Designing a PET Facility -
Shielding and Radiation Protection

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Friday 13 December 2002
Workshop on Positron Emission Tomography
Physics SIG, ANZSNM & ACPSEM

Radiation Protection in a PET facility

<u>PET staff</u>

- technologists
- nurses, doctors

<u>Others</u>

- 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}Ge/^{68}Ga

- ^{68}Ge EC, $T_{1/2}$ 287 d
- ^{68}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

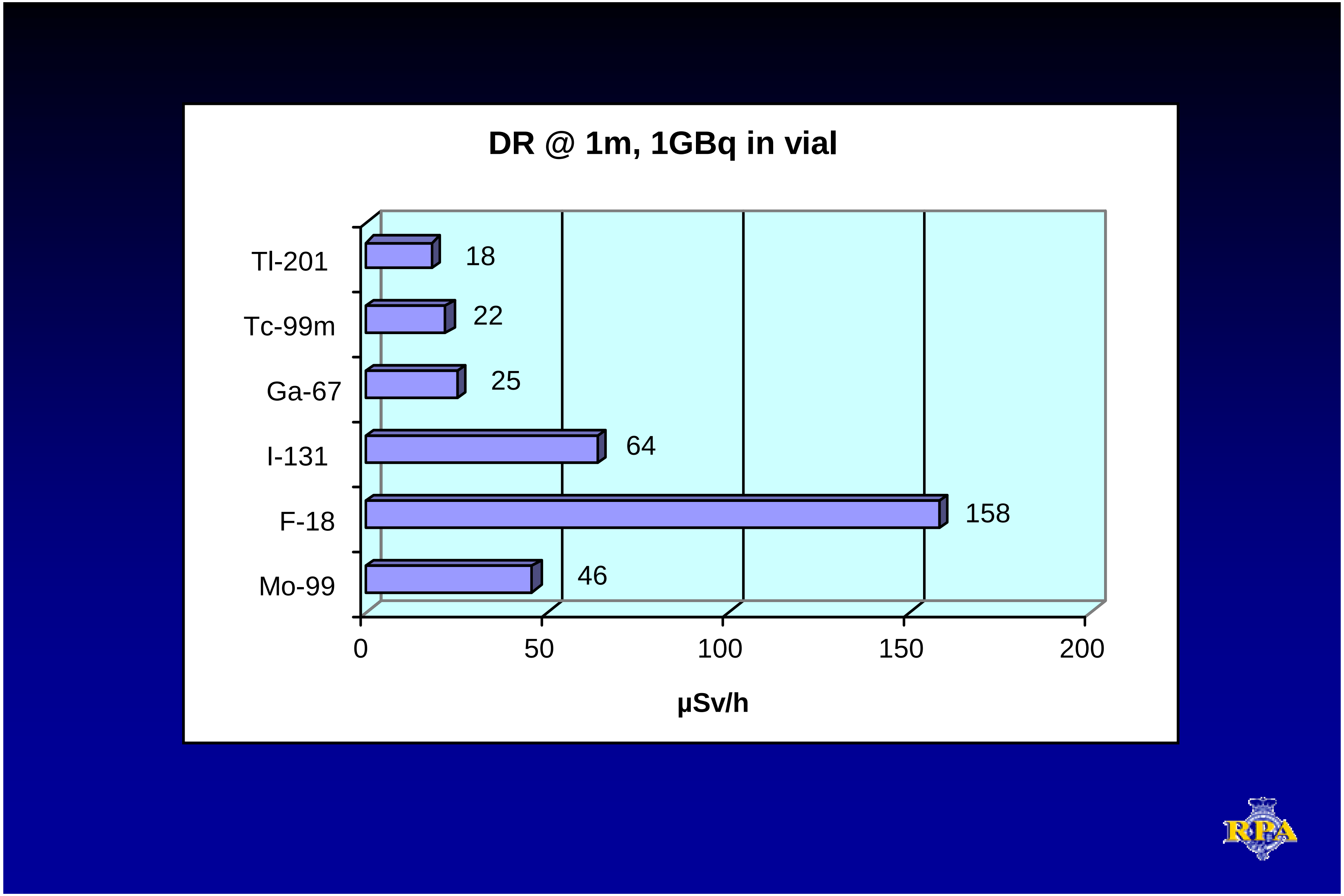
Shielding for positrons

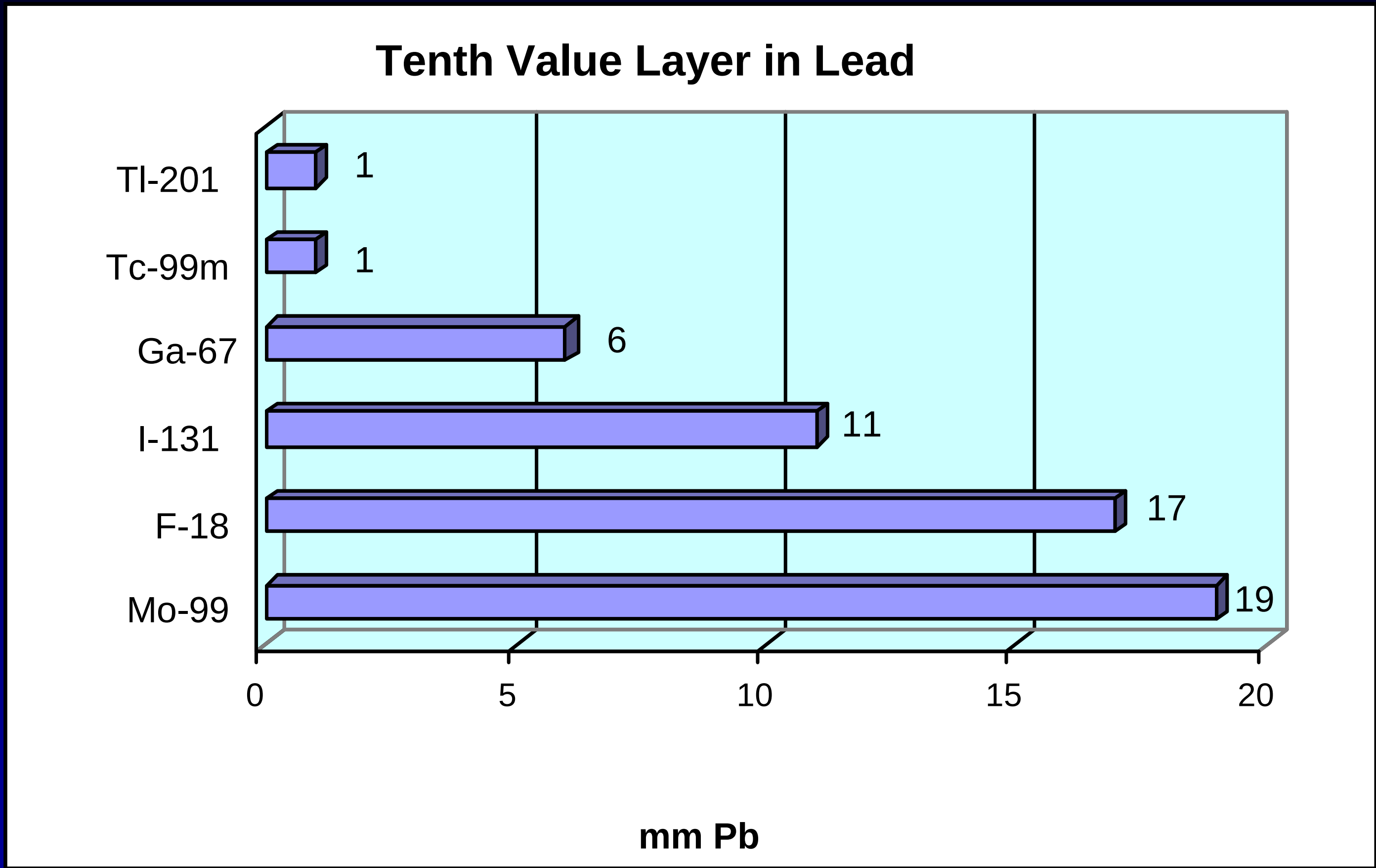
	Max $E_{\beta+}$	range in glass	range in plastic	Bremss. in Pb $E_{\beta+}$ converted
	MeV	mm	mm	%
^{18}F	0.634	0.9	1.7	1.8
^{15}O	1.732	3.4	6.4	5.0
^{13}N	1.199	2.1	4.0	3.4
^{11}C	0.960	1.6	3.0	2.8

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
Tl-201
Tc-99m
Ga-67
I-131
F-18
Mo-99
18
22
25
64
158
46
0
50
100
150
200
µSv/h



Tenth Value Layer in Lead
Tl-201
Tc-99m
Ga-67
I-131
F-18
Mo-99
1
1
6
11
17
19
0
5
10
15
20
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

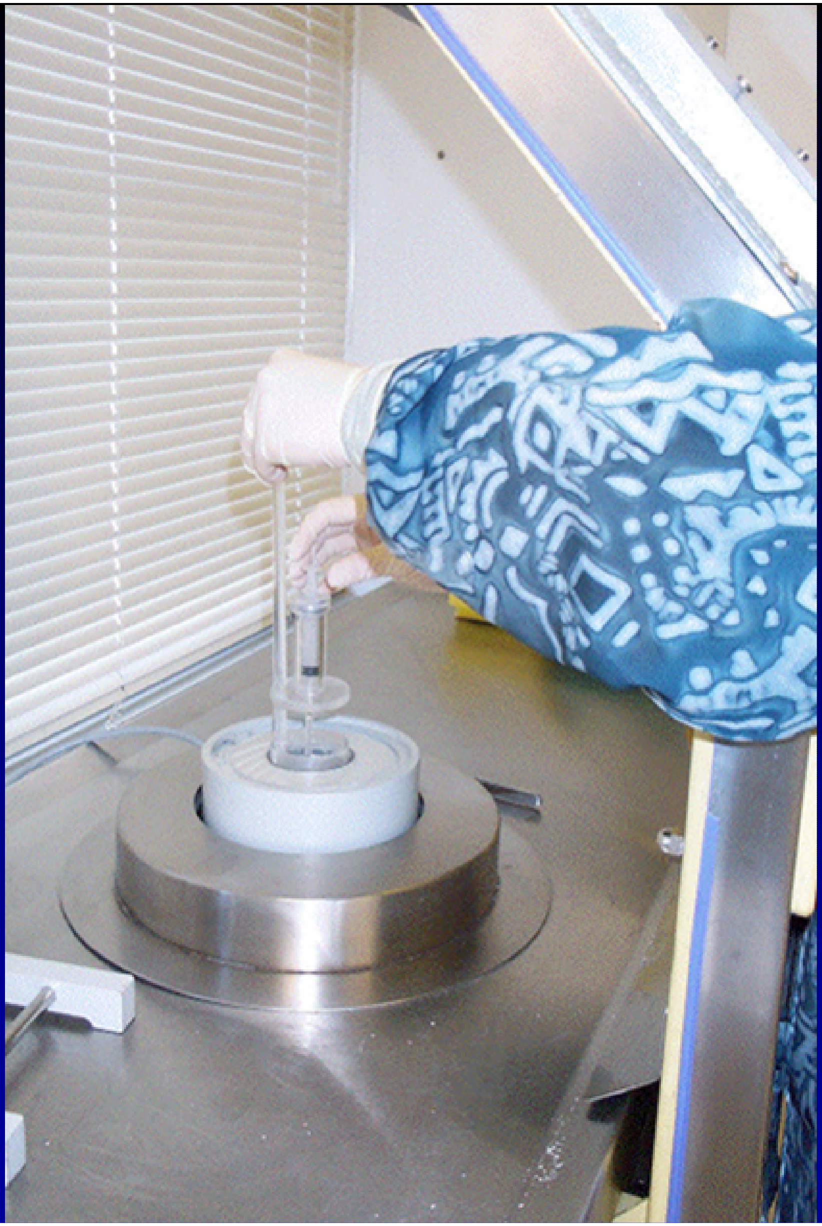
Shields for dispensing and injecting

Vial activity from 0.5 to 10 GBq

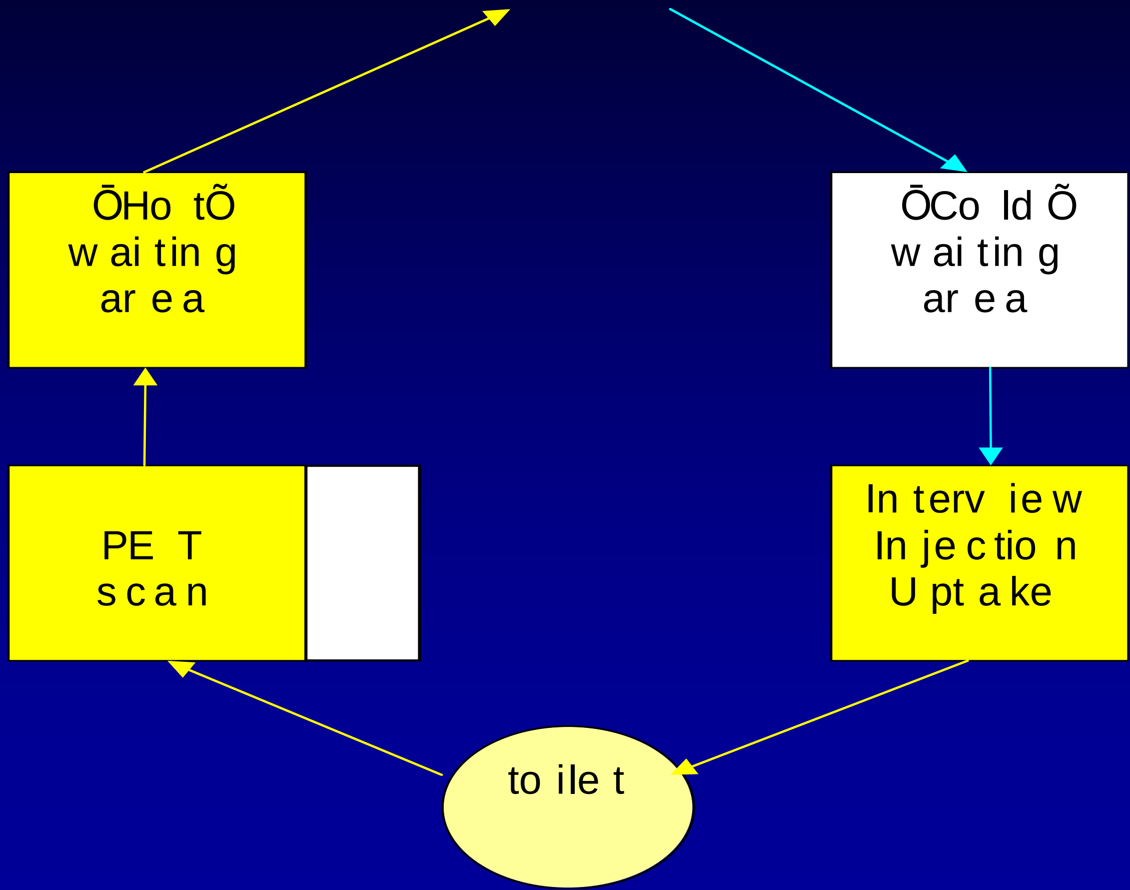
- Vial holder 30 mm Pb
- Bench shield 50 mm Pb / 65 mm Pb-glass
- Dose calibrator chamber 50mm Pb rings

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 = $W * \Gamma * U / f(d)$

Dose constraint P = 10 or 20 µSv/wk (say)

Design dose L = P / T

where T = occupancy

Hence,

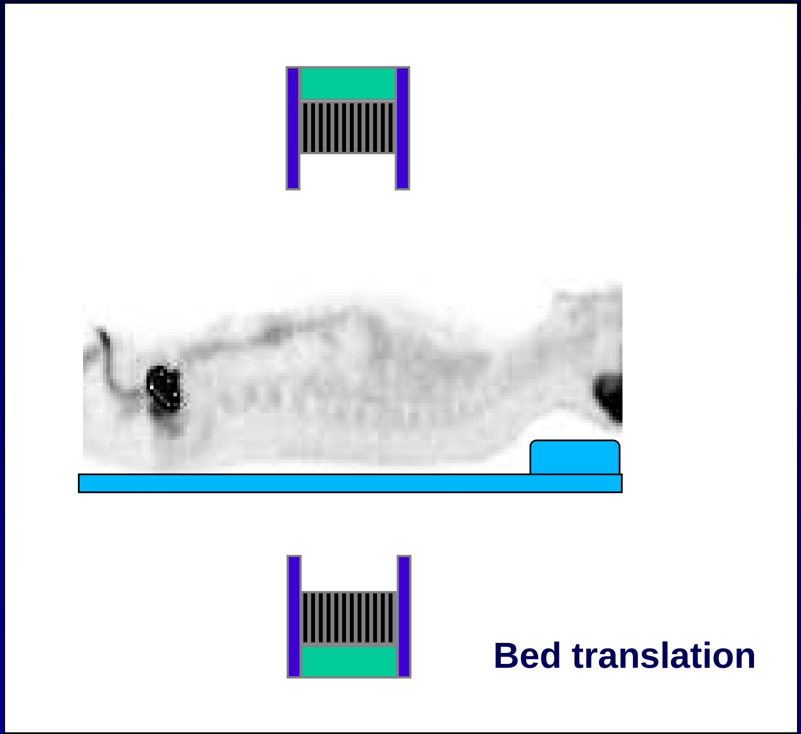
Transmission K = L / D

$= P * f(d) / W * \Gamma * U * T$

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



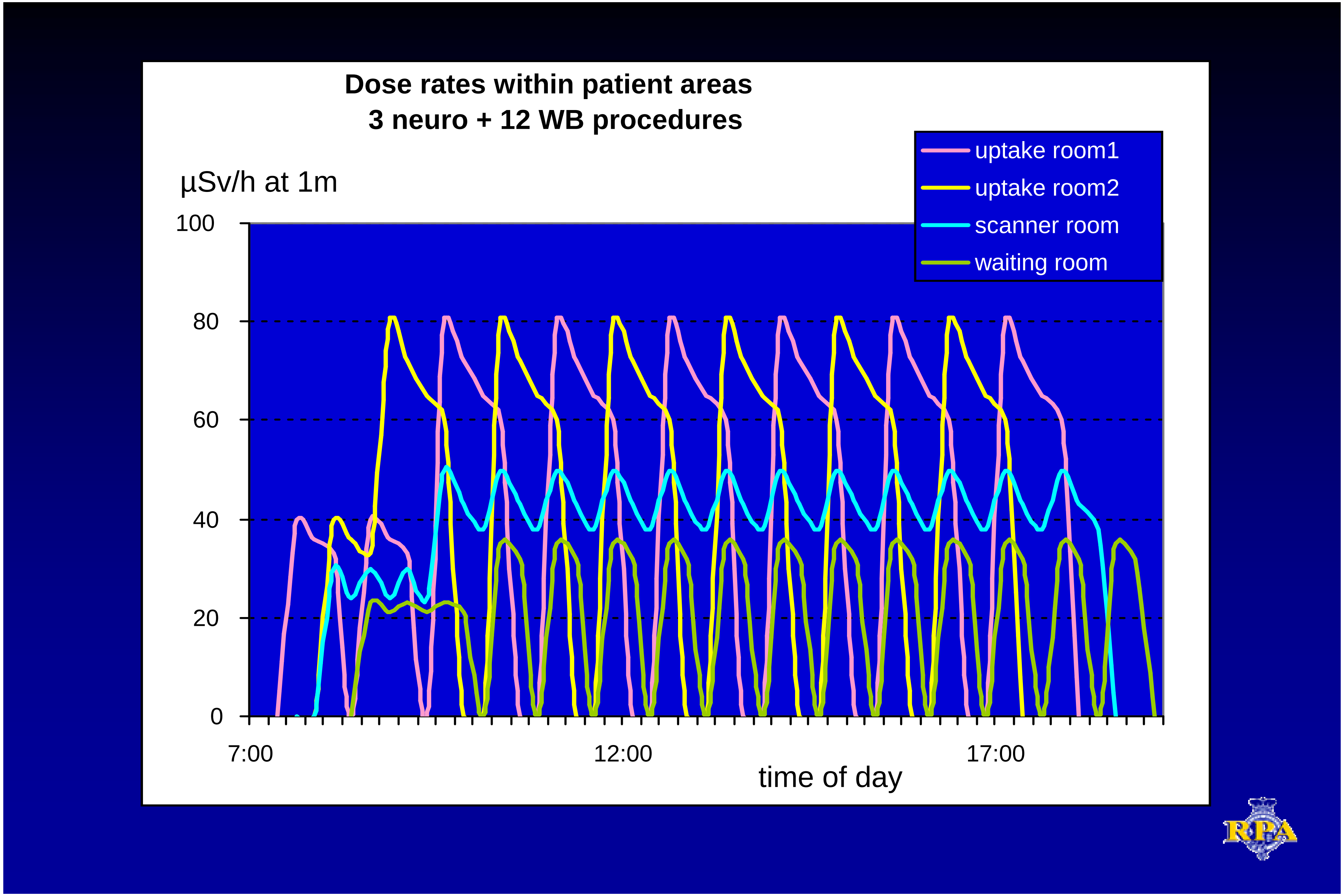
- Assume activity is point source in middle of patient
- All walls are irradiated,

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 Γ = 158 µSv/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
100
80
60
40
20
0
7:00
12:00
17:00
time of day
uptake room1
uptake room2
scanner room
waiting room
RPA

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

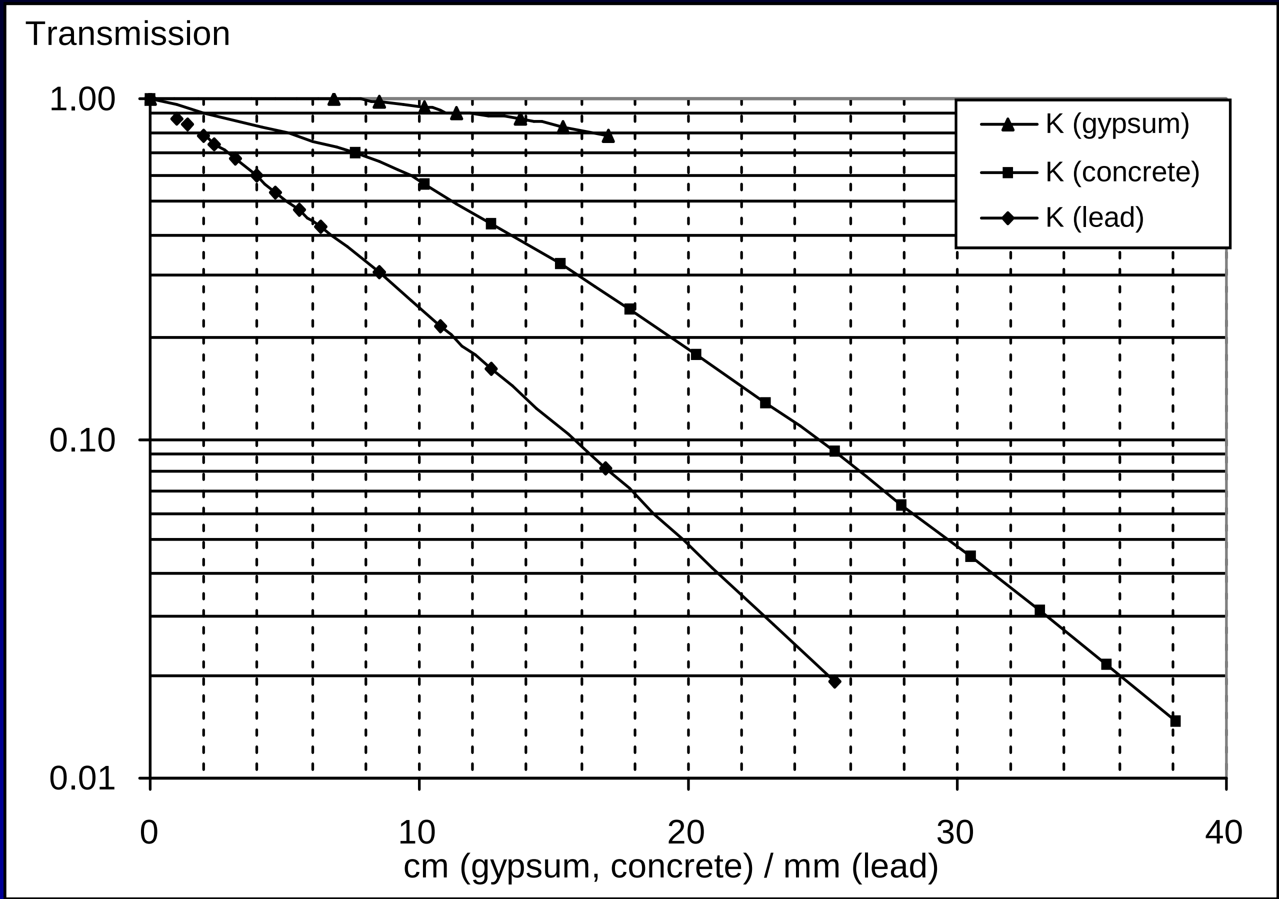
Interpolation between ^{192}Ir and ^{137}Cs transmission curves

Standard concrete

- 1st HVL 160mm
- 1st TVL 240mm
- subsequent TVLs 160 mm

511 keV broad beam attenuation

[Monte Carlo modelling ref. Courtney]



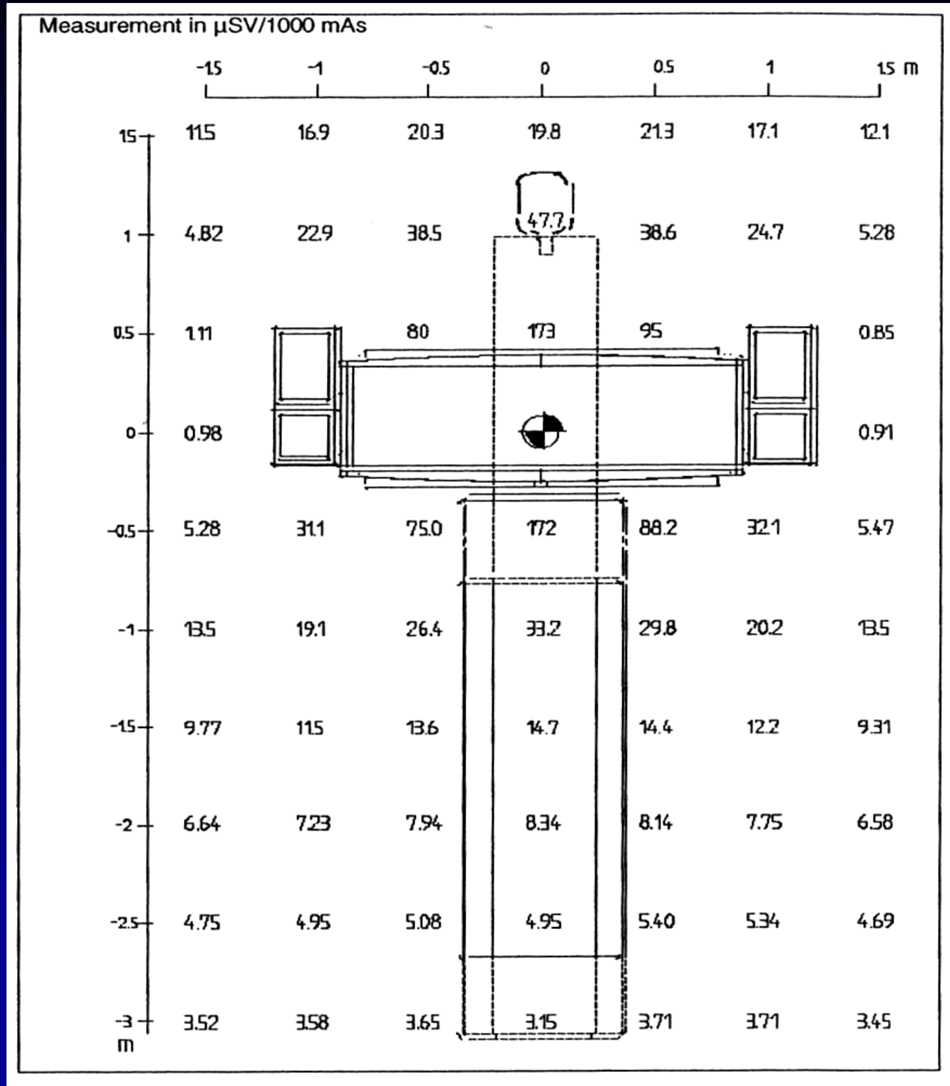
Sources (3): PET/CT hybrid scanner

EPA default CT workload

- 300 mAs/1cm slice, 35 slices/patient, 20 patients/day, 5 d/wk $\Rightarrow$ 17,500 mA-min/wk

PET/CT workload

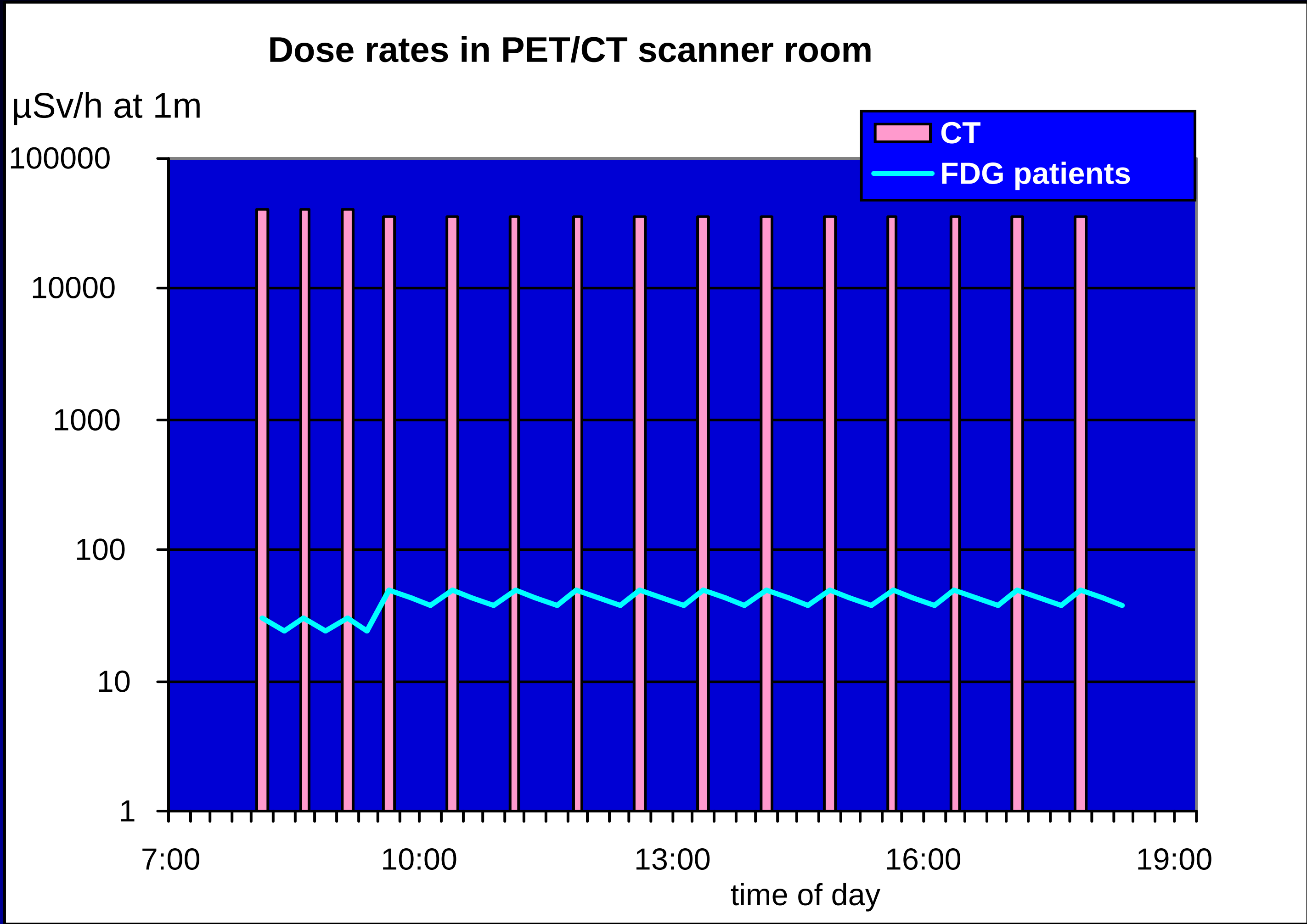
- 300 mAs/1cm slice, 70 slices/patient, 20 patients/day, 5 d/wk $\Rightarrow$ 35,000 mA-min/wk


Measurement in µSV/1000 mAs
-1.5 -1 -0.5 0 0.5 1 1.5 m
1.5 11.5 16.9 20.3 19.8 21.3 17.1 12.1
1 4.82 22.9 38.5 47.7 38.6 24.7 5.28
0.5 1.11 80 173 95 0.85
0 0.98 0.91
-0.5 5.28 31.1 75.0 172 88.2 32.1 5.47
-1 13.5 19.1 26.4 33.2 29.8 20.2 13.5
-1.5 9.77 11.5 13.6 14.7 14.4 12.2 9.31
-2 6.64 7.23 7.94 8.34 8.14 7.75 6.58
-2.5 4.75 4.95 5.08 4.95 5.40 5.34 4.69
-3 3.52 3.58 3.65 3.15 3.71 3.71 3.45
m

CT scatter dose estimate

- Manufacturer's scatter dose map, µSv/1000 mA-s
- Manufacturer's nominal air kerma rate at 1 m from isocentre,

  mGy/mA-min


Dose rates in PET/CT scanner room
µSv/h at 1m
CT
FDG patients
100000
10000
1000
100
10
1
7:00
10:00
13:00
16:00
19:00
time of day

Weekly workload scenarios

	2000	2003	2003
	FDG PET	FDG PET	CT
patients/wk	75	100	100
% neuros	25	20	20
source	500; 250 MBq	500; 250 MBq	125 kVp
"on" hrs/day	10.5	9.5	2

Weekly dose scenarios

	2000/PET	2003/PET	2003/CT
Workload W			
Uptake rooms	20 GBq-h	29 GBq-h	_
Camera Room	13.3 GBq-h	12.6 GBq-h	35,000 mA-m
Dose @ 1m			
conversion	0.158 mGy/GBq-h		0.0024 mGy/mA-m
Uptake rooms	3.3 mGy	4.5 mGy	_
Camera Room	2.1 mGy	2.0 mGy	84 mGy

Adequacy of PET barrier for CT

	FDG PET	125 kVp CT
typical K	0.1 to 0.4	1E-03 to 1E-04
Pb	1 TVL 16 mm	2 TVL 2.85 mm
concrete	1 TVL 25 cm	2 TVL 22.5 cm
[refs]	[Courtney]	[Simpkin]

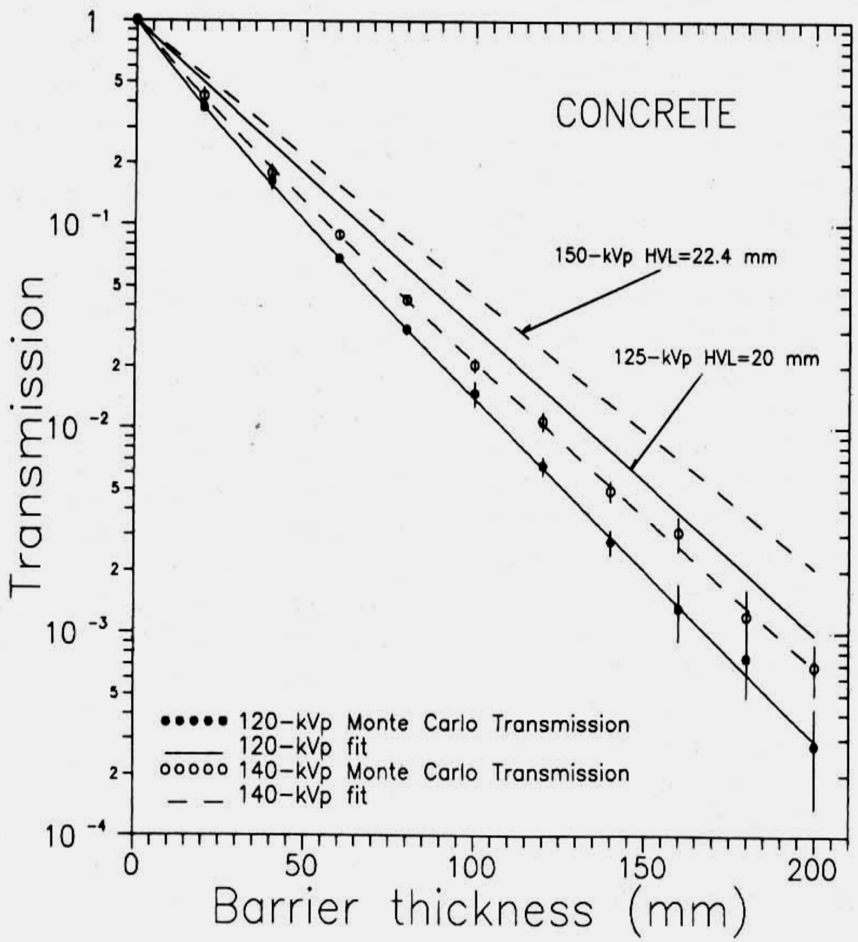
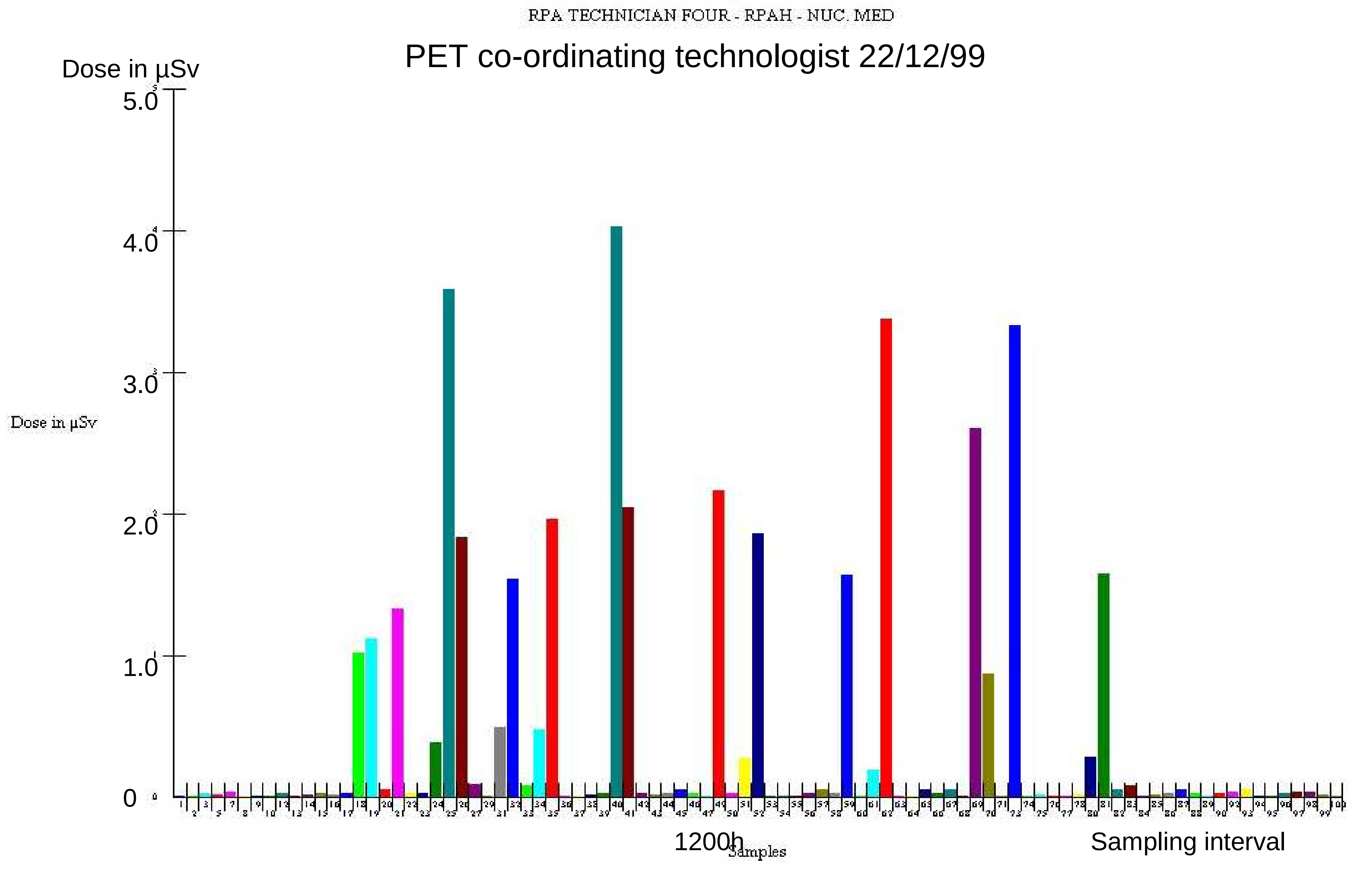


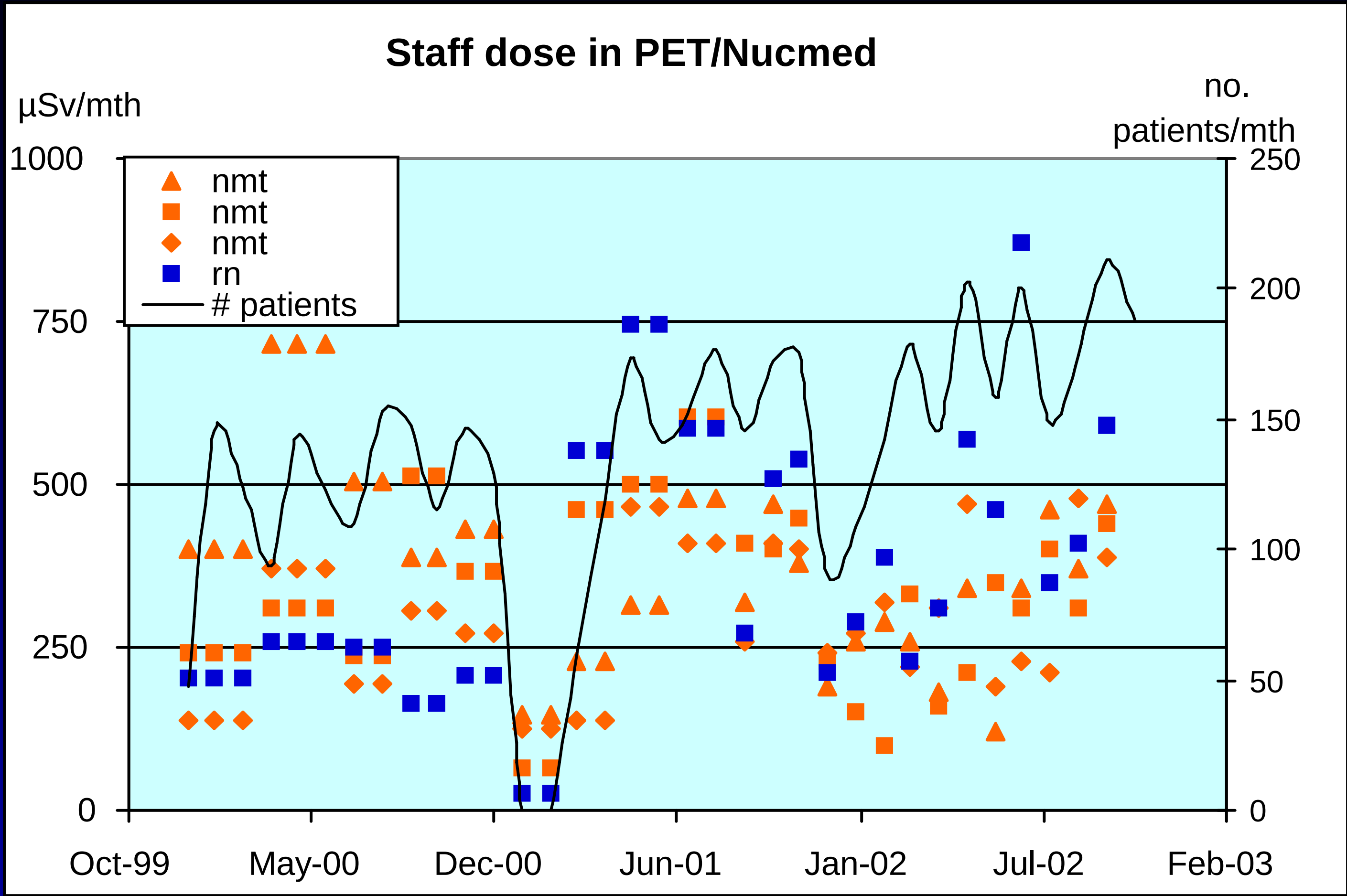
Fig. 2. Transmission of 120- and 140-kVp CT scatter radiation through concrete. Data as in Fig. 1. HVL data from Trout et al. (1959).

Hybrid PET/CT

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

PET co-ordinating technologist 22/12/99





Staff dose in PET/Nucmed
µSv/mth
no. patients/mth
1000
750
500
250
0
250
200
150
100
50
0
nmt
nmt
nmt
rn
patients
Oct-99
May-00
Dec-00
Jun-01
Jan-02
Jul-02
Feb-03

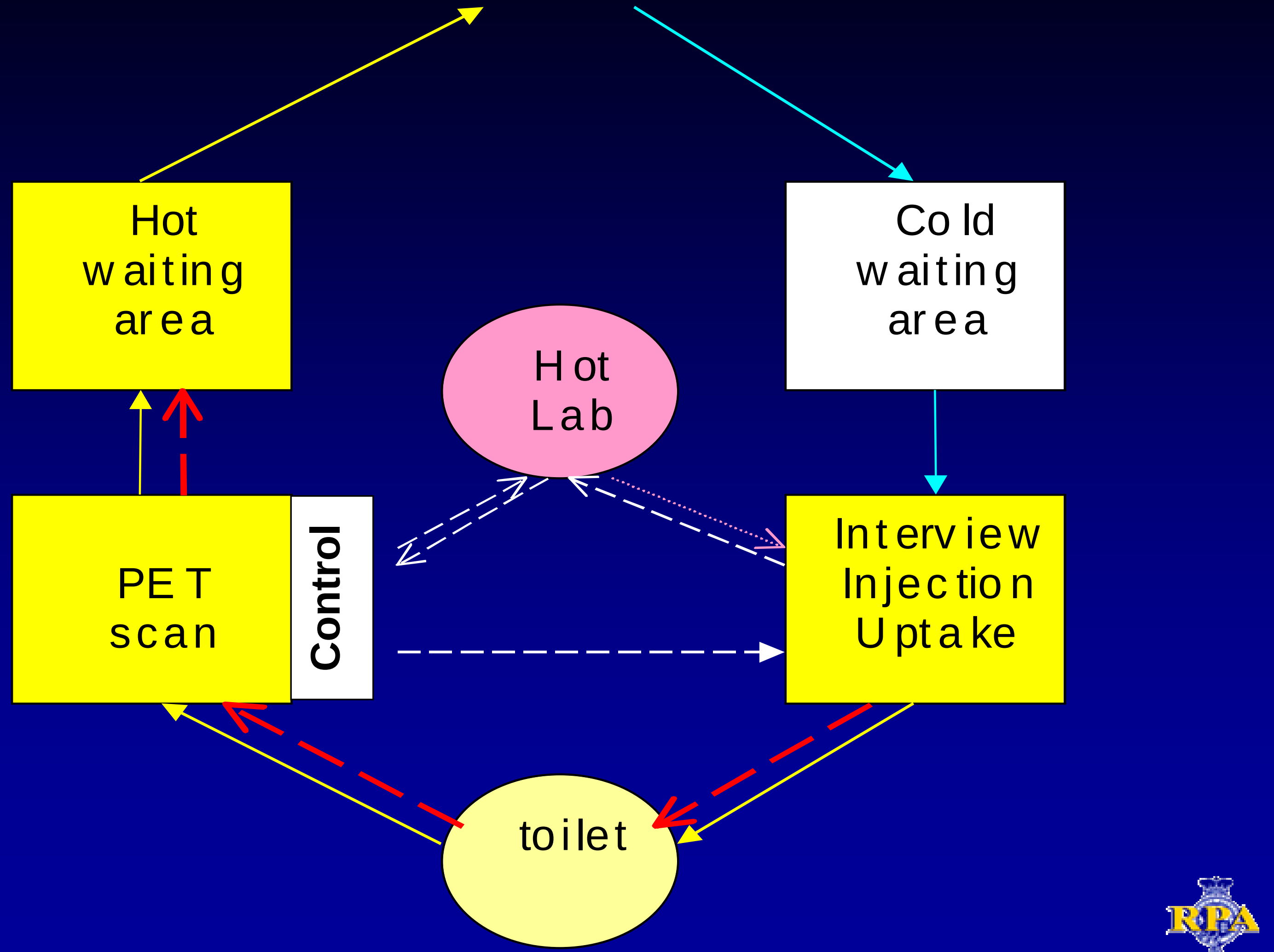
REVIEW OF TECHNOLOGIST EXPOSURES

		no. of patients	FDG inj. MBq	av. dose µSv/pt
Kearfott	1992	-	370	26
Chiesa	1997	44	500	11.5
McElroy	1998	4	555	10.3
Bird	1999	85	185	7.3
RPAH	1999	86	500	4.5

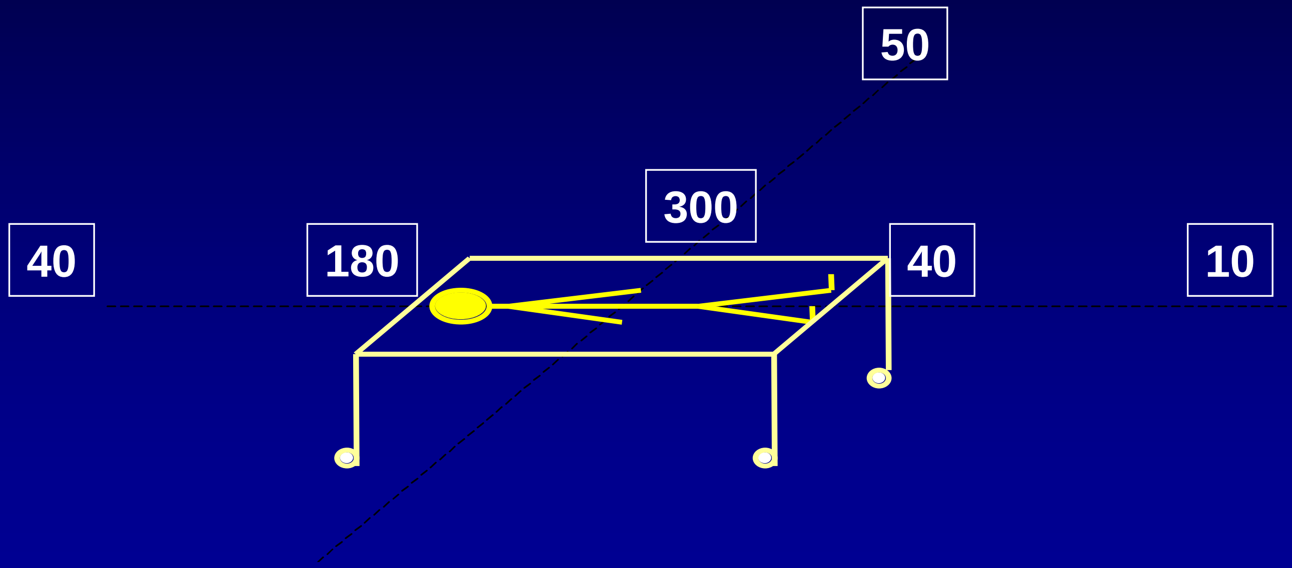
RPAH STUDY 1999

Task	No. of events	μSv mean,s.e.m
unpack FDG	8	2.34 $\pm$ 0.86
dispense/inject	82	2.83 $\pm$ 0.21
take blood sample	36	1.87 $\pm$ 0.27
patients on/off bed	131	2.91 $\pm$ 0.18
misc. patient care	11	1.09 $\pm$ 0.55

FDG tech movements



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