Shielding for Multislice CT Scanners

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Site Planning for CT

- Location, room dimensions
- Equip type
- Electrical
- HVAC
- Water
- Structural loading
- Shielding

... and one or two

Site Planning for CT

* Location, room dimensions
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Project Planning

- Neighboring spaces
  - Adj occup factors if needed
  - Dist of closest approach, ≥ 0.3m
- Design goals or limits
  - Public, Controlled, Pregnant worker
  - Adjust if needed
- Workload estimate

The Shielding Problem

- An administrator’s office is adjacent to a CT scan room. The administrator sits 4m from the scanner. How much shielding is required?

3 mm Pb

If only it were this easy!!!

Preliminary Information

- Architectural drawings (Plan view) of exam room, floor above, and floor below
  - Elevation sections for floor and ceiling
  - Occupancy factors for floors above and below
  - Two rooms away or across hall (remote areas may be more sensitive than adjacent)
- Composition of walls, ceilings and floors
  - Materials and thickness
- Scanner placement from vendor
  - Distance to protected areas beyond barriers
- Scatter contributions from other rooms/floors

MDACC Imaging Physics

Neighboring spaces
Workload Estimates

- Number procedures per week
  - 3 patients per hour
  - 1 to 5 procedures per patient
- Body% and Head%
- Contrast and non-contrast scans
- 120kVp vs other kVp
- Scan parameters of protocol

Multi-Slice Helical CT Shielding

- Thinner slice protocols may require more dose – create more scatter
  - More photons needed to generate adequate photon statistics per slice (smaller voxels, higher noise)
  - Environmental radiation levels typically increase with increase in beam width
  - However, fewer rotations are needed to produce the scan

Multi-Slice Helical CT Shielding

- Over-scan at ends of volume add scatter
  - Worst with widest beams
- Ceiling and floor deserve close scrutiny

Barrier Determination

- NCRP 147, section 5.6, pg 94
- CTDI method
- DLP method
- Scatter plots
CTDI Method

- What we need to know:
  Pitch = table/beam
  Beam width: T_p or (nT)
  Rotation time
  Peripheral CTDI100
  - measure (can scale by kVp2)
  - Look on ImPACT website

Unshielded weekly exposure calculation:
Secondary exposure per procedure at one meter K

\[ K = \frac{1}{p} \times \frac{mAs}{Rotation} \times CTDI_{100, peripheral} \times \text{CTDI}_{kV} \times \left( \frac{\text{Scan kV}}{\text{CTDI}_{kV}} \right)^2 \]

Where:
- \( x \) is the scatter fraction at one meter per cm scanned.
- \( L \) is the length of the scanned volume.
- \( p \) is pitch.

- \( k_{\text{head}} = 9 \times 10^{-7} \text{ cm}^{-1} \)
- \( k_{\text{body}} = 3 \times 10^{-4} \text{ cm}^{-1} \)

CTDI Method

- ImPACT (the UK’s CT evaluation center)
- measured axial and peripheral CTDI100
- for most scanners on the market
- Excel format

www.impactscan.org

NCRP 147 DLP Method

DLP (Dose-Length Product)
- \( CTDI_{kV} = 1/3 \text{ Center CTDI}_{100} + 2/3 \text{ Surface CTDI}_{100} \)
- \( CTDI_{VOL} = CTDI_{kV} / \text{Pitch} \)
- \( DLP = CTDI_{VOL} \times L \)
- \( L = \text{Scan length for average series (cm)} \)
- Units of mGy-cm
- From scanner display … verify these values!

\[ DLP = \left( \frac{1}{3} \text{ Center CTDI}_{100} + \frac{2}{3} \text{ Surface CTDI}_{100} \right) \times L/p \]

NCRP 147 DLP Method

- Weekly Air Kerma at 1m (K'_{sec})

\[ K'_{sec} = k_{\text{head}} \times DLP \]
\[ K'_{sec} = 1.2 \times k_{\text{body}} \times DLP \]

Factor of 1.2 assumes peripheral CTDI{sub}sec, Center CTDI{sub}sec for Body

\[ k_{\text{head}} = 9 \times 10^{-6} \text{ cm}^{-1} \]
\[ k_{\text{body}} = 3 \times 10^{-4} \text{ cm}^{-1} \]

Use inverse square to find unshielded weekly exposure at barrier from K'_{sec}

Scatter plot Method

- Assume an isotropic exposure distribution w/ the vendor-supplied scatter distribution plots (max is approx. 45° to the scanner axis).
- Overestimates shielding for gantry shadows
- W, in mA•min per week
- Determine weekly exp at shielded point
- Pay attention to
  - Beam width
  - kVp and mAs
  - phantom
Use Caution with Scatter Plots

- Choice of plot (Head vs Body)
- Normalization of data
  - kVp of plot vs clinical
  - mAs per scan
  - Beam width of plot vs clinical
- Total mAs per scan
  - Pitch, rotation, total beam-on time
  - Accounts for scan acquisition time for different beam width

Question

Do I really need to put lead in the ceiling of a 64-slice CT scan room?

Method

- Calculate the unshielded weekly exposure rate at 0.5 m beyond the floor above
  - Find the maximum weekly exposure at 1 m from isocenter and inverse-square this out to the occupied area beyond the barrier.
- Perform barrier thickness calculations
  - Occupancy, permissible dose, attenuation of concrete, etc.

Example

- 180 Procedures/week
  - 150 Abdomen & Pelvis
  - 30 Head
- 40% w/o contrast
- 13.0' (4.2 m) ceiling height (finished floor to finished floor) $D_{eff} = 3.7m$
- GE LightSpeed 16
- Ignores overscan at ends!
  - Effect Worsens with wider beams (64-slice)
### Protocols

<table>
<thead>
<tr>
<th></th>
<th>kVp</th>
<th>mA</th>
<th>Time (sec)</th>
<th>Pitch</th>
<th>Beam (mm)</th>
<th>Table (mm/rot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>120</td>
<td>240</td>
<td>1.0</td>
<td>1.375</td>
<td>10</td>
<td>13.75</td>
</tr>
<tr>
<td>Body</td>
<td>120</td>
<td>265</td>
<td>0.8</td>
<td>0.938</td>
<td>20</td>
<td>18.75</td>
</tr>
</tbody>
</table>

### NCRP 147 DLP Method

<table>
<thead>
<tr>
<th>Procedure</th>
<th>CTDI\text{vol} (mGy)</th>
<th>Scan Length (L, cm)</th>
<th>DLP (mGy-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>60</td>
<td>20</td>
<td>1200</td>
</tr>
<tr>
<td>Body</td>
<td>15</td>
<td>35</td>
<td>525</td>
</tr>
<tr>
<td>Abdomen</td>
<td>25</td>
<td>25</td>
<td>625</td>
</tr>
<tr>
<td>Pelvis</td>
<td></td>
<td>20</td>
<td>500</td>
</tr>
<tr>
<td>Body (Chest, Abdomen, or Pelvis)</td>
<td></td>
<td></td>
<td>550</td>
</tr>
</tbody>
</table>

### Unshielded Weekly Exposure at Barrier

- **Average Air Kerma/procedure at 1 m (K_{sec}^v)**
  - 40% w/w/o contrast
  
  \[ K_{sec}^v (\text{head}) = 1.4 \times k_{head} \times DLP = 1.4 \times 9 \times 10^{-5} \text{ cm}^{-1} \times 1200 \text{ mGy-cm} = 0.15 \text{ mGy} \]
  
  \[ K_{sec}^v (\text{body}) = 1.4 \times 1.2 \times k_{body} \times DLP = 1.4 \times 1.2 \times 3 \times 10^{-4} \text{ cm}^{-1} \times 550 \text{ mGy-cm} = 0.28 \text{ mGy} \]

### Required Transmission (B)

\[ B = \frac{P}{K_{sec}^v \times T} \]

- \( P \) = Maximum permissible weekly exposure
- \( T \) = Occupancy Factor

\[ P = 0.02 \text{ mGy} \]
\[ T = 3.37 \text{ mGy} \times 1 \]
\[ B = \frac{0.02 \text{ mGy}}{3.37 \text{ mGy} \times 1} = 5.9 \times 10^{-3} \]
**Total Shielding Required**

Use Simpkin curve fit equations or look up on published attenuation diagrams (NCRP 147 Fig. A-2)

![Graph of Transmission of CT Scanner Secondary Radiation Through Lead (120 kV)](image)

**Existing Shielding**

- Determine attenuation of existing barriers with Tc-99m source and Na-I detector
- Determine lead-equivalence of barrier
- Floors and ceilings
  - Find lead equivalence from documentation of concrete thickness.
  - If necessary, find thickness by drilling a test hole and measuring.
  - Always assume light weight concrete, unless proven otherwise (30% less dense than standard density, coefficients used in NCRP 147)

**Comparison of Methods**

<table>
<thead>
<tr>
<th>DLP NCRP 147</th>
<th>CTDI&lt;sub&gt;100&lt;/sub&gt;</th>
<th>Scatter plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Body</td>
<td>Head</td>
</tr>
<tr>
<td>4.5</td>
<td>42</td>
<td>2.0</td>
</tr>
<tr>
<td>Weekly kerma</td>
<td>@ 3.7m</td>
<td>3.37</td>
</tr>
<tr>
<td>Total Barrier (mm Lead)</td>
<td>1.4</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Ceiling Considerations

- Pb mounting in ceiling is manually applied and très cher! (very expensive!)
- Isotropic distribution is conservative, but not so realistic
- Consider % of scans helical w/o gantry tilt (tilted axials usually for Head only)
- Smaller area of ceiling to cover = smaller cost … THIS time
- Additional cost possibly incurred in future renovation

Acceptable exposures

- 1/8" Lead in Floor
- Wall-to-wall Lead in Ceiling – see attached diagram

Custom support frames
Watcha Gonna Do? #1

- Attended waiting room adjacent to CT room
- New PET-CT to be installed on floor below

Watcha Gonna Do? #2

- CT room on 3rd floor, exterior wall, standard windows
- Lab area across driveway
- Current kerma in labs OK, but close to limit
- New PET-CT to be added adj to existing CT
Thank you!

Acknowledgements:
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