

Shielding techniques Summer School 2007

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Variables

- Primary
- Scatter
- Leakage
- Distance
- Occupancy
- Usage factor for barrier
- Workload

Single projection

- Scatter will not be isotropic
- But scatter is always predictable as a function of energy, angle and area

Techniques

- First principles- back of the envelope
- NCRP 147

Cardiac cath example From NCRP 147

- 160 mAs/patient
- Area of II=730 cm² (30.5 cm diameter)
- Distance of II = 0.9 m
- Stray radiation @ 1m =3.8 mGy/patient
- Scatter angle =135 degrees
- 25 patients/week
- Barrier @ 4m

Primary

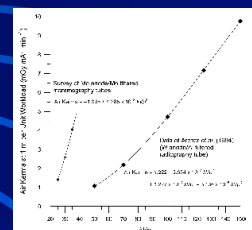
• Primary -rule of thumb

- 100 kVp 10 mR/mAs @ 1m

- mR at distance d

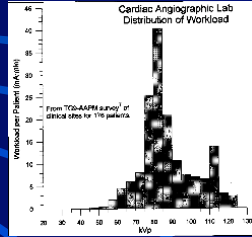
$$=10 * \text{mAs} * ((100/\text{kVp})^2) * (1/d)^2$$

NCRP 147



NCRP 147 assumption

- **Envelope**
- **Primary**
- Use 82 kVp - to get appropriate scatter



Cardiac cath example From NCRP 147 More assumptions

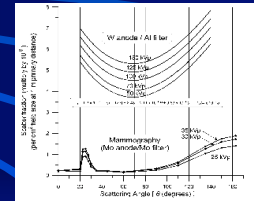
- 82 kVp
- Patient at 46 cms from tube

Results Patient dose

- | | |
|-----------------------|-----------------------|
| • Envelope | • NCRP 147 |
| • 286 R | • 237 R |
| • 2.49 Gy (air kerma) | • 2.06 Gy (air kerma) |

Results Patient Scatter @ 1m NCRP 147

- Envelope
- Rule of thumb
- Patient dose /1000



Results Patient Scatter @ 1m

- | | |
|--------------------------|-----------------------|
| • Envelope | • NCRP 147 |
| • 1/1000 of patient dose | • 135 degrees scatter |
| • 286 mR | • 422 mR |
| • 2.49 mGy | • 3.7 mGy |

Scatter

- The NCRP 147 approach uses a conservative backscatter assumption

Results Patient Scatter @ 1m

- | | |
|--|--|
| <ul style="list-style-type: none"> • Envelope • 1/1000 • 286 mR • 2.49 mGy | <ul style="list-style-type: none"> • NCRP 147 • 90 degrees • 293 mR • 2.55 mGy |
|--|--|

Attenuation options

- Both approaches reduce the radiation by the same factor (1/16) for distance (4m)

Scatter at 4m for 25 patients/week

- | | |
|---|--|
| <ul style="list-style-type: none"> • Envelope • 3.88 mGy /week • 447 mR/week | <ul style="list-style-type: none"> • NCRP 147 • 5.74 mGy/week • 660 mR/week |
|---|--|

Required attenuation to get 0.02 mGy beyond barrier

- | | |
|--|--|
| <ul style="list-style-type: none"> • Envelope • 5.15×10^{-3} | <ul style="list-style-type: none"> • NCRP 147 • 3.49×10^{-3} for 135 degree scatter
or
5.2×10^{-3} for 90 degree scatter |
|--|--|

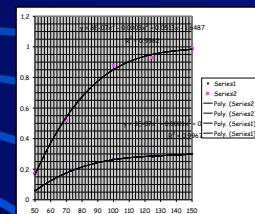
Attenuation options

- | | |
|---|---|
| <ul style="list-style-type: none"> • Envelope • HVL's • TVL's • Attenuation curves (NCRP 49 NCRP 147) | <ul style="list-style-type: none"> • NCRP 147 • Curve Fig c2 • Archer equation |
|---|---|

HVL and TVL s

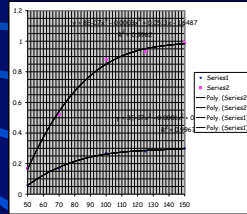
At 82 kVp from NCRP 49

- HVL for lead = 0.23 mms
- TVL for lead = 0.7 mms



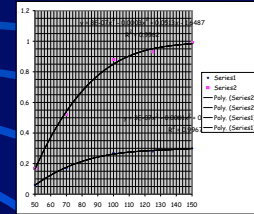
HVL and TVL s

- HVL
- attenuation (B) = $(1/2)^n$
- $n = 3.32 * \log(1/B)$
- TVL
- attenuation = $(0.1)^n$
- $n = \log(1/B)$
- $B = 5.15^{-3}$



HVL and TVL s

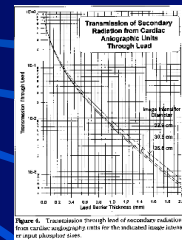
- # of HVLs = $7.6 * 0.23$
- = 1.75 mm of lead
- # of TVLs = $2.3 * 7$
- = 1.61 mm of lead



NCRP 147

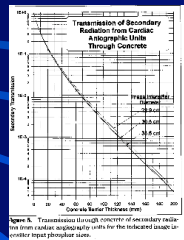
Transmission through lead

- Using Simpkin curve



Transmission through concrete

- Using Simpkin curve



Transmission curve factors

Table 4
Fitting Parameters for Secondary Transmission Curves for Cardiac Angiographic Units

Material	Image Interfilter Diameter (cm)								
	22.9			30.5			35.6		
	α (mm ⁻¹)	β (mm ⁻²)	γ	α (mm ⁻¹)	β (mm ⁻²)	γ	α (mm ⁻¹)	β (mm ⁻²)	γ
Lead	2.384	15.80	0.8727	2.387	15.48	0.7325	2.405	15.33	0.7067
Concrete	0.03749	0.1092	0.8083	0.03749	0.1097	0.5851	0.03749	0.1099	0.5502

Note - In using these parameters with ECUST on (6), enter the thickness (x) in millimeters. See Figures 4 and 5 for graphs of these transmission curves.

NCRP 147 results

Curve Fig c2 = 1.35 mms
Archer equation = 1.35 mms

Attenuation options

- **Envelope**
 - HVL=1.75 mm
 - TVL= 1.61 mm
 - NCRP 49 (100 kVp)
attenuation=0.8 mm
 - NCRP 147
(cardiac)=1.2 mm
- **NCRP 147**
 - Curve Fig c2 = 1.35 mms
 - Archer equation = 1.35 mms

Result

- Apart from the HVL and TVL estimates rounding up to commercially available thicknesses gives 1/16 inch of lead for the shield thickness

NCRP 147

- Fast and easy

The NCRP 147 quick way(1)

- Assumption
Stray radiation is 3.8 mGy /exam @ 1m

The NCRP 147 quick way(1)

- Scatter at barrier at 4m
=3.8mGy/patient*25patients per week/4^2

The NCRP 147 quick way(1)

- Scatter at barrier at 4m
= $3.8 \text{ mGy/patient} * 25 \text{ patients per week} / 4^2$
- = 5.9 mGy/week at the barrier
- (compared to 5.74 mGy we got before)

The NCRP 147 quick way(1)

- Scatter at barrier at 4m
= $3.8 \text{ mGy/patient} * 25 \text{ patients per week} / 4^2$
- = 5.9 mGy/week at the barrier
- Attenuation required = $0.02 / 5.9 = 3.4 \times 10^{-3}$
- (3.5×10^{-3} before)

The NCRP 147 quick way(1)

- Scatter at barrier at 4m
= $3.8 \text{ mGy/patient} * 25 \text{ patients per week} / 4^2$
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- From curve 1.3 mm Pb
- From Archer 1.3 mm Pb

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- = 5.9 mGy/week at the barrier
- Attenuation required = $0.02 / 5.9 = 3.4 \times 10^{-3}$
- From curve 1.3 mm
- From Archer 1.3 mm
- Gives 1/16 inch of lead--again

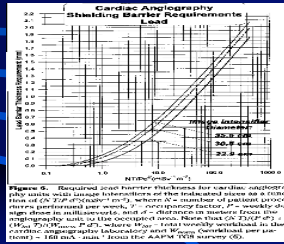
The NCRP 147 quick way(2)

- NT/Pd^2

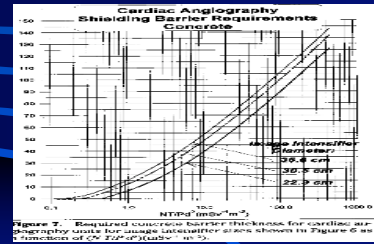
The NCRP 147 quick way(2)

- NT/Pd^2
- $N=25 \quad T=1 \quad P=.02 \text{ mGy} \quad d=4 \text{ m}$
- $NT/Pd^2 = 78.1$

Transmission through lead



Transmission through concrete



The NCRP 147 quick way(2)

- NT/Pd^2
- $N=25$ $T=1$ $P=.02$ mGy $d=4$ m
- $NT/Pd^2 = 78.1$
- From curve thickness of lead = 1.3 mm
- Or rounding up 1/16 inch lead

How effective is 1/16 inch of lead?

- Very

Diagnostic x-ray rooms

- This evaluation was first carried out in 1994 when the exposure limits to the general were lowered from 500 to 100 mR/year
- At that time only TLD were readily available for long-term monitoring with a lower detectable limit of 10 mR

Shielding Investigation

- OSL dosimeters give an order of magnitude increase in sensitivity over TLD
- Dosimeters were exposed in groups of two for eight weeks to minimize spurious results

Optically Stimulated Luminescent Dosimeters

- Range from 1 mR - 1,000 R
- Good long term stability
- Convenient for environmental monitoring

Technique factors

- Technique factors were evaluated by a random sampling over several days
- Room and protective cubicle shielding was confirmed by doing Tc- 99m transmission studies and comparing with known thicknesses of lead sheet.

Rooms

Room1	Dedicated chest	5 days/week
Room 6	General purpose Radiographic room	7 days/week
Room 7	General purpose Radiographic room	7 days/week
Room 5	General purpose R&F room	5 days/week

Dedicated chest room

Location	mR inside	mR outside	% Transmission
Behind chest stand	63-103	0	<1%
Protective cubicle glass	75-103	0	<1%

General purpose Rad room

Location	mR inside	mR outside	% Transmission
Behind chest stand	69-112	0	<1%
Protective cubicle glass	297-414	0	<.3%
Wall inside	319-322	0	<0.3%

General purpose Rad room

Location	mR inside	mR outside	% Transmission
Behind chest stand	43-22	0	<3 %
Protective cubicle glass	97-117	0	<.9%
Wall inside	209-205	0	<0.5%

General purpose R / F room

Location	mR inside	mR outside	% Transmission
Behind chest stand	43-22	0	<3 %
Protective cubicle glass	323-308	0	<.3%
Wall inside	197-192	0	<0.5%
Corridor wall	39-41	0	<2.5%

Conclusion

- All the rooms examined were designed according to NCRP 49 to 10 mR/week with corridor occupancy factor of 0.25 and full occupancy behind protective cubicle

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- The corridor should expect about 320 mR over 8 weeks

Conclusion

- All the rooms examined were designed according to NCRP 49 to 10 mR/week with corridor occupancy factor of 0.25 and full occupancy behind protective cubicle
- Each room actually had 1/16 inch of lead everywhere-except behind the chest stand (1/8 inch)
- The corridor should expect about 320 mR over 8 weeks
- We see less than 1 mR therefore these rooms are overshielded by at least 2 to 3 orders of magnitude



"It started out with lactose, but now he's intolerant of everything."

Mammography

Mammography

- Good news!

Mammography

- Good news!
- If you're in Michigan it's all been done for you



Michigan requirements

• Required shielding (for pre 9/30/99 machines)		• Required shielding (for post 9/30/99 machines)	
• Lead	0.19 mm	• Lead	0.139 mm
• Concrete	23.1 mm	• Concrete	16.6 mm
• Gypsum	60.3 mm	• Gypsum	45.8 mm
• Steel	1.03 mm	• Steel	0.731 mm
• Plate glass	24.5 mm	• Plate glass	17.4 mm
• Wood	389 mms	• Wood	238 mms

Assumptions

• Michigan		• NCRP 147	
• # of patients/week	150	• # of patients/week	80-160
• mAmin/patient	8	• mAmin/patient	6.8
• mAmin/week	1200	• mAmin/week	550-1075
• kVp	23-35	• kVp	23-35
• Occupancy factor	1	• Occupancy factor	1-1/40
• Primary use factor	0.25	• Primary use factor	0
• Secondary use factor	1	• Secondary use factor	1

Assumptions

• Michigan

- Leakage 100mR/hr
- Primary distance(m) 1.5
- Secondary distance(m) 1.5
- Leakage distance(m) 1.5
- SID (m) 0.65
- Beam size) 24x30
- Scatter angle 135

• NCRP 147

- Leakage 0 mR/hr
- Primary distance(m) ?
- Secondary distance(m) ?
- Leakage distance(m) ?
- SID (m) 0.6
- Beam size) 24x30
- Scatter angle 135

NCRP 147

• NCRP 147 calculation for Michigan example

- Only assumption for calculation is that scatter at 1m
= 3.6×10^{-2} mGy /patient

NCRP 147

• NCRP 147 calculation

- Only assumption for calculation is that scatter at 1m
- = 3.6×10^{-2} mGy /patient
- = $3.6 \times 10^{-2} * 150$ mGy/week

NCRP 147

• NCRP 147 calculation

- Only assumption for calculation is that scatter at 1m
- = 3.6×10^{-2} mGy /patient
- = $3.6 \times 10^{-2} * 150$ mGy/week
- = $3.6 \times 10^{-2} * 150 / (1.5)^2$ mGy for barrier at 1.5 m

NCRP 147

• NCRP 147 calculation

- Only assumption for calculation is that scatter at 1m
- = 3.6×10^{-2} mGy /patient
- = $3.6 \times 10^{-2} * 150$ mGy/week
- = $3.6 \times 10^{-2} * 150 / (1.5)^2$ mGy for barrier at 1.5 m
- = 1.6 mGy/week

NCRP 147

• NCRP 147 calculation

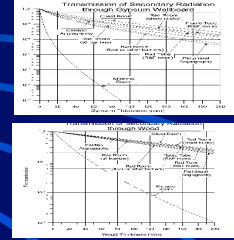
- Only assumption for calculation is that scatter at 1m
- = 3.6×10^{-2} mGy /patient
- = $3.6 \times 10^{-2} * 150$ mGy/week
- = $3.6 \times 10^{-2} * 150 / (1.5)^2$ mGy for barrier at 1.5 m
- = 1.6 mGy/week
- Attenuation = $0.02 / 1.6$

NCRP 147

- NCRP 147 calculation
- Only assumption for calculation is that scatter at 1m
- = 3.6×10^{-2} mGy /patient
- = $3.6 \times 10^{-2} * 150$ mGy/week
- = $3.6 \times 10^{-2} * 150 / (1.5)^2$ mGy for barrier at 1.5 m
- = 1.6 mGy/week
- Attenuation = $0.02 / 1.6$
- = 1.25×10^{-2}

Transmission through wood and sheetrock

- Required transmission is 1.25×10^{-2}



Required shielding

- NCRP 147
- Attenuation factor = 1.25×10^{-2}
- From transmission curve
- Sheetrock = 10 mm
- Wood = 110 mm

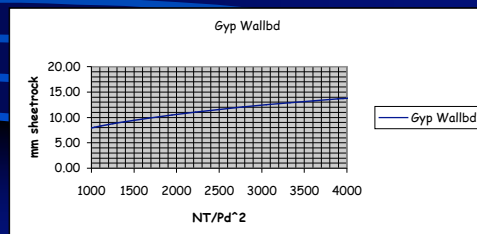
NT/Pd² method

- NCRP 147
- Or using NT/Pd²
- = $(150 * 1) / (0.02 * 1.5^2)$

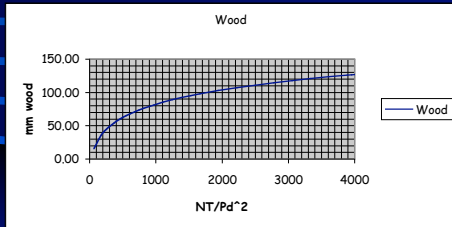
NT/Pd²

- NCRP 147
- Or using NT/Pd²
- = $(150 * 1) / (0.02 * 1.5^2)$
- = 3333 mGy⁻¹ m²

Sheetrock



Wood

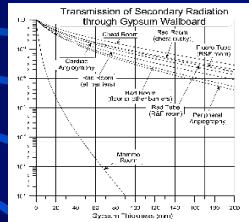


NT/Pd²

- NCRP 147
- Or using NT/Pd²
- = $(150 \cdot 1) / (0.02 \cdot 1.5^2)$
- = 3333 mGy⁻¹ m⁻²
- = 12.9 mms sheetrock
- = 120.8 mm wood

Using Michigan requirements

- Transmission for suggested sheetrock thicknesses
- 45.8 mms ~ $8e-5$
- 60.3 mms ~ $2e-5$
- Compared to $1.25e-2$



Michigan requirements

- These differ by ~ 2 and 3 orders of magnitude respectively

Michigan requirements

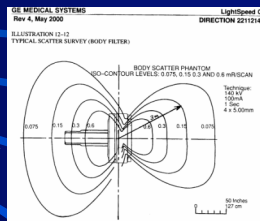
- These differ by ~ 2 and 3 orders of magnitude respectively
- Which would be even more if real room dimensions were used for the NCRP 147 calculations

CT shielding

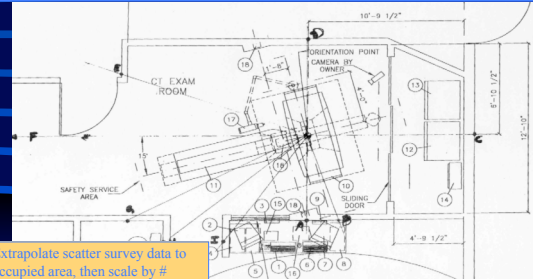
Overview

CT Scanners: Estimate Unshielded Kerma

- Estimate ambient kerma around scanner
 - Manufacturer's isoexposure curves
 - extrapolate using $1/r^2$ from isocenter
 - scale by mAs used clinically vs. for isoexposure curve
 - varies with phantom!



Estimate unshielded kerma around room



CT Shielding

- Due to multiple projection scanning scatter will be generated isotropically
- Modified by the gantry
- So scatter at a distance will be determined by
 - The dose to the patient
 - The length (area or volume) scanned
 - Modified by pitch

CT

- Dose to the patient is related to CTDI (in some form)
- Scatter will depend on the phantom chosen
- So FDA dosimetry phantoms are chosen as standard scattering objects
- And the axis 1 cm from the periphery chosen as the CTDI measurement location

CT

- $CTDI_{vol} = (1/3 CTDI_{100,center} + 2/3 CTDI_{100,periphery})/p$
- Where p is pitch
- $DLP = CTDI_{vol} * \text{length scanned}$
- So scatter is a direct function of DLP

CT

- $CTDI_{vol} = (1/3 CTDI_{100,center} + 2/3 CTDI_{100,periphery})/p$
- For the FDA Body phantom where the central dose is about half of the peripheral dose
- $CTDI_{vol} = (1/6 CTDI_{100,center} + 4/6 CTDI_{100,periphery})/p$
- $= 5/6 CTDI_{100,periphery})/p$
- $CTDI_{100,periphery})/p = 6/5 * CTDI_{vol}$
- $CTDI_{100,periphery} = 1.2 * CTDI_{vol} * p$

CT

- Scatter = constant * DLP for the standard measurements
- Head scatter = constant * DLP
- Body scatter = (some other constant) * DLP


CT

- Head scatter = constant * DLP
Constant = 9×10^{-5} per cm NCRP 147
- = 1.1×10^{-4} per cm Larson (2007)
- Body scatter = other constant * DLP
Constant = 3.0×10^{-4} per cm NCRP 147
- = 5.2×10^{-4} per cm Larson (2007)

CT

- Head scatter = constant * DLP
= Head constant * DLP
- Body scatter = other constant * DLP
- Constant = $1.2 \times$ Body constant * DLP
- if we use $CTDI_{vol}$ to determine DLP

CT Scanner Shielding: Overview

- Estimate unshielded weekly kerma in occupied area near scanner, K_{un}
- Presume P/T
- Barrier requires transmission 
- Get barrier thickness
– Data in NCRP Rept 147 from Simpkin *Health Phys* 58, 363-7; 1990 (refit)

CT Scanners: Estimate Unshielded Kerma

- Estimate Workload
 - Ben Archer (c.1993) guessed that there were ~40 (10 mm thick) slices/patient
 - Helical/multislice scanners: probably more like
 - 20 cm total thickness imaged for head patients
 - 40-60 cm total thickness imaged for body patients
 - $\times 2$ for patients scanned with & without contrast
- 100 - 200 patient/wk typically

Unshielded Kerma from CTDI

- Estimate, for either head or body scans, the ambient kerma per patient around scanner for a slice t (mm) thick generated by N_R rotations each at technique

*mAs*_{Clinical}



Unshielded Kerma from CTDI

- Can recast this in terms of the thickness of each patient imaged, $L = N_R \times t \times pitch$, with each rotation acquired at technique $mAs_{Clinical}$



- or, equivalently, the total imaging time t_{CT} (sec) per patient, with beam width t (mm) per rotation



Unshielded Kerma from DLP

- Since the product of the CTDI used for each patient and the thickness of the patient imaged is the Dose Length Product, DLP , can simplify:



- The DLP values can be read off of the scanner, or from European Commission Guidelines:
 - $DLP = 1,200$ mGy cm for heads
 - $DLP = 550$ mGy cm for bodies

CT Scanner Example

- Wall (or floor, or ceiling) of CT scanner room: $P/T = 0.02$ mGy wk^{-1} , $d=3$ m
- 200 patients wk^{-1} (125 bodies + 75 heads)
- Assume (per NCRP Rept #147)
 - $DLP = 1,200$ mGy cm for each body patient
 - $DLP = 550$ mGy cm for each body patient
- Assume 40% of patients will have scans both pre- and post-contrast medium injection
- Assume 140 kVp operation

CT Scanner Example

The unshielded kerma per head patient at 1 m is:



The unshielded kerma per body patient at 1 m is:



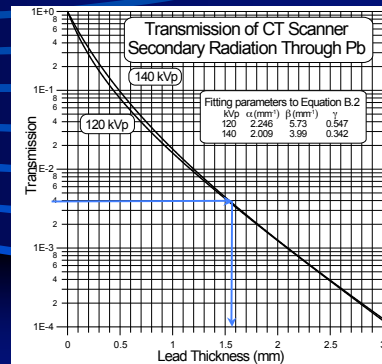
So total unshielded weekly kerma at 1 m is

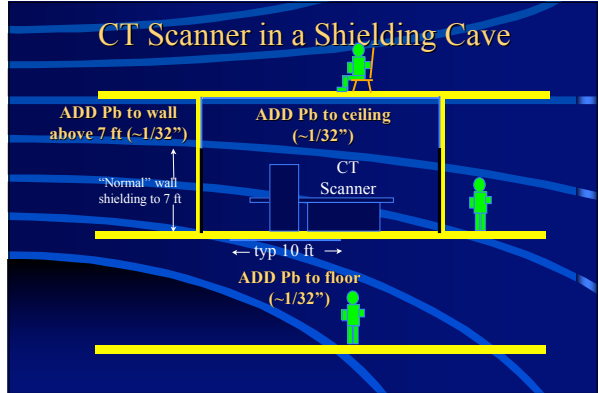
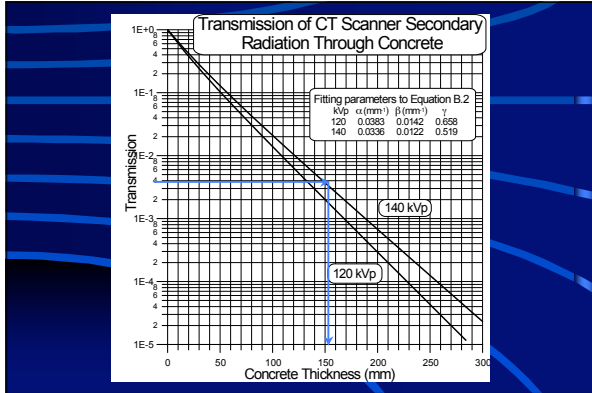
$$K_{un}^1 = 75 \text{ head pat} \times 0.15 \frac{\text{mGy}}{\text{head pat}} + 125 \text{ body pat} \times 0.28 \frac{\text{mGy}}{\text{body pat}} = 46.3 \text{ mGy}$$

CT Scanner Example

- The unshielded weekly kerma at 3 m is
- The transmission required in this wall is therefore
- which, at 140 kVp
 - 1.52 mm Pb,
 - 150 mm = 5.9 inches standard density concrete

WATCH OUT ABOVE & BELOW!





- ### Summary
- NCRP 147 calculations are simple and fast
 - Only a few assumptions are required
 - These can be modified for local circumstances or changes in technology

