Task Group 108 Overview

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University of Iowa

Motivation for Task Group 108

- Explosion of PET and PET/CT facilities since 2000.
- Conflicting advice from physicists and manufacturers.
- AAPM Leadership Role

Comparison of x-rays and Annihilation Radiation

- X-rays
- Limited duration
  - CT Scan Time (minutes per patient)
- Low energy
  - 60 – 100 keV
- Easily shielded
  - 1.5 mm of Pb yields 1000 x dose reduction

- Annihilation Radiation
- Always “on”
  - Patient is main source
  - Clinic time > 1 hour/patient
- High energy
  - 511 keV
- Substantial shielding
  - 10 mm of Pb provides x 4 reduction

Task Group 108 charge …

- Create a document that provides information for determining radiation protection shielding for PET and PET/CT facilities.
- Get it done quickly (< 2 years!)

Task Group 108 Members

- Mark T. Madsen
- Jon A. Anderson
- James R. Halama
- Jeff Kleck
- Douglas J. Simpkin
- John R. Votaw
- Richard E. Wendt
- Lawrence E. Williams
- Michael V. Yester

Jim Halama, PhD

- Chair of AAPM Nuclear Medicine Committee
- Creates Task Group 108 and names chair.
- Approval process
  - Committee approval
  - Science council approval

Preparing People to Lead Extraordinary Lives
LOYOLA UNIVERSITY CHICAGO
Stritch School of Medicine

Doug Simpkin, PhD, FAAPM

- Expert in diagnostic shielding
- Member of NCRP 147 Group:
  - **Structural Shielding Design for Medical X-Ray Imaging Facilities: Recommendations of the NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS**
- Calculated transmission values for Task Group 108

St. Luke's Medical Center, Milwaukee, WI

UT SOUTHWESTERN MEDICAL CENTER

Jon Anderson, PhD

- PET Physicist at UTSW Medical Center
- Valuable input on patient dose exposures
- Expertise in PET facility design
- Member of:
  - AAPM Nuclear Medicine Subcommittee
  - AAPM Task Group No. 111 The future of CT dosimetry
  - Chair of Task Group No. 126: PET/CT Acceptance Testing and Quality Assurance
  - Medical Physics Education of Physicians
  - Task Group No. 3 Radiation Effects & Protection Lecture for Medical Students

Michael Yester, PhD, FAAPM

- Expertise in PET imaging
- Valuable information on patient exposure levels.
- Member of:
  - Continuing Professional Development (Chair)
  - Member of Education Council
  - Summer School Subcommittee
    Task Group No. 127 MOC (Chair)

University of Alabama at Birmingham Medical Center

Larry Williams, PhD, FAAPM

- Expertise in PET imaging.
- Provided careful review and many useful suggestions.
- Member of :
  - Member of Board of Editors - Medical Physics *as Associate Editor*
  - Data Acquisition Methods and Radionuclide Dose Estimation Working Group (Chair)
  - Task Group No. 144 Dosimetry and Procedures for ^{90}Y Microsphere Brachytherapy for Liver Cancer
  - Special Brachytherapy Modalities Working Group

City of Hope®

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Bud Wendt, PhD

THE UNIVERSITY OF TEXAS
MD ANDERSON
CANCER CENTER

John Votaw, PhD

EMORY
UNIVERSITY

- Both Bud and John provided valuable review and insights.
- Bud: Conservative dose advocate
- John: Liberal dose advocate

Jeff Kleck

attainia

- Provided valuable resource information
- Founder and Director of Attaina, Inc:
  - Attainia, Inc. is dedicated to improving the management of the capital equipment lifecycle in healthcare.

Who (or what) needs protection?

- **PET Technologists and Nurses**
  - Radiation workers in the PET center
- **Facility employees**
  - Radiation workers (Non-PET)
  - Non-radiation workers
- **General public**
  - Relatives and associates of patients
- **Radiation detection equipment**
  - Probes, well counters, gamma cameras

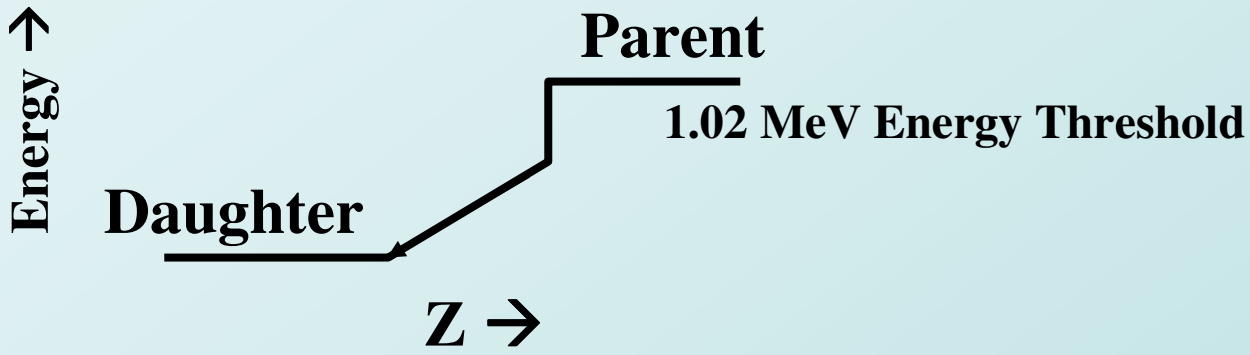
What specific areas should be considered?

- Radionuclide storage & disposal
- Radiopharmaceutical administration
- Uptake room
- Tomograph room
  - Control room
- Patient bathroom
- Surrounding areas (especially uncontrolled areas with high occupancy factor).

FACTORS AFFECTING RADIATION PROTECTION

- **Radionuclide**
  - Half life, emissions
- **Procedure protocol**
  - Administered activity, uptake time, scan time
- **Dose rate from the patient**
  - Dose constants, patient attenuation, decay, number of patients per week.
- **Facility layout**
  - Controlled vs uncontrolled areas, occupancy factors, detection instrumentation
- **Regulatory Limits**

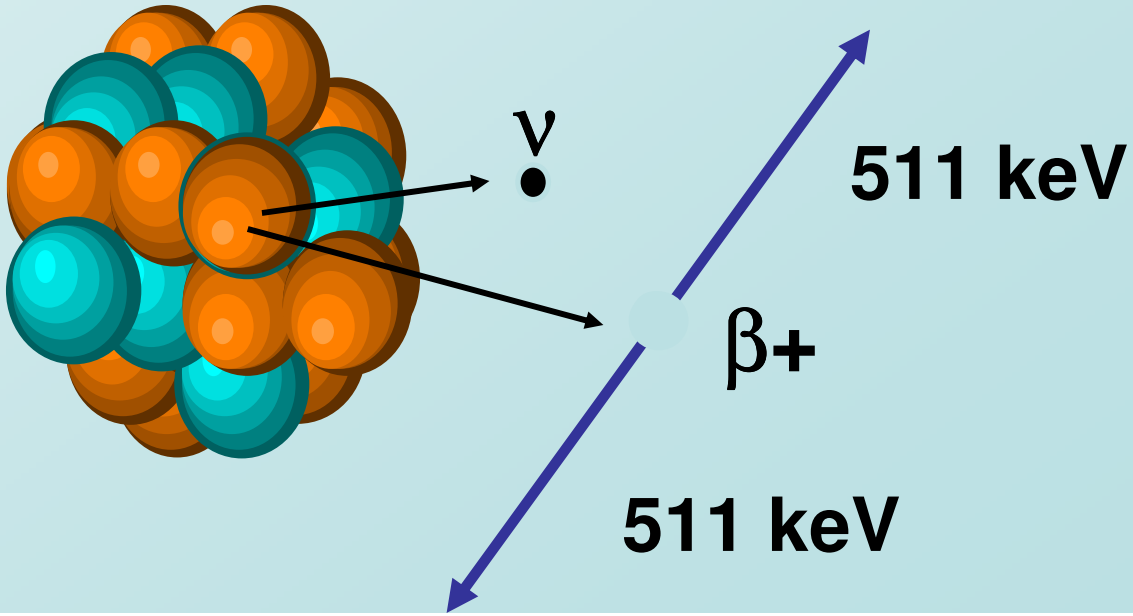
Positron (β+) Decay



Daughter

Parent

$^{A}_{Z}X$



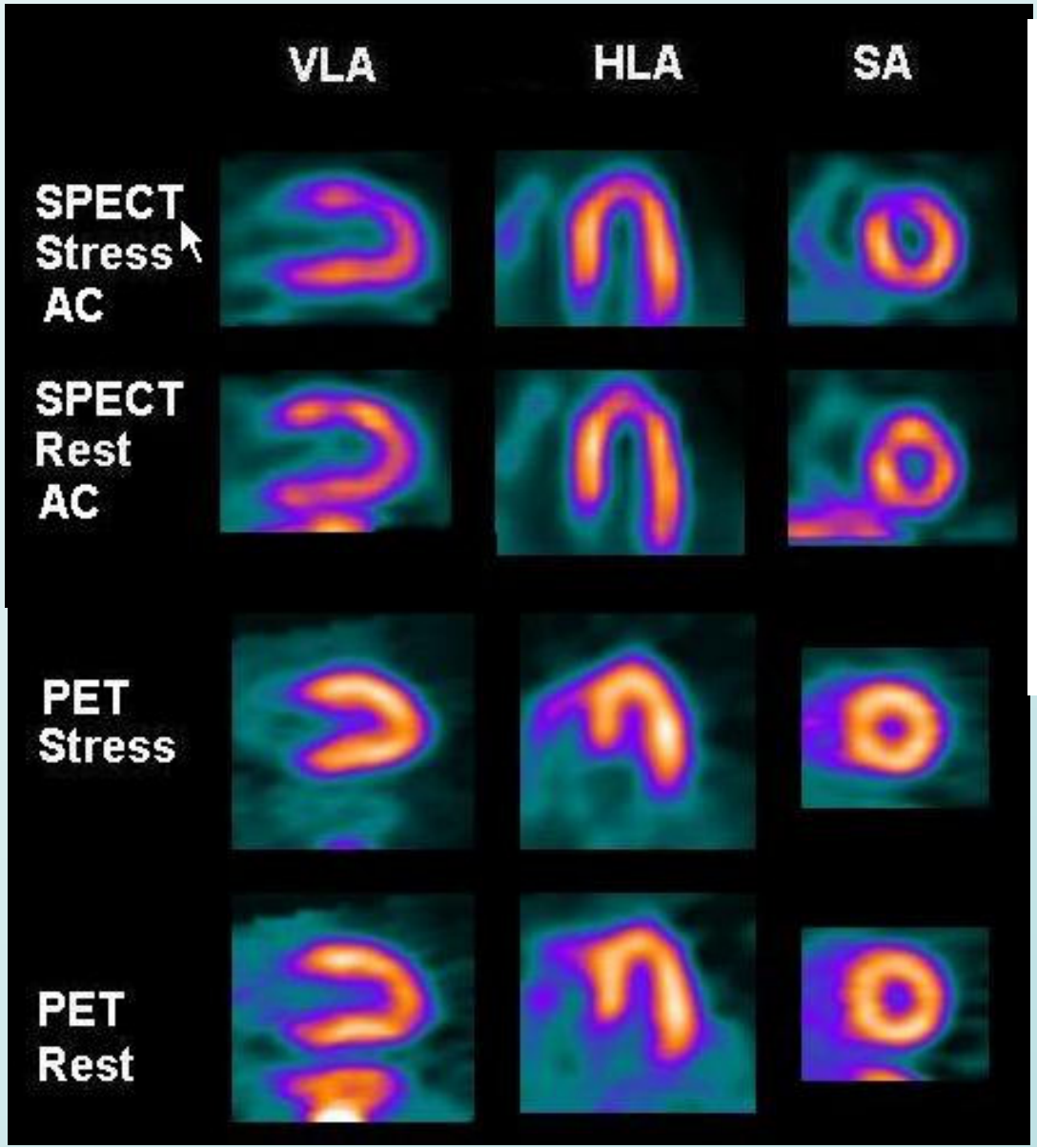
PET Radionuclides

	$T_{1/2}$	Decay Mode	Eβmax (MeV)	Energy (keV)	photons/decay
^{18}F	109.8 m	β+ ,EC	0.63	511	1.93
^{124}I	4.2 d	β+, EC	1.54, 2.17	511	0.5
				603	0.62
				1693	0.3

What types of studies should be considered?

- Myocardial Perfusion
  - ^{82}Rb, ^{13}N-Amonia
- Neurological Studies
  - ^{15}O-Water Cognitive Activation
  - Receptor imaging (^{18}F-Fluorodopa)
- Oncologic Research
  - ^{11}C-Methionine, ^{11}C-Choline
- Clinical Onology
  - ^{18}F-Fuorodeoxyglucose (FDG)

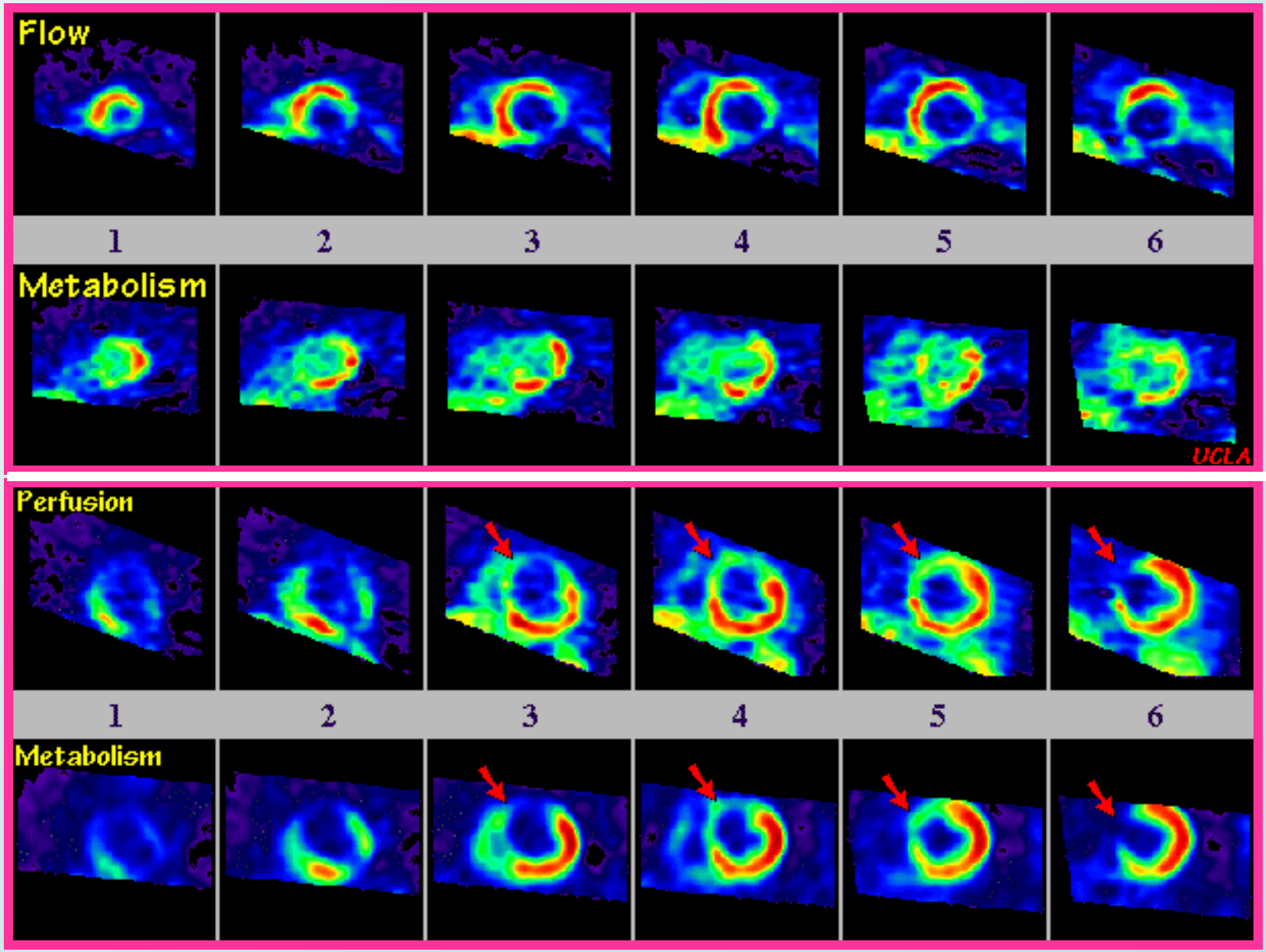
Myocardial Perfusion with Rb-82



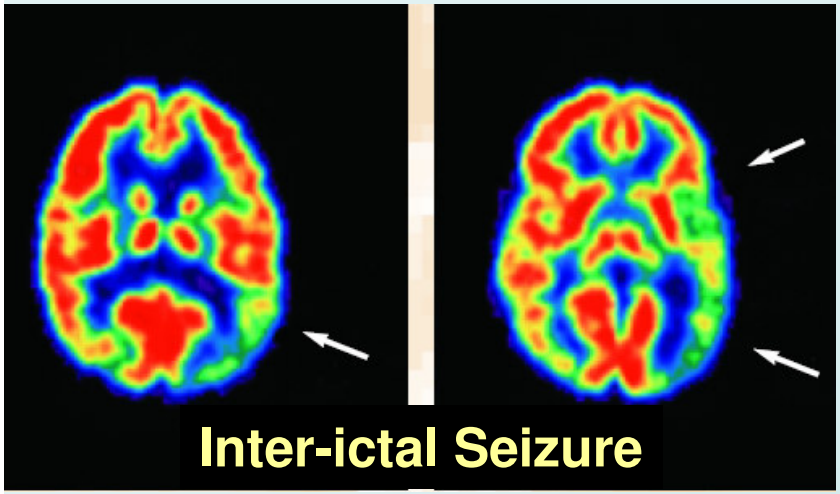
Rb-82 has a 72 second half life. It is supplied from a radionuclide generator that has a shelf life of 1 month.

PET myocardial perfusion is reimbursed for both the study and the radio-pharmaceutical.

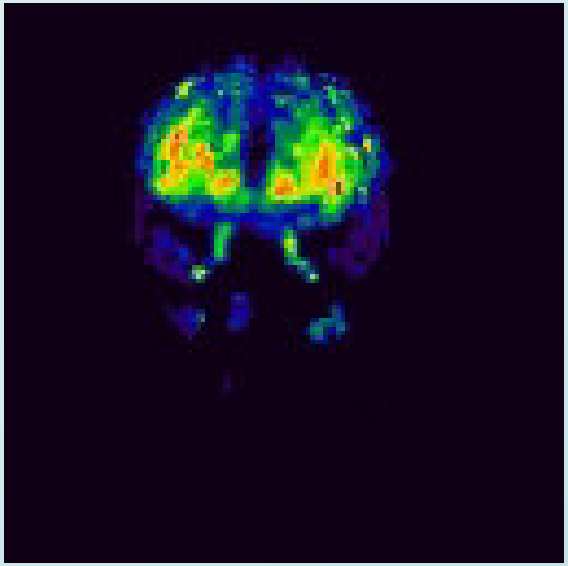
Cardiac Viability

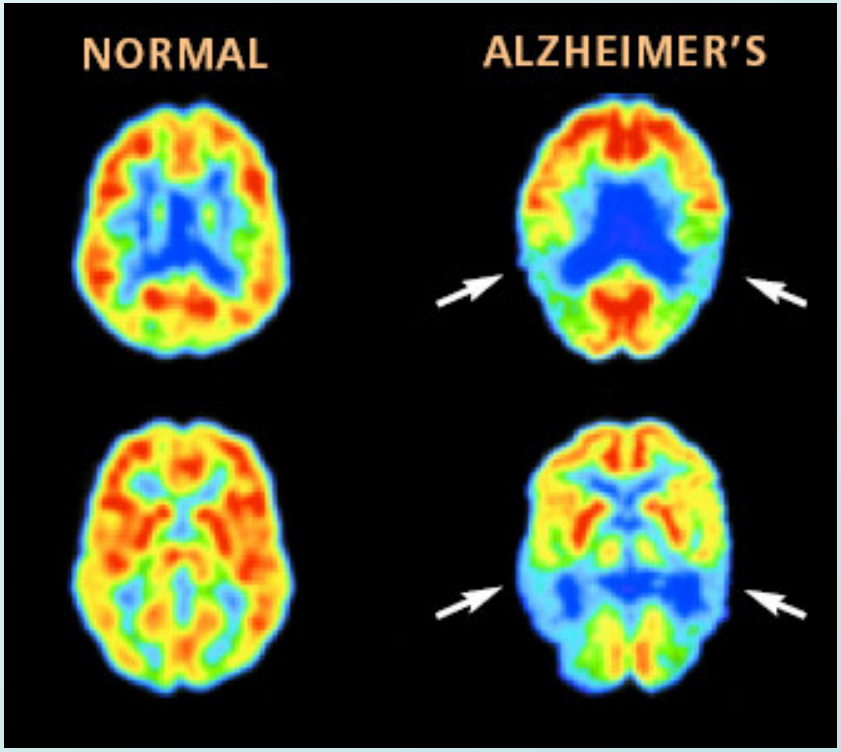


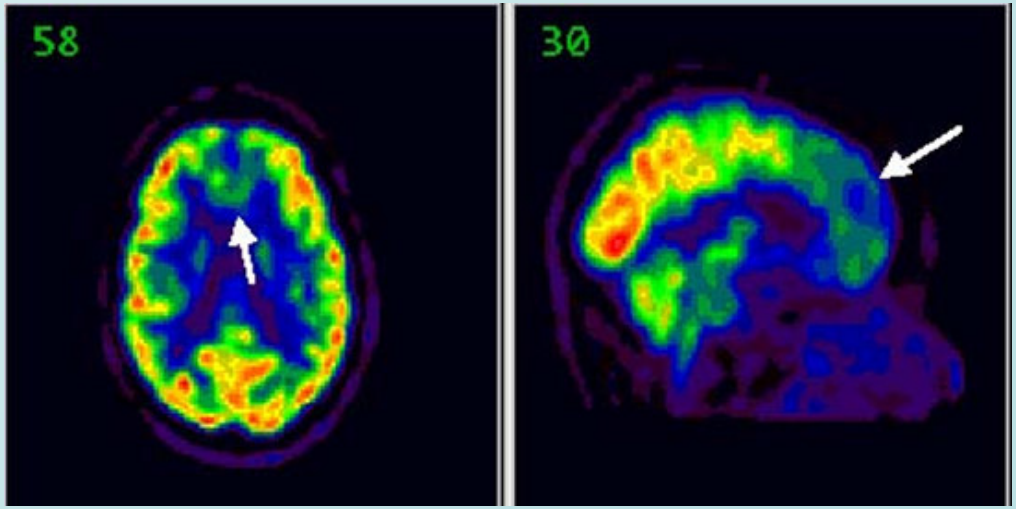
Neurological PET Studies



Inter-ictal Seizure

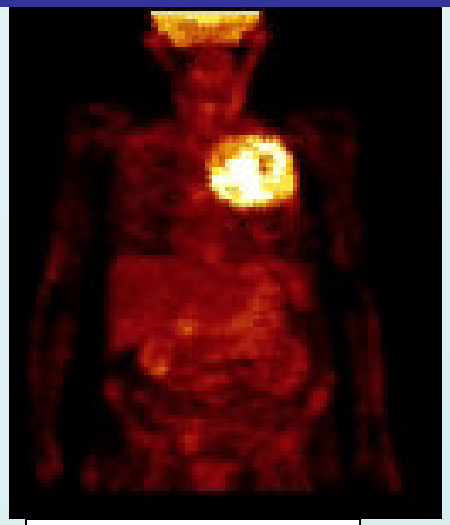




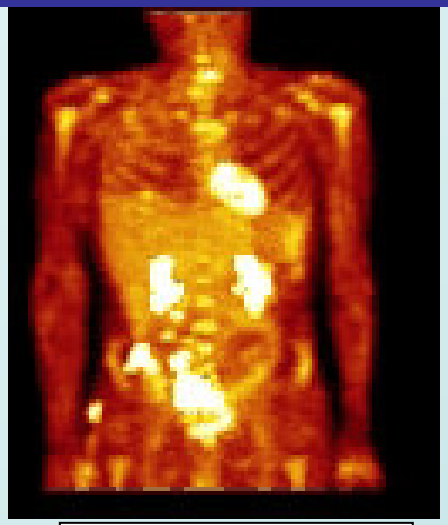


Pick's Disease

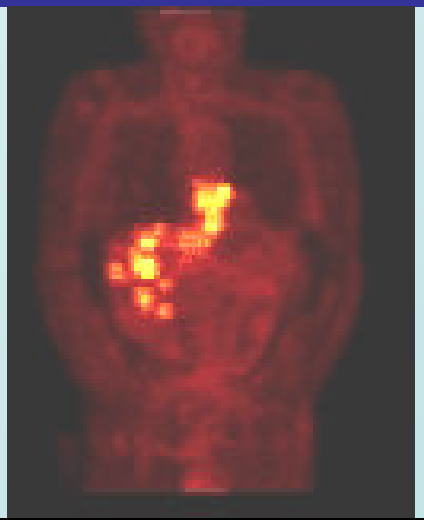
Oncologic Imaging with F-18 FDG



Lung Cancer

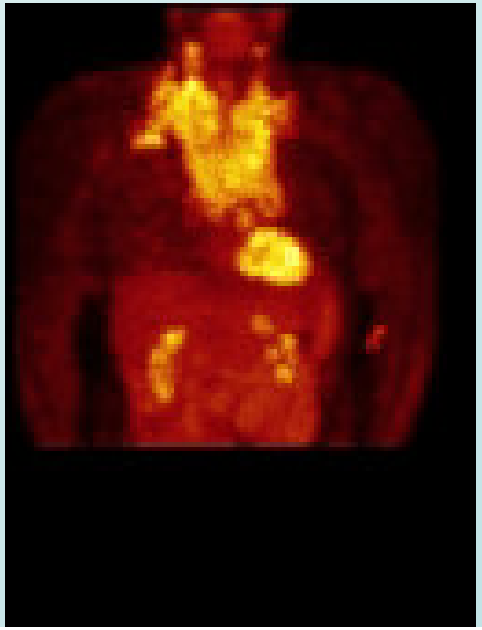


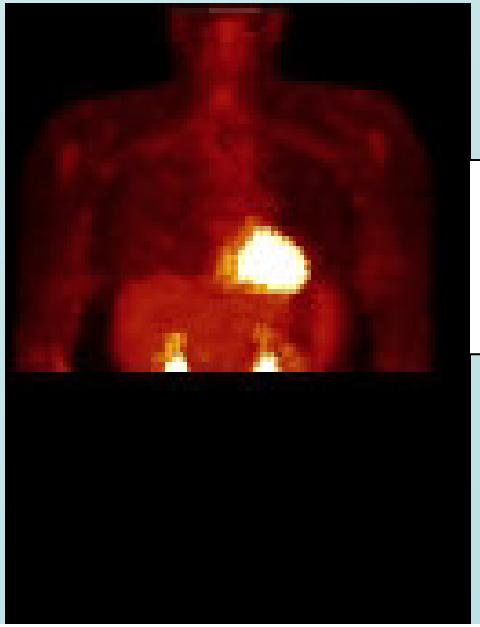
Colon Cancer



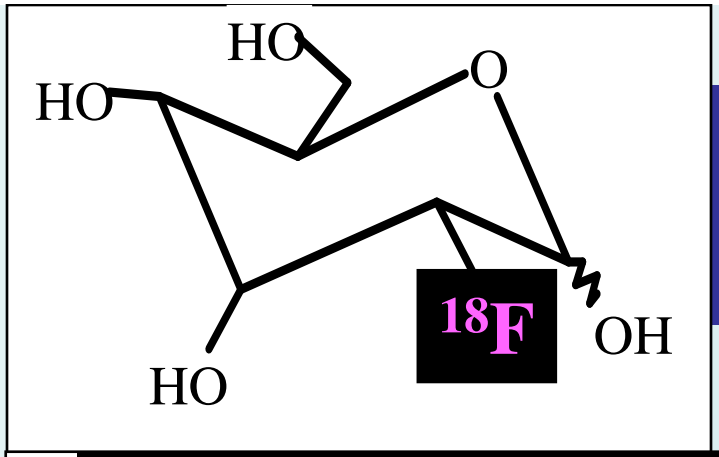
Esophogeal Cancer

Hodgkins Lymphoma Pre-Treatment





Hodgkins Lymphoma Post-Treatment



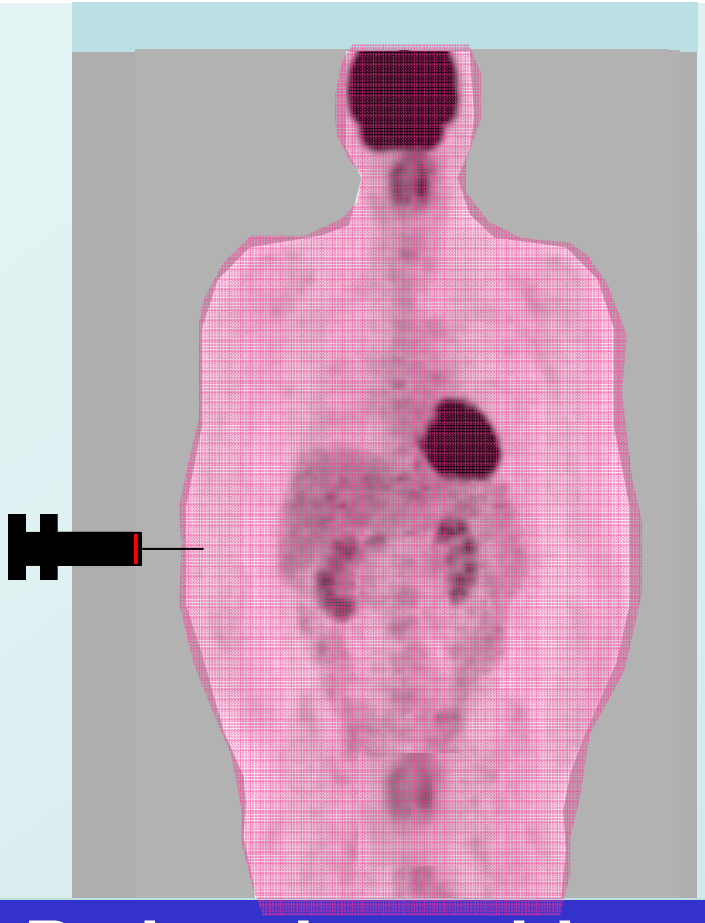
Fludeoxyglucose F18 (^{18}F- FDG)

	Production	Half-life	Decay constant	Decay mode	Principle emissions (MeV)	γ ray constant (R-cm^2/mCi-hr)
^{18}F	^{18}O(p,n)^{18}F	109.8 min	0.0063 min^{-1}	β$^+$, EC	0.65 β$^+$(97%) 0.511 γ(194%)	5.73

Mechanism of Action

- FDG is a glucose analog that competes with glucose for hexokinase phosphorylation to FDG-6-phosphate (FDG-6-P).
- Because FDG-6-P is not a substrate for further glycolytic pathways and has a low membrane permeability, the tracer becomes entrapped within the tissues in proportion to the rate of glucose utilization of that tissue.

^{18}F FDG Oncologic Studies



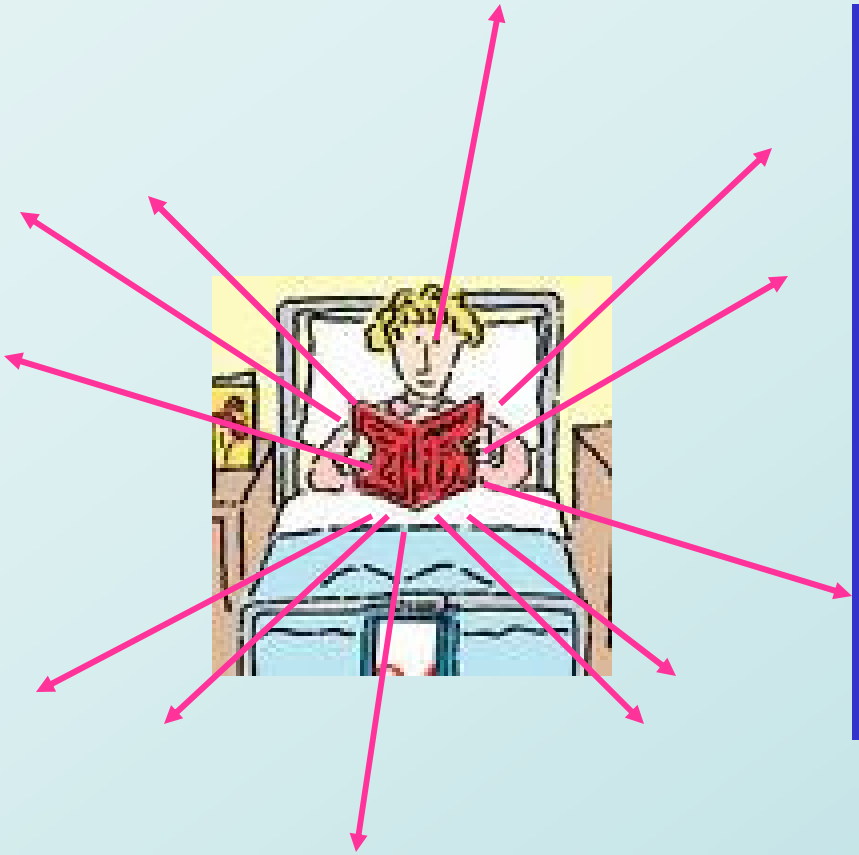
- Patient is administered ~ 555 Mbq of F-18 FDG in a quiet, low light room.
- Patient remains at rest for 30-90 minutes prior to PET study.
  - No walking or other muscular activity
- Patient voids prior to imaging

•Patient is positioned on imaging system.
•CT transmission acquired 1st, then PET emission.
•Patient is released.

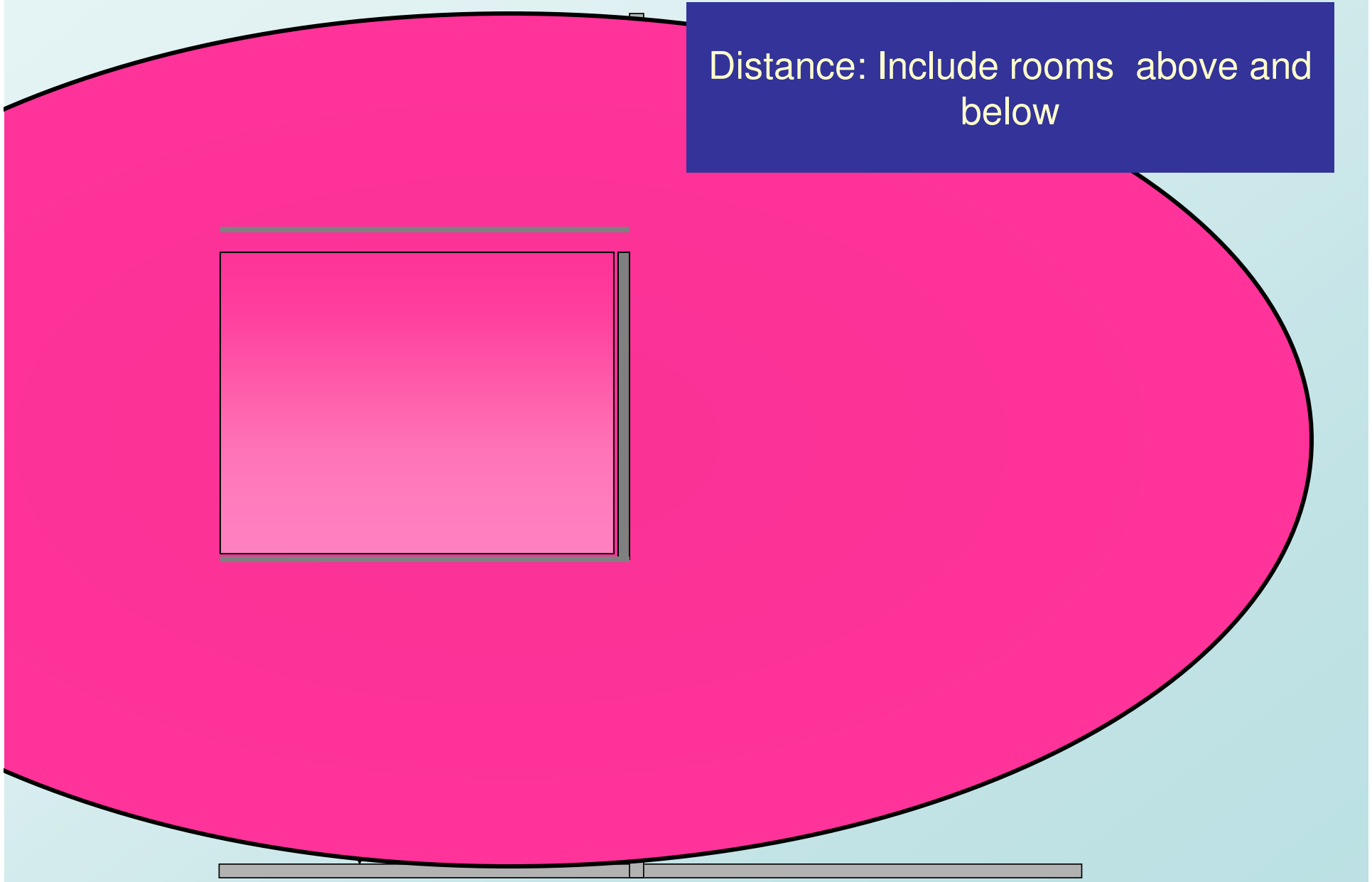
Patient Dose Constant

- Unshielded ^{18}F source constant is 0.143 μSv m^2/MBq h
- Self absorption when distributed in patient.
- Wide variation in measured values reported in published reports.
- Task Group 108 recommends using 0.092 μSv m^2/MBq h

Patient as a source of radioactivity



- The patient associated dose rate depends on:
  - Number of patients
    - **50 patients/week**
  - Administered activity
    - **370 - 740 MBq**
  - Procedure time
    - **Uptake time: 1hour**
    - **Scanning time: 0.5 hour**



Distances to be used in shielding calculations

Parameter	Definition	Formulation
Ao	Administered activity (MBq)	
t	Time (h)	
t_U	Uptake time (h)	
t_I	Imaging time (h)	
$D(t)$	Total dose for time t(μSv)	
$D(0)$	Initial dose rate (μSv/h)	
$T_{1/2}$	Radionuclide half-life (h)	
R_t	Dose reduction factor over time t	$=1.443\times(T_{1/2}/t)\times[1-\exp(-0.693t/T_{1/2})]$
R_{tU}	Dose reduction factor over uptake time time t	$=1.443\times(T_{1/2}/t_U)\times(1-\exp(-0.693t_U/T_{1/2}))$
R_{tI}	Dose reduction factor over imaging time t	$=1.443\times(T_{1/2}/t_I)\times[1-\exp(-0.693t_I/T_{1/2})]$
N_w	Number of patients per week	
d	Distance from source to barrier (m)	
F_U	Uptake time decay factor **(µSv)**	$=\exp[\ -0.693t_U/T_{1/2})]$
T	Occupancy factor	
P	Weekly dose limit **(µSv)**	
	Transmission factor (uptake room)	$=10.9\times P\times d^2/[T\times N_w\times Ao\times t_U(h)\times R_{tU}]$
B	Transmission factor (scanner room)	$=12.8\times P\times d^2/[T\times N_w\times Ao\times F_U\times t_I(h)\times R_{tI}]$

The Equations …

Basic Equation

B = Design Goal Dose/Estimated Dose

Design Goal Dose = P/T

Estimated Dose = Nw Ao t' / K d^2

$$B = K P d^2 / [T Nw Ao t']$$

Basic Equation

$$B = K P d^2 / [T Nw Ao t']$$

For uptake, K = 10.9 and

$$t' = t_U \times RtU$$

For imaging, K = 12.8 and

$$t' = F_U \times t_I \times R_{tI}$$

Barrier Transmission Factor: B

- B represents the factor that the dose rate has to be reduced by:

  B = *Target dose/Actual (estimated) dose
- If B < 1, then shielding is required. No shielding is necessary for B > 1.
- Once B is determined, the appropriate thickness of shielding material can be found from the shielding tables or graphs.

*Target dose = Regulatory dose limit modified by occupancy factor

$$B = K P d^2 / [T Nw Ao t']$$

Units constant: K

K is a constant that depends on the units used. When the units are expressed using those in Table VI from the Task Group report,

K = 10.9 for uptake room calculations and

K = 12.8 for imaging room calculations.

$$B = K P d^2 / [T Nw Ao t']$$

Weekly dose limit: P

- The weekly dose limit is set by regulatory agencies.
- It should be expressed in units of μSv.
- The value of P depends on the type of area that is being protected (controlled or uncontrolled), the regulatory limits and whether additional ALARA factors are included.

$$B = K P d^2 / [T Nw Ao t']$$

P values based on NRC 10CFR20.1201 & 10CFR20.1301

Occupational:	1000 μSv/week
ALARA (typical):	100 μSv/week
Public:	20 μSv/week

Occupancy Factors: T

- The occupancy factor, T, is a dimensionless number that reflects that people are unlikely to remain in certain areas for extended periods of time.
- Standard occupancy factors are taken from NCRP Report #147.
- Target dose = P/T

$$B = K P d^2 / [T Nw Ao t']$$

NCRP 147 Occupancy Factors

TABLE 4.1—*Suggested occupancy factors*[a] *(for use as a guide in planning shielding where other occupancy data are not available).*

Location	Occupancy Factor (T)
Administrative or clerical offices; laboratories, pharmacies and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent x-ray rooms, film reading areas, nurse's stations, x-ray control rooms	1
Rooms used for patient examinations and treatments	0.5
Corridors, patient rooms, employee lounges, staff rest rooms	0.2
Corridor doors[b]	0.125
Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, patient holding areas	0.05
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), attics, stairways, unattended elevators, janitor's closets	0.02

Administered Activity: Ao

- Typical 555 MBq (370-740 MBq)
- Patient age
  - Pediatric activity: 4–5 MBq/ kg.
- Body habitus
  - Increasing activity generally NOT beneficial for large patients.
- Type of scanner
  - BGO scanners operating in 3D have activity constraints
  - Should plan for future upgrades

$$B = K P d^2 / [T Nw Ao t']$$

Patients per week: Nw

- The number of patients per week depends on the referral load to the facility, the health status of the patients and the throughput capability of the equipment.
- Current PET/CT systems can easily handle 12 patients/ 8 hour day. PET-only systems can handle 8 patients/8 hour day.

$$B = K P d^2 / [T Nw Ao t']$$

Decay Corrected Exposure Times: t'

- Uptake (t_U)
  - Patients are kept at rest for 30-60 minutes prior to imaging.
- Imaging (t_I)
  - Patients are in the scanner room for 15-30 minutes.
- Consultation?
  - Patients are usually released after the PET study is completed. If they are routinely kept in the clinic for any reason, this has to be included in the shielding design plan.

$$B = K P d^2 / [T Nw Ao t']$$

Timing: Decay Factors

- Decay related reductions
  - R_{tU} (Uptake decay factor)
    - **$1.443 \times T_{1/2}/t_U \times [1-\exp(-0.693\ t_U/T_{1/2})]$**
  - F_U (Remaining fraction post uptake)
    - **$\exp(-0.693\ t_U/T_{1/2})]$**
  - R_{tI} (Imaging decay factor)
    - **$1.443 \times T_{1/2}/t_I \times [1-\exp(-0.693\ t_I/T_{1/2})]$**

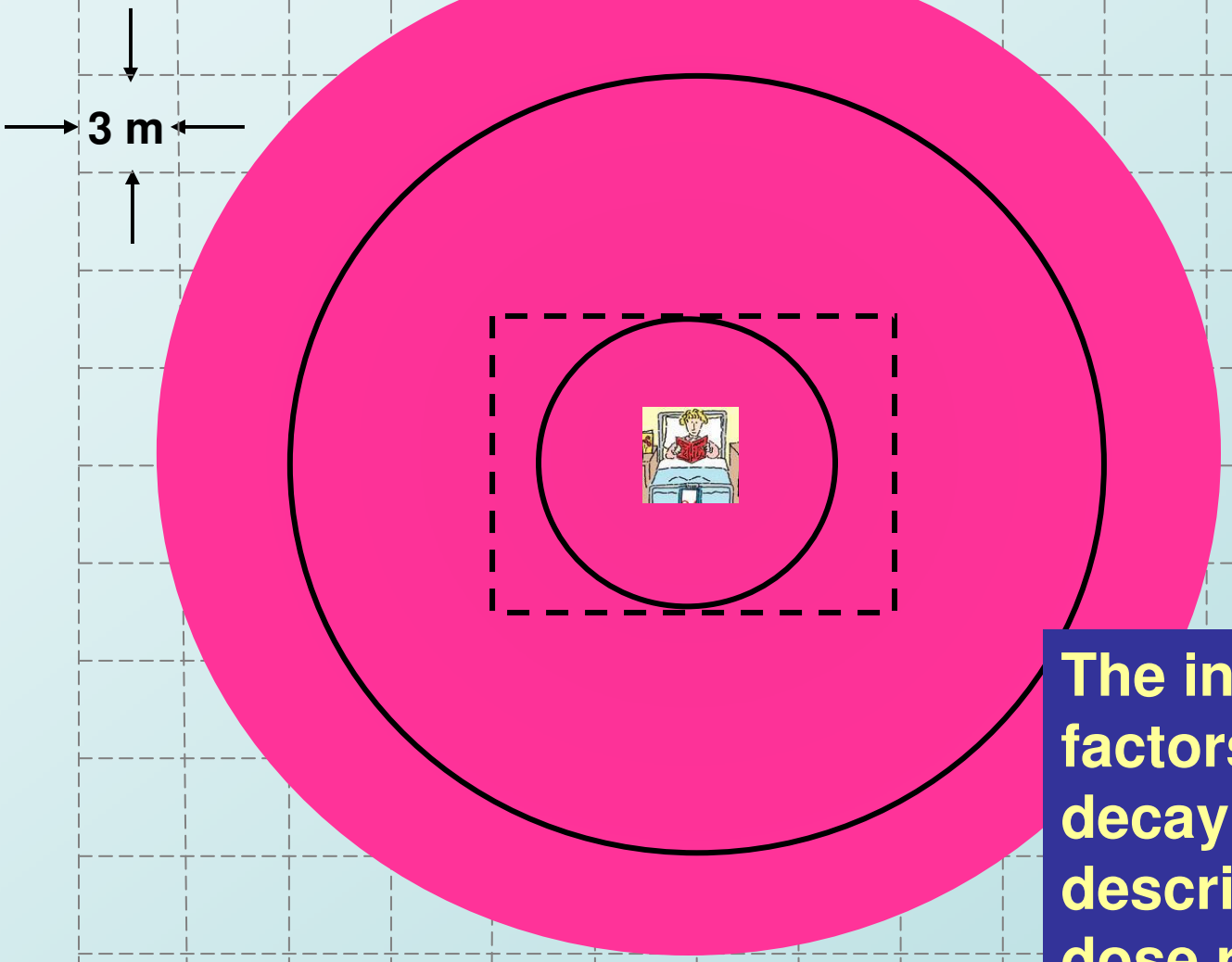
Typical decay related factors

- R_{tU} = 0.83 (t_U = 60 minutes)
  - Accounts for decay during t_U
- F_U = 0.68 (t_U = 60 minutes)
  - Activity decay to start of imaging
- R_{tI} = 0.91 (t_I = 30 minutes)

  R_{tI} = 0.95 (t_I = 15 minutes)

  Accounts for decay during t_I

Timing Considerations Included from Task Group 108



ALARA Distance: 4 meters

Uncontrolled Area Distance: 12 meters

The inclusion of factors for radioactive decay more accurately describes the actual dose rate from patients.

Patient Voiding

- Patients typically eliminate at least 15% of the remaining activity from their bladder when they void after the uptake period.
- Note: A bathroom should be available within the immediate PET facility. Problems are often encountered when a radioactive PET patient walks through a nuclear medicine clinic.

Distance: d

- The distance, d, is measured from the source (patient) to the point of interest and is expressed in meters.
- Because the intensity of the annihilation radiation falls as the square of the distance, maintaining large distances from uncontrolled areas is a good design practice.

$$B = K P d^2 / [T Nw Ao t']$$

Shielding Transmission Factors

- Shielding information is available in the scientific literature, but …
  - Variability among authors
  - Insufficient methodological information
- Task Group 108 relied on the Monte Carlo calculations of Doug Simpkin.
  - Mathematical model is known
  - All calculations were performed consistently

Parameters for Archer Equation

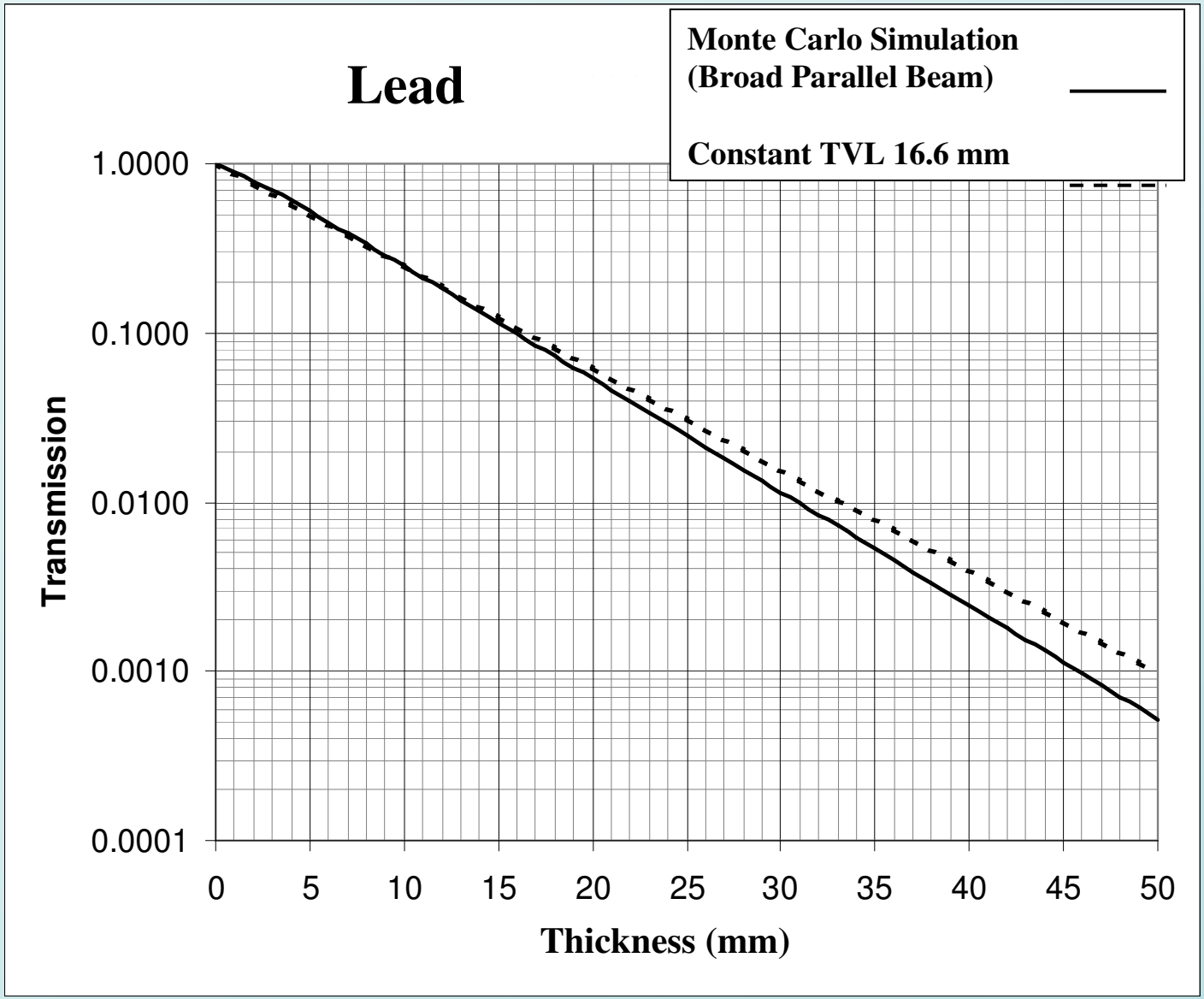
TABLE V. Fitting parameter for broad beam 511 keV transmission data.

Shielding material	$\alpha(\mathrm{cm}^{-1})$	$\beta(\mathrm{cm}^{-1})$	γ
Lead	1.543	–0.4408	2.136
Concrete	0.1539	–0.1161	2.0752
Iron	0.5704	–0.3063	0.6326

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

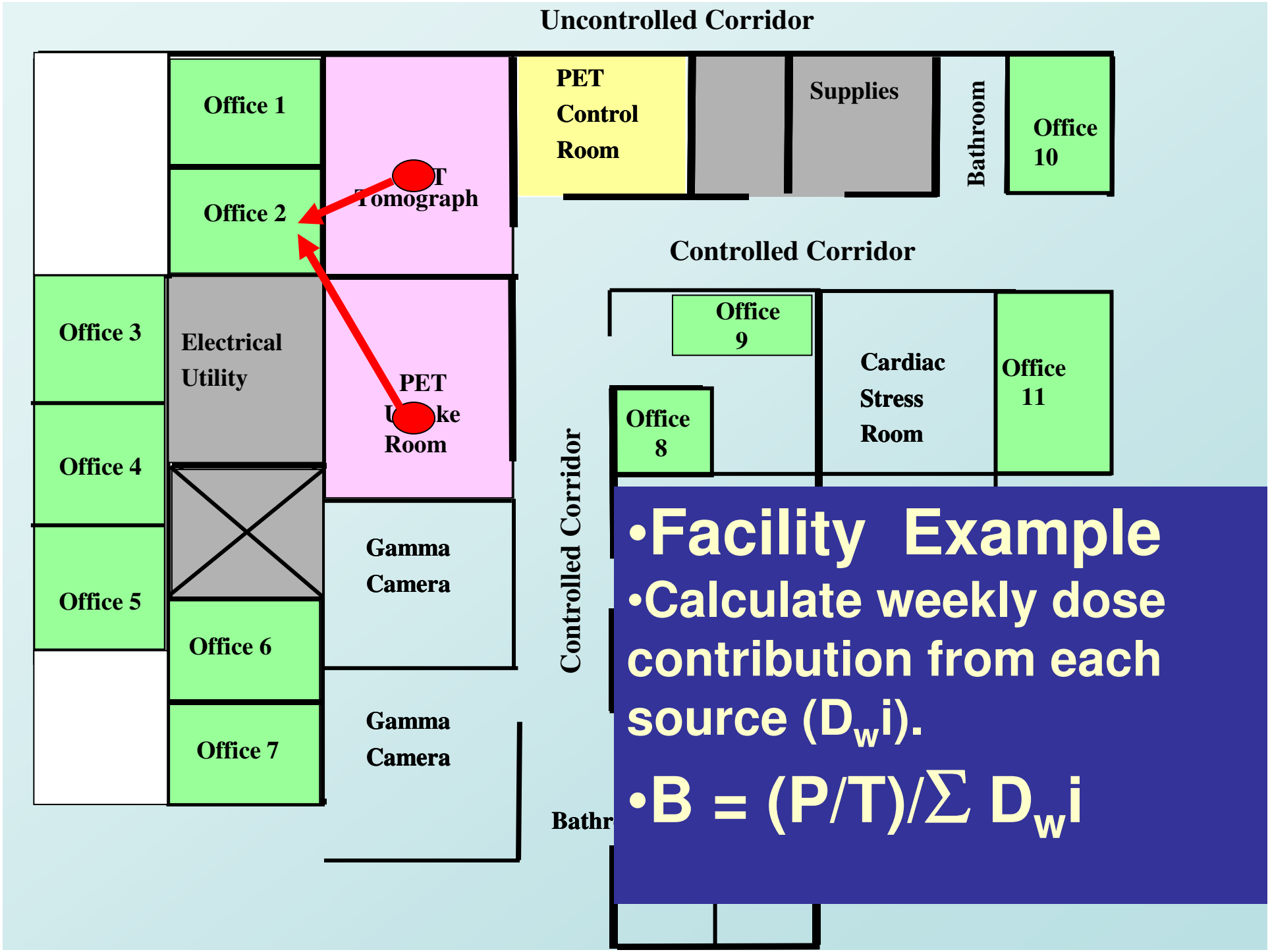
$$x = \frac{1}{\alpha\gamma}\ln\left(\frac{B^{-\gamma}+\frac{\beta}{\alpha}}{1+\frac{\beta}{\alpha}}\right)$$

Lead Transmission Factors



Example calculations

1. Uptake room
2. Scanner room
3. Facility example
4. Rooms above and
5. below the PET facility
6. Control room
7. Nearby gamma cameras


Uncontrolled Corridor
Office 1
Office 2
PET Tomograph
PET Control Room
Supplies
Bathroom
Office 10
Controlled Corridor
Office 3
Electrical Utility
PET Uptake Room
Office 9
Cardiac Stress Room
Office 11
Office 4
Office 8
Office 5
Office 6
Gamma Camera
Controlled Corridor
Office 7
Gamma Camera
Bathr
•Facility Example
•Calculate weekly dose contribution from each source ($D_w i$).
•$B = (P/T)/\Sigma D_w i$

Facility Approach

- Calculate weekly dose (Dw) from each source (i). (i denotes uptake or scanner).
  - $\mathbf{Dw_i = Nw\ Ao\ t_i' / K_i\ d_i^2}$
- Determine the total barrier thickness from $\mathbf{B = (P/T)/\Sigma\ Dw_i}$.
- Spread the lead out over as many walls as possible.
- Recheck the calculation to confirm that radiation levels comply with regulations.

Table VII: Facility Example

TABLE VII. Sample calculation for a dedicated PET Facility (Fig. 4). This calculation is based on the following assumptions: 40 patients per week, 555 MBq administration, 1 h uptake, and 30 min imaging time. Transmission data are measured with sources built into the camera that do not significantly increase the exposure of personnel.

	Uptake distance	Tomograph distance	Weekly target dose	Occupancy	Weekly uptake	Weekly tomograph	Total[a]	Transmission
Room	(m)	(m)	(uSv)	Factor	Dose(uSv)	Dose(uSv)	Dose(uSv)	Factor
Office 1	8	3	20	1	27.1	70.1	97.2	0.206
Office 2	6	3	20	1	48. 7	70.1	118.8	0.169
Office 3	8	7	20	1	27.1	12.9	40	0.500
Office 4	8.5	9	20	1	24	7.8	31.8	0.629
Office 5	8.5	11	20	1	24	5.2	29.2	0.685
Office 6	9.5	13	20	1	19.2	3.7	22.9	0.872
Office 7	12	15	20	1	12	2.8	14.8	[b]
Office 8	7	8	20	1	35.4	9.9	45.3	0.442
Office 9	9	9	20	1	21.4	7.8	29.2	0.685
Corridor 1	2.5	2.5	100	0.25	277.8	101	378.8	[b]
Corridor 2	9	4	20	0.25	21.6	39.6	60.2	[b]
PET Control Room	9	2.5	100	1	21.4	101	122.4	0.817
Gamma Camera	3	10	100	1	192.7	6.3	199	0.503

CT Barrier Transmission using NCRP #147

$$B = \frac{P d^2}{T N_W K_S^1}$$

$$K_S^1 = \kappa \frac{L}{p} mAs \, CTDI_{100}^n$$

κ_{head} = 9 x 10^{-5} cm^{-1}

κ_{body} = 3 x 10^{-4} cm^{-1}

- **P** is weekly regulatory limit (µGy).
- **d** is the distance in meters from the CT scanner to the protection area.
- **T** is the occupancy factor.
- **N_W** is the number of patients scanned per week.

SUMMARY AND CONCLUSIONS

- Calculations need to focus on who (or what) needs protection, what studies will be done, numbers of patients and the design of the facility.
- Careful planning with the equipment vendor, facility architect, and a qualified medical physicist is necessary to produce a cost effective design while maintaining radiation safety standards.