Unflattened (FFF) Photon Beams

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Objectives

• Review linear accelerator components of FFF
• Understand dosimetry of FFF beams
• Describe issues of FFF beam commissioning
Review of Linac System

- Standing Wave Accelerator
- Energy Switch
- Beam Steering
- Triode Electron Gun
- Solenoid
- Bending Magnet
- Klystron and RF Driver (not shown)
- Ion Chamber
- MLC
Beam Steering

Bending Magnet

Solenoid
Varian Truebeam

- Primary collimator also moves in and out with the photon targets.
- Chamber axis is shared with the field light.
Field light mirror

Mounted on field flattener platter
Effect of high dose per pulse flattening filter-free beams on cancer cell survival

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Dose rate:

20 cGy/min

400 cGy/min

2400 cGy/min

FFF

400 cGy/min

FFF
Dose Monitoring System
w/ Filter

**Target**
- **Flattening Filter**
  - **Direct photons**
  - **Extra-focal photons**

**Patient**
- **Photon Energy**
  - **Charged Particles**
  - **Scatter Photons**
  - **Charged Particles**
- **Primary Dose**
  - **Charged Particles**
  - **Scatter Photons**
  - **Charged Particles**

**Charged Particle Dose (contaminant)**
- **Charged Particles**
- **Extra-focal photon energy**

**Head Scatter Dose**
- **Charged Particles**
- **Scatter Photons**
- **Charged Particles**

**Phantom Scatter Dose (from direct beam)**
- **Charged Particles**
- **Scatter Photons**
- **Charged Particles**

**Phantom Scatter Dose (from extra-focal beam)**
- **Charged Particles**
- **Scatter Photons**
- **Charged Particles**
FFF

Patient

Primary Dose

Charged Particles

Photon Energy

Phantom Scatter Dose (from direct beam)

Direct photons

Target

Scatter Photons

Charged Particles
FFF vs. w/Filter

6X PDD vs. 6F PDD

Hrbacek et al. IJROBP, 2011.

6X: PDD(5,10x10) = 85.9
6F: PDD(5,10x10) = 84.3

Table 1. Depth dose curve parameters (2 standard deviations in brackets)

<table>
<thead>
<tr>
<th></th>
<th>$d_{\text{max}}$ (mm)</th>
<th>$%dd$ (0.025 mm)</th>
<th>$%dd$ (1 mm)</th>
<th>$%dd$ (100 mm)</th>
<th>TPR 20/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>X6</td>
<td>14.3 (0.44)</td>
<td>18.9 (0.4)</td>
<td>47.3 (0.4)</td>
<td>66.0 (0.4)</td>
<td>0.667 (0.004)</td>
</tr>
<tr>
<td>X6FFF</td>
<td>12.1 (0.17)</td>
<td>24.3 (0.4)</td>
<td>56.1 (0.4)</td>
<td>63.2 (0.2)</td>
<td>0.631 (0.004)</td>
</tr>
<tr>
<td>X10</td>
<td>22.3 (0.60)</td>
<td>14.0 (1.0)</td>
<td>32.3 (1.0)</td>
<td>73.5 (0.5)</td>
<td>0.738 (0.004)</td>
</tr>
<tr>
<td>X10FFF</td>
<td>21.0 (1.2)</td>
<td>19.1 (1.6)</td>
<td>43.6 (1.0)</td>
<td>69.1 (1.0)</td>
<td>0.692 (0.012)</td>
</tr>
</tbody>
</table>

Abbreviations: TPR 20/10 = tissue-phantom ratio at the depths of 20 and 10 cm; $\%dd$ = percentage depth dose.
$6X \ d_{\text{max}} \ \text{vs.} \ 6F \ d_{\text{max}}$

**Surface Dose Investigation of the Flattening Filter-Free Photon Beams**

Yuenan Wang, Ph.D.,* Mohammad K. Khan, M.D., Ph.D., † Joseph Y. Ting, Ph.D.,*, and Stephen B. Easterling, M.S. *

*Melbourne Cancer Center, Melbourne, Fl; and †Radiation Oncology, Winship Cancer Center, Emory University, Atlanta, GA
Output: 6X vs. 6F

Table 4. Dosimetric leaf gap and transmission of HDMLC
(2 standard deviations in brackets)

<table>
<thead>
<tr>
<th>MLC transmission</th>
<th>DLG (mm)</th>
<th>depth 5 cm</th>
<th>depth 10 cm</th>
<th>depth 20 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>X6</td>
<td>0.93 (+/−0.08)</td>
<td>1.19 %</td>
<td>1.21 %</td>
<td>1.30 %</td>
</tr>
<tr>
<td>X10</td>
<td>1.03 (+/−0.08)</td>
<td>1.38 %</td>
<td>1.39 %</td>
<td>1.41 %</td>
</tr>
<tr>
<td>X6FFF</td>
<td>0.91 (+/−0.07)</td>
<td>0.98 %</td>
<td>1.02 %</td>
<td>1.13 %</td>
</tr>
<tr>
<td>X10FFF</td>
<td>1.04 (+/−0.08)</td>
<td>1.17 %</td>
<td>1.20 %</td>
<td>1.27 %</td>
</tr>
</tbody>
</table>
Output factors

• Careful measuring output factors
• Need to look for the center spot of field
6X Profile vs. 6F Profile

**Graph:**
- **Y-axis:** Relative Dose (%)
- **X-axis:** Offaxis Distance (mm)
- **Legend:**
  - Red: 6F_10X10_Profile @Dmax
  - Blue: 6X_10X10_Profile @Dmax

**Note:**
This graph compares the dose profiles of 6X and 6F beams at the reference point Dmax.
4 x 4 Profiles

Depth = 5 cm
40 x 40 Profiles

Depth = 10 cm
Diagonal Profiles

Truebeam Diagonal Profile

“C” Series Diagonal Profile
Dose to Air and Dose to Water

- Conversion of the air cavity dose $D_{air}$ to dose to medium $D_{med}$ is based on:
  - Bragg-Gray cavity theory
    - Average *unrestricted* mass collision stopping power
      \[
      D_{med} = D_{air} \left( \frac{\bar{S}}{\rho} \right)_{med} \left/ \left( \frac{\bar{S}}{\rho} \right)_{air} \right.
      \]
  - Spencer-Attix cavity
    - Average *restricted* mass collision stopping power
Beam Quality

Relationship between \( \%dd(10)_x \) and stopping-power ratios for flattening filter free accelerators: A Monte Carlo study

Guoming Xiong\textsuperscript{a}) and D. W. O. Rogers

\textit{Physics Department, Carleton University, Ottawa, Ontario, K1S 5B6 Canada}

\textbf{Med. Phys. 35 (5), May 2008}

- Different ways to determine \( (\bar{L}/\rho)_{\text{water}} \)
- \( \%dd(10)_x \)
  - Results in 0.4\% error in TG-51 protocol
- \( TPR^{20}_{10} \)
  - Different relationships can result in 0.4-1.0\% error

\( \rho_{\text{water}} \) air

\( \bar{L} \)
Ion Recombination

• Three categories
  – Continuous beams
  – Scanning beams
  – Pulsed beams (i.e., conventional linacs and FFF mode)

• For operating voltage $V_H = 2V_L$

$$f_{g,pul} = 2 - \frac{M_H}{M_L}$$

M is the chamber signal for high and low voltage.
FFF Beam Calibration

• Protocols for output calibration still apply
• Still need to check correction factors for FFF
  – Ion recombination correction ~ 0.5% for 6FFF
  – Polarity correction ~ 1.0

• Eclipse data is same as for flattened beams

Implementation: End-to-End

• Small water tank measurements
• Scan, Plan, and Deliver
  – Phantoms
    • Solid water phantom
    • Homogeneous CIRS phantom
    • Heterogeneous CIRS phantom
  – Evaluation
    • Point dose comparison
    • 2D dose comparison
    • Independent MU calculation
Heterogeneous Phantom Tests

Geometry 11
- Farmer ion chamber & EBT2 Film
- Energies = 6XGB, 6XUCSD, 6FFF
- Plans
  - Cylindrical PTV
    - 4 Field Box (+ EDWs)
    - 7 Field IMRT
    - 2 Arc RapidArc
  - C-Shape PTV
    - 7 Field IMRT
CIRS Heterogeneous Phantom
## CIRS Heterogeneous Phantom

<table>
<thead>
<tr>
<th>Plan</th>
<th>Mode</th>
<th>Meas Dose (cGy)</th>
<th>Plan Dose (cGy)</th>
<th>% diff</th>
<th>% points passing 3%/3mm Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-f IMRT C-shape PTV</td>
<td>6XGB</td>
<td>197.8</td>
<td>200.5</td>
<td>-1.3%</td>
<td>98.1</td>
</tr>
<tr>
<td></td>
<td>6XUCSD</td>
<td>198.4</td>
<td>200.8</td>
<td>-1.2%</td>
<td>98.9</td>
</tr>
<tr>
<td></td>
<td>6X-FFF</td>
<td>201.4</td>
<td>204.1</td>
<td>-1.3%</td>
<td>99.3</td>
</tr>
<tr>
<td>RapidArc</td>
<td>6XGB</td>
<td>197.3</td>
<td>201.4</td>
<td>-2.1%</td>
<td>99.3</td>
</tr>
<tr>
<td></td>
<td>6XUCSD</td>
<td>197.0</td>
<td>201.2</td>
<td>-2.1%</td>
<td>98.9</td>
</tr>
<tr>
<td></td>
<td>6X-FFF</td>
<td>193.5</td>
<td>197.6</td>
<td>-2.1%</td>
<td>99.7</td>
</tr>
</tbody>
</table>
Patient-Specific QA (UCSD)

• Starting Out and for all FFF plans
  – Point dose and planar dosimetry
    • IMRT phantom
    • EBT2 film and analysis using RIT

• Conventional IMRT – Portal dosimetry
Point Dose and Planar Dosimetry
Patient-Specific QA Summary

Pretreatment quality assurance of flattening filter free beams on 224 patients for intensity modulated plans: A multicentric study

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Luca Cozzi  
Medical Physics Unit, Oncology Institute of Southern Switzerland, 6500 Bellinzona, Switzerland

Pietro Mancosu(a)  
Department of Radiation Oncology, IRCCS Istituto Clinico Humanitas, 20089 Rozzano, Italy

• 224 patients with 1–6 lesions in various anatomical regions
• Point dose verification was performed on 52 cases, obtaining a dose deviation of 0.34%
AAPM Task Group 103 report on peer review in clinical radiation oncology physics


RESULTS OF TLD CHECK OF PHOTON BEAM OUTPUT

<table>
<thead>
<tr>
<th>Institution:</th>
<th>Moores UCSD Cancer Center, La Jolla, CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTF Number</td>
<td>3105</td>
</tr>
<tr>
<td>Person irradiating dosimeters:</td>
<td>Todd Pawlicki, Ph.D.</td>
</tr>
<tr>
<td>Radiation Machine:</td>
<td>TrueBeam Serial 18 (DelMarTB)</td>
</tr>
<tr>
<td>Radiation Quality:</td>
<td>6 (FF) MV X-rays</td>
</tr>
<tr>
<td>Distance from source to reference point:</td>
<td>100.0 cm</td>
</tr>
</tbody>
</table>
Brain SRS

15Gy x 1
6FFF
Brain SRS

18Gy x 1
6FFF
Spine SRS

18Gy x 1
6FFF
3 min/arc
(2 arcs)
Planning – 6X vs. 6FFF

- 6F; 1295 MU
- 6X; 1204 MU
- 7.6% less MU


Showed a decrease in MU for FFF beams.
Planning – 6X vs. 6FFF

- 6FFF; 3729 MU + 3846 MU = 7575 MU
- 6X; 3354 MU + 3460 MU = 6814 MU
  - 11.2% less MU
Summary

• FFF Beams require careful implementation

• Follow existing protocols

• Start out planning both flat and FFF beams
  – Establish a patient-specific QA program

• Use external audits to check implementation