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.
1. Remote audits of machine output: 2,155 institutions, ~17,800 beams measured with TLD and OSLD in North America and Internationally.

2. Patient treatment record reviews: 1,076 charts for NRG, Alliance, pharma trials.

3. On-site dosimetry reviews: 17 institutions visited (5 proton/12 photon).

4. Credentialing: 643 Phantom irrad./2,217 CSI/2,842 cred'ls.

5. Proton Approvals: 617/23 clinically active centers approved.

55 countries
IROC-H Verification of Delivery of Tumor Dose

Reference calibration (NIST traceable)

×

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

Evaluated by IROC Dosimeters

Evaluated by IROC visits and chart review

Evaluated by IROC phantoms

Tumor Dose

Global Leaders in Clinical Trial Quality Assurance
On-Site Dosimetry Review Audit

BEAM CALIBRATION
IROC Houston Onsite Visits

Percent within 3% Criterion

YEAR


Global Leaders in Clinical Trial Quality Assurance
TG-51 Addendum

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

Malcolm McEwen
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 cm³
  • Smaller volume chambers (> 0.05 cm³) okay if traceable to another 0.6 cm³ 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

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

- 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 $k_{\text{ecal}}$ – bad
  – Use of $(N_{D,w} \cdot k_{\text{ecal}})$ results in an error of 1-2%
ONE EXCEPTION – Exradin P11 seems to be okay
  – FUTURE: TG-51 electron addendum new $k_{\text{ecal}}$ 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 RnC (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 Shenka air-equivalent plastic
- P11 – D400 polystyrene-equivalent plastic
- T11 – Polymethylmethacrylate (PMMA)
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"

- 0.6\( r_{cav} \) shift to effective point
- 100 cm beam quality SSD
- 100 cm SSD
- 10 x 10 cm\(^2\) field size
- \( \geq 10 \times 10 \text{ cm}^2 \)
Beam Quality Conversion Factors

- For spreadsheets plot the tabular data and derive empirical fit for specific chamber.
- Be sure to have an independent check of the empirical fit function.

My favorite part.
Beam

- Electrons – $k_{R_{50}}$
  - Only some figures, no tables
  - Good figures at:
Charge Measurements

\[ M = P_{\text{ion}} \cdot P_{TP} \cdot P_{\text{elec}} \cdot P_{\text{pol}} \cdot M_{\text{raw}} \]

- \( P_{TP} \) 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

- Pion correction factor:
  - High dose rate capabilities result in higher Pion
  - Change in bias requires irradiation (600-800 cGy) to re-equilibrate chamber.
  - Pion depends on chamber, beam energy, linac and beam modality
- Greater than 1.000
- Tends to increase with energy

![Graph showing response norm to 1st rdg (-300V) for a beam](image)

- CI 2100CD (2105) data (75 mu) dated 19-Feb-00
- Monitor's drift due to Ktp & machine fluctuation
- (All other chamber data are norm to monitor)
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

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

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

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

\[
\frac{M(d_{\text{ref}} + 0.5r_{cav})}{M_{\text{raw}}(d_{\text{ref}})}
\]
Charge Measurements

Physical depth

Effective depth

\[ \frac{M(d_{\text{ref}} + 0.5r_{\text{cav}})}{M_{\text{raw}}(d_{\text{ref}})} \]
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 ($d_{\text{max}}$)
  – 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 \( d_{\text{max}} \)

• 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

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

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

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

Criteria
3%/2 mm

Varian 6 MV IMRT H&N

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Heterogeneity Corrections

<table>
<thead>
<tr>
<th>System</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinnacle SC</td>
<td>96</td>
</tr>
<tr>
<td>Eclipse AAA</td>
<td>90</td>
</tr>
<tr>
<td>Eclipse PB</td>
<td>50</td>
</tr>
<tr>
<td>XiO SC</td>
<td>86</td>
</tr>
<tr>
<td>XiO Clarkson</td>
<td>52</td>
</tr>
<tr>
<td>TomoTherapy SC</td>
<td>85</td>
</tr>
<tr>
<td>MultiPlan MC</td>
<td>94</td>
</tr>
<tr>
<td>MultiPlan PB</td>
<td>31</td>
</tr>
<tr>
<td>Corvus PB</td>
<td>61</td>
</tr>
</tbody>
</table>
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……
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

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From Das et al 2000
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 then 0.5 x 0.5 cm²

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.