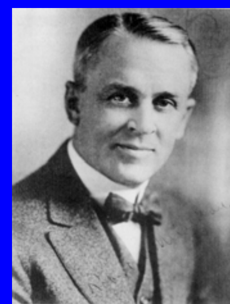
PET Shielding

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
Radiology, University of Texas Southwest Texas Medical Center at Dallas

James R. Halama
Nuclear medicine, Loyola University Medical Center

Jeff Kleck
Attainia, Inc.

Douglas J. Simpkin
Radiology, St. Luke's Medical Center

John R. Votaw
Radiology, Emory University

Richard E. Wendt III
University of Texas MD Anderson Cancer Center

Lawrence E. Williams
Radiology, City of Hope Medical Center

Michael V. Yester
Radiology, University of Alabama at Birmingham Medical Center

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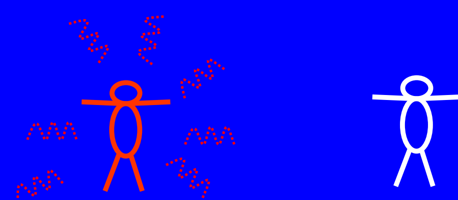
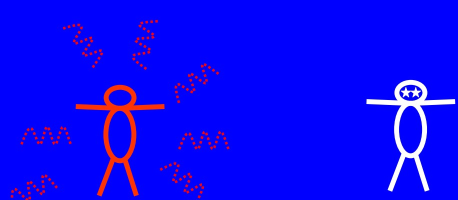
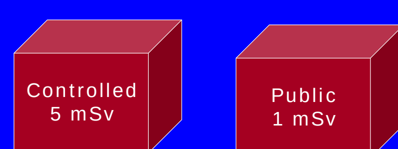
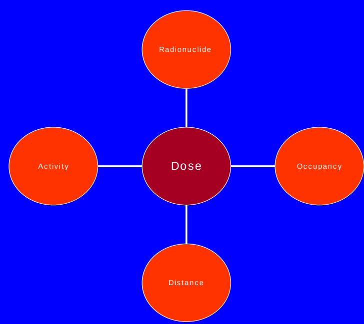


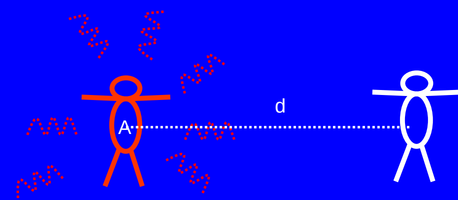


Design Values
Annual Limits
Same as NCRP 147





$$\dot{D} = A\Gamma / d^2$$



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
F-18	0.14	0.119
Cu-64	0.03	0.024
Ga-68	0.13	0.101
Rb-82	0.16	0.006
I-124	0.19	0.184

F-18 Rate Constants

uSv-m²/ MBq-h

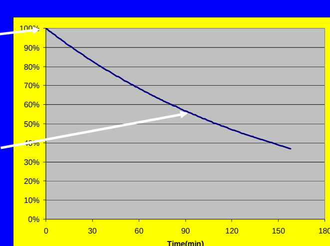
F-18 Rate Constants	Value
Air Kerma Exposure Rate	0.134
Effective Dose Equivalent (ANS-1991)	0.143
Tissue Dose Constant	0.148
Deep Dose Equivalent (ANS-1977)	0.183
Maximum Dose (ANS-1977)	0.188
Maximum Dose (ANS-1977)	0.188

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

What Is the Activity?

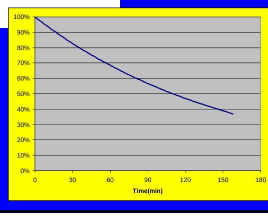
A_0 – Administered Activity

t_u -time patient waits in uptake room



What Is the Activity?

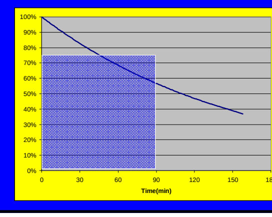
$$A_u = \int_0^{t_u} A_0 \, e^{-\lambda t} \, dt$$



What Is the Activity?

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

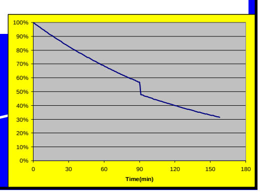
t_u	
30	0.91
60	0.83
90	0.76



Scan Room Activity

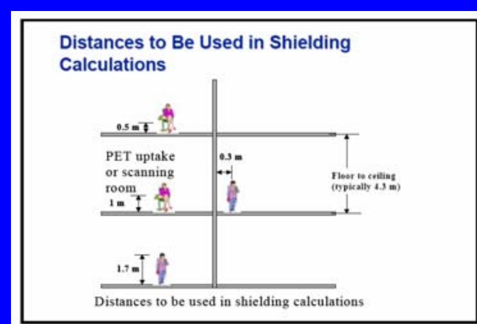
$$A_s = A_0 \, \kappa \, (1/2)^{(t_u/T_{1/2})} \int_{t_u}^{t_s} e^{-\lambda t} \, dt$$

Voiding factor 0.85

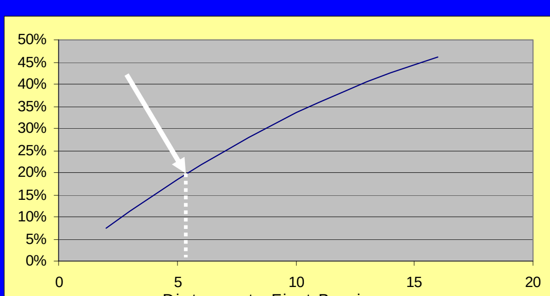


Distance

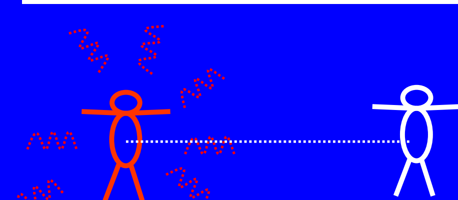
Report Distances Are in Meters



Across 8 ft Corridor Fully Occupied Space



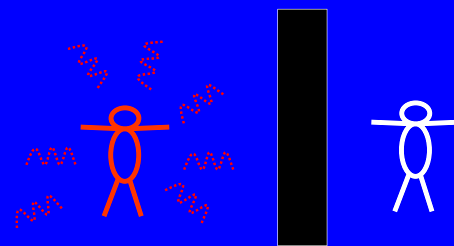
$$Dose_{ann} = \bar{A}_u \, t_u \, \Gamma N / d^2$$



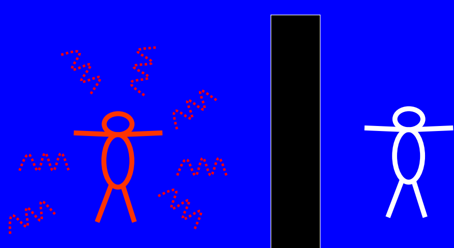
Occupancy Factor

Same as NCRP 147

Transmission Factor



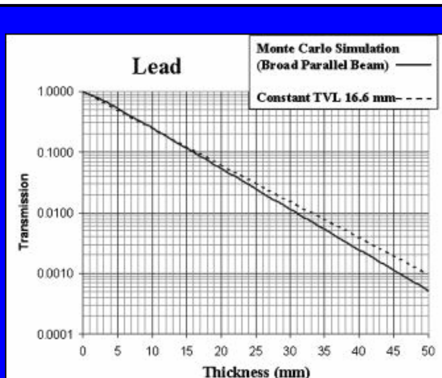
$$B = Pd^2 / T\,\bar{A}_u\,t_u\,\Gamma N$$



Scan Room

$$Dose_{ann} = \bar{A}_s\,t_s\,\Gamma N / d^2$$

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



Use Archer Equation

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

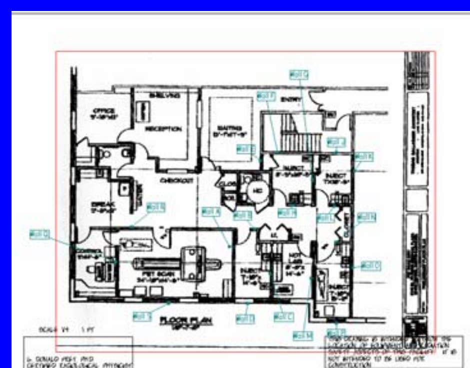
Table V. Fitting parameter for broad beam 511 keV transmission data.

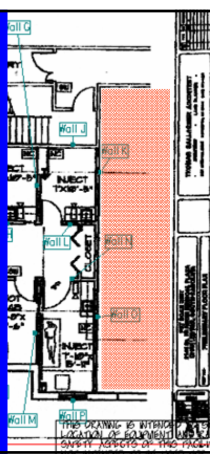
Shielding material	Alpha (cm^{-1})	Beta (cm^{-1})	Gamma
Lead	1.543	–0.4408	2.136
Concrete	0.1539	–0.1161	2.0752
Iron	0.5704	–0.3063	0.6326

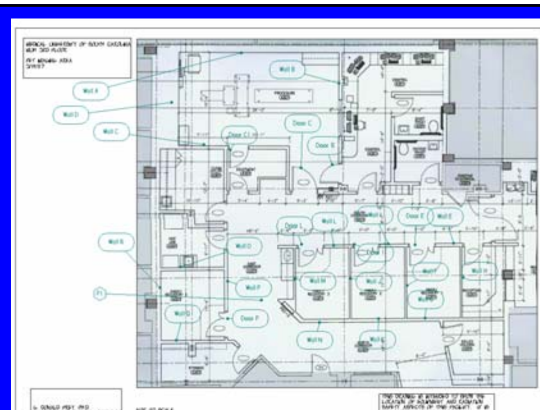
Effective Design of PET Shielding

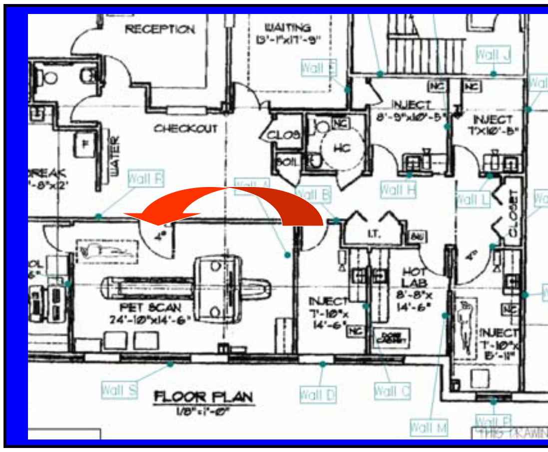
Early Intervention

- 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





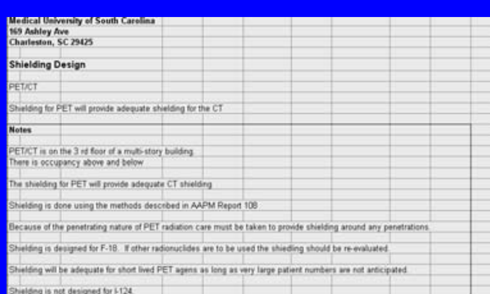




Other Possibilities

- 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

PET/CT

Shielding for PET will provide adequate shielding for the CT

Notes

PET/CT is on the 3 rd floor of a multi-story building
There is occupancy above and below

The shielding for PET will provide adequate CT shielding

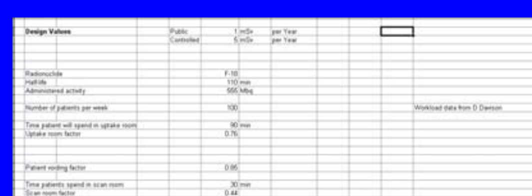
Shielding is done using the methods described in AAPM Report 108

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 shieding should be re-evaluated.

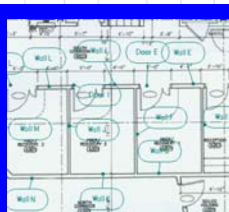
Shielding will be adequate for short lived PET agens as long as very large patient numbers are not anticipated.

Shielding is not designed for I-124.

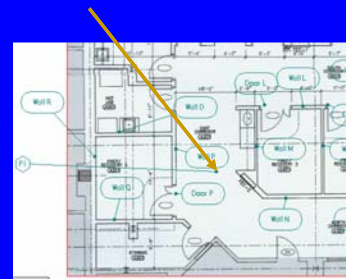


Design Values	Public	1	mSv	per Year	
	Controlled	5	mSv	per Year	
Radionuclide		F-18			
Half-life		110	min		
Administered activity		555	Mbq		
Number of patients per week		100			Workload data from D Dawson
Time patient will spend in uptake room		90	min		
Uptake room factor		0.76			
Patient voiding factor		0.85			
Time patients spend in scan room		30	min		
Scan room factor		0.44			
Scan Room Transfer		0.57			

Room		Injection 2		A319							
Patients per week		30									
	Intercom should be provided so technologist can talk with patient from corridor										
Barrier	Adjacent Space	Distance (ft)	Distance (m)	Occupancy	Design (mSv/yr)	Barrier Factor	Concrete (cm)	Lead (cm)	Recommended Shielding (in)	Description	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	0.125	1	6.9E-01	5.5	0.3	0.12	1/8 in lead door	
Wall F	Prep 1	4.5	1.4	1	5	1.1E-01	18.9	1.5	0.75	3/4 in lead	Deck
Wall K	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	Prep 3	7.5	2.3	1	5	3.0E-01	12.1	0.9	0.75	3/4 in lead	Deck
Ceiling	Ceiling	15	4.6	1	1	2.4E-01	13.6	0.5	0.25	1/4 in lead	
Floor	Floor	9.5	2.9	1	1	9.6E-02	19.6	1.12	0.50	1/2 in lead	
Room		Injection 3		A314							
Patients per week		30									
	Intercom should be provided so technologist can talk with patient from corridor										



Location irradiated by two sources



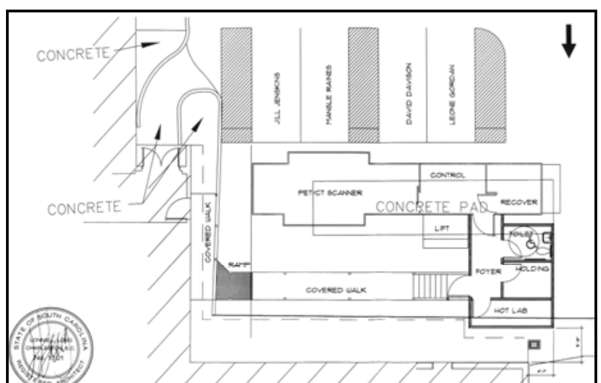
Multiple Exposure Area

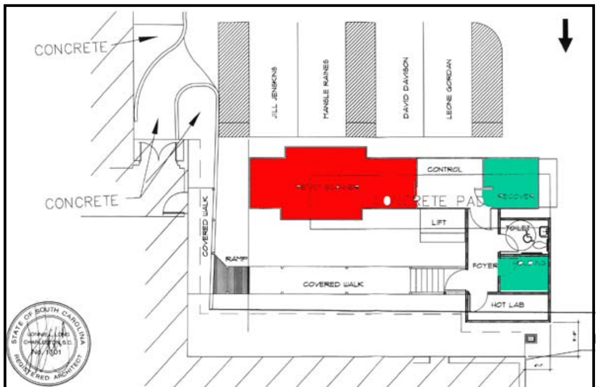
Location		East Corridor				
Barrier	Distance ft	Distance m	Shielding Distance m	Inverse Square la	Occupancy Estimated Annual Exposure mSv	Corrected Corrected Annual Exposure mSv
Wall P	12	3.7	2.7	1.8	1.0	0.56
Wall M	11	3.4	2.4	1.9	0.5	0.26
				Total		0.82
				Limit		1
				Fraction		82%

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

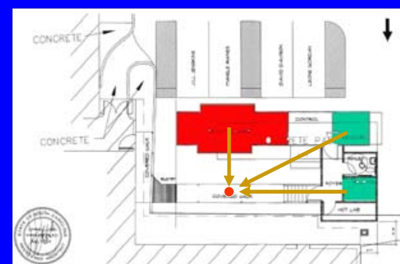
Instrument of Choice

- 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

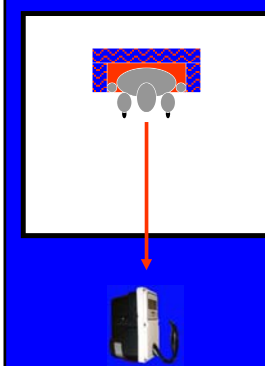
- Use source in each location
- Use meter to scan for gaps and voids

Evaluating the Annual Exposure at a Location

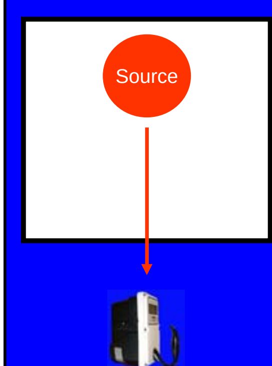


Scaled Source Method

- 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

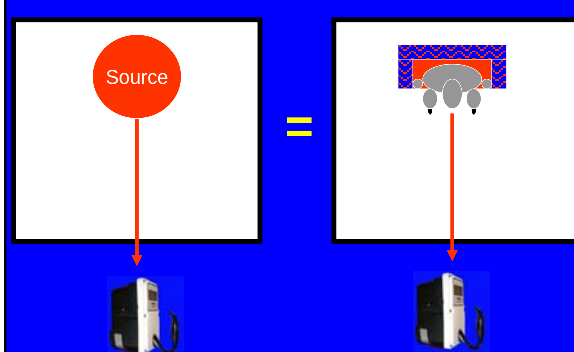


Annual Dose = Dose Rate x
Number of Patients x
Time Each Patient is in the Room



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

Annual Dose = Dose Rate x
1 hour



Or

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

Average Patient Activity Uptake Room

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

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

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

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

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

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

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

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

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

$$\alpha_{si} = \bar{A}_s N_{si} \tau_s / \sigma$$

So from all rooms

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

Compare Results to Design Values

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

- 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	

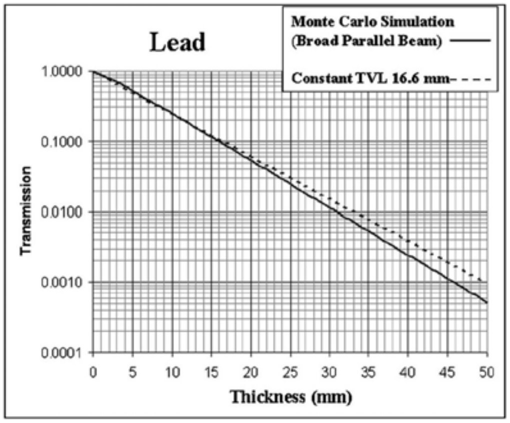
Room	Uptake Room 1	
Time between injection and beginning of room use	0 min	
Decay Factor	1	
Time patient remains in room	90	
Decay Dose Rate Factor	0.76	
Voiding Factor (Retention when patient enter room)	1	
Patients per week	32	
Effective Activity	759826 MBq	20536 mCi

	Location	Distance	Design Value (P)	Time	Meter Reading
Inside	Control Room Operator		5	8:43 AM	2.30
	Control Room Secondary Operator		5	8:45	5.30
	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*

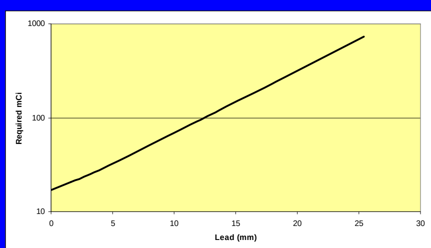
$$x = (1 / \alpha\gamma) \ln \{ [B^{-\gamma} + (\beta / \alpha)] / [1 + (\beta / \alpha)] \}$$

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

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

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

How Much Activity Do You Need?



Desired distance 3 meters

Desire Air KERMA 10 uSv/hr

US Inches	Metric mm	Attenuation	Activity MBq	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 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%

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