Disclosure: the author is a part-time consultant to Elekta, Inc.
AAPM Task Group 178

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Sunnybrooke Med Center
USC Medical Center
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<tr>
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<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
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<td>University of Wisconsin ADCL</td>
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<td>McGill University Med Center</td>
</tr>
<tr>
<td>Jonas Johansson</td>
<td>Elekta Corporation</td>
</tr>
</tbody>
</table>
Calibration of GSR Units

- No current external beam protocols apply to certain devices
- Gamma Knife, Tomotherapy, Cyberknife and Viewray are "noncompliant" with TG-51 Absorbed Dose in Water protocol
- What's a poor physicist to do?
- Improvise!!
TG21 and TG 51: Presumes Point Source Diverging to 10x10cm$^2$ field at 100cm

- **Cyberknife** comes closest: 6cm diameter field size at 80cm. New M6 gives up to 10 by 12cm$^2$ at 80cm
- **Tomotherapy**: up to 5 by 40cm$^2$ at 85cm
- **Viewray**: 105cm isocenter (rotational) up to 27.3cm$^2$
- **Gamma Knife Perfexion**: 192 sources converging on 4, 8 or 16mm diameter field at roughly 40cm
A new formalism for reference dosimetry of small and nonstandard fields

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Authors laid out a path by which a unique geometry “noncompliant” with TG-51 Absorbed Dose Protocol could be adapted to comply

- Defined two fields: $f_{\text{ref}}$ and $f_{\text{fmsr}}$
- The **first field** $f_{\text{ref}}$ is “standard” field size: 10 by 10cm$^2$
- The **second field** $f_{\text{fmsr}}$ is a “machine-specific reference field”
## Background: Dose Calibration Protocols

### Ionization chamber calibrated in water

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Advantages</td>
<td>Simple measured</td>
<td>Simple measured</td>
<td>Simple measured + Monte Carlo (MC) generated</td>
</tr>
<tr>
<td></td>
<td>• Simple to use</td>
<td></td>
<td>• Machine-specific correction factor</td>
</tr>
<tr>
<td></td>
<td>• Likely to achieve consistent results across different institutions</td>
<td></td>
<td>• Accounts for different ionization chambers and phantom types</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Designed for use with linear accelerators:</td>
<td></td>
<td>MC parameters must be generated for each ionization chamber and phantom combination</td>
</tr>
<tr>
<td></td>
<td>• 10 x 10 cm² field</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water phantom</td>
<td></td>
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</table>

### Equipment and Measurements

<table>
<thead>
<tr>
<th>Ionization Chambers</th>
<th>Collecting Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTW TN31010 (PTW)</td>
<td>0.125 cc</td>
</tr>
<tr>
<td>Standard Imaging Exradin A16 (Ex)</td>
<td>0.007 cc</td>
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</tbody>
</table>

**Electrometer:** Standard Imaging Max 4000

**Phantom One:**

Elekta (gray) ABS plastic 16cm diameter solid phantom
Phantom Two: Elekta Solid Water 16cm diameter phantom

Phantom Three: Phantom Laboratories Liquid Water 16cm diameter hemispherical phantom
Phantom Four: Standard Imaging In-air phantom
## Summary of Measurements

<table>
<thead>
<tr>
<th>Phantom</th>
<th>Chamber model</th>
<th>Protocol/formalism</th>
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</thead>
<tbody>
<tr>
<td>ABS</td>
<td>A16</td>
<td>TG-21, ALF</td>
</tr>
<tr>
<td>ABS</td>
<td>TN31010</td>
<td>TG-21, ALF</td>
</tr>
<tr>
<td>SW</td>
<td>A16</td>
<td>TG-21, TG-51, ALF</td>
</tr>
<tr>
<td>SW</td>
<td>TN31010</td>
<td>TG-21, TG-51, ALF</td>
</tr>
<tr>
<td>LW</td>
<td>A16</td>
<td>TG-21, TG-51, ALF</td>
</tr>
<tr>
<td>LW</td>
<td>TN31010</td>
<td>TG-21, TG-51, ALF</td>
</tr>
<tr>
<td>IA</td>
<td>A16</td>
<td>MDW</td>
</tr>
<tr>
<td>IA</td>
<td>TN31010</td>
<td>MDW</td>
</tr>
</tbody>
</table>
Results Averaged over all Institutions Sorted by Dosimetry Protocol/Formalism
### IAEA (Alfonso) Formalism $k_{Q_{\text{ref}}/Q_{\text{mrs}}}$ factors from Elekta Phys. Rep.*

<table>
<thead>
<tr>
<th>Chamber type</th>
<th>PFX</th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>SW</td>
<td>ABS</td>
<td>H$_2$O</td>
<td></td>
<td>SW</td>
<td>ABS</td>
<td>H$_2$O</td>
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<tr>
<td>PTW 31010</td>
<td>1.0037</td>
<td>1.0146</td>
<td>1.0001</td>
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<td></td>
<td>0.9958</td>
<td>0.9990</td>
<td>0.9924</td>
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<tr>
<td>PTW 31016</td>
<td>1.0040</td>
<td>1.0110</td>
<td>0.9991</td>
<td></td>
<td></td>
<td>1.0014</td>
<td>1.0025</td>
<td>0.9964</td>
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<tr>
<td>Exradin A1SL</td>
<td>1.0046</td>
<td>1.0138</td>
<td>1.0006</td>
<td></td>
<td></td>
<td>1.0009</td>
<td>1.0014</td>
<td>0.9967</td>
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<tr>
<td>Exradin A14SL</td>
<td>1.0154</td>
<td>1.0194</td>
<td>1.0112</td>
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<td>1.0116</td>
<td>1.0060</td>
<td>1.0058</td>
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<tr>
<td>Exradin A16</td>
<td>1.0167</td>
<td>1.0295</td>
<td>1.0127</td>
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<td></td>
<td>1.0163</td>
<td>1.0217</td>
<td>1.0104</td>
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<tr>
<td>IBA CC01</td>
<td>1.0213</td>
<td>1.0292</td>
<td>1.0169</td>
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<td>1.0203</td>
<td>1.0208</td>
<td>1.0157</td>
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<tr>
<td>IBA CC04</td>
<td>1.0107</td>
<td>1.0117</td>
<td>1.0062</td>
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<td>1.0086</td>
<td>1.0049</td>
<td>1.0040</td>
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<tr>
<td>PR05-P (4.7 mm)</td>
<td>1.0059</td>
<td>1.0070</td>
<td>1.0010</td>
<td></td>
<td></td>
<td>1.0007</td>
<td>0.9960</td>
<td>0.9951</td>
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<tr>
<td>PR05-P (7.6 mm)</td>
<td>1.0025</td>
<td>1.0126</td>
<td>0.9976</td>
<td></td>
<td></td>
<td>0.9885</td>
<td>0.9972</td>
<td>0.9844</td>
</tr>
</tbody>
</table>

Alfonso $k_{Q_{mrs},Q}^{f_{mrs},f_{ref}}$ factors for PFX from Elekta Phys. Rep.
### IAEA (Alfonso) formalism $k_{Q_{mrs}, Q_{ref}}$ Factors for PFX

From previous slide: Average values for ionization chambers with collecting volume $\geq 0.05 \text{ cm}^3$

<table>
<thead>
<tr>
<th>Material</th>
<th>$k_{Q_{mrs}, Q_{ref}}$</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Water</td>
<td>1.000 ± 0.0015</td>
<td></td>
</tr>
<tr>
<td>Solid Water</td>
<td>1.004 ± 0.0014</td>
<td></td>
</tr>
<tr>
<td>ABS Plastic</td>
<td>1.012 ± 0.0034</td>
<td></td>
</tr>
</tbody>
</table>
A round-robin gamma stereotactic radiosurgery dosimetry interinstitution comparison of calibration protocols

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Conclusions

- Four different procedures were carried out on four different phantoms, utilizing two small volume ion chambers and four protocols
- All results were quite consistent
- TG-51 modified by factors (announced but not yet published) following the formalism of Alfonso et al, yielded the overall best results
- This procedure uses the Elekta ABS phantom supplied w every Elekta Gamma Knife in the world
Reference

Elekta white papers (available on request):

1. Accuracy of co-registration of planning images with Cone Beam CT images

2. Automatic positional delivery correction using a stereotactic CBCT in Leksell Gamma Knife Icon™

3. Design and performance characteristics of a Cone Beam CT system for Leksell Gamma Knife Icon™

4. Geometric quality assurance for Leksell Gamma Knife Icon™

5. Automatic positional delivery correction using a stereotactic CBCT in Leksell Gamma Knife Icon™

6. Li et al “Impact of Immobilization on Intrafraction Motion for Dedicated Cobalt Radiosurgery Unit Using Cone Beam Computed Tomography” Int J Rad Onc Biol Phys Sep 2014 (abstract)