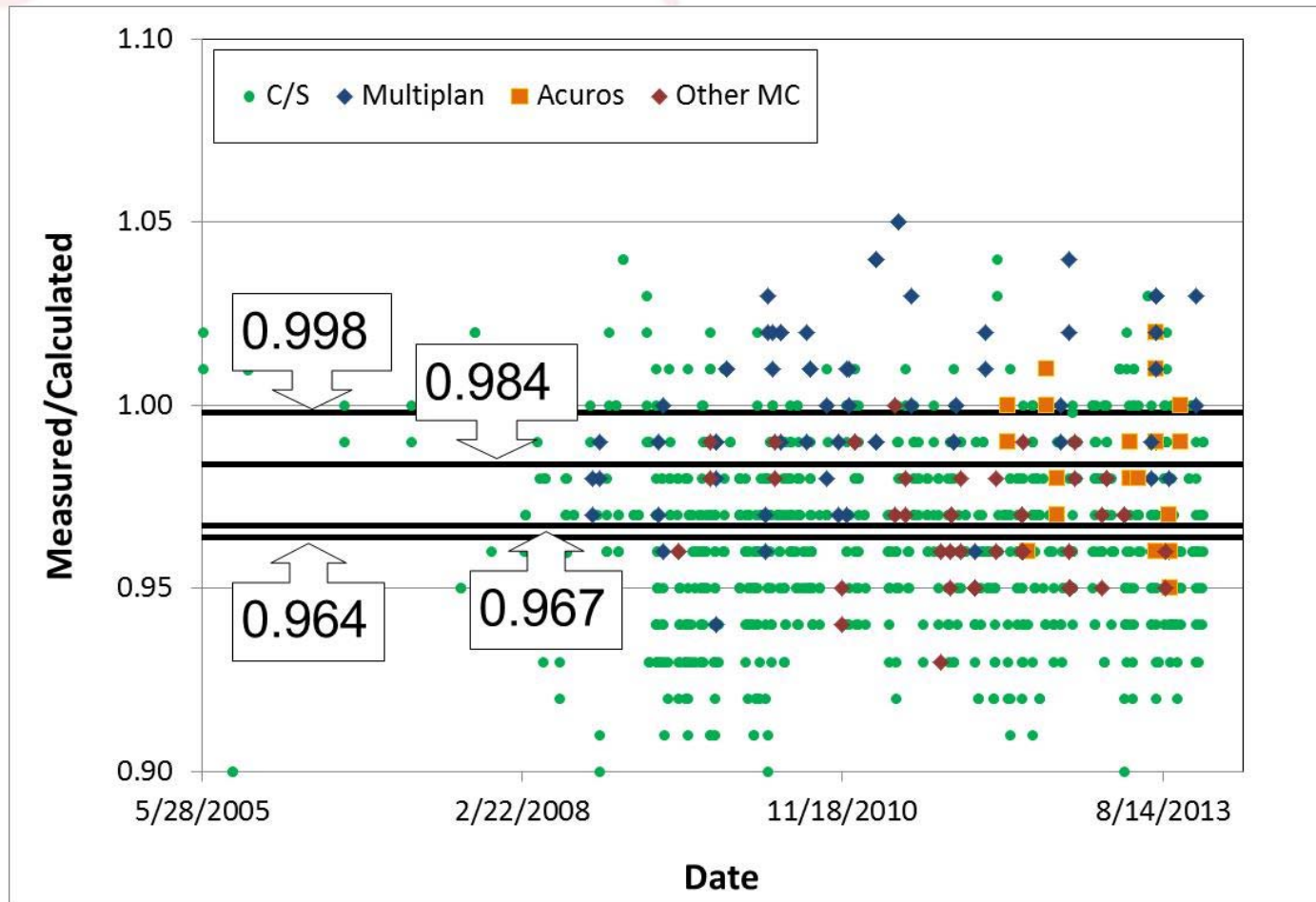
# Lung: TLD dose vs TPS calc



# Lung: TLD dose vs TPS calc

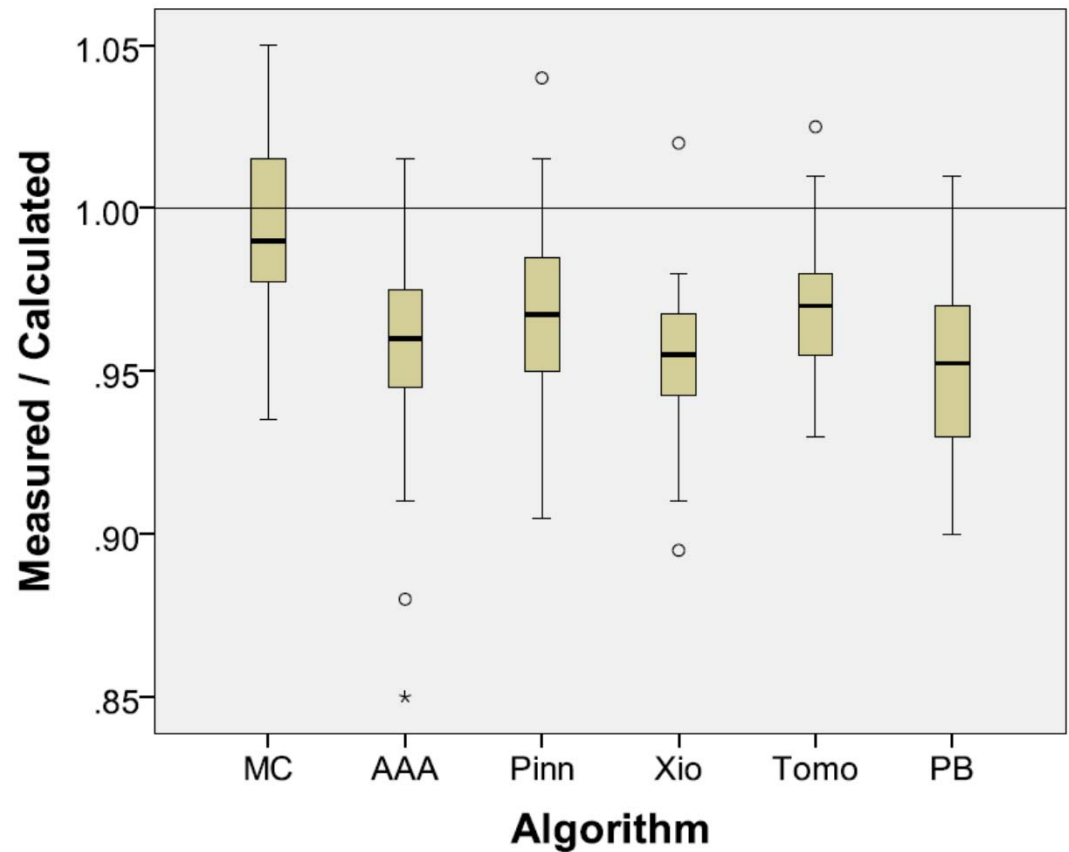


# Lung: TLD dose vs TPS calc



# TLD Dose Findings

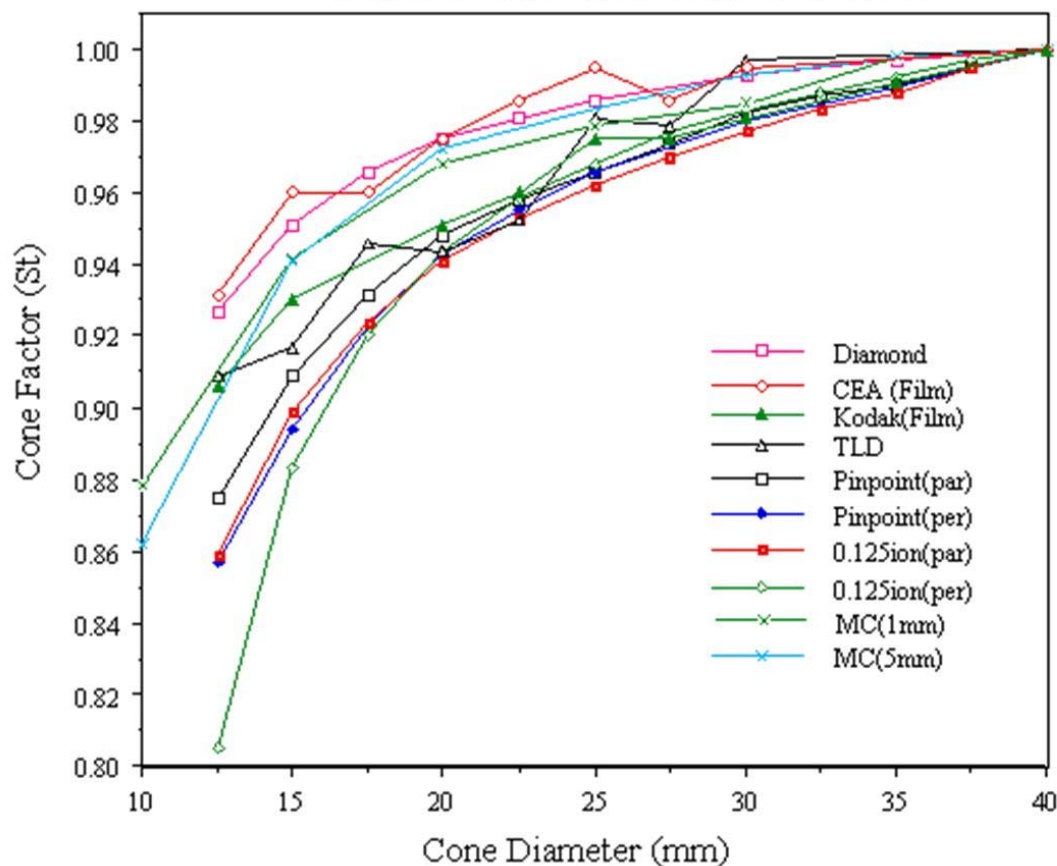
- Measured doses systematically lower than calculated doses for C/S AAA algorithms ( $p < 0.0001$ )
- No significant difference between C/S AAA algorithms



# Small Field Dosimetry

## What is the truth?

Total scatter factor with various detectors

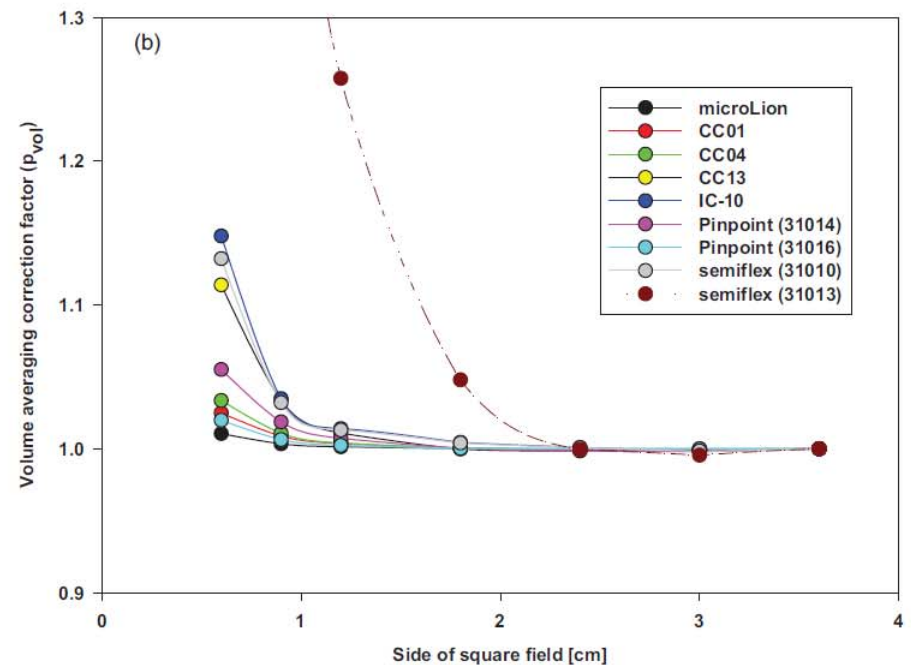
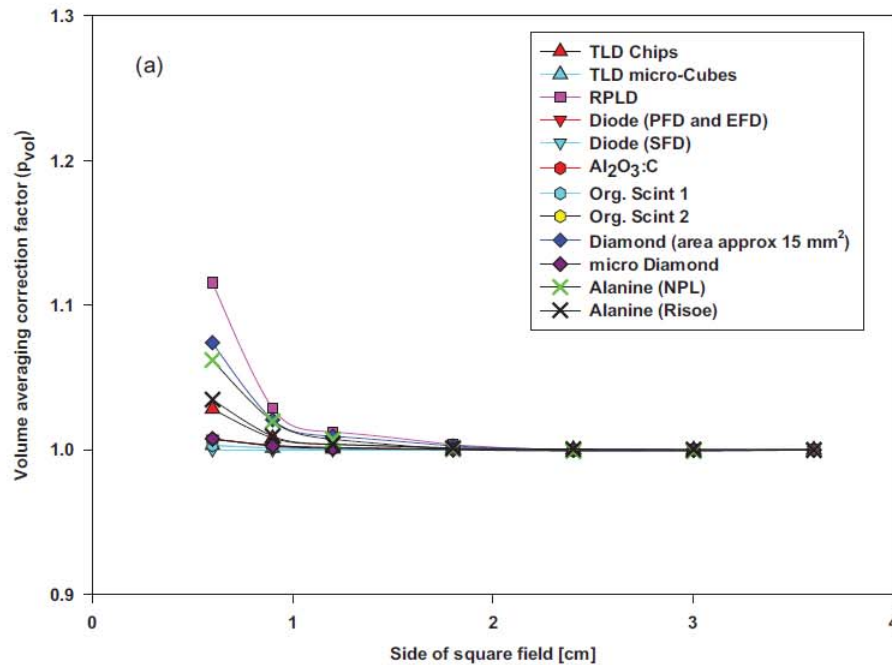


Help is on the way!

Joint AAPM/IAEA  
Small Field Dosimetry  
CoP will be published  
soon.



# Small Field Dosimetry Volume Averaging Correction

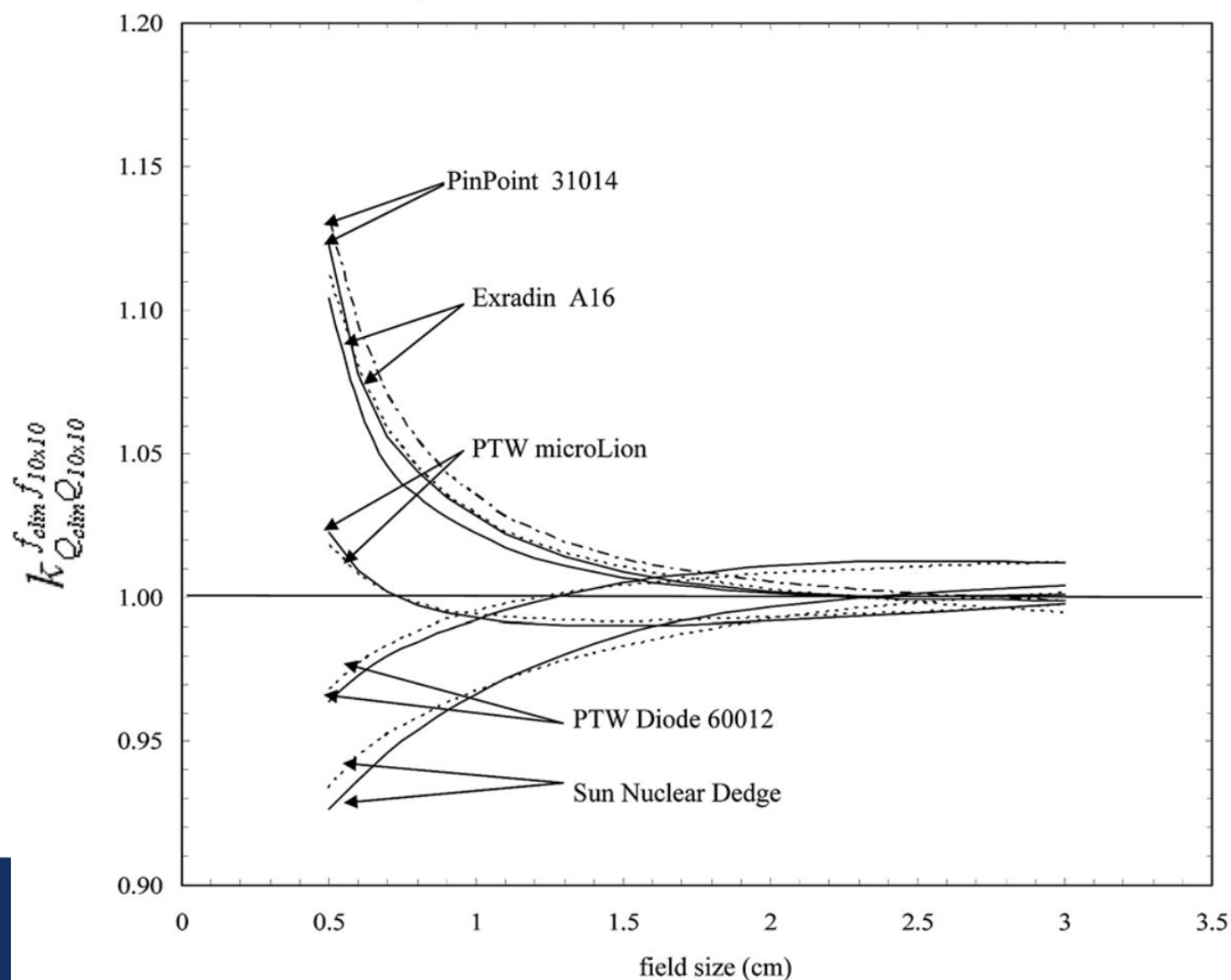


G. Azangwe, Med Phys. 41 (7) 2014

# Small Field Dosimetry Fluence Corrections

Situation is even worse if you consider using field sizes less than  $0.5 \times 0.5 \text{ cm}^2$

Francescon et al  
2011 data

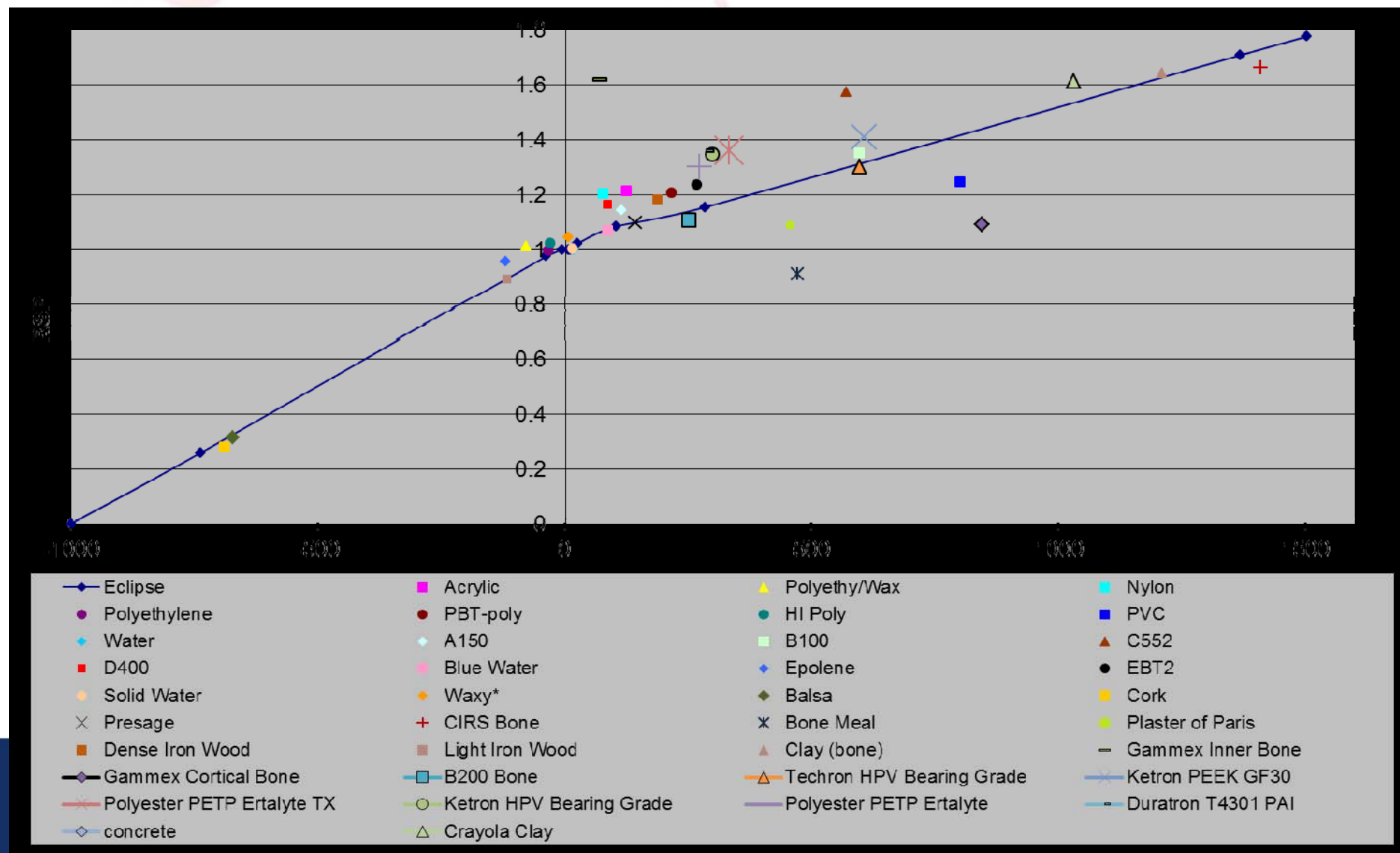


# Proton Therapy

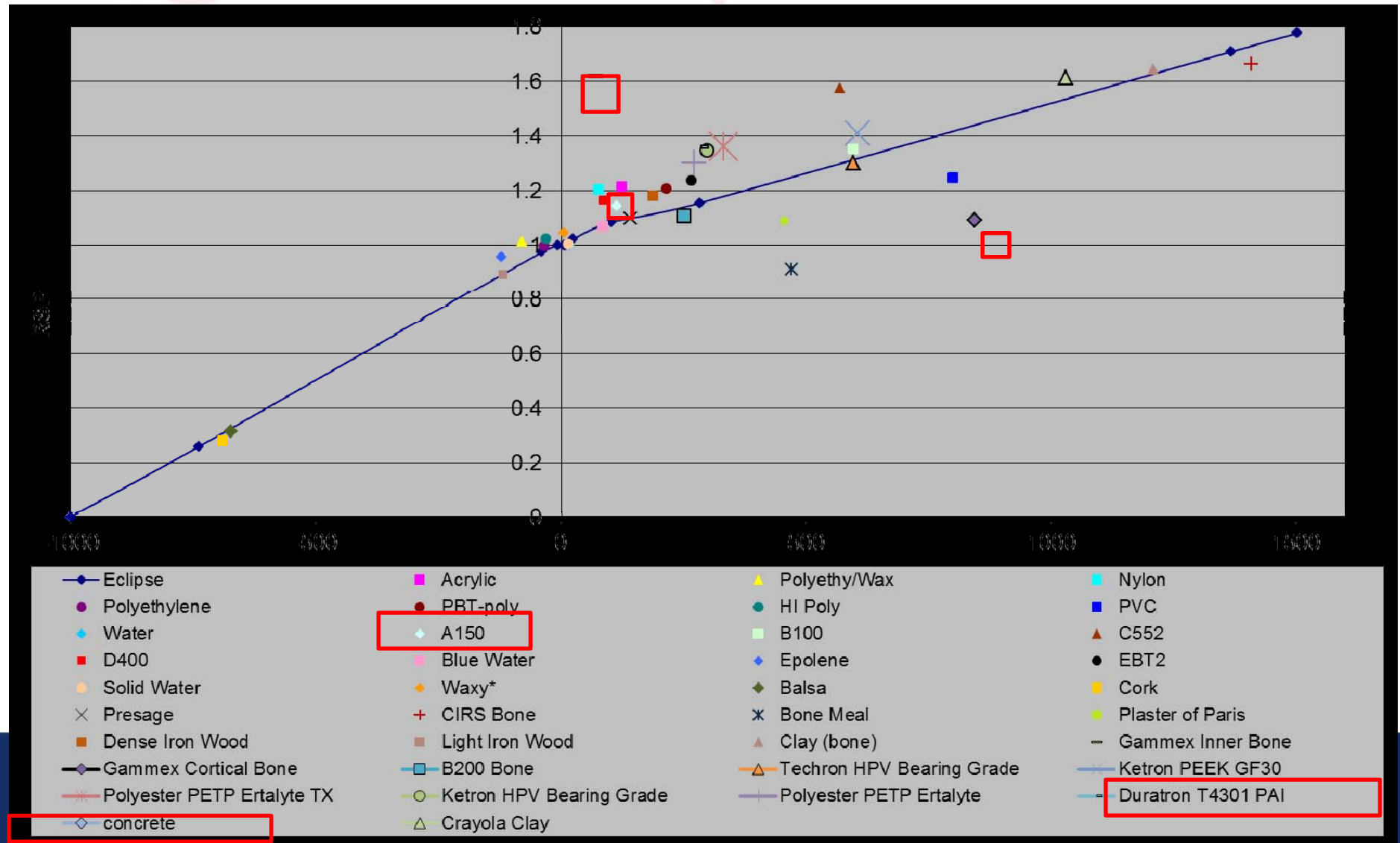
Human tissue: equal in the eyes of both photons and protons

Tissue Substitutes: There's discrimination, as they are not equal in the eyes of photons and protons

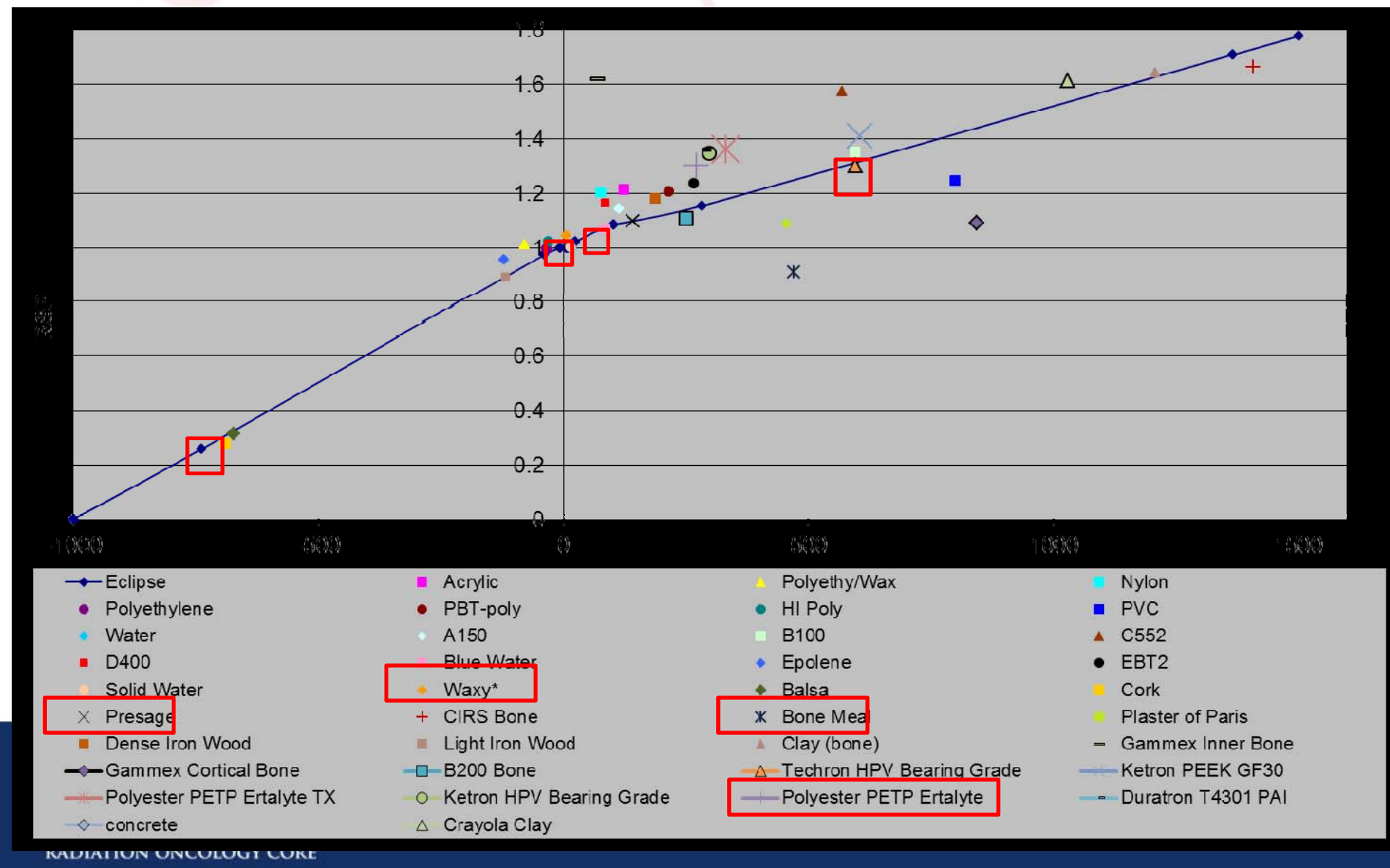
# Stopping Power vs. HU Curve



# Not so good.....



# Stopping Power vs. HU Curve



# Summary

- TG-51 Implementation is straightforward
  - Must read the protocol and follow the prescriptive steps
  - Many suggestions to clarify confusion have been made
- MLC QA is critical
- Heterogeneity correction algorithms are not all the same
- Small field dosimetry requires extra attention
- Proton tissue substitutes are unique
- IROC Houston QA Center is always available for assistance. Give us a call if you have questions.