Radiation Protection in a PET facility

PET staff
- technologists
- nurses, doctors

Others
- EEG technicians, radiographers, ward nurses, porters, escorts
- Carers
- Family and friends
SOURCES (1): Unsealed

$^{18}F, ^{13}N, ^{11}C, ^{15}O$

Activity in liquid form
- Receive 5-20 GBq in **vial**
- Use 200-500 MBq in **syringe, patient**; blood samples, QC phantoms
- About 60% leaves in patient, 15% in sewer line

Activity in gas form
- Supplied via gas line
- Leaves via gas line or room exhaust
SOURCES (2) : Sealed $^{68}\text{Ge}/^{68}\text{Ga}$

- $^{68}\text{Ge}$ EC, $T_{1/2}$ 287 d
- $^{68}\text{Ga}$ (88%) positrons, $T_{1/2}$ 1.13 h
- Cylinders 150-200 MBq each
- Rods 100-150 MBq each
  - NB high contact dose to fingers through stainless steel encapsulation, max positron energy 1.9 MeV
### Shielding for positrons

<table>
<thead>
<tr>
<th></th>
<th>Max $E_{\beta^+}$</th>
<th>range in glass</th>
<th>range in plastic</th>
<th>Bremss. in Pb $E_{\beta^+}$ converted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MeV</td>
<td>mm</td>
<td>mm</td>
<td>%</td>
</tr>
<tr>
<td>$^{18}$F</td>
<td>0.634</td>
<td>0.9</td>
<td>1.7</td>
<td>1.8</td>
</tr>
<tr>
<td>$^{15}$O</td>
<td>1.732</td>
<td>3.4</td>
<td>6.4</td>
<td>5.0</td>
</tr>
<tr>
<td>$^{13}$N</td>
<td>1.199</td>
<td>2.1</td>
<td>4.0</td>
<td>3.4</td>
</tr>
<tr>
<td>$^{11}$C</td>
<td>0.960</td>
<td>1.6</td>
<td>3.0</td>
<td>2.8</td>
</tr>
</tbody>
</table>
Shielding for
511 keV photons

Compared to other imaging nuclides, PET nuclides:
• have higher dose rates to start with
• are more difficult to attenuate
DR @ 1m, 1GBq in vial

- TI-201: 18 µSv/h
- Tc-99m: 22 µSv/h
- Ga-67: 25 µSv/h
- I-131: 64 µSv/h
- F-18: 158 µSv/h
- Mo-99: 46 µSv/h
Tenth Value Layer in Lead

- TI-201: 1 mm Pb
- Tc-99m: 1 mm Pb
- Ga-67: 6 mm Pb
- I-131: 11 mm Pb
- F-18: 17 mm Pb
- Mo-99: 19 mm Pb
Broad beam attenuation
511 keV photons in lead

Half Value Layer
- Cember 5 mm
- RRPDH 6 mm
- Wachsmann 5.6 mm

Tenth Value Layer
- Cember 16 mm
- RRPDH 17 mm
- Wachsmann 20 mm
Shielding inanimate PET sources

eg. Dose rate at 30 cm from 5 GBq $^{18}$F in vial is reduced from 9000 μSv/h to <10 μSv/h by 50 mm Pb

Weight of Pb shields require

- Strong bench supports
- Manual handling aids
Shields for dispensing and injecting

Vial activity from 0.5 to 10 GBq
• Vial holder 30 mm Pb
• Bench shield 50 mm Pb / 65 mm Pb-glass
• Dose calibrator chamber 50mm Pb rings

Syringe activity up to 0.7 GBq
• Syringe carrier 25 mm Pb
FDG patient movements
Shielding the patient

Adapt NCRP 49 method:

• Estimate the dose at 1 m from the source term W GBq-h/wk
• Correct for distance to other side of barrier
• Estimate transmission (K) to reduce the dose to the design level
• Translate K into barrier thickness
The only equation in this presentation

Weekly dose \( D = \frac{W \times \Gamma \times U}{f(d)} \)

Dose constraint \( P = 10 \text{ or } 20 \, \mu\text{Sv/wk} \) (say)

Design dose \( L = \frac{P}{T} \)

where \( T = \text{occupancy} \)

Hence,

Transmission \( K = \frac{L}{D} \)

\[ = \frac{P \times f(d)}{W \times \Gamma \times U \times T} \]
Assumptions

P  20 μSv  in 1 week in designated radiation areas
    10 μSv  in 1 week in public areas

U  1   PET camera & waiting room
    1/2  Uptake rooms

T  1   PET work station, lab, offices
    1/20 utility rooms
    1/40 waiting room, corridor, lift, stairwell
$^{18}$F-FDG in patients

- Assume activity is point source in middle of patient
- All walls are irradiated, $U = 1$
- Isotropic field, ignore attenuation in gantry
Assumptions for FDG workload, W

- Assume dose rate varies inversely as $d^{1.5}$ at less than 3m from patient
- Ignore attenuation in patient, use dose constant $\Gamma = 158 \mu$Sv/GBq-h as for vial
- Locate FDG patient in centre of room or at 1 m from wall at head of bed
Dose rates within patient areas
3 neuro + 12 WB procedures

µSv/h at 1m

upptake room1
uptake room2
scanner room
waiting room

time of day
Broad beam attenuation at 511 keV

- **Published graphs**: mostly for radiotherapy sources and strengths. Somewhere between $^{137}$Cs and $^{192}$Ir.

- **Build-up calculations**: significant in concrete.

- **Monte Carlo modelling**
Interpolation between $^{192}$Ir and $^{137}$Cs transmission curves

Standard concrete
- 1st HVL 160mm
- 1st TVL 240mm
- subsequent TVLs 160 mm
511 keV broad beam attenuation

[Monte Carlo modelling ref. Courtney]
Sources (3): PET/CT hybrid scanner

EPA default CT workload
- 300 mAs/1cm slice, 35 slices/patient, 20 patients/day, 5 d/wk ⇒ 17,500 mA-min/wk

PET/CT workload
- 300 mAs/1cm slice, 70 slices/patient, 20 patients/day, 5 d/wk ⇒ 35,000 mA-min/wk
CT scatter dose estimate

- Manufacturer’s scatter dose map, \( \mu \text{Sv}/1000 \text{ mA-s} \)
- Manufacturer’s nominal air kerma rate at 1 m from isocentre, \( \text{mGy/mA-min} \)
Dose rates in PET/CT scanner room

µSv/h at 1m

CT
FDG patients

7:00 10:00 13:00 16:00 19:00
time of day
## Weekly workload scenarios

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2003</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDG PET</td>
<td></td>
<td>FDG PET</td>
<td>CT</td>
</tr>
<tr>
<td>patients/wk</td>
<td>75</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>% neuros</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>source</td>
<td>500; 250 MBq</td>
<td>500; 250 MBq</td>
<td>125 kVp</td>
</tr>
<tr>
<td>&quot;on&quot; hrs/day</td>
<td>10.5</td>
<td>9.5</td>
<td>2</td>
</tr>
</tbody>
</table>
# Weekly dose scenarios

<table>
<thead>
<tr>
<th></th>
<th>2000/PET</th>
<th>2003/PET</th>
<th>2003/CT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Workload W</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uptake rooms</td>
<td>20 GBq-h</td>
<td>29 GBq-h</td>
<td>_</td>
</tr>
<tr>
<td>Camera Room</td>
<td>13.3 GBq-h</td>
<td>12.6 GBq-h</td>
<td>35,000 mA-min</td>
</tr>
<tr>
<td><strong>Dose @ 1m</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conversion</td>
<td>0.158 mGy/GBq-h</td>
<td>0.0024 mGy/MA-min</td>
<td></td>
</tr>
<tr>
<td>Uptake rooms</td>
<td>3.3 mGy</td>
<td>4.5 mGy</td>
<td>_</td>
</tr>
<tr>
<td>Camera Room</td>
<td>2.1 mGy</td>
<td>2.0 mGy</td>
<td>84 mGy</td>
</tr>
</tbody>
</table>
# Adequacy of PET barrier for CT

<table>
<thead>
<tr>
<th></th>
<th>FDG PET</th>
<th>125 kVp CT</th>
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</thead>
<tbody>
<tr>
<td>typical K</td>
<td>0.1 to 0.4</td>
<td>1E-03 to 1E-04</td>
</tr>
<tr>
<td>Pb</td>
<td>1 TVL 16 mm</td>
<td>2 TVL 2.85 mm</td>
</tr>
<tr>
<td>concrete</td>
<td>1 TVL 25 cm</td>
<td>2 TVL 22.5 cm</td>
</tr>
</tbody>
</table>

[refs] [Courtney] [Simpkin]
Fig. 2. Transmission of 120- and 140-kVp CT scatter radiation through concrete. Data as in Fig. 1. HVL data from Trout et al. (1959).
Hybrid PET/CT

- Shielding for PET workload should be adequate for CT also
- Shield doors to Control Room and Corridor
- X-ray warning light
Staff dose in PET/Nucmed

- µSv/mth
- no. patients/mth

- Oct-99
- May-00
- Dec-00
- Jun-01
- Jan-02
- Jul-02
- Feb-03

# patients
## REVIEW OF TECHNOLOGIST EXPOSURES

<table>
<thead>
<tr>
<th></th>
<th>no. of patients</th>
<th>FDG inj. MBq</th>
<th>av. dose µSv/pt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kearfott</td>
<td>1992</td>
<td>-</td>
<td>370</td>
</tr>
<tr>
<td>Chiesa</td>
<td>1997</td>
<td>44</td>
<td>500</td>
</tr>
<tr>
<td>McElroy</td>
<td>1998</td>
<td>4</td>
<td>555</td>
</tr>
<tr>
<td>Bird</td>
<td>1999</td>
<td>85</td>
<td>185</td>
</tr>
<tr>
<td>RPAH</td>
<td>1999</td>
<td>86</td>
<td>500</td>
</tr>
</tbody>
</table>
## RPAH STUDY 1999

<table>
<thead>
<tr>
<th>Task</th>
<th>No. of events</th>
<th>$\mu$Sv mean, s.e.m</th>
</tr>
</thead>
<tbody>
<tr>
<td>unpack FDG</td>
<td>8</td>
<td>$2.34 \pm 0.86$</td>
</tr>
<tr>
<td>dispense/inject</td>
<td>82</td>
<td>$2.83 \pm 0.21$</td>
</tr>
<tr>
<td>take blood sample</td>
<td>36</td>
<td>$1.87 \pm 0.27$</td>
</tr>
<tr>
<td>patients on/off bed</td>
<td>131</td>
<td>$2.91 \pm 0.18$</td>
</tr>
<tr>
<td>misc. patient care</td>
<td>11</td>
<td>$1.09 \pm 0.55$</td>
</tr>
</tbody>
</table>
Dose rates @ 0.5m and 2m, p.i. 500 MBq $^{18}$F-FDG
Designing for Distance and Time

Objective: to avoid or minimise close contact with patients, especially those who are frail, unsteady, claustrophobic or unwell

- Clear signposting, short pathways
- Toilets close to uptake rooms
- Seating while waiting to go on scanner
- Facilities as for disabled: eg. handrails, extra space, call buttons, chairs with armrests
- CCTV, intercom, sound system