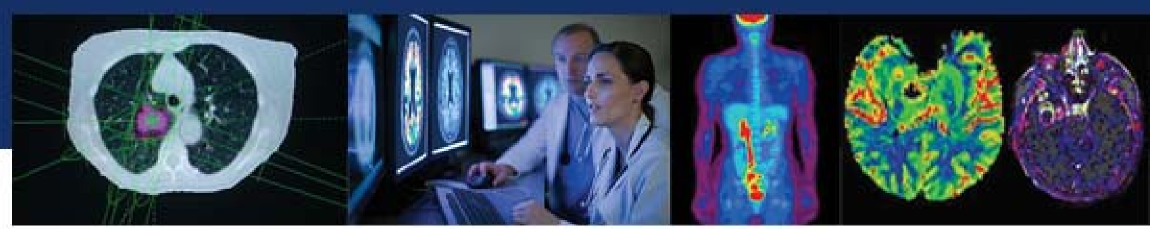
Lessons Learned from IROC Houston Audits



IROC™
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

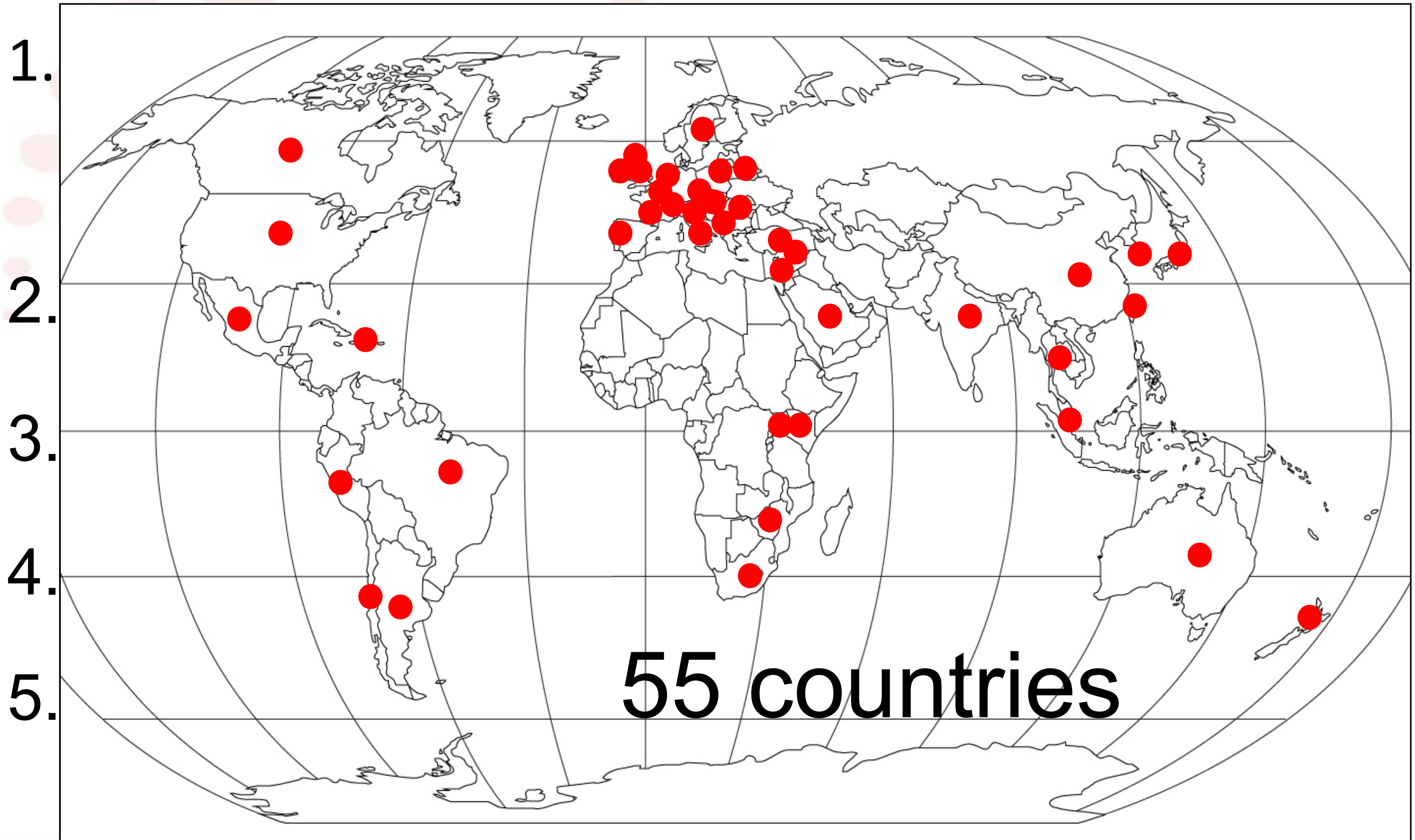
Mission

1. Assure NCI and cooperative groups that institutions participating in clinical trials deliver prescribed doses that are comparable and consistent. (Minimize dose uncertainty)

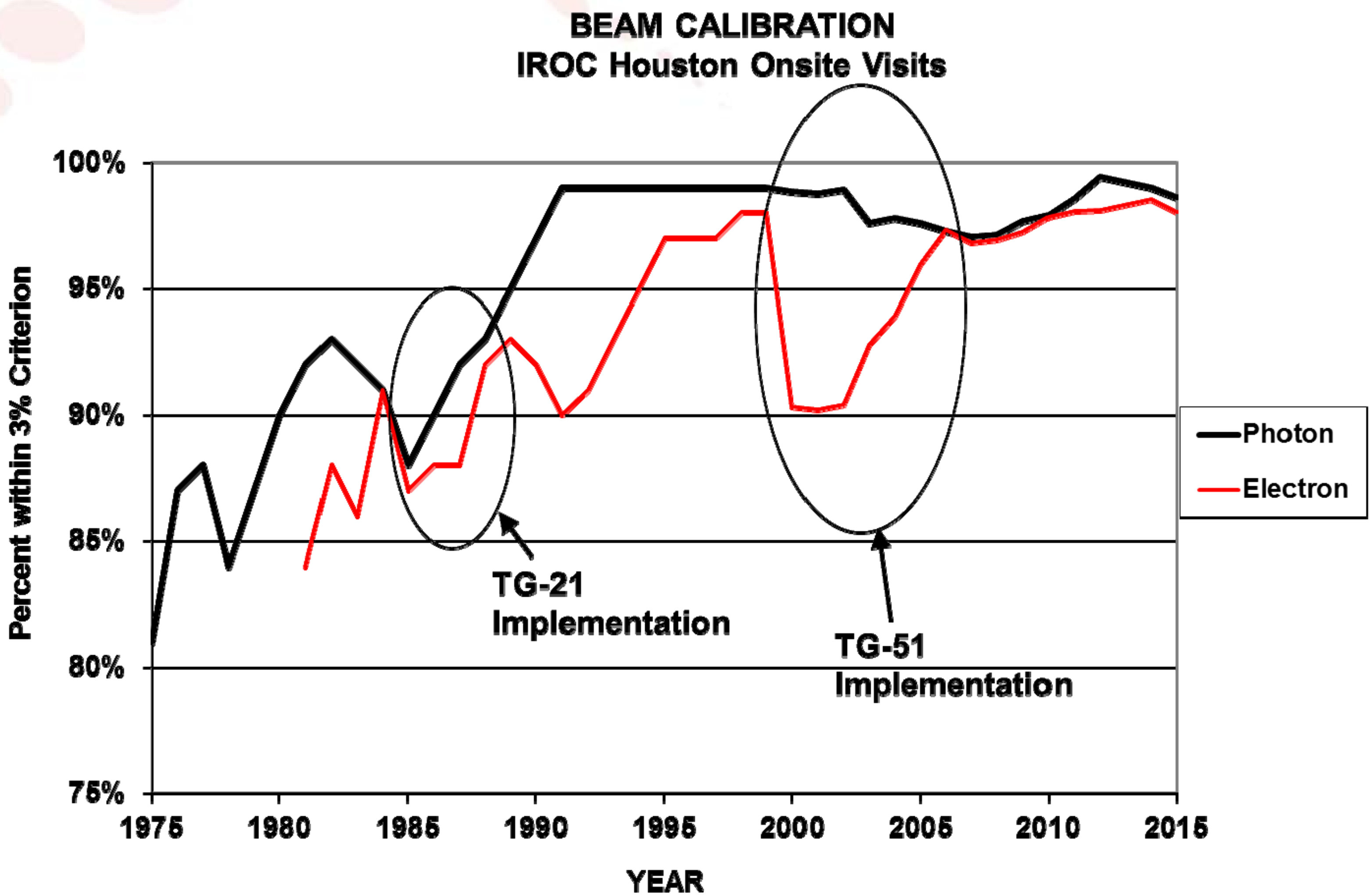
2. Help institutions to make any corrections that might be needed.

3. Report findings to the community.

IROC Houston QA Program (2015)



On-Site Dosimetry Review Audit



TG-51 Addendum

TABLE III. Specification of a reference-class ionization chamber for megavoltage photon-beam dosimetry. Note that upper-limit values at the reference depth are given, not standard uncertainties.

Measurand[a]	Specification
Chamber settling	Should be less than a 0.5% change in chamber reading per monitor unit from beam-on for a warmed up machine, to stabilization of the ionization chamber.
P_{leak}	< 0.1 % of chamber reading ($0.999 < P_{leak} < 1.001$)
P_{pol}	< 0.4 % correction ($0.996 < P_{pol} < 1.004$)
	< 0.5 % maximum variation in P_{pol} with energy (total range)
$P_{ion} = 1 + C_{init} + C_{gen} D_{pp}$[b]	
General	P_{ion} should be linear with dose per pulse.
Initial	Initial recombination should be less than 0.2%, that is, $C_{init} < 0.002$, for the TG-51 reference conditions[c].
Polarity dependence	Difference in initial-recombination correction between opposite polarities should be less than 0.1%.
Chamber stability	Should exhibit less than a 0.3%[d] change in calibration coefficient over the typical recalibration period of 2 years.

Ion Chambers - Photons

- ADCL calibrated 0.6 cm^3 seen most often
  - Smaller volume chambers (> 0.05 cm^3) okay if traceable to another 0.6 cm^3 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

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 ($N_{D,w} \bullet k_{ecal}$) results in an error of 1-2%

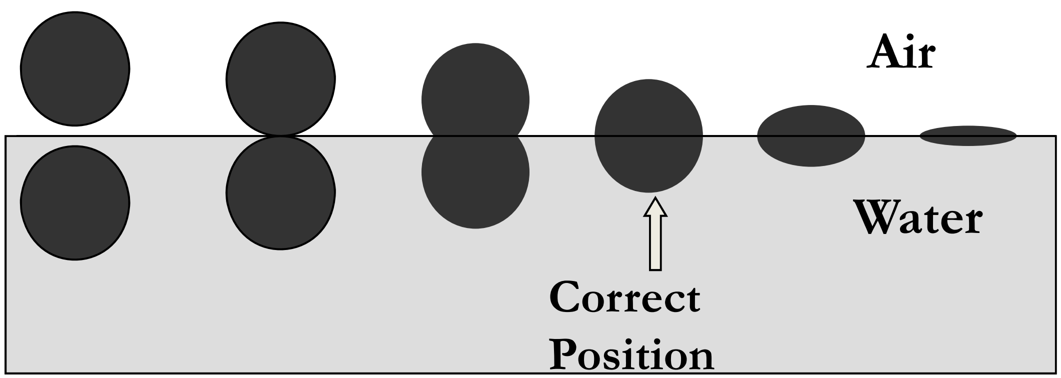
  ONE EXCEPTION – Exradin P11 seems to be okay
  - FUTURE: TG-51electron addendum new k_{ecal} values

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**

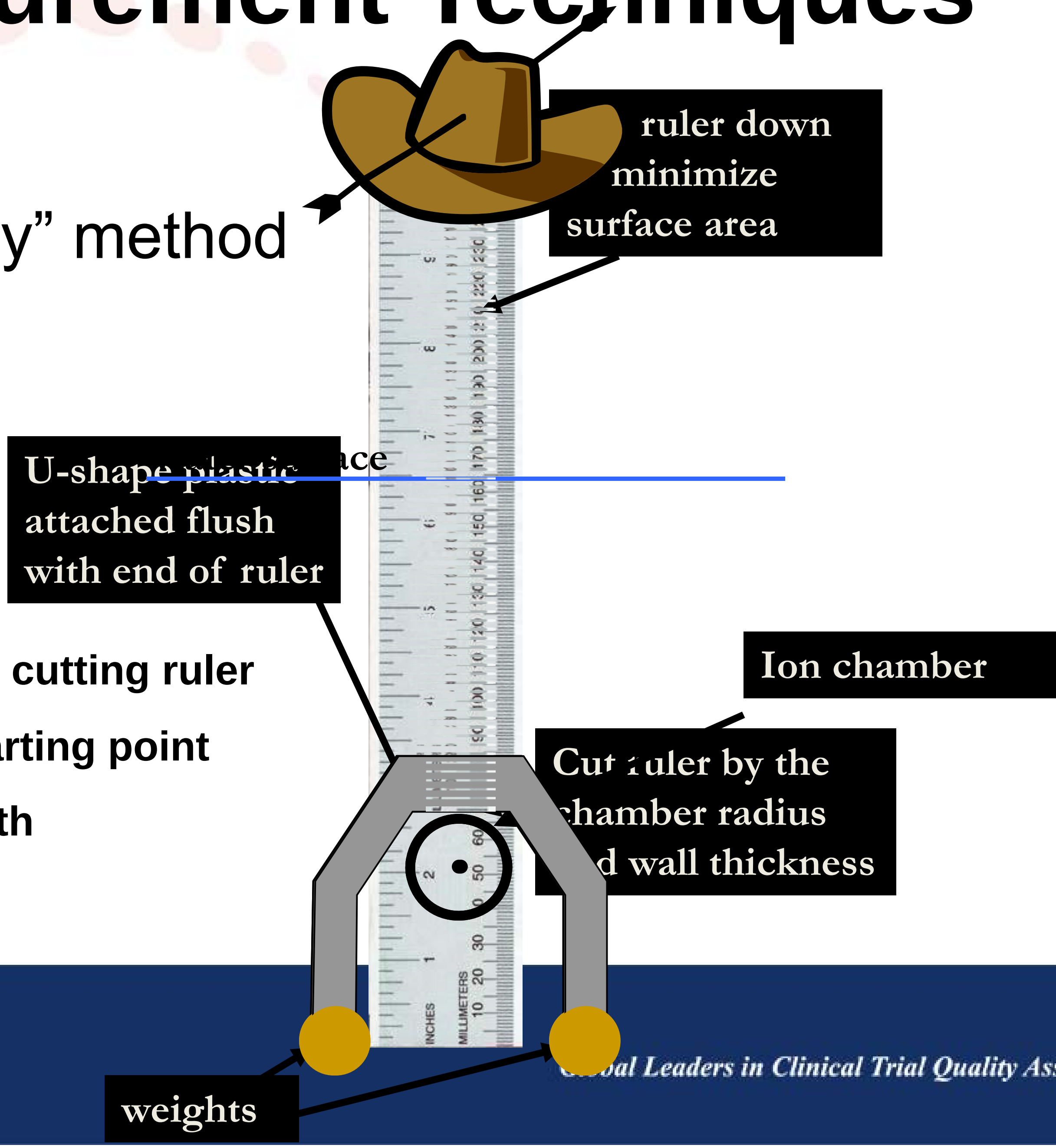
Two techniques

1. Surface method



Measurement Techniques

2. "Cowboy" method



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

Measurement Techniques

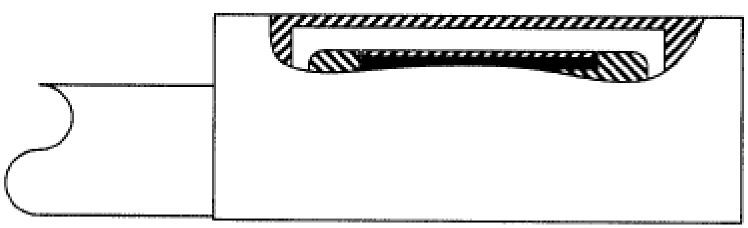
- Parallel plate ion chambers

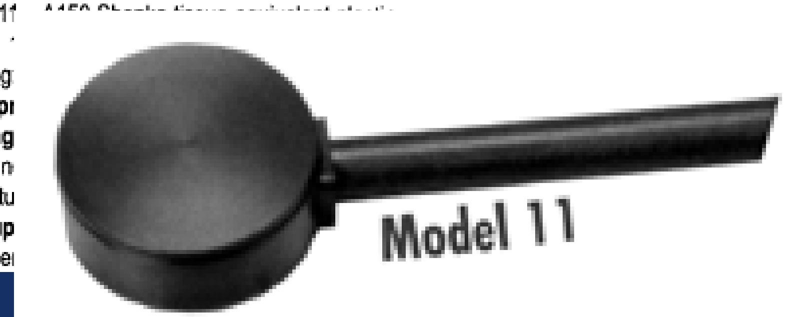
1. Flat surface makes it easy to measure depth
2. Accurate ruler needed
3. Must know where the inside surface of the front window is located

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/μC (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:
cm long
Waterpr
Venting
body an
inside tu
Buildup
chamber





Effective Point of Measurement and Beam Quality

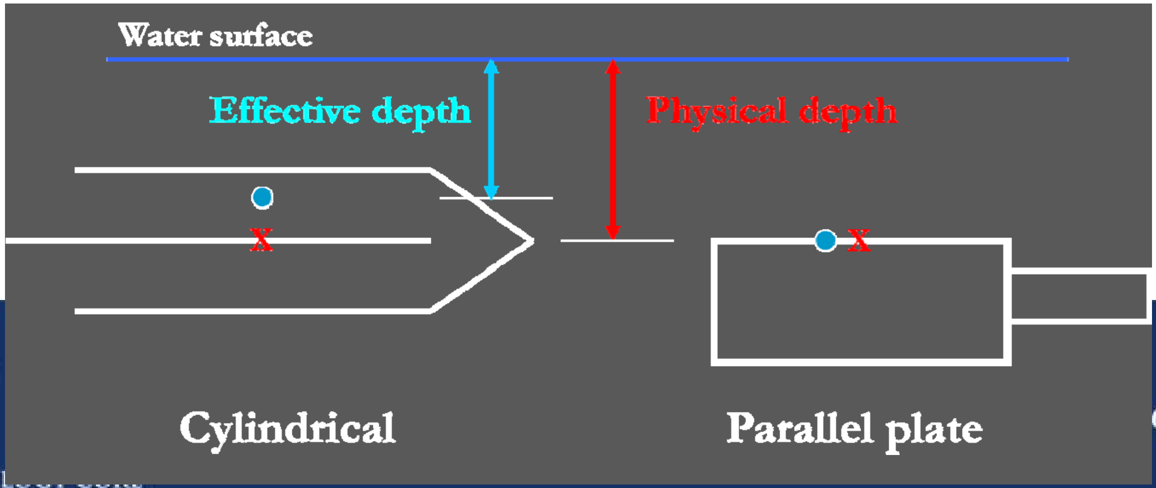
Photons		Electrons
10 cm	calibration depth	d_{ref}

"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	R_{50}

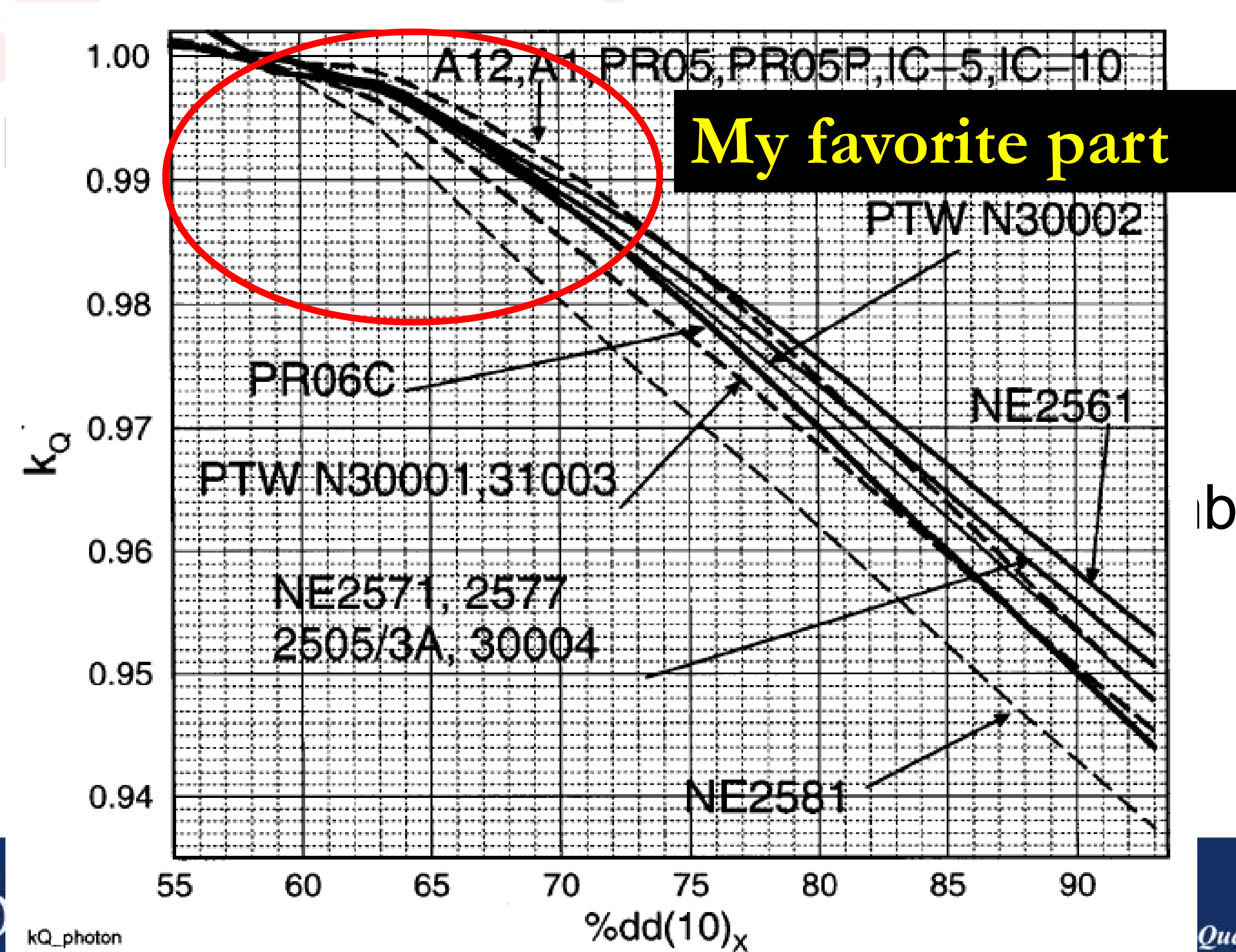
Beam quality should always be measured using the "effective point of measurement"

$0.6r_{cav}$	shift to effective point	$0.5r_{cav}$
100 cm	beam quality SSD	100 cm
$10 \times 10\ cm^2$	field size	$\geq 10 \times 10\ cm^2$



Beam Quality Conversion Factors

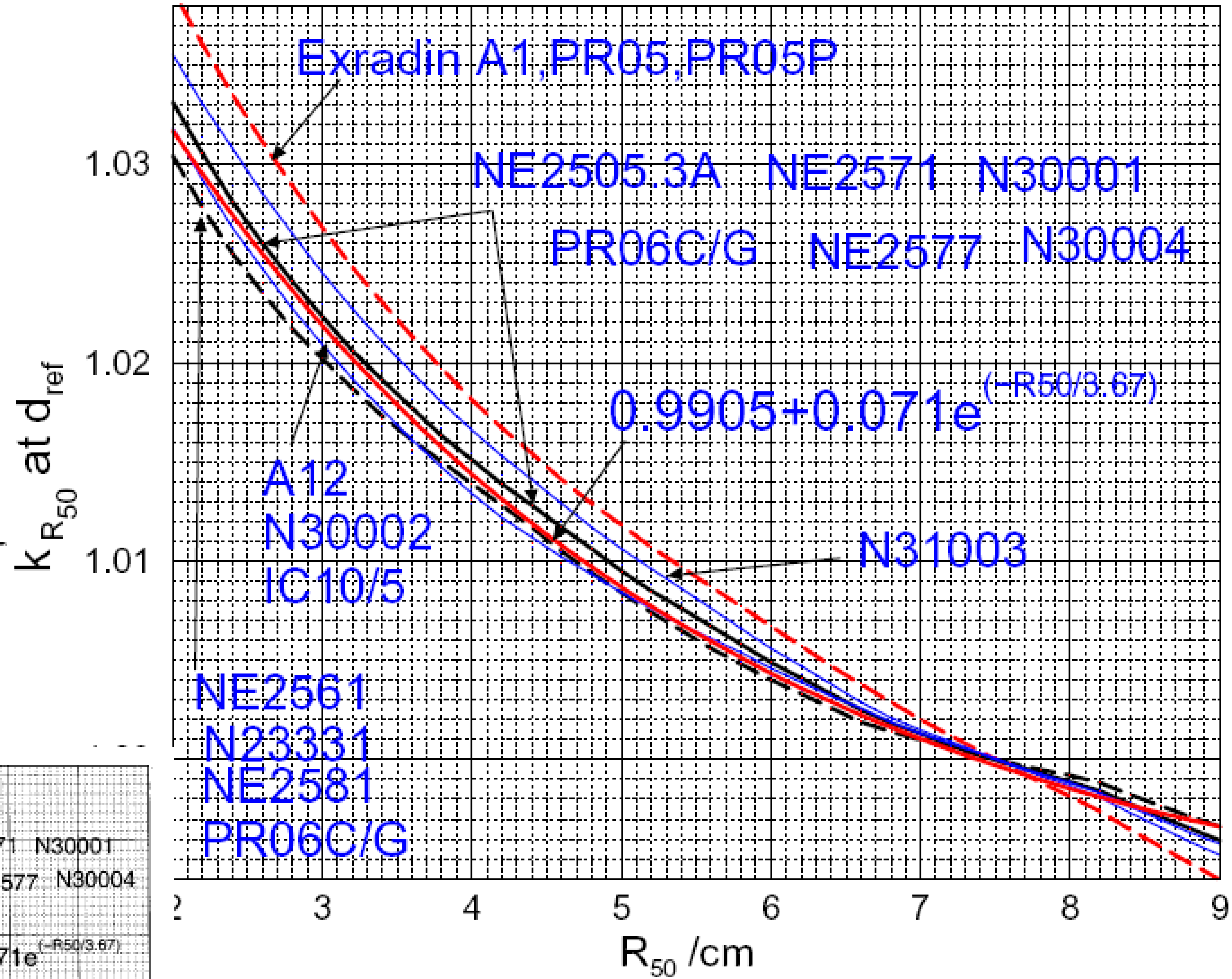
-

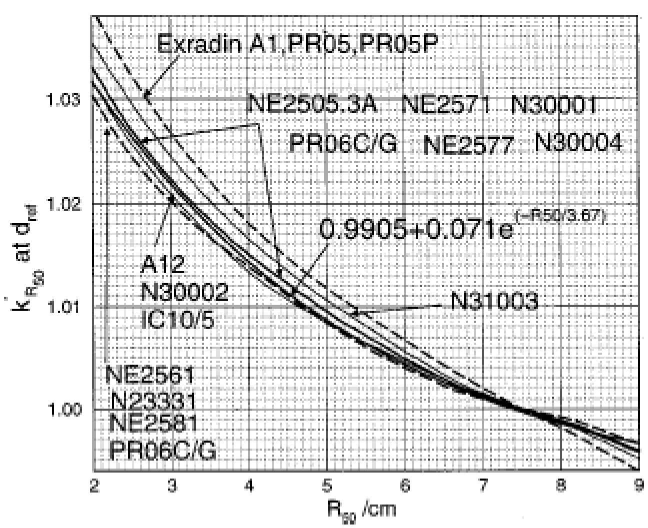


ber

Beam

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





Charge Measurements

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

- 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

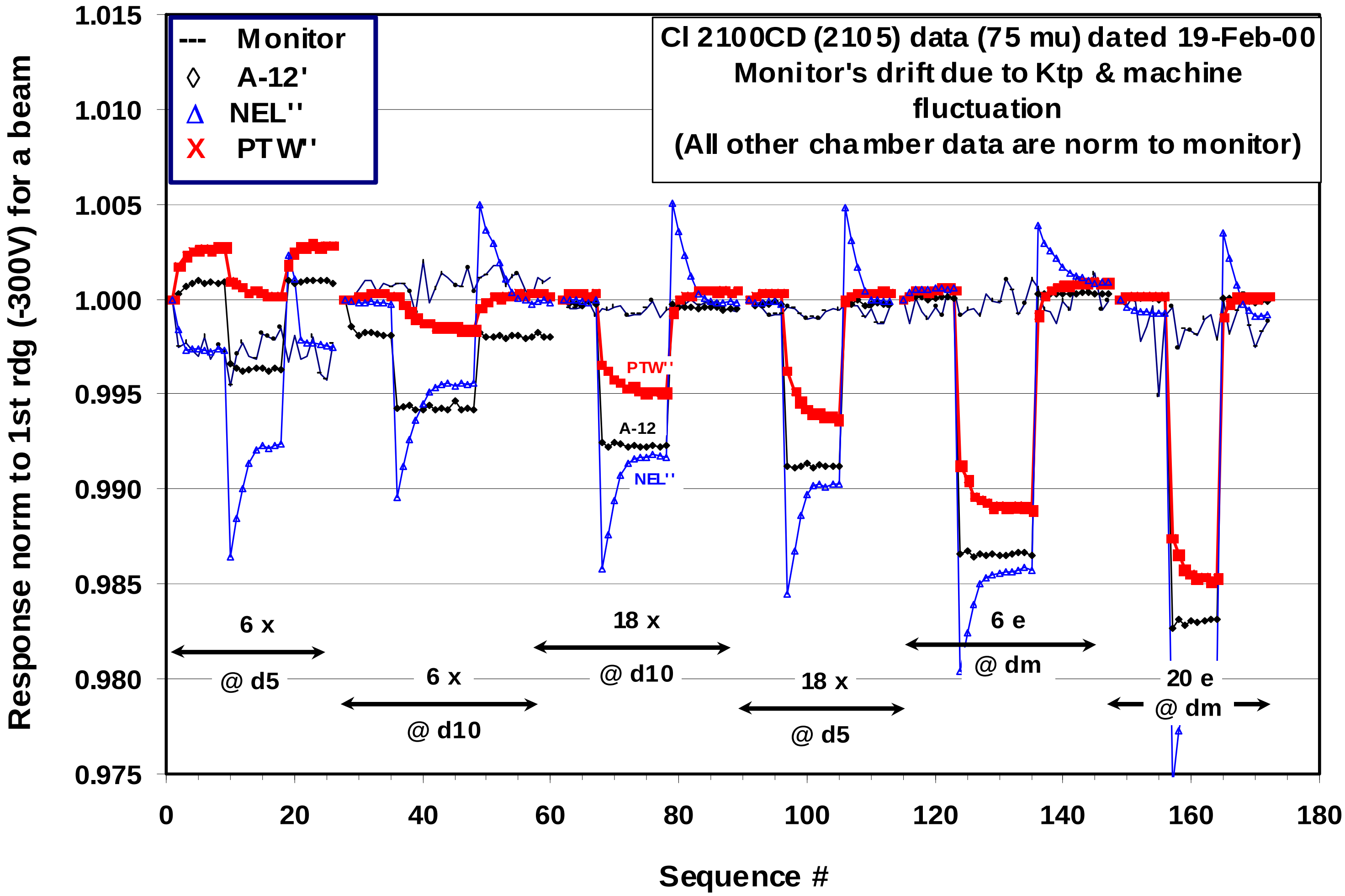
- P_{elec} correction factor
  - ADCL calibration for each scale needed
- P_{pol} correction factor
  - Change polarity requires irradiation (600 to 800 cGy) to re-equilibrate chamber
  - Use of eq 9 in TG-51 requires that you preserve the sign of the reading or

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

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

Charge Measurements

•



IROC
IMAGING AND
RADIATION ONCOLOGY CORE
...urance

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

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

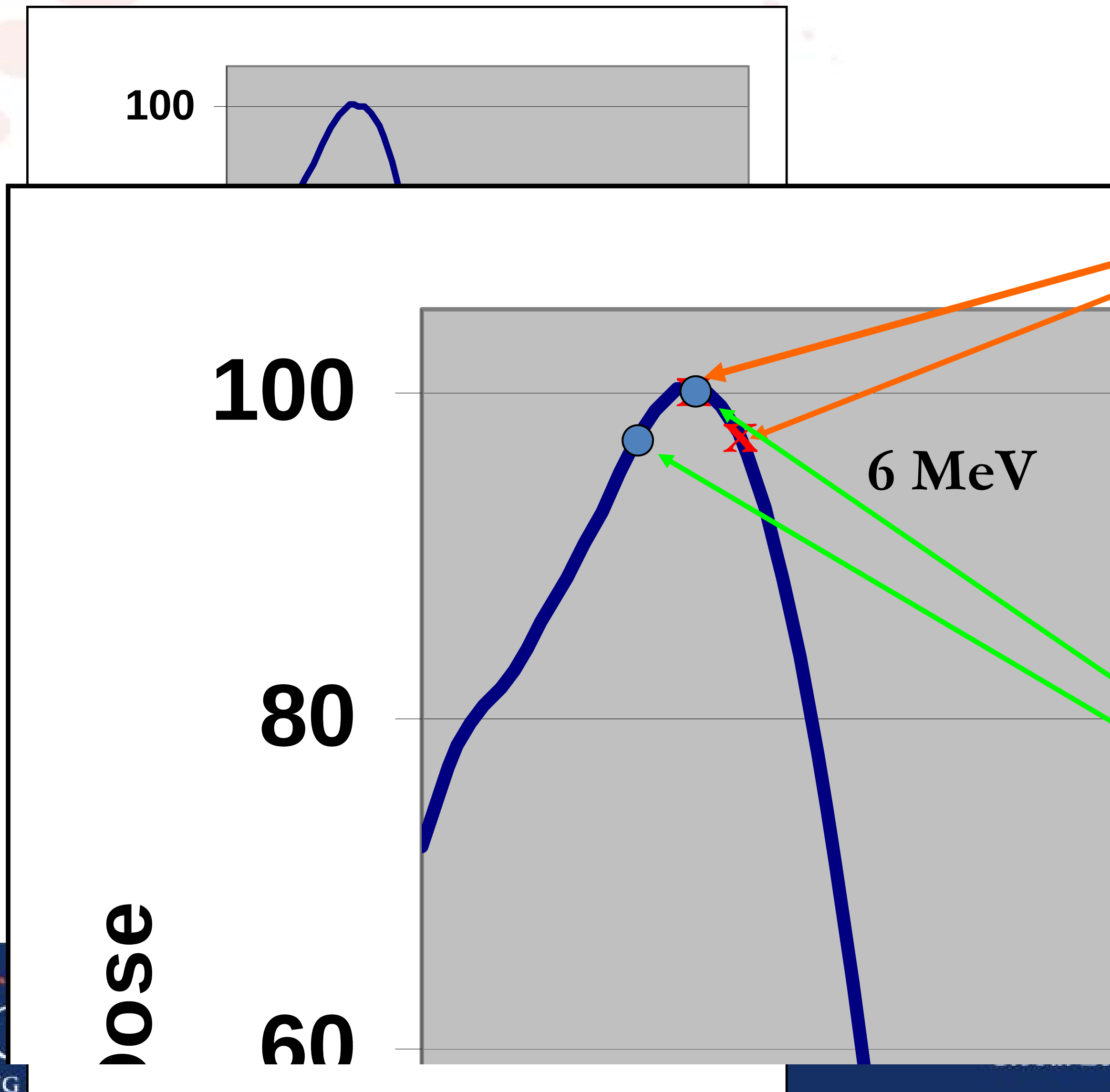
  - The reading at $d_{ref}+0.5r_{cav}$ should have the same precision as the reading at d_{ref} since:

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

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

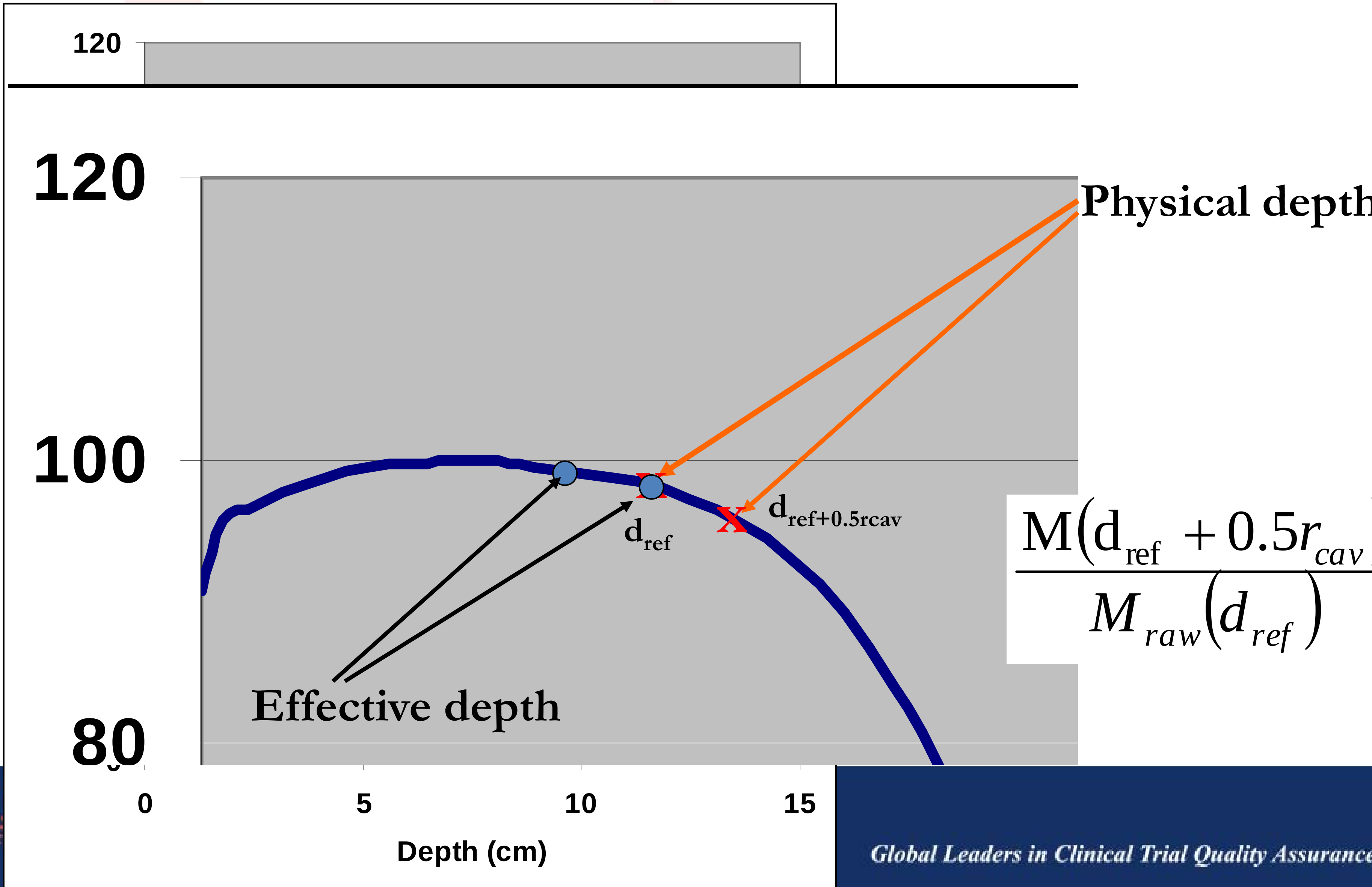


Physical depth

Effective depth

$$\frac{M\left(d_{ref} + 0.5r_{cav}\right)}{M_{raw}\left(d_{ref}\right)}$$

Charge Measurements



$$\frac{M\left(d_{ref}+0.5r_{cav}\right)}{M_{raw}\left(d_{ref}\right)}$$

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 ≥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)

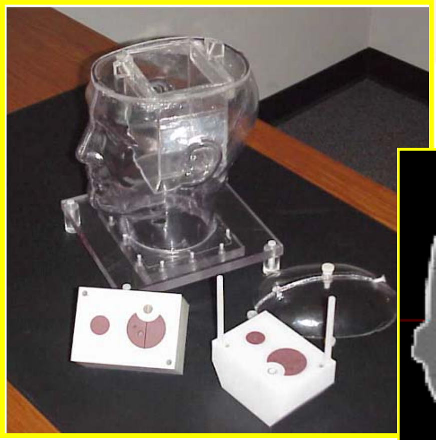
MLC QA a la TG-142

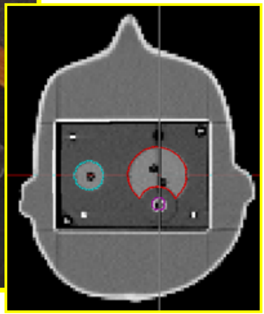
TABLE V. Multileaf collimation (with differentiation of IMRT vs non-IMRT machines).

Procedure	Tolerance
Weekly (IMRT machines)	
Qualitative test (i.e., matched segments, aka "picket fence")	Visual inspection for discernable deviations such as an increase in interleaf transmission
Monthly	
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. (*Picket fence* test may be used, test depends on clinical planning-segment size)
Annually	
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

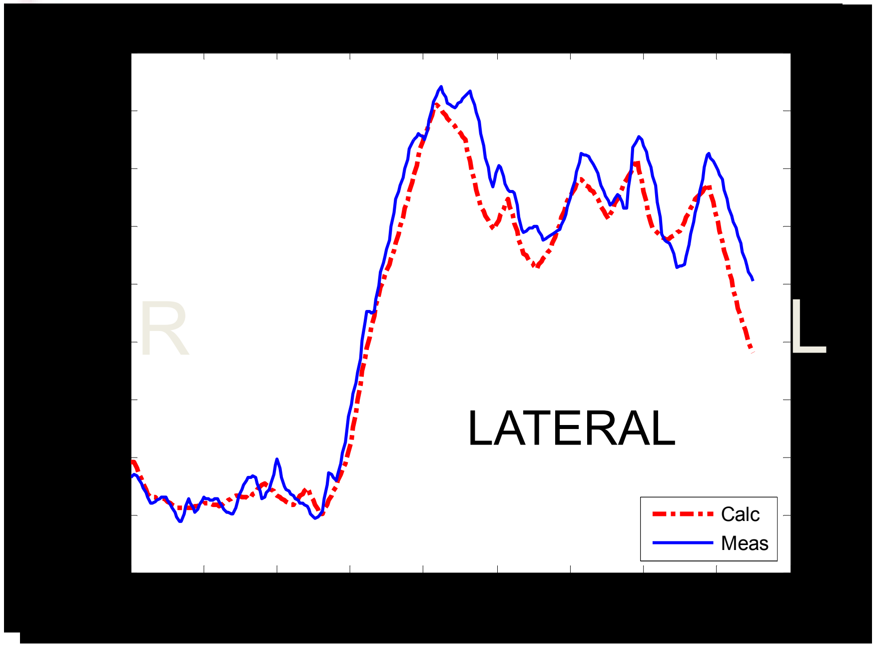
It's all about leaf position accuracy!

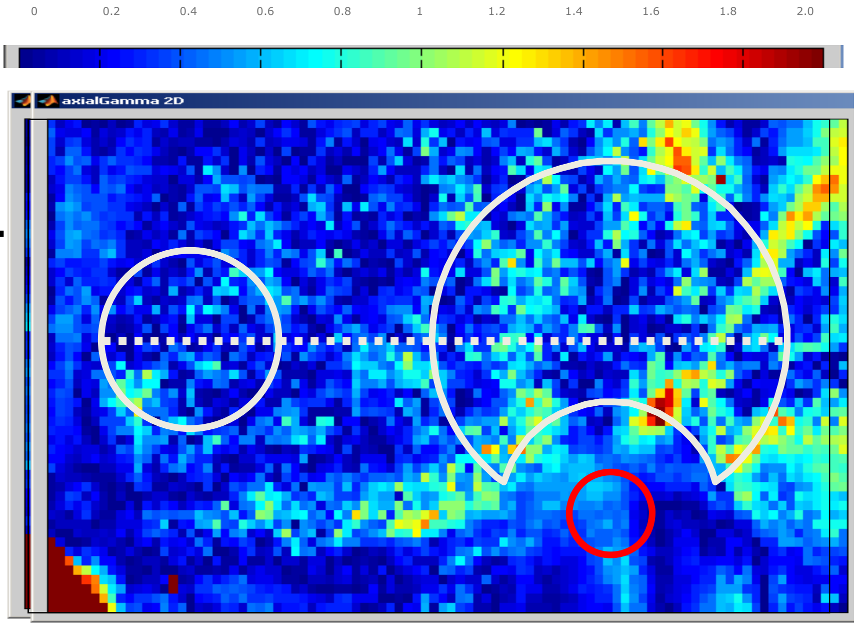
Measurement vs. Monte Carlo





Criteria
3%/2 mm

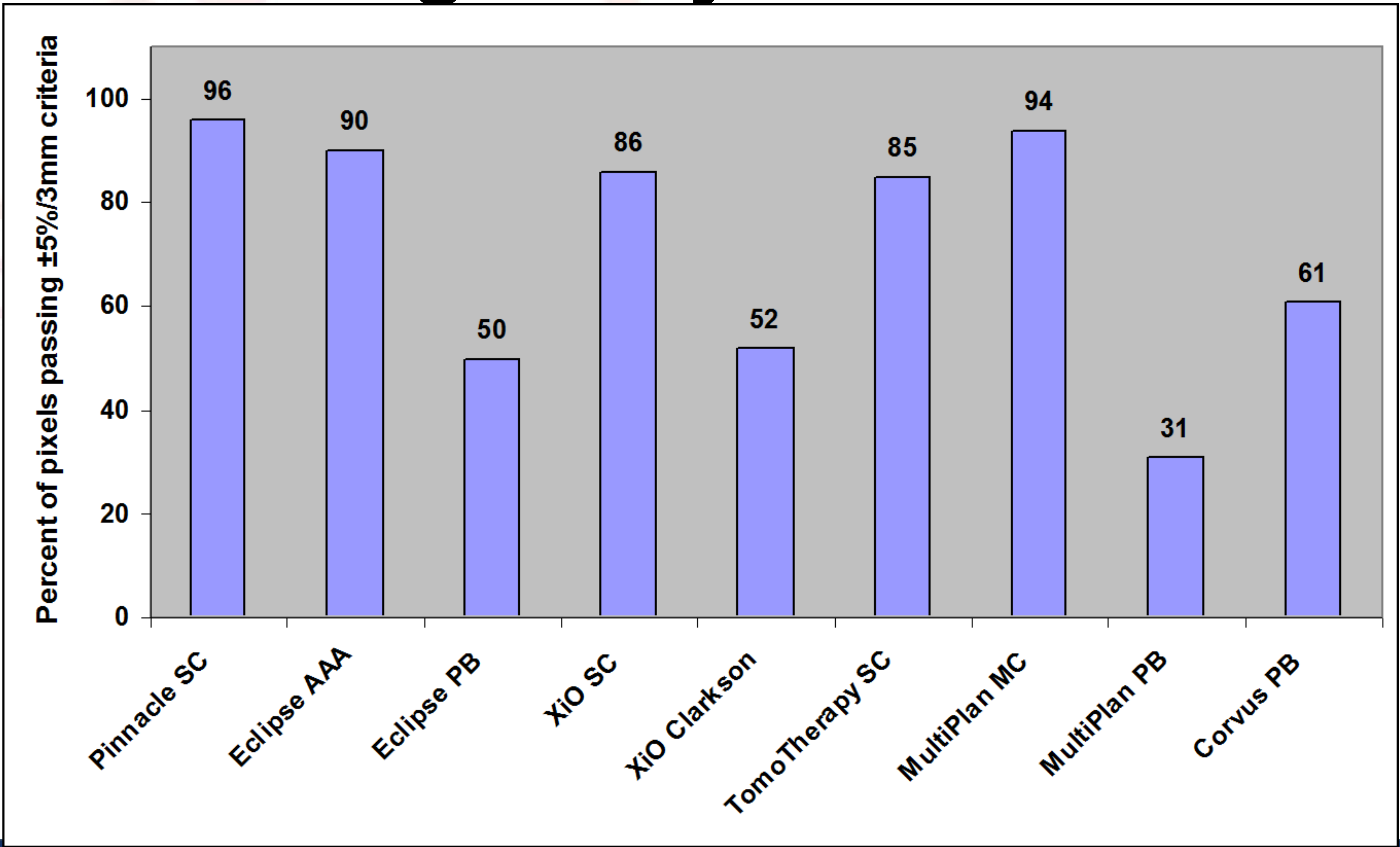




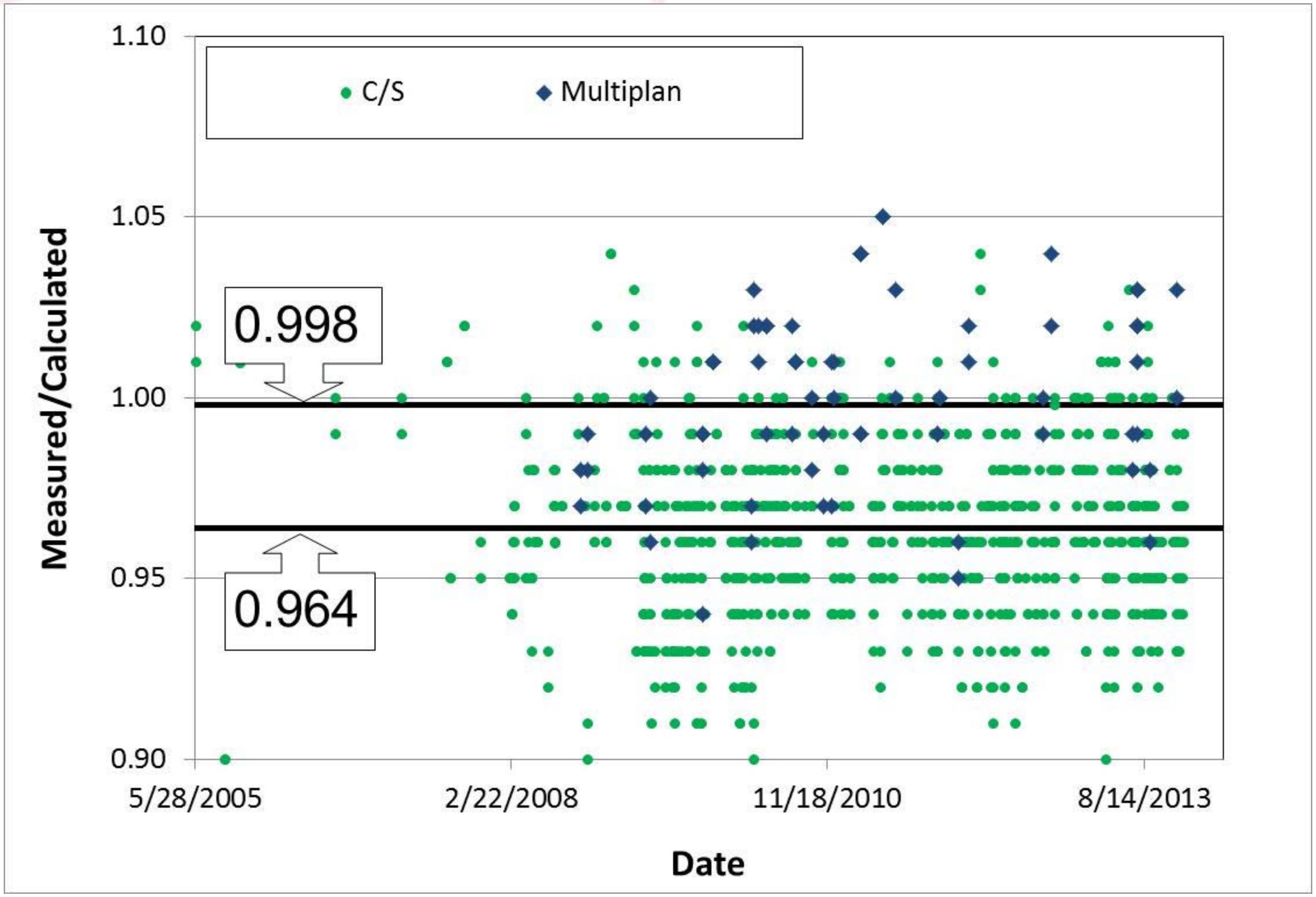
Axial

Varian 6 MV IMRT H&N

Heterogeneity Corrections

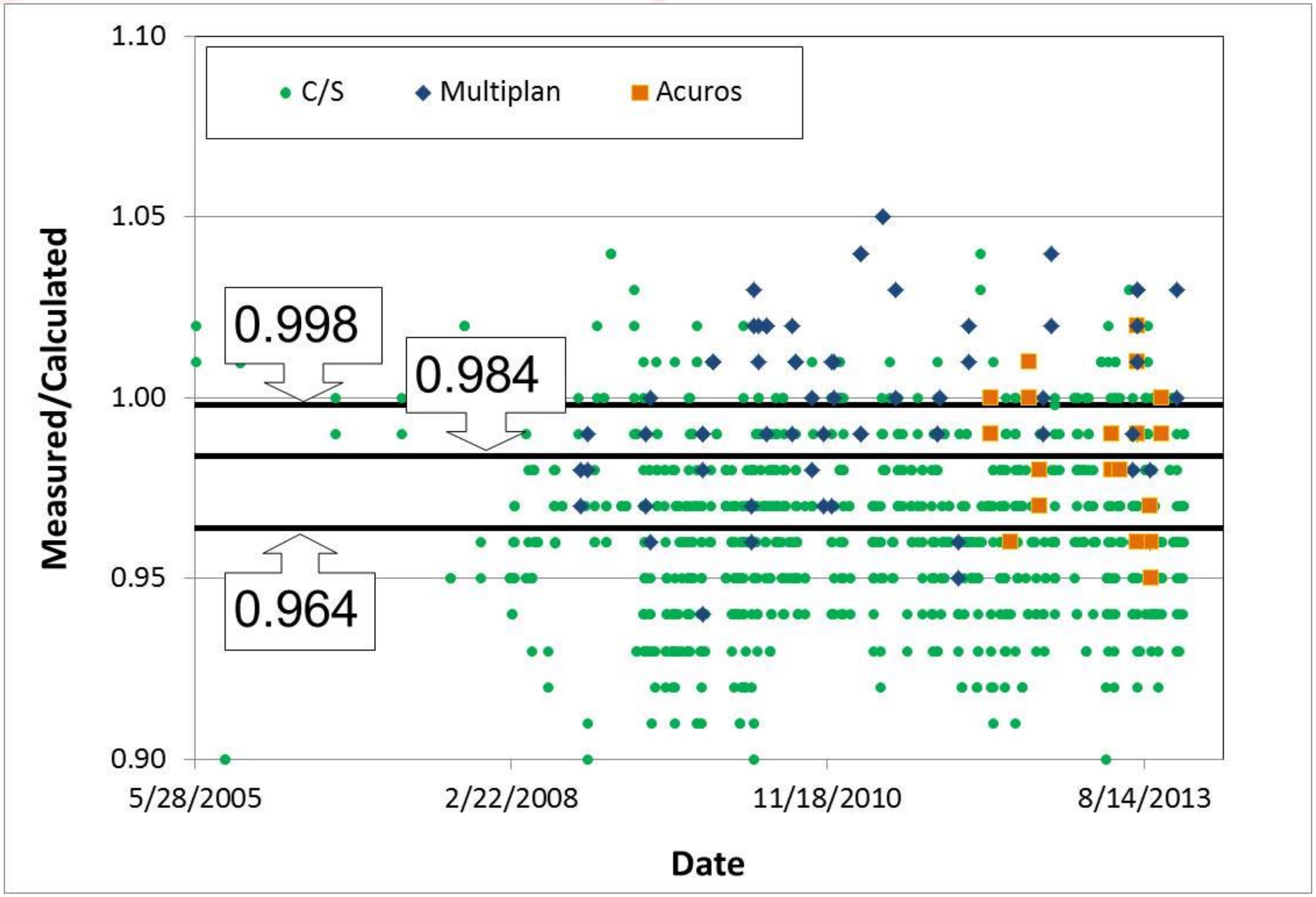


Lung: TLD dose vs TPS calc



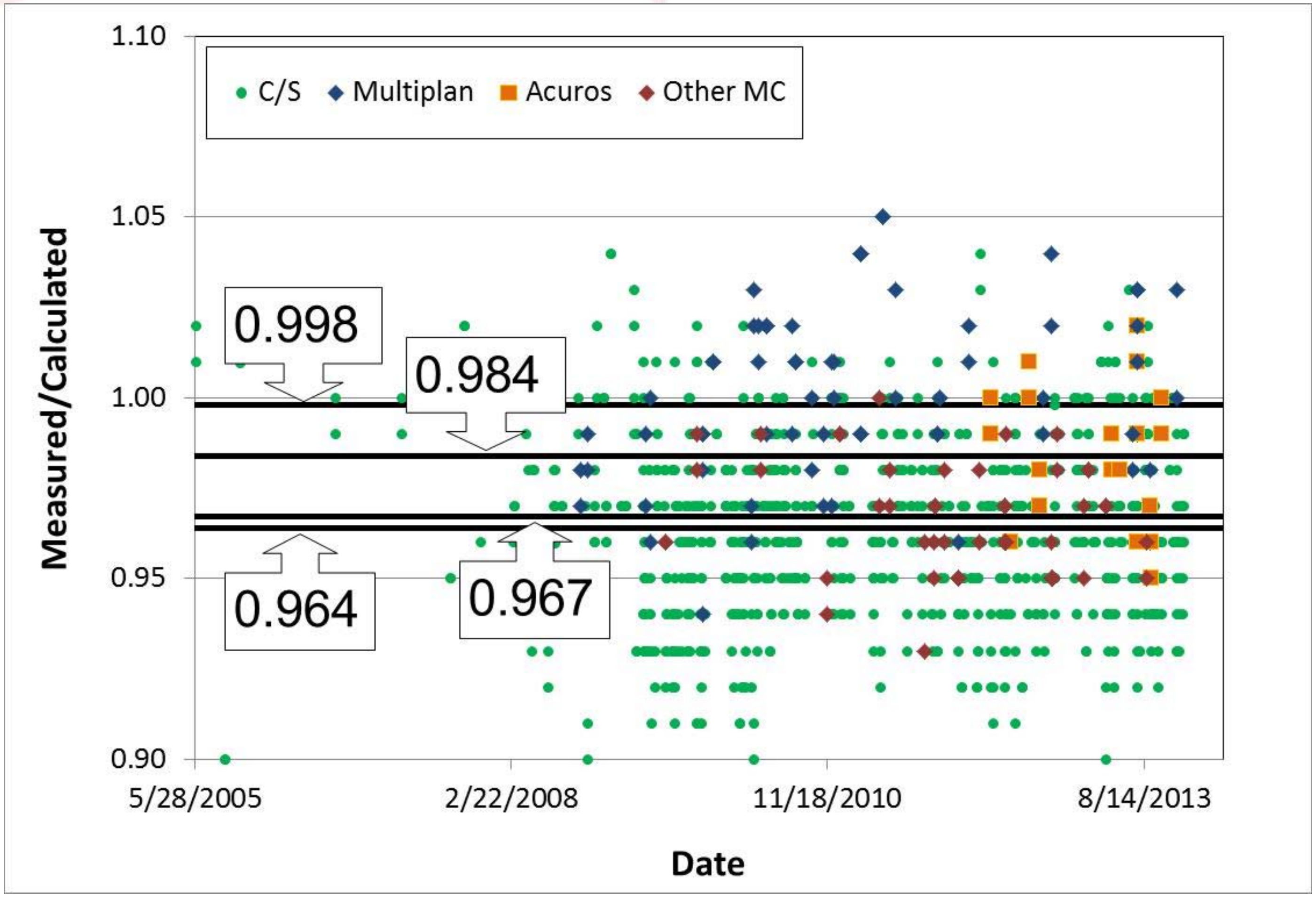
C/S and MC (Multiplan) show a difference

Lung: TLD dose vs TPS calc



Acuros shows good results, but not identical

Lung: TLD dose vs TPS calc



Monte Carlo results are not consistent……

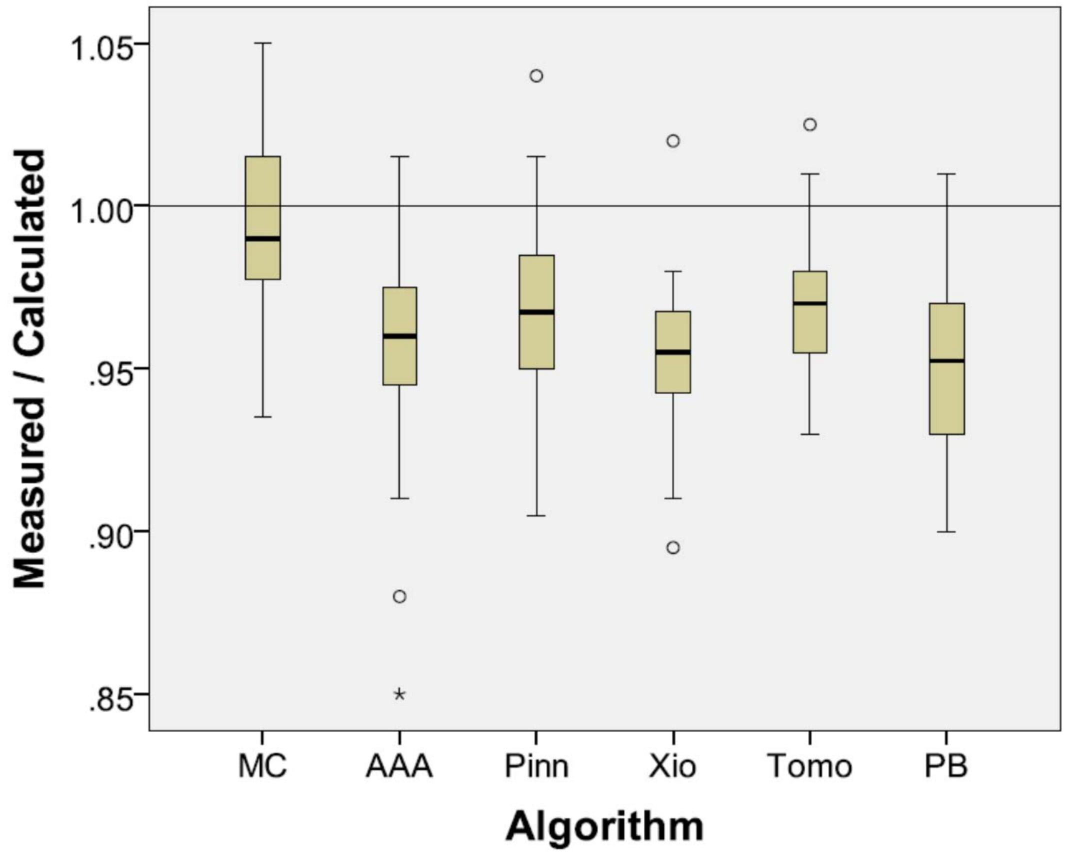
IROC™
IMAGING AND
RADIATION ONCOLOGY CORE

Global Leaders in Clinical Trial Quality Assurance

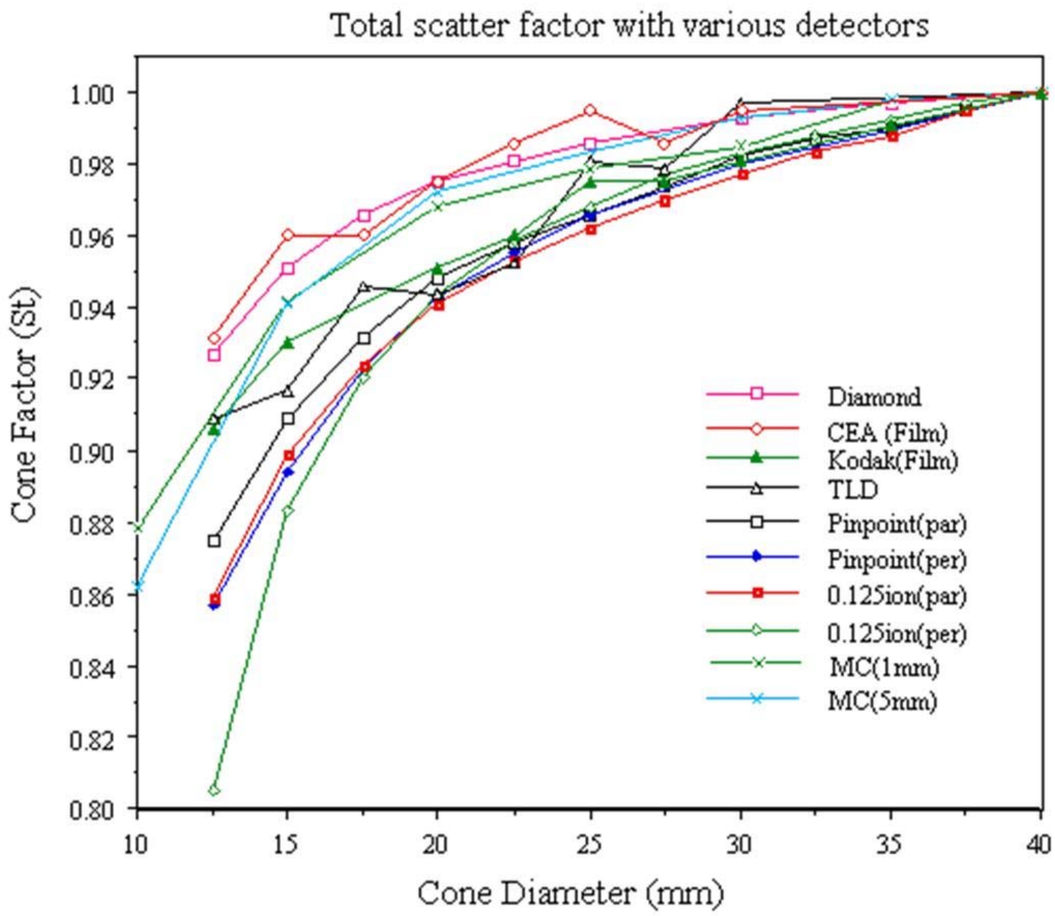
TLD Dose Findings

- 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?



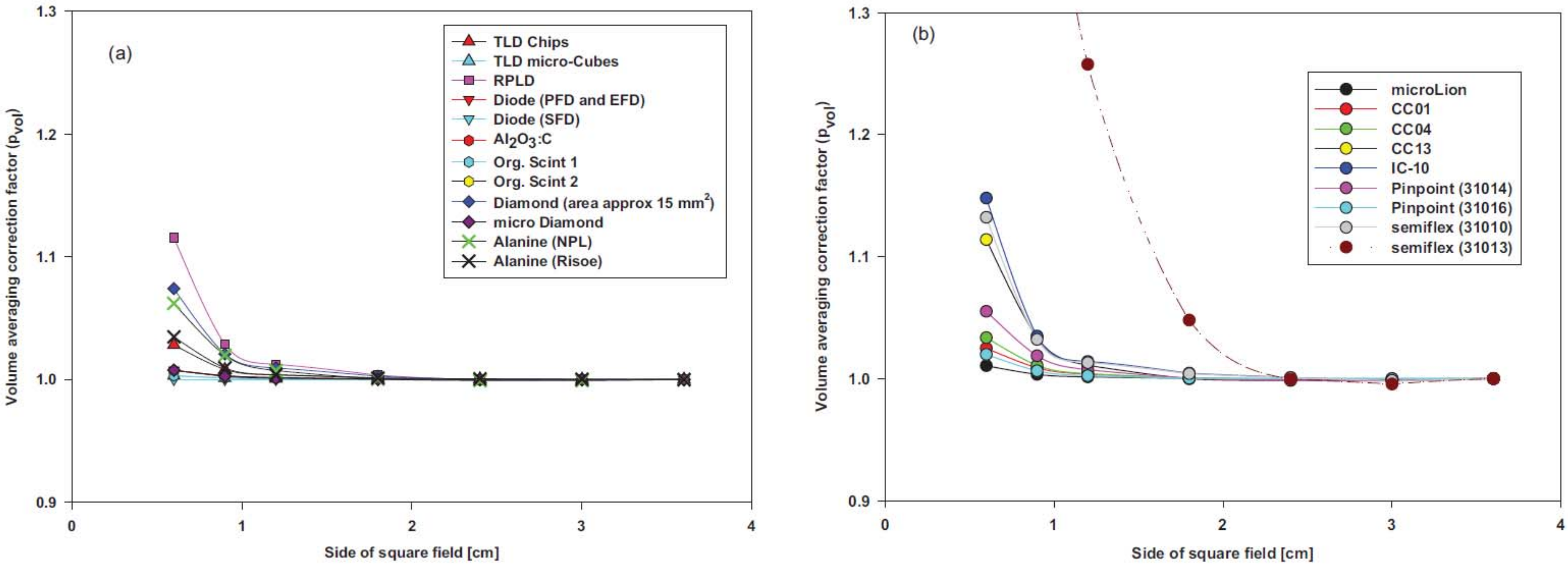
Help is on the way!

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

Das et al
TG-155

From Das et al 2000

Small Field Dosimetry Volume Averaging Correction



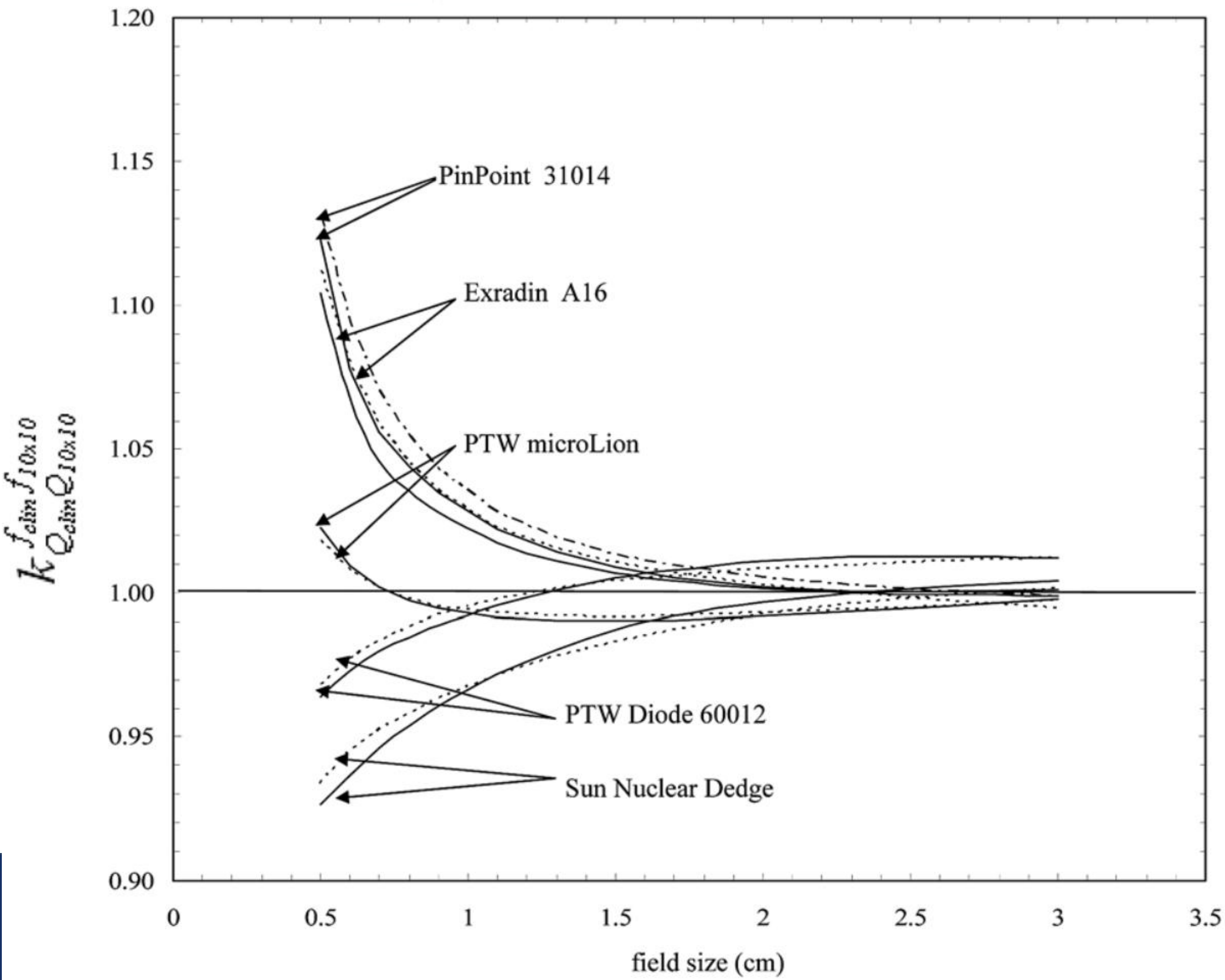
G. Azangwe, Med Phys. 41 (7) 2014

IROC™ IMAGING AND RADIATION ONCOLOGY CORE

Global Leaders in Clinical Trial Quality Assurance

Small Field Dosimetry Fluence Corrections

Situation is even worse if you consider using field sizes less then 0.5 x 0.5 cm²



Francescon et al 2011 data

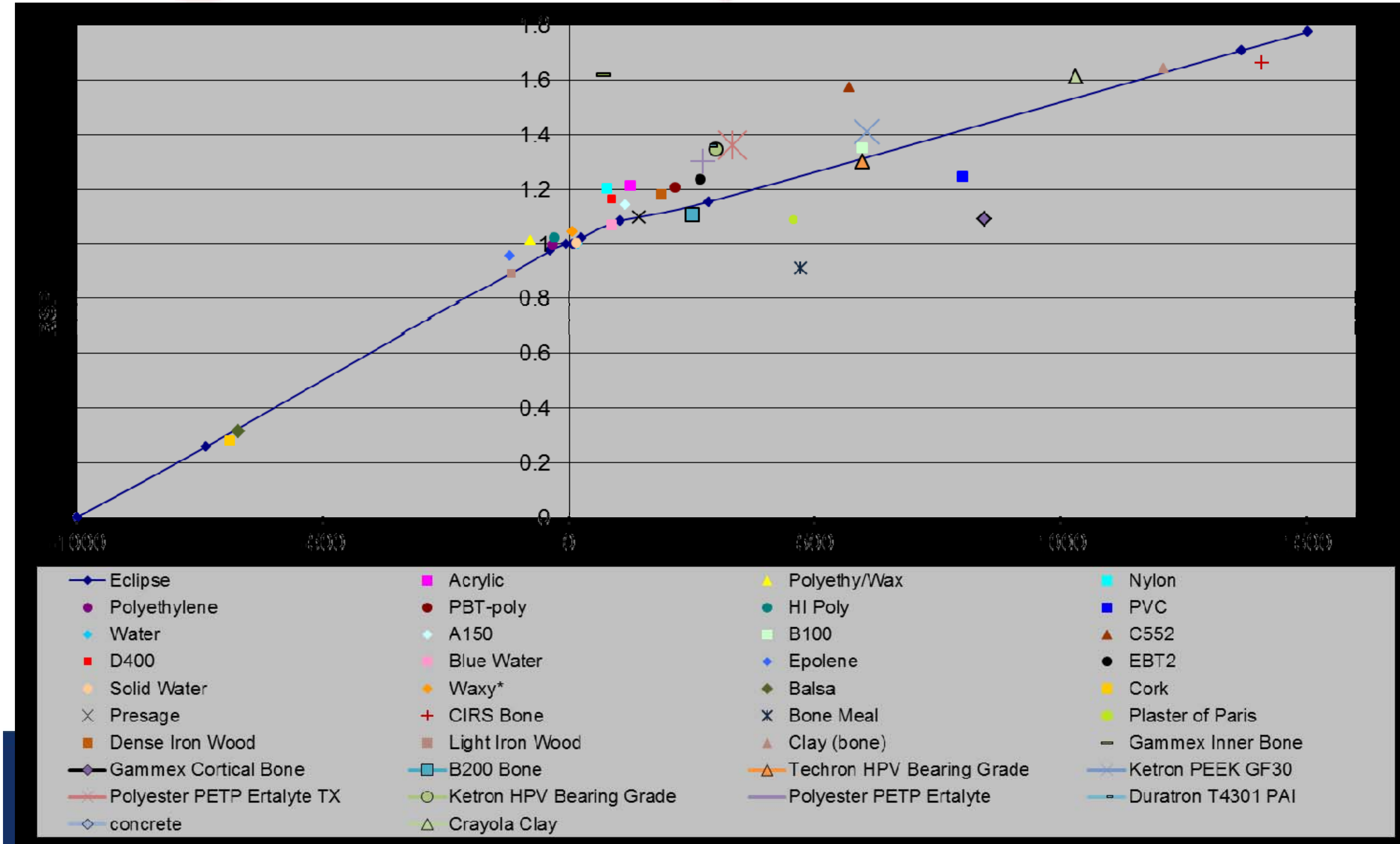
IROC™
IMAGING AND RADIATION ONCOLOGY CORE

Proton Therapy

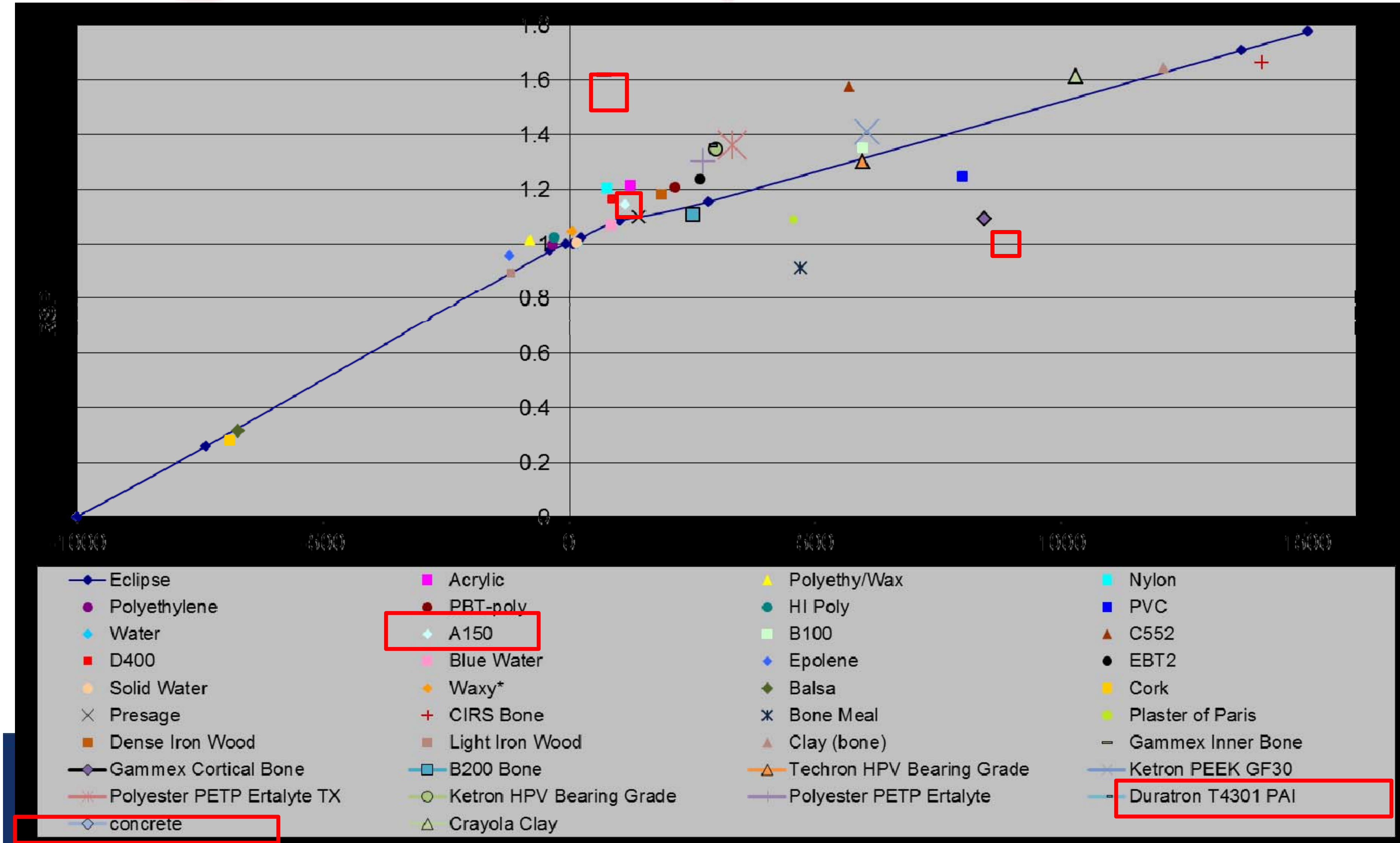
Human tissue: equal in the eyes of both photons and protons

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

Stopping Power vs. HU Curve

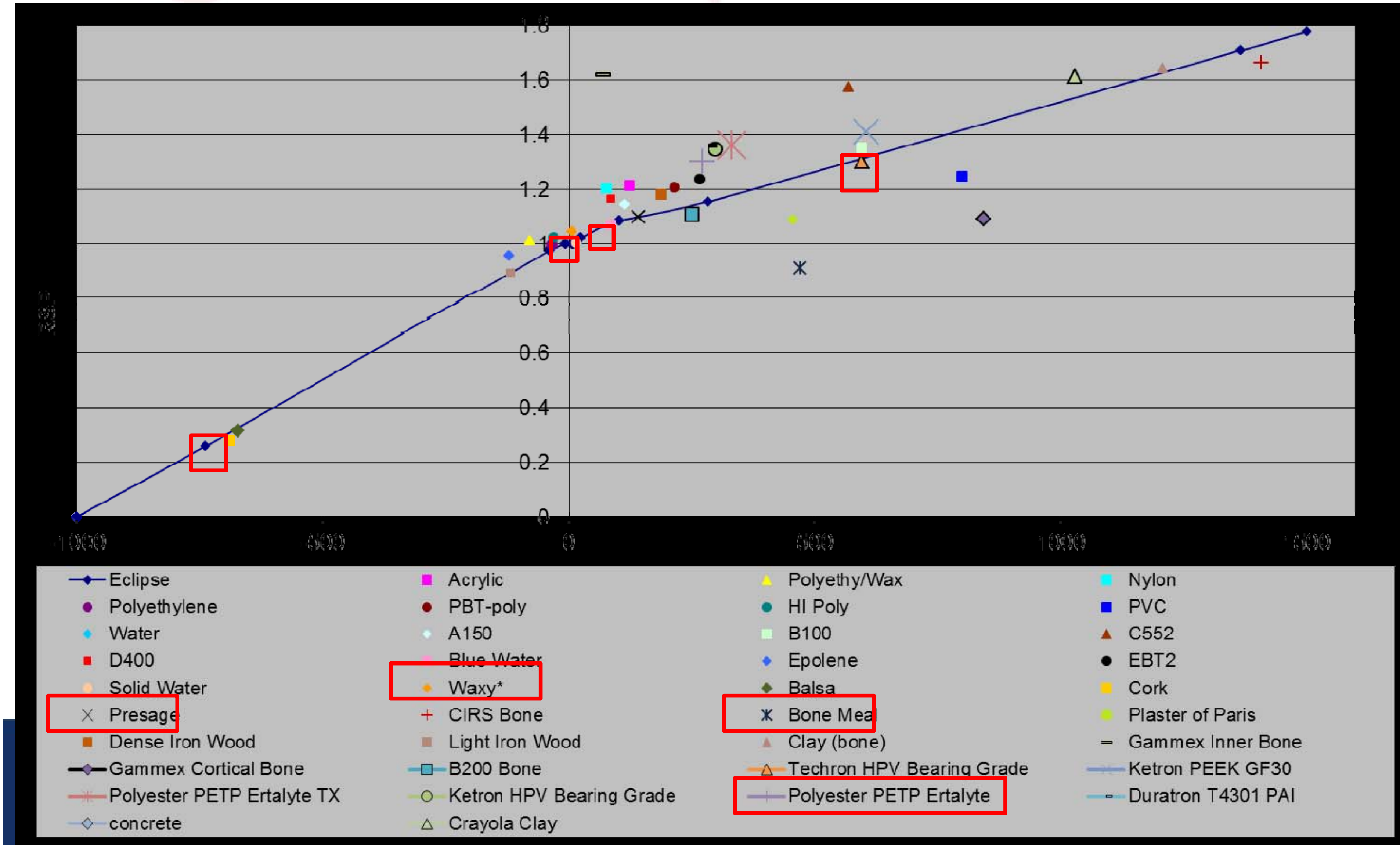


Not so good…..



1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Eclipse
Polyethylene
Water
D400
Solid Water
Presage
Dense Iron Wood
Gammex Cortical Bone
Polyester PETP Ertalyte TX
concrete
Acrylic
PBT-poly
A150
Blue Water
Waxy*
CIRS Bone
Light Iron Wood
B200 Bone
Ketron HPV Bearing Grade
Crayola Clay
Polyethy/Wax
HI Poly
B100
Epolene
Balsa
Bone Meal
Clay (bone)
Techron HPV Bearing Grade
Polyester PETP Ertalyte
Nylon
PVC
C552
EBT2
Cork
Plaster of Paris
Gammex Inner Bone
Ketron PEEK GF30
Duratron T4301 PAI

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.