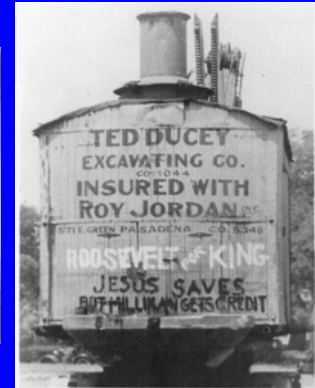
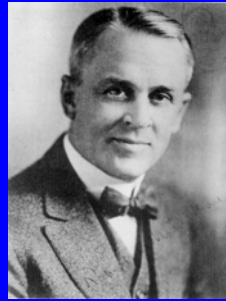


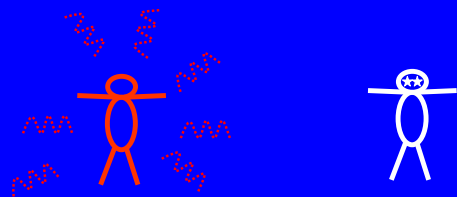
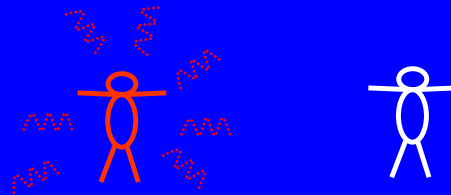
# PET Shielding

G. Donald Frey, Ph.D.  
Department of Radiology  
Medical University of South Carolina  
Charleston, SC

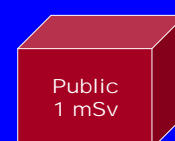


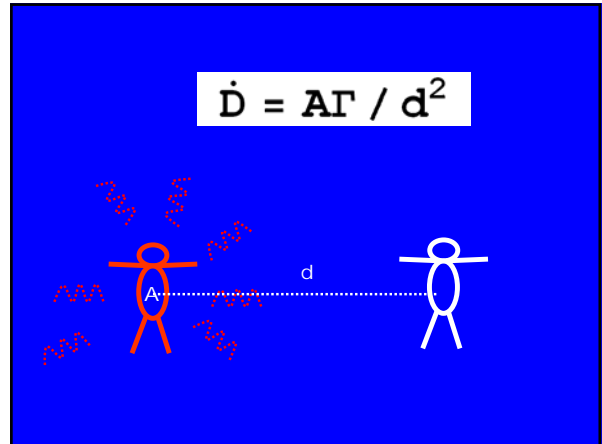
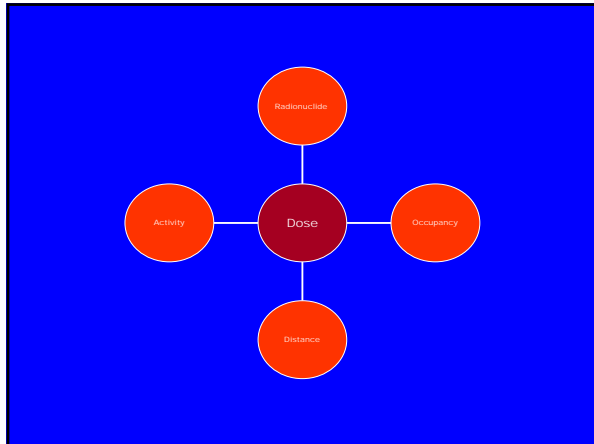
## AAPM Task Group 108: PET and PET/CT Shielding Requirements

- Mark T. Madsen  
*Radiology, University of Iowa*
  - Jon A. Anderson  
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- (Received 21 July 2005; revised 17 October 2005; accepted for publication 18 October 2005; published 19 December 2005)



Design Values  
Annual Limits  
Same as NCRP 147





What radionuclides and radiopharmaceuticals should we design for?

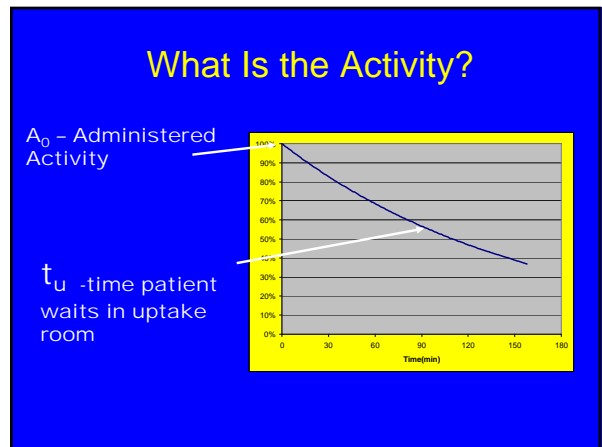
### Comparison of PET Decay Constants

Rate Constants	Value	1 Hr Integrated
C-11	0.15	0.063
N-11	0.15	0.034
O-15	0.15	0.007
<b>F-18</b>	<b>0.14</b>	<b>0.119</b>
Cu-64	0.03	0.024
Ga-68	0.13	0.101
Rb-82	0.16	0.006
<b>Y-124</b>	<b>0.18</b>	<b>0.188</b>

### F-18 Rate Constants uSv-m<sup>2</sup>/ MBq-h

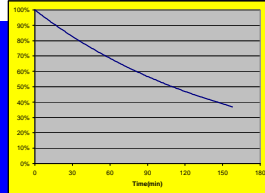
F-18 Rate Constants	Value
Air Kerma Exposure Rate	0.134
Effective Dose Equivalent (ANS-1981)	0.143
<b>Tissue Dose Constant</b>	<b>0.148</b>
Deep Dose Equivalent (ANS-1977)	0.189
Maximum Dose (ANS-1977)	0.188
Maximum Dose (ANS-1977)	0.188

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



## What Is the Activity?

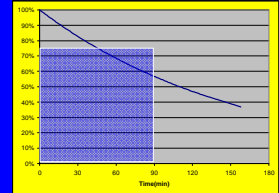
$$A_u = \int_0^{t_u} A_0 e^{-\lambda t} dt$$



## What Is the Activity?

$$\bar{A}_u = (A_0 / \ln(2)) (T_{1/2} / t_u) (1 - (1/2)^{(t/T_{1/2})})$$

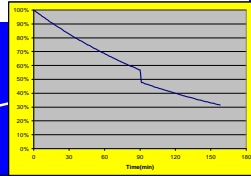
$t_u$	
30	0.91
60	0.83
90	0.76



## Scan Room Activity

$$A_s = A_0 \kappa (1/2)^{(t_u/T_{1/2})}$$

$$\int_{t_u}^{t_s} e^{-\lambda t} dt$$

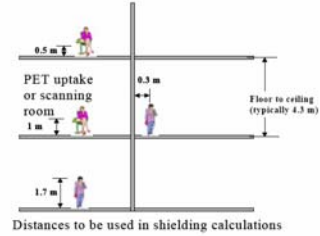


Voiding factor 0.85

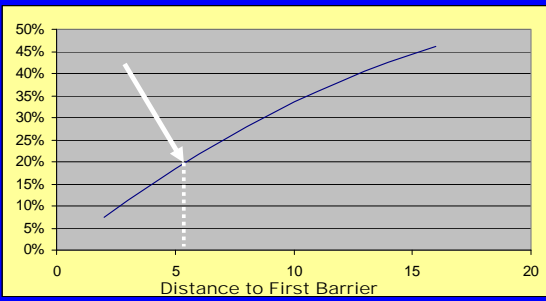
## Distance

Report Distances Are in Meters

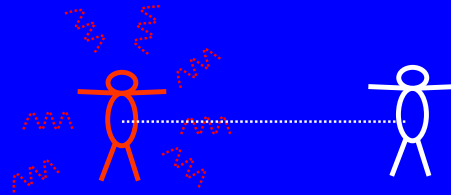
### Distances to Be Used in Shielding Calculations



## Across 8 ft Corridor Fully Occupied Space



$$Dose_{ann} = \bar{A}_u t_u \Gamma N / d^2$$

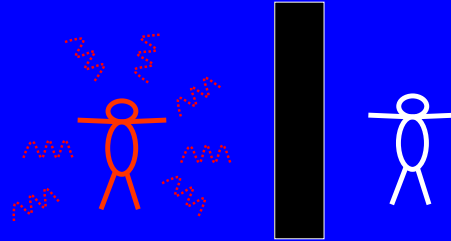


## Occupancy Factor

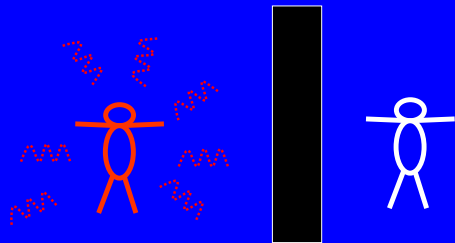


Same as NCRP 147

## Transmission Factor



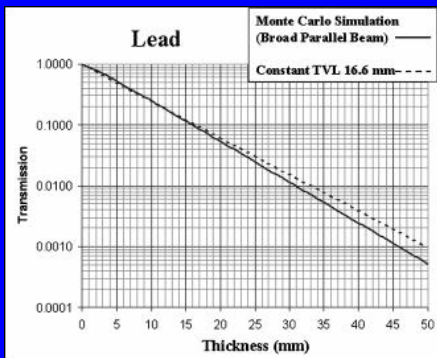
$$B = Pd^2 / T \bar{A}_u t_u \Gamma N$$



## Scan Room

$$\text{Dose}_{\text{ann}} = \bar{A}_s t_s \Gamma N / d^2$$

$$B = Pd^2 / T \bar{A}_s t_s \Gamma N$$



## Use Archer Equation

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

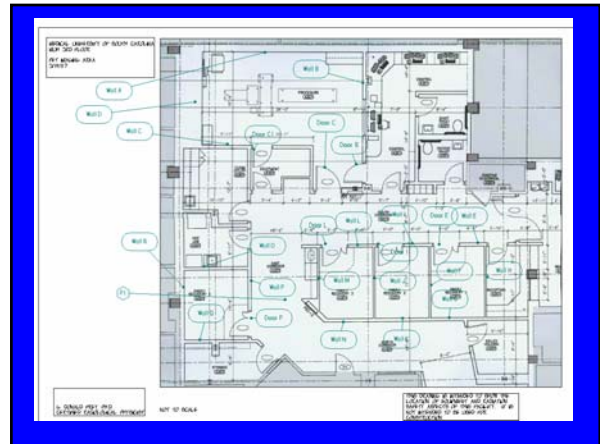
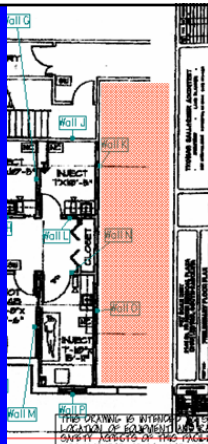
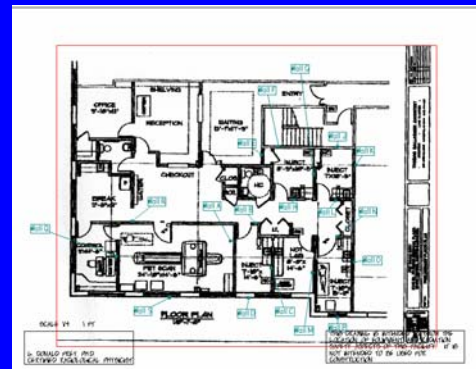
Table V. Fitting parameter for broad beam 511 keV transmission data.

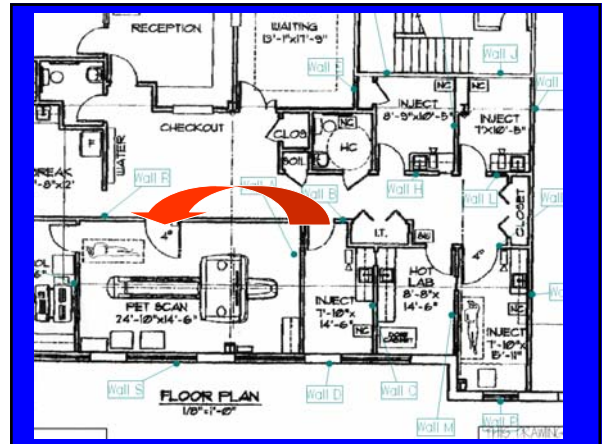
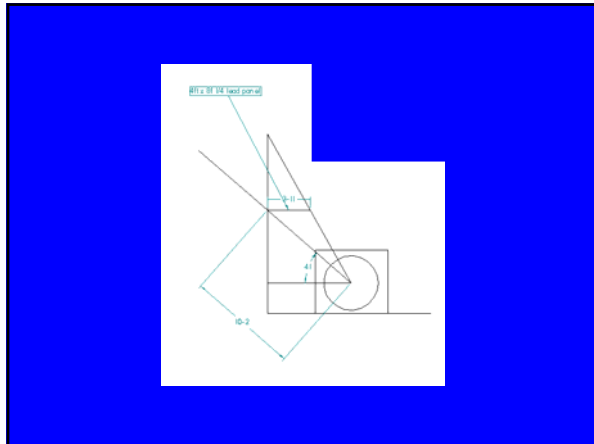
Shielding material	Alpha (cm <sup>-1</sup> )	Beta (cm <sup>-1</sup> )	Gamma
Lead	1.543	-0.4408	2.136
Concrete	0.1539	-0.1161	2.0752
Iron	0.5704	-0.3063	0.6326

## 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 naïve 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

Medical University of South Carolina  
169 Ashley Ave  
Charleston, SC 29425

**Shielding Design**

PECT

Shielding for PET will provide adequate shielding for the CT

**Notes**

PECT is on the 3rd floor of a multi-story building. There is occupancy above and below.

The shielding for PET will provide adequate CT shielding.

Shielding is done using the methods described in AAPM Report 100.

Because of the penetrating nature of PET radiation care must be taken to provide shielding around any penetrations.

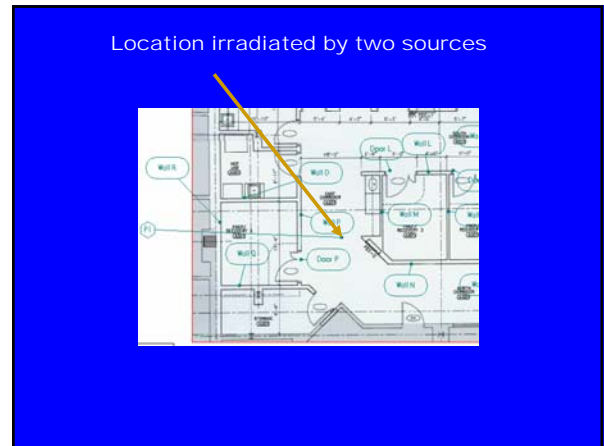
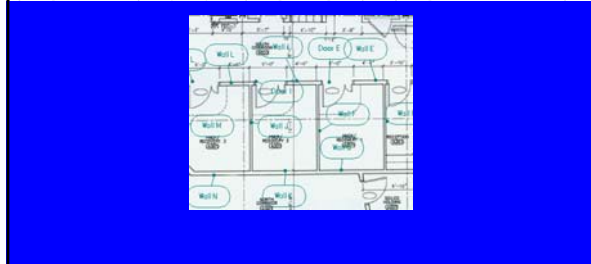
Shielding is designed for F-18. If other radionuclides are to be used the shielding should be re-evaluated.

Shielding will be adequate for short lived PET agents as long as very large patient numbers are not anticipated.

Shielding is not designed for I-124.

Design Values	Public	Occupational	Limit mSv/yr	Limit rem/yr	per Year per Year	
Radionuclide			F-18			
Half-life			110 min			
Administrative activity			500 mSv/yr			
Number of patients per week			100			Workload data from D. Dawson
Time patient will spend in uptake room			30 min			
Uptake room factor			0.75			
Patient waiting factor			0.95			
Time patients spend in exam room			30 min			
Exam room factor			0.44			
Exam Room Transfer			0.67			

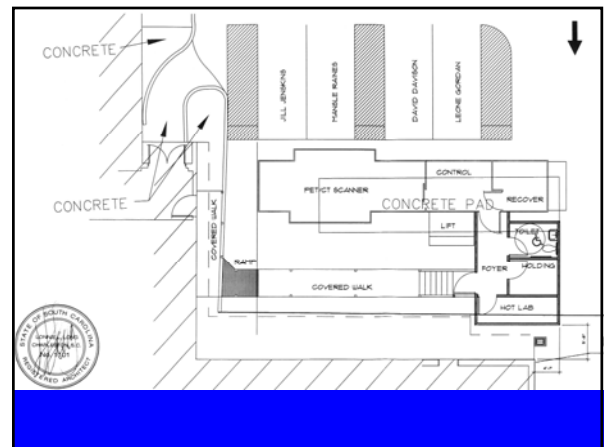
Room	Injection 2	A319								
Patients per week	20									
Intercom should be provided so technologist can talk with patient from corridor										
Barrier	Adjacent Space	Distance (ft)	Distance (m)	Occupancy Factor	Design (m <sup>2</sup> /kg)	Barrier Factor	Concrete Lead (cm)	Lead (mm)	Recommended Shielding (mm)	Shielding Height
Wall L	Corridor	9	2.7	0.2	1	4.3E-01	9.4	0.6	0.25 1/4 in lead	Deck
Door L	Corridor	9	2.7	0.105	1	6.9E-01	9.5	0.3	0.12 1/2 in lead door	Deck
Wall P	Php 1	4.5	1.4	1	5	1.1E-01	18.9	1.5	0.75 3/4 in lead	Deck
Wall M	North Corridor	4.5	1.4	0.2	1	1.1E-01	18.9	1.5	0.75 3/4 in lead	Deck
Wall J	Php 3	7.5	2.3	1	5	3.0E-01	12.1	0.9	0.75 3/4 in lead	Deck
Control	Control	16	4.9	1	1	2.4E-01	12.8	0.8	0.25 1/4 in lead	Deck
Floor	Floor	9.5	2.9	1	1	9.6E-02	19.6	1.12	0.60 1/2 in lead	

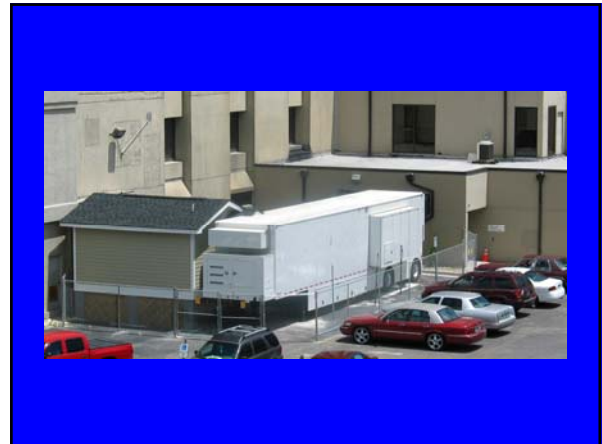
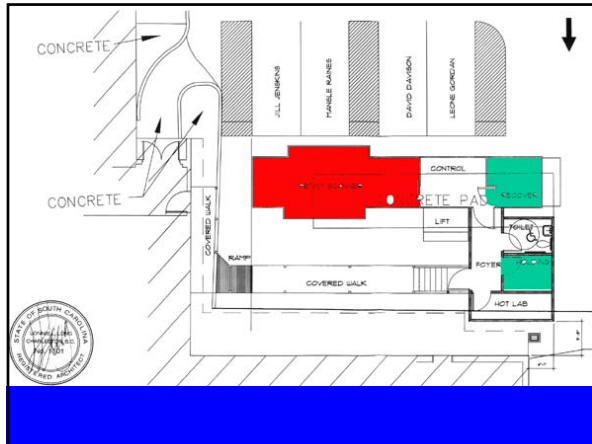


Multiple Exposure Area						
Location	East Corridor			Occupancy Corrected Estimated Corrected		
Barrier	Distance m	Distance m	Shielding Inverse Square m <sup>2</sup>	Annual Exposure mSv	Annual Exposure mSv	Annual Exposure mSv
Wall P	12	3.7	2.7	1.8	1.0	0.56
Wall M	11	3.4	2.4	1.9	0.5	0.26
Total						0.82
Limit						1
Fraction						82%

# Shielding Evaluation

- ## 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

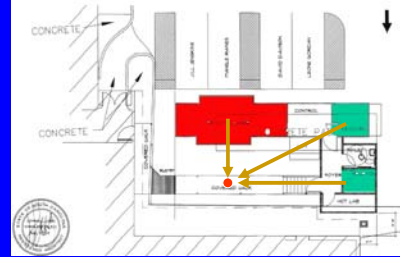
- ### Instrumentation
- We have used three types of instruments
    - Large volume ionization chamber
      - Radcal 9010 w/ 10X5-1800
    - Portable pressurized ionization chamber
      - Innovision 451P
    - Portable NaI(Tl) Survey Meter
      - Exploranium GR-135

- ### 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

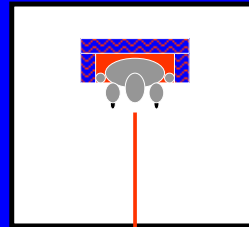
- Use source in each location
- Use meter to scan for gaps and voids

## Evaluating the Annual Exposure at a Location

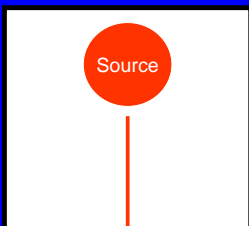


## Scaled Source Method

- 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

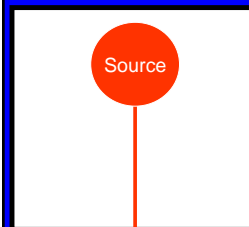


$$\text{Annual Dose} = \text{Dose Rate} \times \text{Number of Patients} \times \text{Time Each Patient is in the Room}$$

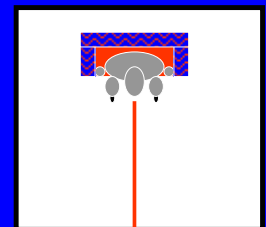


$$\text{Activity} = \text{Average Patient Dose} \times \text{Number of Patients} \times \text{Time Each Patient is in the Room}$$

$$\text{Annual Dose} = \text{Dose Rate} \times 1 \text{ hour}$$



=



Or

$$AN\tau \rightarrow R_A = D(x, y, z) = \dot{D} N\tau \leftarrow A$$

## Average Patient Activity Uptake Room

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

$$\bar{A}_u = \zeta (A_0 / 1n(2)) (T_{1/2} / \tau_u) (1 - (1/2)^{\tau_u/T_{1/2}})$$

## 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

$$\bar{A}_s = \zeta (A_0 / 1n(2)) (1/2)^{\tau_u/T_{1/2}} \times (T_{1/2} / \tau_u) (1 - (1/2)^{\tau_u/T_{1/2}})$$

## 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

$$\sum_i \bar{A}_s N_{si} \tau_u + \sum_i \bar{A}_u N_{ui} \tau_u \rightarrow D(x, y, z)$$

## So from all rooms

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

## So we need to Scale the Activity

$$\left( \sum_i \bar{A}_s N_{si} \tau_u + \sum_i \bar{A}_u N_{ui} \tau_u \right) / \sigma \rightarrow D(x, y, z) / \sigma$$

$$a_{ui} = \bar{A}_u N_{ui} \tau_u / \sigma$$

$$a_{si} = \bar{A}_s N_{si} \tau_u / \sigma$$

## So from all rooms

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

## Compare Results to Design Values

$$P / TD(x, y, z) \leq 1$$

- 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

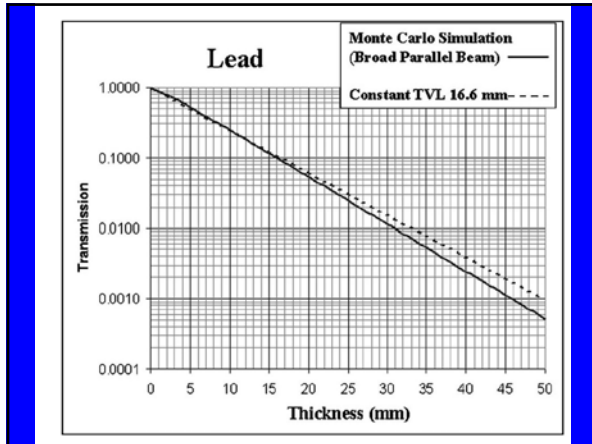
Location	Distance	Design Value (P)	Time	Meter Reading	Time			Percent			Occupancy		
					Corrected	Estimate	P-Value	Status	Factor	Estimate	P-Value	Status	
Inside			8:43 AM	2.30	1.42	0.71	14%	Pass	1.00	0.71	14%	Pass	
Control Room Operator	5	8.45	8:30	3.30	1.65	0.83	33%	Pass	1.00	1.65	33%	Pass	
Control Room Secondary Operator	5	8.45	8:40	4.60	2.87	1.43	29%	Pass	1.00	1.43	29%	Pass	
Door to Corridor	5	8.45	8:50	8.50	4.21	2.11	29%	Pass	1.00	2.11	29%	Pass	
Entrance Corridor	5	8.48	30:00	19.06	9.53	4.77	191%	Fail	1.00	9.53	191%	Fail	
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	191%	Fail	1.00	9.53	191%	Fail	
Outside Porch	5	8.49	14:10	14.10	9.01	4.51	90%	Pass	1.00	4.51	90%	Pass	

Location	Distance	Design Value (P)	Time	Meter Reading	Time			Percent				
					Corrected	Estimate	P-Value	Status	Factor	Estimate	P-Value	Status
Inside			8:43 AM	2.30	1.42	0.71	14%	Pass	1.00	0.71	14%	Pass
Control Room Operator	5	8.45	8:30	3.30	1.65	0.83	33%	Pass	1.00	1.65	33%	Pass
Control Room Secondary Operator	5	8.45	8:40	4.60	2.87	1.43	29%	Pass	1.00	1.43	29%	Pass
Door to Corridor	5	8.45	8:50	8.50	4.21	2.11	29%	Pass	1.00	2.11	29%	Pass
Entrance Corridor	5	8.47	8:50	8.50	4.21	2.11	29%	Pass	1.00	2.11	29%	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	191%	Fail	1.00	9.53	191%	Fail
Outside Porch	5	8.49	14:10	14.10	9.01	4.51	90%	Pass	1.00	4.51	90%	Pass

Time	Annual Corrected	Estimate	Percent P-Value	Status	Occupancy Factor	Annual Estimate	Percent P-Value	Status
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



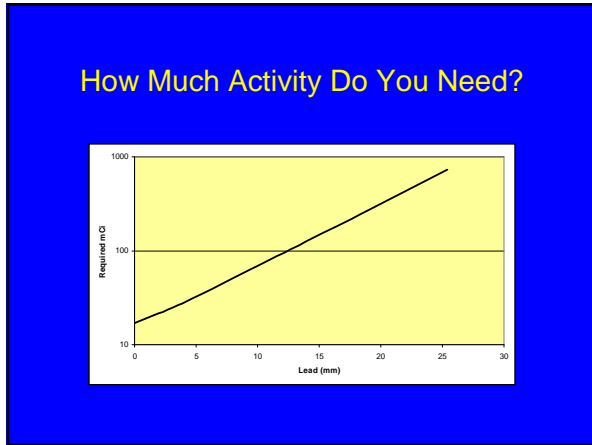
## Direct Calculation

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

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

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

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

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


Desired distance		3 meters			
Desire Air KERMA		10 uSv/hr			
US Inches	Metric mm	Attenuation	Activity MBq	mCi	Unshielded uSv/hr
0	0	1.000	629	17	10
1/16	1.6	0.829	759	21	12
1/8	3.2	0.674	933	25	15
1/4	6.4	0.430	1465	40	23
3/8	9.5	0.267	2357	64	37
1/2	12.7	0.164	3826	103	61
3/4	19.1	0.062	10168	275	162
1	25.4	0.023	27078	732	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	Measured	NET	Unshielded		Calculated Lead mm	Specified Lead mm	Deviation
				Air Kerma uGy/hr	Bkg nGy/hr	Air Kerma uGy/hr	Calculated B				
Note	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%



Some day you will look  
back upon this and run  
into a bus