PET/CT Shielding Evaluation

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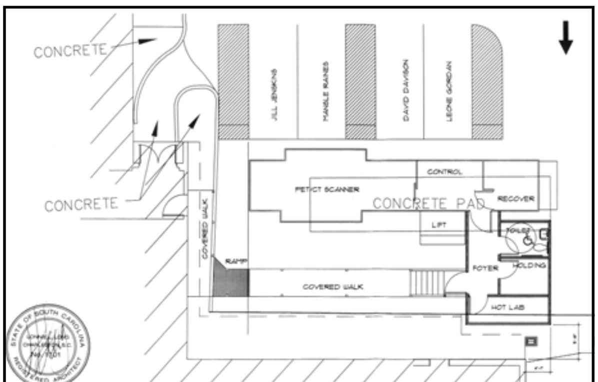
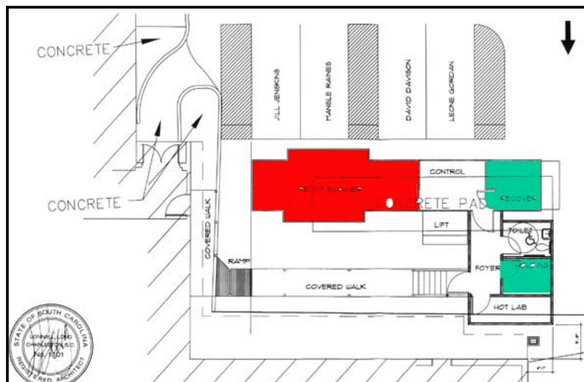
PET Shielding Is Complex

- 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

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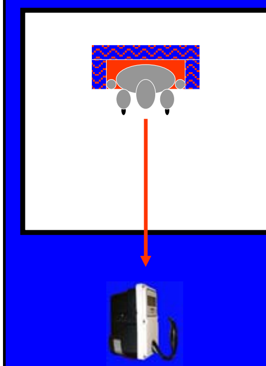

Annual Dose = Dose Rate x
Number of Patients x
Time Each Patient is in the Room

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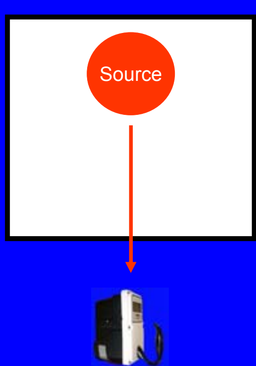

Activity =
Average Patient Dose x
Number of Patients x
Time Each Patient is in the Room

Annual Dose = Dose Rate x
1 hour

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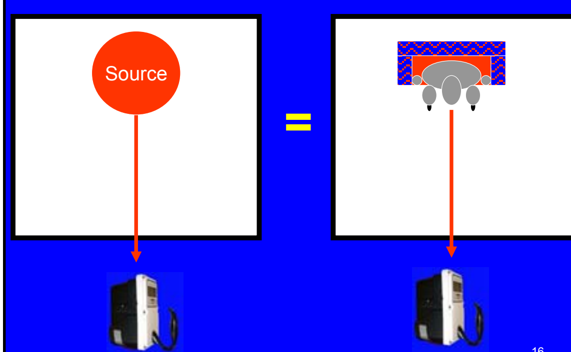

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Or

$$AN\tau \longrightarrow \dot{R}_A = D\,(x,\ y,\ z) \ = \ \dot{D}\,N\tau \longleftarrow A$$

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Average Patient Activity Uptake Room

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

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Average Patient Activity Uptake Room

$$A_u = \xi A_0 \int_0^{\tau_u} (1/2)^{t/T_{1/2}} \, dt$$

$$A_u = \xi \, (A_0 / \ln(2)) \, (T_{1/2} / \tau_u) \, (1 - (1/2)^{(\tau_u/T_{1/2})})$$

Annual Dose Uptake Room

$$A_u \longrightarrow \dot{D}_{ui} \, (x, y, z)$$

$$A_u \, N_{ui} \, \tau_u \longrightarrow \dot{D}_{ui} \, (x, y, z) \, N_{ui} \, \tau_u \longrightarrow D_{ui} \, (x, y, z)$$

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

Average Patient Activity Scan Room

$$A_s = \xi A_0 \, (1/2)^{(\tau_u/T_{1/2})} \, \kappa \int_0^{\tau_s} (1/2)^{t/T_{1/2}} \, dt$$

$$A_s = \xi \, (A_0 / \ln(2)) \, (1/2)^{(\tau_u/T_{1/2})} \, \kappa \, (T_{1/2} / \tau_s) \times (1 - (1/2)^{(\tau_s/T_{1/2})})$$

Annual Dose Scan Room

$$A_s \longrightarrow \dot{D}_{si} \, (x, y, z)$$

$$A_s \, N_{si} \, \tau_u \longrightarrow \dot{D}_{si} \, (x, y, z) \, N_{si} \, \tau_s \longrightarrow D_{si} \, (x, y, z)$$

Dose from All Rooms

$$\sum_i A_s \, N_{si} \, \tau_u + \sum_i A_u \, N_{ui} \, \tau_u \longrightarrow D \, (x, y, z)$$

So from all rooms

Room	mCi Effective Activity
Uptake Room 1	20536
Uptake Room 2	5134
Scan Room	9001

So we need to Scale the Activity

$$\left(\sum_i A_s N_{si} \tau_u + \sum_i A_u N_{ui} \tau_u\right) \Big/ \sigma \longrightarrow D(x, y, z) / \sigma$$

$$\alpha_{ui} = A_u N_{ui} \tau_u / \sigma$$

$$\alpha_{si} = A_s N_{si} \tau_s / \sigma$$

So from all rooms

Scaling Factor	500	
Room	mCi Effective Activity	Scaled Activity
Uptake Room 1	20536	41
Uptake Room 2	5134	10
Scan Room	9001	18

Compare Results to Design Values

$$p / TD(x, y, z) \leqslant 1$$

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

Source Size Calculation

Facility	**Medical University of South Carolina PET/CT Facility**	
Date	1/9/2006	
Administered Activity	555 MBq	15 mCi
Half Life of Radionuclide	110 min	
Self Absorption Factor	0.72	

Room	Uptake Room 1	
Time between injection and beginning of room use	0 min	
Decay Factor	1	
Time patient remains in room	90	
Decay Dose Rate Factor	0.76	
Voiding Factor (Retention when patient enter room)	1	
Patients per week	32	
Effective Activity	759826 MBq	20536 mCi

	Location	Distance	Design Value (P)	Time	Meter Reading	Time Corrected	Annual Estimate	Percent P-Value	Status	Occupancy Factor	Annual Estimate	Percent P-Value	Status
Inside	Control Room Operator		5	8:43 AM	2.30	1.42	0.71	14%	Pass	1.00	0.71	14%	Pass
	Control Room Secondary Operator		5	8:45	5.30	3.30	1.65	33%	Pass	1.00	1.65	33%	Pass
	Door to Corridor		5	8:45	4.60	2.87	1.43	29%	Pass	1.00	1.43	29%	Pass
	Entrance Corridor		5	8:47	8.90	5.62	2.81	56%	Pass	1.00	2.81	56%	Pass
	Corridor Door to Uptake Room	Design Limit	5	8:48	30.00	19.06	9.53	191%	Fail	1.00	9.53	191%	Fail
	Corridor Door to Uptake Room	Annual Limit	50	8:48	30.00	19.06	9.53	19%	Pass	1.00	9.53	19%	Pass
	Outside Porch		5	8:49	14.10	9.01	4.51	90%	Pass	1.00	4.51	90%	Pass

	Location	Distance	Design Value (P)	Time	Meter Reading
Inside	Control Room Operator		5	8:43 AM	2.30
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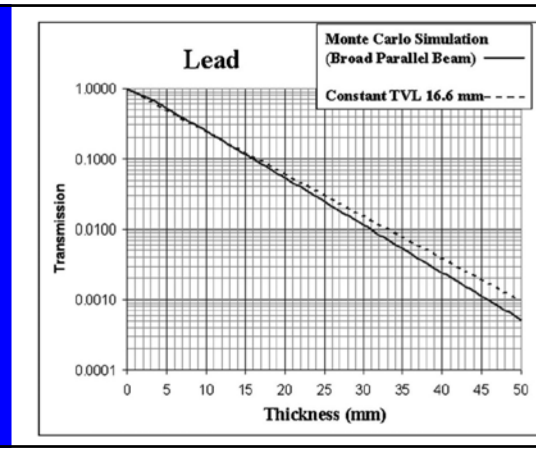
	Door to Corridor		5	8:45	4.60
	Entrance Corridor		5	8:47	8.90
	Corridor Door to Uptake Room	Design Limit	5	8:48	30.00
	Corridor Door to Uptake Room	Annual Limit	50	8:48	30.00
	Outside Porch		5	8:49	14.10

Time Corrected	Annual Estimate	Percent P-Value	Status	Occupancy Factor	Annual Estimate	Percent P-Value	Status
1.42	0.71	14%	Pass	1.00	0.71	14%	Pass
3.30	1.65	33%	Pass	1.00	1.65	33%	Pass
2.87	1.43	29%	Pass	1.00	1.43	29%	Pass
5.62	2.81	56%	Pass	1.00	2.81	56%	Pass
19.06	9.53	191%	Fail	1.00	9.53	191%	Fail
19.06	9.53	19%	Pass	1.00	9.53	19%	Pass
9.01	4.51	90%	Pass	1.00	4.51	90%	Pass

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*

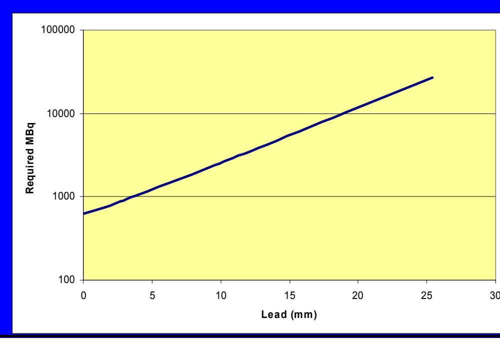
$$x = (1/\alpha\gamma) \ln \{[B^{-\gamma} + (\beta/\alpha)] / [1 + (\beta/\alpha)]\}$$

$$D_c = A_0 \Gamma / d^2$$

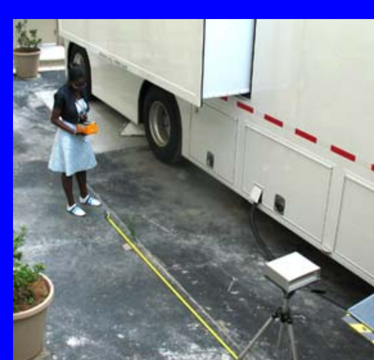
$$B = D_m d^2 / A_0 \Gamma$$

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

How Much Activity Do You Need?



Desired distance		3 meters		
Desire Air KERMA		10 uSv/hr		
US Inches	Metric mm	Attenuation	Activity MBq	Unshielded uSv/hr
0	0	1.000	629	10
1/16	1.6	0.829	759	12
1/8	3.2	0.674	933	15
1/4	6.4	0.430	1465	23
3/8	9.5	0.267	2357	37
1/2	12.7	0.164	3826	61
3/4	19.1	0.062	10168	162
1	25.4	0.023	27078	430



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

Barrier	Time	Activity MBq	Distance m	Measured Air Kerma uGy/hr	Measured Bkg nGy/hr	NET Air Kerma uGy/hr	Unshielded Calculated Air Kerma uGy/hr	B	Calculated Lead mm	Specified Lead mm	Deviation
None	3:50 PM	1586	3.0	25.5	110	25.39	24	1.04	-0.4	0	
Uptake 1 (Rear)	3:58 PM	1508	3.0	5.3	110	5.19	23	0.22	10.7	10	7%
Uptake 1 (Rear)	4:04 PM	1452	1.5	19	110	18.89	89	0.21	11.1	10	11%

Symbols

A_0 = Administered Activity
A_u = Average activity per patient in the uptake room
A_s = Average activity per patient in the scan room
$T_{1/2}$ = Physical Half - life for F - 18
τ_u = time patient waits after injection
τ_s = time it takes to complete the PET / CT exam
$\varkappa$ = fraction of the administered activity the patient voids
ξ = self absorption factor
N = total patients per year
N_{ui} = number of patients per year in uptake room i
N_{si} = number of patients per year in scan room i

$$N = \sum_i N_{si} = \sum_i N_{ui}$$

$\dot{D}_{ui}(x, y, z)$ = The average dose rate at any location (x, y, z) from a patient in uptake room 1
$\dot{D}_{si}(x, y, z)$ = The average dose rate at any location (x, y, z) from a patient in scan room 1
$D_{ui}(x, y, z)$ = the annual dose to any location (x, y, z) from all of the patients in uptake room i
$D_{si}(x, y, z)$ = the annual dose to any location (x, y, z) from all of the patients in scan room i
$D(x, y, z)$ = the annual dose to any location (x, y, z) from all the patients in the facility
σ = the dose scaling parameter
α_{ui} = the scalled activity for uptake room i
α_{si} = the scalled activity for scan room i
p = design value (p = 1 mSv / yr for non - controlled areas, 5 mSv for controlled areas)
T = occupancy factor