PET/CT Shielding Design Examples

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Sources of Exposure: F-18 in Patients

- Task Group 108 recommends a realistic Effective Dose Rate Constant $\Gamma$ for F-18 in patient:
  \[
  \Gamma = 0.092 \, \mu \text{Sv m}^2 \text{ MBq}^{-1} \text{ h}^{-1}
  \]
- Assume all photons emitted from patient are 511 keV
Time determines Dose Rate

• Then Dose Rate $\dot{D}$ at distance $r$ (m) from activity $A$ (MBq) is

$$\dot{D} = \frac{\Gamma A}{r^2}$$

• The Dose, $D$, accumulated over time $t$ is

$$D = 1.44 \times \dot{D} \times T_{1/2} \times \left(1 - e^{-\frac{0.693}{T_{1/2}} \times t}\right)$$

• And track decay of activity from moment-to-moment

$$A(t) = A_0 \, e^{-\frac{0.693}{T_{1/2}} \times t}$$
The patient is the source

- FDG patient is in “incubation” (in a quiet, isolated room) for ~45 minutes. Shielding for this room must be considered.
- Patient in scanner for 30-60 minutes. Shielding for scanner room must be considered.
Shielding People to $P/T$

- In *uncontrolled areas* in USA
  - Must restrict dose in any one hour to < 0.02 mSv and
  - Must restrict annual dose to < regulated limit of 1 mSv y$^{-1}$

- **Controlled areas** in USA
  - (For pregnant workers), must restrict annual occupational dose to 5 mSv y$^{-1}$
Corridor Outside Uptake Room

- Presume the patient is injected with 555 MBq $^{18}$F. The patient remains quiescent in the Uptake Room for 45 minutes.
- At 3 m (to the corridor) the initial dose rate upon injection at is

$$\dot{D}_0 = \frac{\Gamma A}{r^2} = \frac{0.092 \frac{\mu Sv \ m^2}{MBq \ h} \times 555 \ MBq}{(3 \ m)^2} = 0.0057 \ \frac{mSv}{h}$$

- So in the USA, 0.02 mSv in any h is satisfied
Corridor Outside Uptake Room

• Assume 40 PET patients per week = 2080 patients per year

• The annual unshielded dose in the corridor outside the uptake room is then

\[
D = 2080 \frac{\text{pat}}{\text{y}} \times 1.44 \times 0.0057 \frac{\text{mSv}}{\text{h}} \times 1.83 \text{h} \times \left( 1 - e^{-\frac{0.693}{1.83} \times 0.75 \text{h}} \right)
\]

\[
= 7.72 \frac{\text{mSv}}{\text{y}}
\]
Corridor Outside Uptake Room

• If the corridor is uncontrolled, $P=1 \text{ mSv y}^{-1}$ and $T$ for the wall is $= 1/5$, so $P/T = 5 \text{ mSv y}^{-1}$

• The wall must be shielded so $B = 5 / 7.2 = 0.69$, which requires 3 mm thick Pb.

• The door has an occupancy factor $T = 1/8$, so that $P/T = 8 \text{ mSv y}^{-1}$. Since the unshielded dose is 7.2 mSv y$^{-1}$, the door needs no shielding.
Office Above Uptake Room

- Consider a fully occupied \((T=1)\) uncontrolled \((P=1 \text{ mSv y}^{-1})\) office 3.5 m above Uptake Room. The initial dose rate is

\[
\dot{D}_0 = \frac{\Gamma A}{r^2} = \frac{0.092 \mu\text{Sv} \text{m}^2}{\text{MBq h}} \times 555 \text{ MBq} \times \frac{1}{(3.5 \text{ m})^2} = 0.0042 \frac{\text{mSv}}{\text{h}}
\]

- So again, 0.02 mSv in any 1 h is satisfied
Office Above Uptake Room

• For 2080 patients per year, the annual dose in the office is then

\[
D = 2080 \frac{pat}{y} \times 1.44 \times 0.0042 \frac{mSv}{h} \times 1.83 h \times \left(1 - e^{-\frac{0.693}{1.83h} \times 75h}\right)
\]

\[
= 5.65 \frac{mSv}{y}
\]

• The ceiling must provide shielding, with \(B = 1 \text{ mSv y}^{-1} / 5.65 \text{ mSv y}^{-1} = 0.177\). This requires 15.6 cm std density concrete
Office Above Uptake Room

• In my facility, the ceiling was only 7.6 cm thick. Thus we had to add the equivalent of 15.6 - 7.6 = 8 cm of concrete = 8 cm /22 cm = 0.36 TVL.

• This required 0.36 × 1.8 cm Pb = 0.65 cm Pb to be added to the concrete ceiling.
Note: Activity in patient will have decayed in uptake room (i.e. from ~555 MBq on injection to ~420 MBq when patient enters scanner)
Office adjacent to PET/CT Scanner

- Fully occupied uncontrolled area, shield to
  \[ P/T = 1 \text{ mSv y}^{-1} / 1 = 1 \text{ mSv y}^{-1} \]
- At 3.5 m distance, with initially 420 MBq in patient

\[
\dot{D}_0 = \frac{\Gamma A}{r^2} = \frac{0.092 \frac{\mu \text{Sv m}^2}{\text{MBq h}} \times 420 \text{ MBq}}{(3.5 \text{ m})^2} = 0.0032 \frac{\text{mSv}}{\text{h}}
\]
Office adjacent to PET/CT Scanner

- For 2080 patients per year, the annual dose in the office for a 45 min scan is then

\[
D = 2080 \frac{\text{pat}}{\text{y}} \times 1.44 \times 0.0032 \frac{\text{mSv}}{\text{h}} \times 1.83 \text{h} \times \left(1 - e^{-\frac{0.693}{1.83 \text{h} \times 0.75 \text{h}}}ight)
\]

\[
= 4.3 \frac{\text{mSv}}{\text{y}}
\]

- The wall must provide shielding, with

\[
B = 1 \text{ mSv y}^{-1} / 4.3 \text{ mSv y}^{-1} = 0.23. \text{ This requires 1.1 cm Pb in the wall.}
\]
PET/CT scanner

- Patient in scanner 0.5 – 1 h
- 2D PET done: 3-4 min/bed stop, 15 cm coverage/stop, 47 × 3.27 mm slices/stop
- CT done for
  - Anatomical co-registration of PET images
  - Attenuation correction of PET images
- For cancer patients typically scan from “eye to thigh”
PET/CT Scanner

• Typical (GE Discovery ST) CT scan technique:
  – (8 row scanner)
  – 100-175 mA,
  – 140 kVp,
  – 0.8 sec/rot,
  – 3.75mm thick slices,
  – pitch = 1.675:1
  – 2 cm beam width
PET/CT Scanner

• Methods for shielding CT scanners are in NCRP-147
• Determine unshielded dose based on
  – Manufacturer’s isoexposure curves
  – Scatter factor applied to CTDI
  – Height of patient scanned
  – mA
• Consider that CT may be used as a stand-alone scanner
PET/CT Scanner

- Calculate $B$ to reduce dose to $P/T$
- Look up barrier thickness required to achieve that transmission
- CT typ. requires
  - 1 to 2 mm Pb
  - 13 cm concrete
Shielding PET AND CT

• PET:
  – Lower unshielded dose rates
  – Penetrating photons require an order of magnitude thicker barriers than the CT scan

• CT
  – Much higher unshielded dose rates
    • All persons entering scanner room while x ray is on must wear a Pb apron
  – Low energy x rays require much thinner barriers.
Shielding PET AND CT

• Shielding requirements for F-18 in the patient predominates (~ 0.5 – 2 cm Pb)

• However, the CT scanner will ~always require some shielding in all barriers (~1 - 2 mm Pb)
  – (For example, as with the uptake room, the door to the scanner room may not require shielding for F-18, but will require 1-2 mm Pb for CT)
Conclusions

• The injected patient is the primary source of radiation exposure in the PET facility
• For $^{18}$FDG, the uptake room and scanner will probably require lead shielding
• This shielding will often be 2-10× thicker than what’s typically in a diagnostic x-ray room
• Shielding for the CT scan in a PET/CT scanner must be considered