PET Shielding

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Design Values
Annual Limits
Same as NCRP 147
What radionuclides and radiopharmaceuticals should we design for?

Comparison of PET Decay Constants

<table>
<thead>
<tr>
<th>Rate Constants</th>
<th>Value</th>
<th>1 Hr Integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-11</td>
<td>0.184</td>
<td>0.063</td>
</tr>
<tr>
<td>N-11</td>
<td>0.180</td>
<td>0.034</td>
</tr>
<tr>
<td>O-15</td>
<td>0.190</td>
<td>0.007</td>
</tr>
<tr>
<td>F-18</td>
<td>0.168</td>
<td>0.119</td>
</tr>
<tr>
<td>Cu-64</td>
<td>0.03</td>
<td>0.024</td>
</tr>
<tr>
<td>Ga-68</td>
<td>0.13</td>
<td>0.101</td>
</tr>
<tr>
<td>Rb-82</td>
<td>0.16</td>
<td>0.006</td>
</tr>
<tr>
<td>O-15</td>
<td>0.15</td>
<td>0.183</td>
</tr>
</tbody>
</table>

F-18 Rate Constants

<table>
<thead>
<tr>
<th>F-18 Rate Constants</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Kerma Exposure Rate</td>
<td>0.136</td>
</tr>
<tr>
<td>Effective Dose Equivalent (ANS-1991)</td>
<td>0.145</td>
</tr>
<tr>
<td>Tissue Dose Constant</td>
<td>0.148</td>
</tr>
<tr>
<td>Deep Dose Equivalent (ANS-1977)</td>
<td>0.162</td>
</tr>
<tr>
<td>Maximum Dose (ANS-1977)</td>
<td>0.198</td>
</tr>
</tbody>
</table>

Note: The equations in the TG Report correct this for self absorption

What Is the Activity?

\[ \dot{D} = \frac{A_r}{d^2} \]
What Is the Activity?

\[ A_u = \int_0^{t_u} A_0 e^{-\lambda t} \, dt \]

Scan Room Activity

\[ A_s = A_0 \kappa \left( \frac{1}{2} \right)^{t_u/T_{1/2}} \int_{t_u}^{t_u} e^{-\lambda t} \, dt \]

Voiding factor 0.85

Across 8 ft Corridor

Fully Occupied Space

Distance

Report Distances Are in Meters

Dose_{ann} = \frac{\tilde{A}_u \, t_u \, T_{60} / d^2}{V}

\begin{align*}
\tilde{A}_u &= \left( \frac{A_0}{\ln(2)} \right) \left( \frac{T_{1/2}}{t_u} \right) \\
&\quad \times \left( 1 - \left( \frac{1}{2} \right)^{t/T_{1/2}} \right) \\
\end{align*}

<table>
<thead>
<tr>
<th>t_u</th>
<th>0.91</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.91</td>
</tr>
<tr>
<td>60</td>
<td>0.83</td>
</tr>
<tr>
<td>90</td>
<td>0.76</td>
</tr>
</tbody>
</table>
Occupancy Factor

Same as NCRP 147

Transmission Factor

Use Archer Equation

\[
B = \frac{pd^2}{T \tilde{A}_u t_u \Gamma N}
\]

Scan Room

\[
Dose_{ann} = \tilde{A}_s t_s \Gamma N / d^2
\]

\[
B = \frac{pd^2}{T \tilde{A}_s t_s \Gamma N}
\]

Use Archer Equation

\[
\chi = \frac{1}{\alpha \gamma} \ln \left[ \left( \frac{B^{-\gamma} + (\beta / \alpha)}{1 + (\beta / \alpha)} \right) \right]
\]
Table V. Fitting parameter for broad beam 511 keV transmission data.

<table>
<thead>
<tr>
<th>Shielding material</th>
<th>Alpha (cm(^{-1}))</th>
<th>Beta (cm(^{-1}))</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>1.543</td>
<td>0.4408</td>
<td>2.136</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.1539</td>
<td>0.1161</td>
<td>2.0752</td>
</tr>
<tr>
<td>Iron</td>
<td>0.5704</td>
<td>0.3063</td>
<td>0.6326</td>
</tr>
</tbody>
</table>

Effective Design of PET Shielding

Early Intervention

- Design can greatly influence
  - Shielding costs
  - Easy of use
- Sites often have 3 dimensional aspects that affect shielding
- Architects often have naive ideas based on nuclear or x-ray shielding
- There are other radiation protection aspects besides shielding
Other Possibilities

- Maze for uptake rooms
- No window in control room
  - Use video viewing
  - Increase distance
- General assistance with design
  - Lighting
  - Intercoms

Spreadsheet for Calculations
PET Shielding Is Complex

• More lead is used than for typical radiographic installations
• The safety factor is much less than for most diagnostic installations
• Exposure usually occurs from multiple sources
Shielding Evaluation
• To Insure
  ◦ Radiation Doses are below the levels required by regulation
  ◦ Are consistent with the shielding design
  ◦ That the shielding is properly installed

My Priorities
• Check for proper construction
• Determine the adequacy of the shielding
• NCRP 147

Instrumentation
• We have used three types of instruments
  ◦ Large volume ionization chamber
    • Radcal 9010 w/ 10X5-1800
  ◦ Portable pressurized ionization chamber
    • Innovision 451P
  ◦ Portable NaI(Tl) Survey Meter
    • Exploranium GR-135

Instrument of Choice
• All three devices gave approximately equal readings
• All could produce accurate measurements
• The portable NaI(Tl) survey meter was somewhat more sensitive and convenient to use
Proper Construction

- Use source in each location
- Use meter to scan for gaps and voids

Evaluating the Annual Exposure at a Location

Scaled Source Method

- Find scaled source strengths that give the same radiation exposure (air kerma) as the total activity that is used in the room
- Place sources in all patient locations
- Measure dose at appropriate

Annual Dose = Dose Rate x Number of Patients x Time Each Patient is in the Room

Activity = Average Patient Dose x Number of Patients x Time Each Patient is in the Room

Annual Dose = Dose Rate x 1 hour

Source

Annual Dose = Dose Rate x Number of Patients x Time Each Patient is in the Room

Source
Average Patient Activity

Uptake Room

- Factors
  - Administered activity
  - Time patient spends in room
  - Number of patients in the room
  - Patient self attenuation factor

\[ \dot{\lambda}_u = \xi \left( \frac{\lambda_0}{1 + (2)^{\left(\frac{T_{1/2}}{T_u}\right)}} \right) (1 - (1/2)^{T_u/T_{1/2}}) \]

Average Patient Activity

Scan Room

- Factors
  - Administered activity
  - Time patient spends in uptake room
  - Fraction of activity voided by patient
  - Time patient spends in scan room
  - Number of patients in the room
  - Patient self attenuation factor

\[ \dot{\lambda}_s = \xi \left( \frac{\lambda_0}{1 + (2)^{\left(\frac{T_{1/2}}{T_u}\right)}} \right) \left(1 - (1/2)\left(\frac{T_{1/2}}{T_u}\right)^{\left(\frac{T_u}{T_{1/2}}\right)}\right) \]

So for all rooms

- The equivalent activity is the product of
  - The average activity
  - The number of patients
  - The time they are in the room

\[ \sum \dot{\lambda}_u n_s t_s + \sum \dot{\lambda}_s n_s t_s \rightarrow D (x, y, z) \]

So from all rooms

<table>
<thead>
<tr>
<th>Room</th>
<th>Effective Activity (mCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uptake Room 1</td>
<td>20536</td>
</tr>
<tr>
<td>Uptake Room 2</td>
<td>5134</td>
</tr>
<tr>
<td>Scan Room</td>
<td>9001</td>
</tr>
</tbody>
</table>

So we need to Scale the Activity

\[ \left( \sum \dot{\lambda}_u n_s t_s + \sum \dot{\lambda}_s n_s t_s \right) \n_\rightarrow D (x, y, z) / \sigma \]

\[ \sigma_{\text{all}} = \dot{\lambda}_u n_u t_u / \sigma \]

\[ \sigma_{\text{all}} = \dot{\lambda}_s n_s t_s / \sigma \]
So from all rooms

### Scaling Factor

<table>
<thead>
<tr>
<th>Room</th>
<th>Effective Activity</th>
<th>Scaled Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uptake Room 1</td>
<td>20536 mCi</td>
<td>41 mCi</td>
</tr>
<tr>
<td>Uptake Room 2</td>
<td>5134 mCi</td>
<td>10 mCi</td>
</tr>
<tr>
<td>Scan Room</td>
<td>9001 mCi</td>
<td>18 mCi</td>
</tr>
</tbody>
</table>

### Compare Results to Design Values

\[
\frac{p}{TD(x, y, z)} \leq 1
\]

- Correct for Occupancy Factors
- Correct for decay of sources during the measurement

### Evaluating Lead in Wall

- Use a source in room
- Measure air kerma at point outside wall
- Determine B
- Evaluate using chart from TG 108
- Calculate Using Archer Equation
Direct Calculation

- The thickness can also be calculated using the model of Archer et al.

\[
x = \left( \frac{1}{\alpha \gamma} \right) \ln \left[ \frac{B \cdot e^{-\gamma} + (\beta / \alpha)}{1 + (\beta / \alpha)} \right]
\]

\[
D_0 = \frac{A_0}{d^2}
\]

\[
B = \frac{D_m}{A_0} d^2
\]

\[
x = \left( \frac{1}{\alpha \gamma} \right) \ln \left[ \left( \frac{D_m}{A_0} d^2 \right)^{-\gamma} + (\beta / \alpha) \right] / \left( 1 + (\beta / \alpha) \right)
\]

---

How Much Activity Do You Need?

- The table below shows the required activity in mCi and MBq for different lead thicknesses to achieve a certain amount of shielding.

<table>
<thead>
<tr>
<th>US Inches</th>
<th>Metric mm</th>
<th>Attenuation</th>
<th>Activity MBq</th>
<th>mCi</th>
<th>uSv/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1.000</td>
<td>629</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>1/16</td>
<td>1.6</td>
<td>0.829</td>
<td>759</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>1/8</td>
<td>3.2</td>
<td>0.674</td>
<td>933</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>1/4</td>
<td>6.4</td>
<td>0.430</td>
<td>1465</td>
<td>40</td>
<td>23</td>
</tr>
<tr>
<td>3/8</td>
<td>9.5</td>
<td>0.267</td>
<td>2357</td>
<td>64</td>
<td>37</td>
</tr>
<tr>
<td>1/2</td>
<td>12.7</td>
<td>0.164</td>
<td>3826</td>
<td>103</td>
<td>61</td>
</tr>
<tr>
<td>3/4</td>
<td>19.1</td>
<td>0.062</td>
<td>10168</td>
<td>275</td>
<td>162</td>
</tr>
<tr>
<td>1</td>
<td>25.4</td>
<td>0.023</td>
<td>27078</td>
<td>732</td>
<td>430</td>
</tr>
</tbody>
</table>

Desired distance: 3 meters

Desired Air Kerma: 10 uSv/hr

Lead Thickness Evaluation

- F-18 Source: 1742.7 MBq
- Calibration Time: 3:35 PM
- Gamma Constant: 0.143 uSv-m²/MBq-h
- Alpha 1.5430 per cm
- Beta -0.4408 per cm
- Gamma 2.1360
Some day you will look back upon this and run into a bus