Diagnostic X-Ray Shielding

Radiographic / Fluoroscopic Rooms
Multi-Slice CT Rooms
Using NCRP 147 Methodology

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Therapy Physics Inc., Torrance, CA

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Refresher Course
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Acknowledgement

Radiographic / Fluoroscopic Room Slides Courtesy of:

Ben Archer, Ph.D, FACR, FAAPM

Baylor College of Medicine, Houston, TX

Required Information for Shielding Designs

- Architectural drawings of equipment layout in room
- Architectural drawings of surrounding areas indicating usage of these areas - offices, restrooms, corridor, exterior, etc.
- Elevation view of room or construction of floor and ceiling and distance between floors

Nomenclature for Radiation Design Criteria

Required thickness = NT/Pd^2

where:

N = total no. of patients per week

T = Occupancy Factor

P = design goal (mGy/wk)

d = distance to occupied area (m)

Shielding Design Goal (Air Kerma):

Uncontrolled Areas

Annual: P = 1 mGy per year
Weekly: P = 0.02 mGy per week

Controlled Areas

Annual: P = 5 mGy per year
Weekly: P = 0.1 mGy per week

New Formalism for Radiation Design Criteria

Required thickness = NT/Pd^2

where:

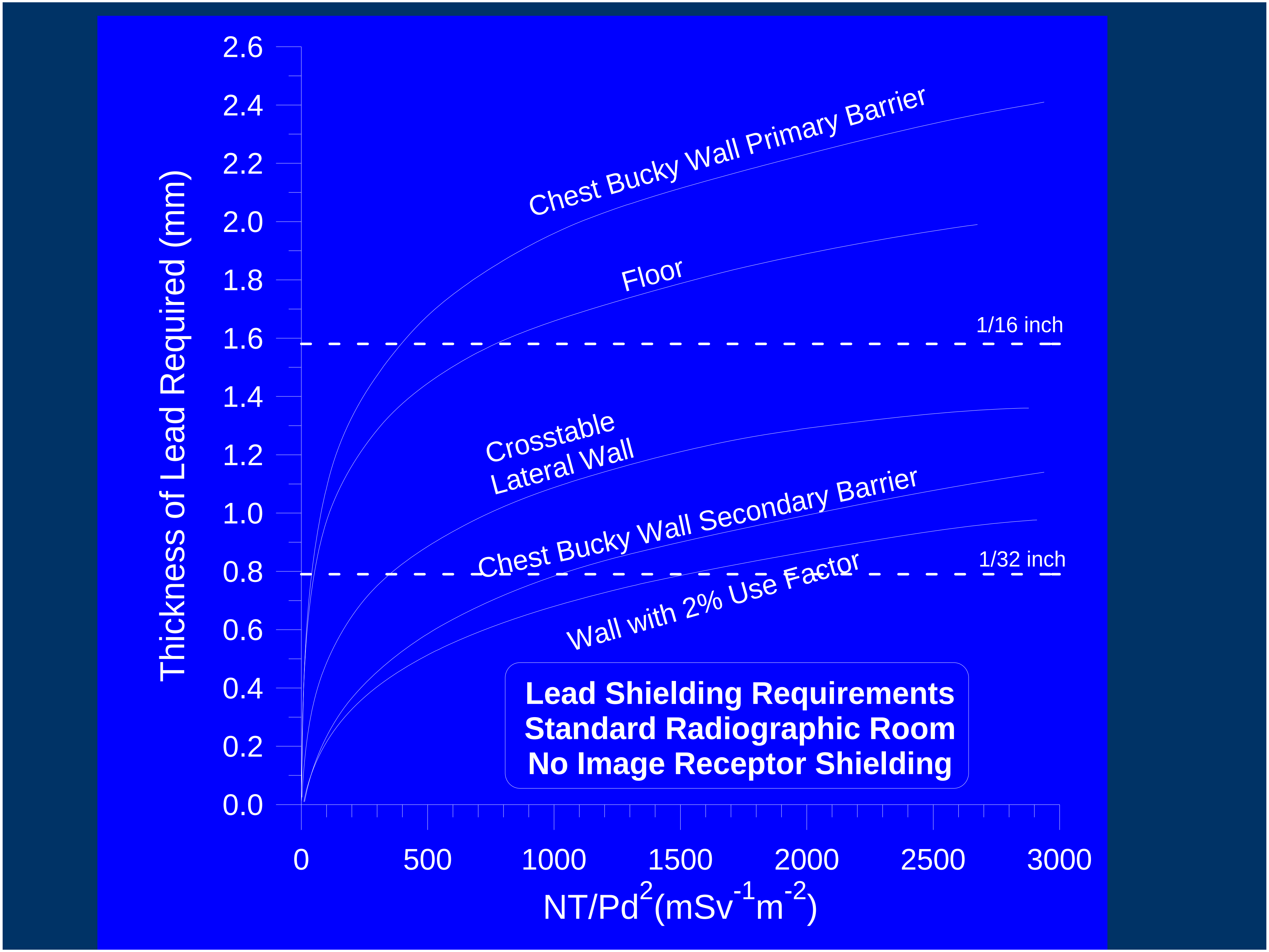
N = total no. of patients per week

T = Occupancy Factor

P = design goal (mGy/wk)

d = distance to occupied area (m)

Easy to use graphs for R and RF rooms developed by Simpkin are included in Report.


Chest Bucky Wall Primary Barrier
Floor
1/16 inch
Crosstable
Lateral Wall
Chest Bucky Wall Secondary Barrier
1/32 inch
Wall with 2% Use Factor
Lead Shielding Requirements
Standard Radiographic Room
No Image Receptor Shielding
Thickness of Lead Required (mm)
NT/Pd2(mSv-1m-2)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
0
500
1000
1500
2000
2500
3000

Shielding Design Goal (Air Kerma):

Uncontrolled Areas

Annual: P = 1 mGy per year

Weekly: P = 0.02 mGy per week

Controlled Areas

Annual: P = 5 mGy per year

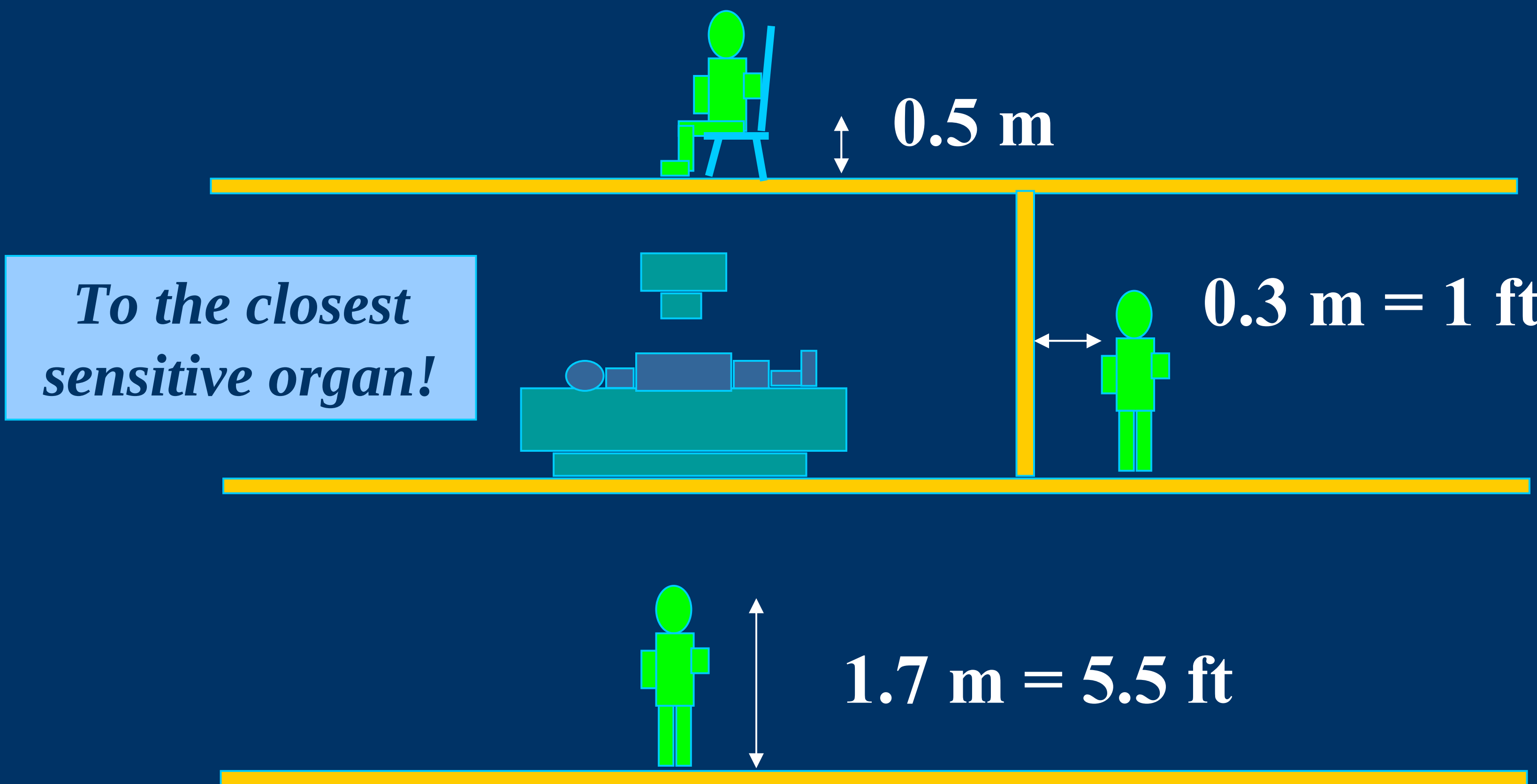
Weekly: P = 0.1 mGy per week

Distance (d)

The distance in meters from either the primary or secondary radiation source to the occupied area.

New recommendations in Report 147 for areas above and below source.

Where in the occupied area do you calculate the dose?



Recommended Occupancy Factors for Uncontrolled Areas:

T=1 Clerical offices, labs, fully occupied work areas, kids' play areas, receptionist areas, film reading areas, attended waiting rooms, adjacent x-ray rooms, nurses' stations, x- ray control rooms

T=1/2 Rooms used for patient examinations and treatments

T=1/5 corridors, patient rooms, employee lounges, staff rest rooms

T=1/8 **corridor doors**

Recommended Occupancy Factors for Uncontrolled Areas:

T=1/20 public toilets, vending areas, storage rooms, outdoor area with seating, unattended waiting rooms, patient holding areas

T=1/40 minimal occupancy areas; transient traffic, attics, unattended parking lots, stairways, janitor's closets, unattended elevators

Pre-shielding *(x_{pre})* for Radiographic Room Workload Distributions

(Dixon RL, Med Phys 1994)

Grid + cassette: (cross table)

Equivalent to: 0.3 mm Pb

or 3 cm concrete

Grid + cassette + table/chest bucky supports: (over table and chest)

Equivalent to: 0.85 mm Pb

or 7.2 cm concrete

Equivalency of Shielding Materials

Table 4.8 Page 67

Steel thickness requirement:

8 × Pb thickness requirement

Gypsum wallboard thickness requirement:

3.2 × concrete thickness requirement

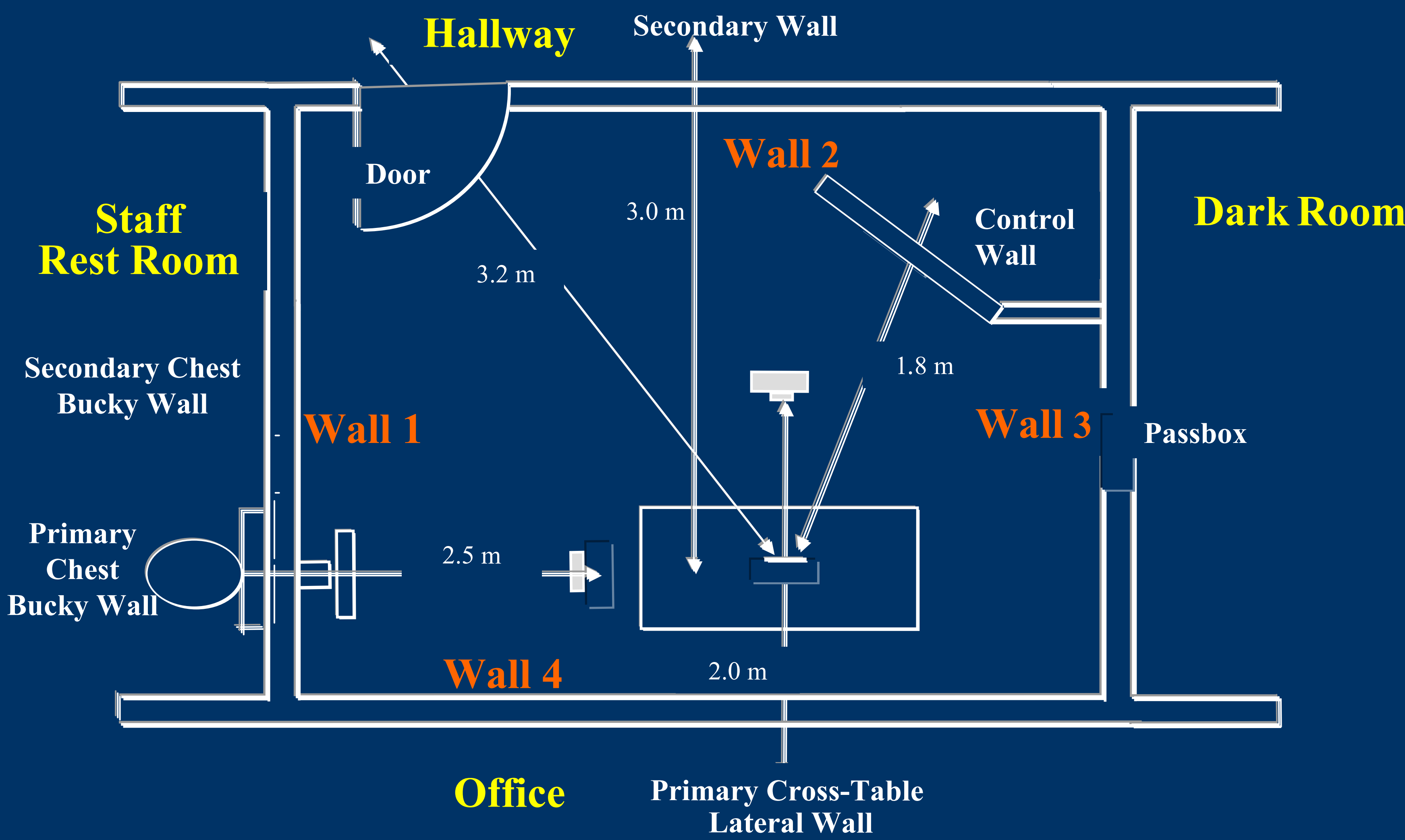
Plate Glass thickness requirement:

1.2 × concrete thickness requirement

Light-weight concrete thickness requirement:

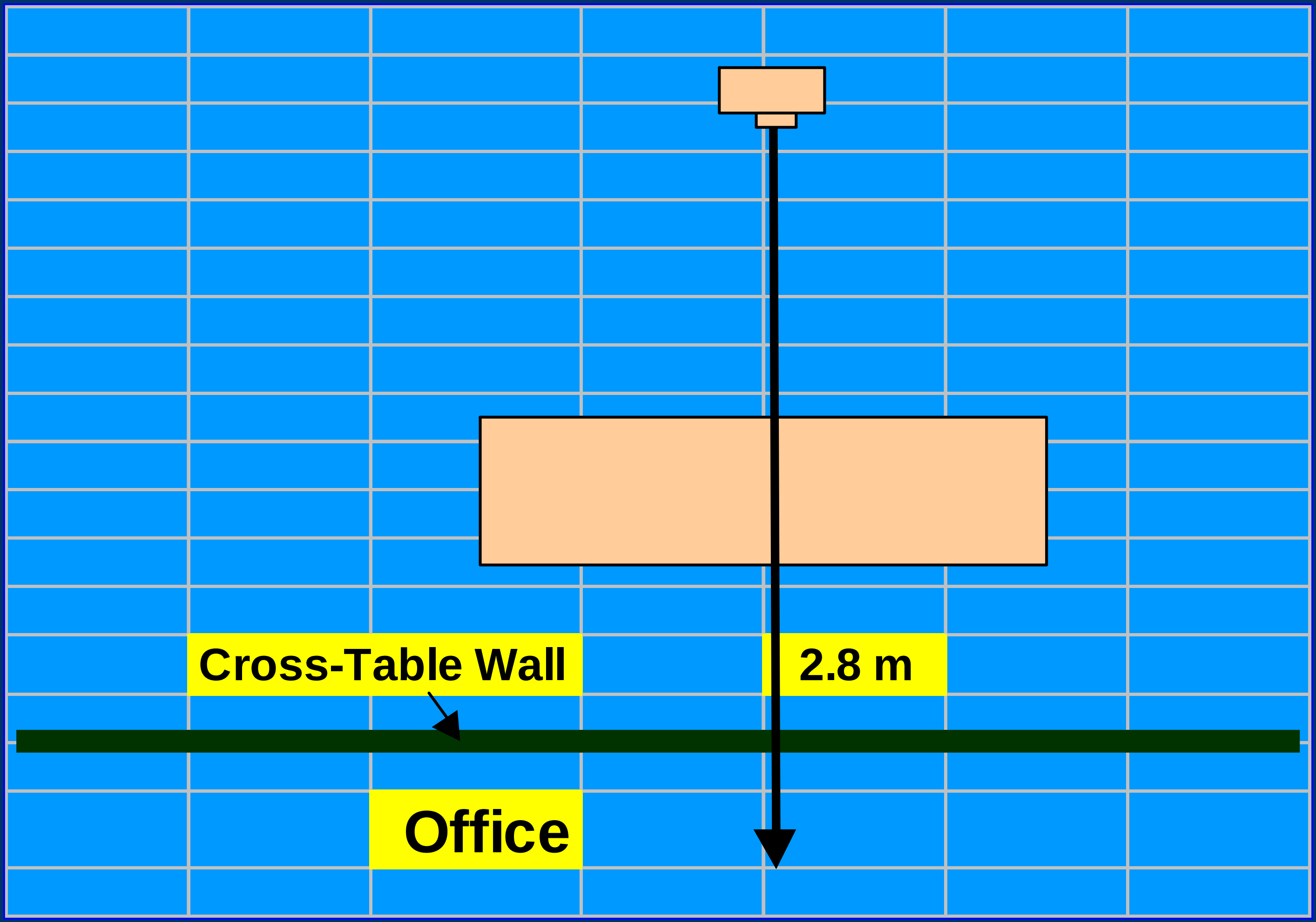
1.3 × std-weight concrete thickness requirement

Figure 5.2 Radiographic Room page 75



PRIMARY BARRIER

Cross-Table Wall in Rad Room



Simplified Graphical Solution

Cross-Table Wall in Rad Room

Required thickness ► NT/Pd^2

where:

N = 125 patients/ week

T = 1

P = 0.02 mGy/wk

d = 2.8 m

$$NT/Pd^2 = 797\ mGy^{-1}\ m^{-2}$$

Simplified Graphical Solution

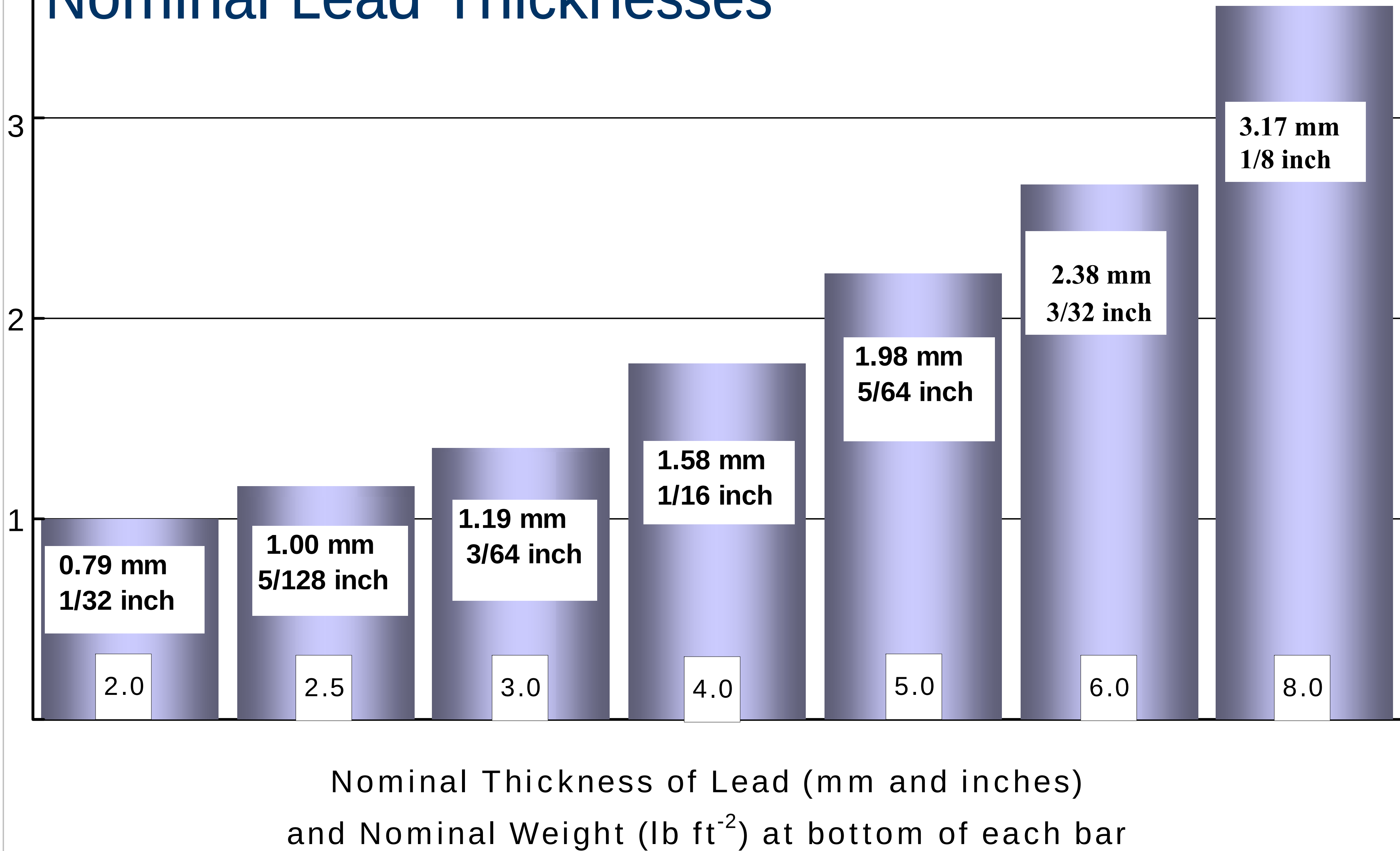
Cross-Table Wall in Rad Room

1. Go to page 54, Fig. 4.5a (Primary, lead, with no pre-shielding)
2. Look up $NT/Pd^2 = 797$ (Cross-table Wall)

Pb required = 1.03 mm

Specify: 4/64” (1/16”); 4 lb/sqft

Nominal Lead Thicknesses



Simplified Graphical Solution

Cross-Table Wall in Rad Room

OR

1. **Go to page 55, Fig. 4.5b (Primary, lead, with pre-shielding)**
2. **Look up $NT/Pd^2 = 797$ (Cross-table Wall)**

Pb required = 0.83 mm

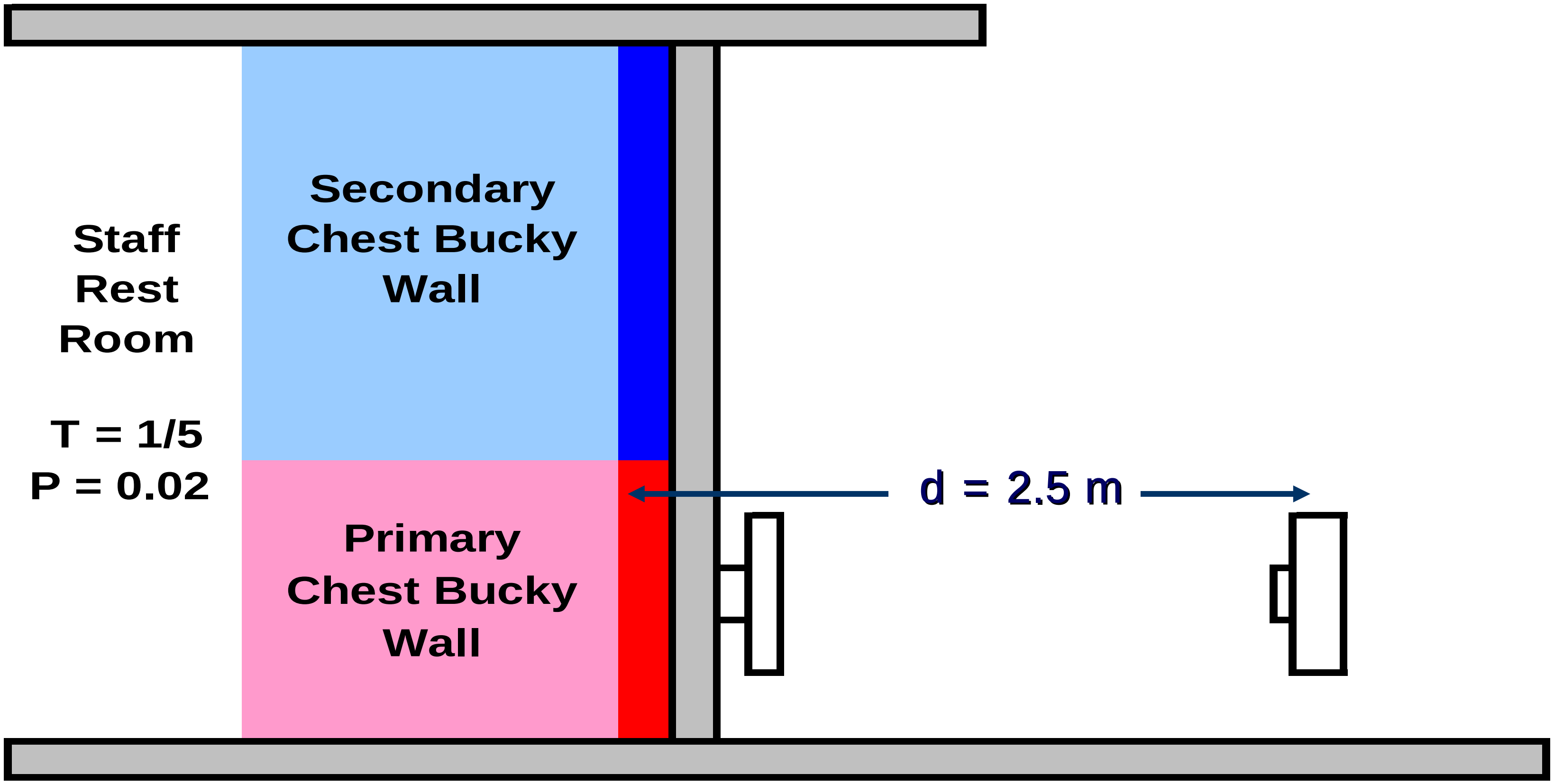
Specify: 5/128”; 2.5 lb/sqft (minimum)

Recommended: 1/16”; 4 lb/sq ft

NCRP 49– Calculated Requirements for Cross-Table Lateral Wall in Radiographic Room

Using the NCRP 49 attenuation data and recommendations of W = 1000 mA-min per wk, U = ¼, T=1, the new dose limit of P = 0.02 mGy (0.002 R) per wk, and assuming all exposures are made at 100 kVp, the required barrier thickness is 2.6 mm Pb (1/8 in. or 8 lbs per sq ft).

Wall Containing Chest Image Receptor
Rad Room



Wall Containing Chest Image Receptor

Chest Receptor Wall

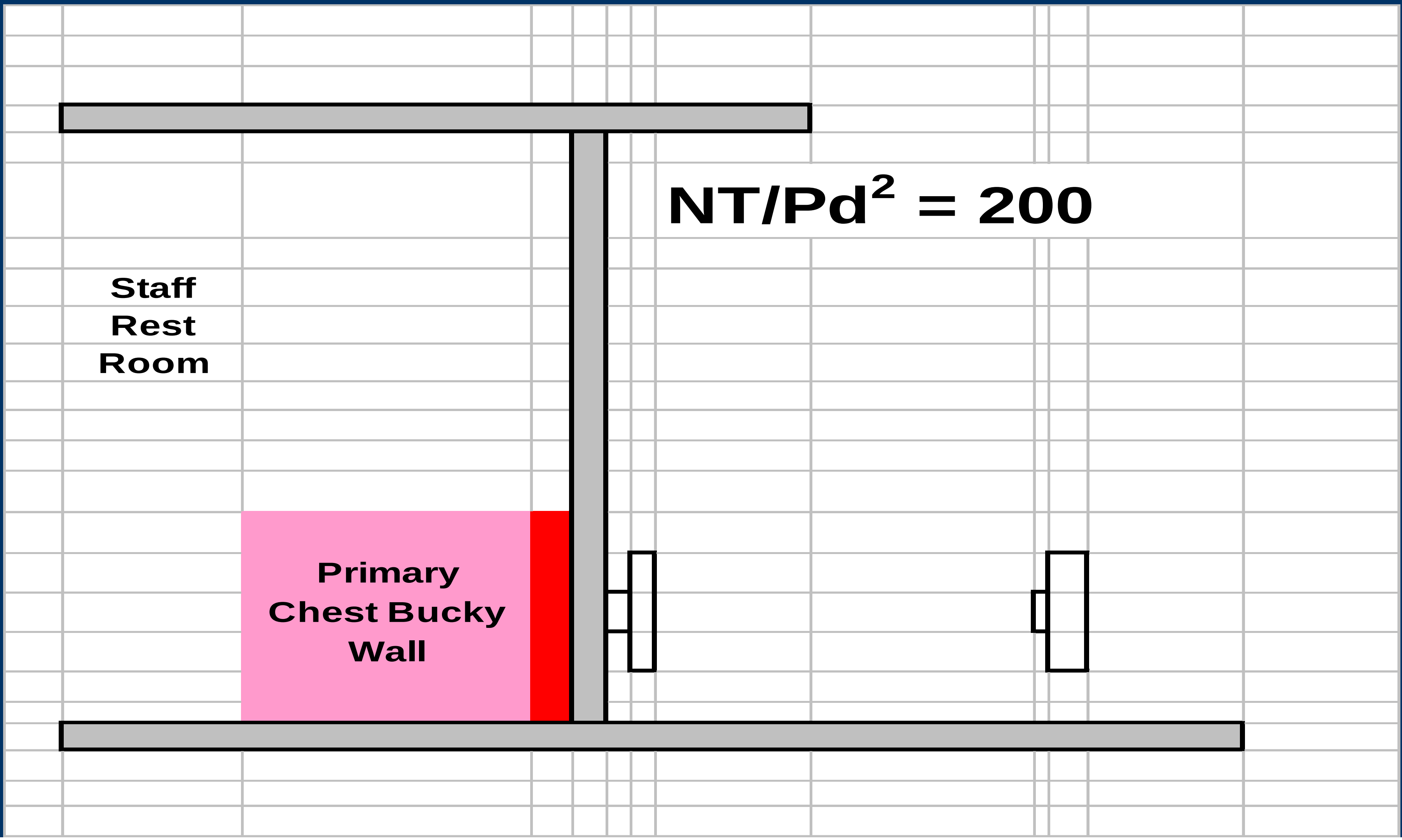
- Required thickness ⇨ NT/Pd^2

  where:
- N = 125 patients/ week
- T = 1/5 (staff rest room)
- P = 0.02 mGy/wk
- d = 2.5 m

- $NT/Pd^2 = 200\ mGy^{-1}\ m^{-2}$

Wall Containing Chest Image Receptor

Primary Barrier- Chest Receptor Area



Wall Containing Chest Image Receptor

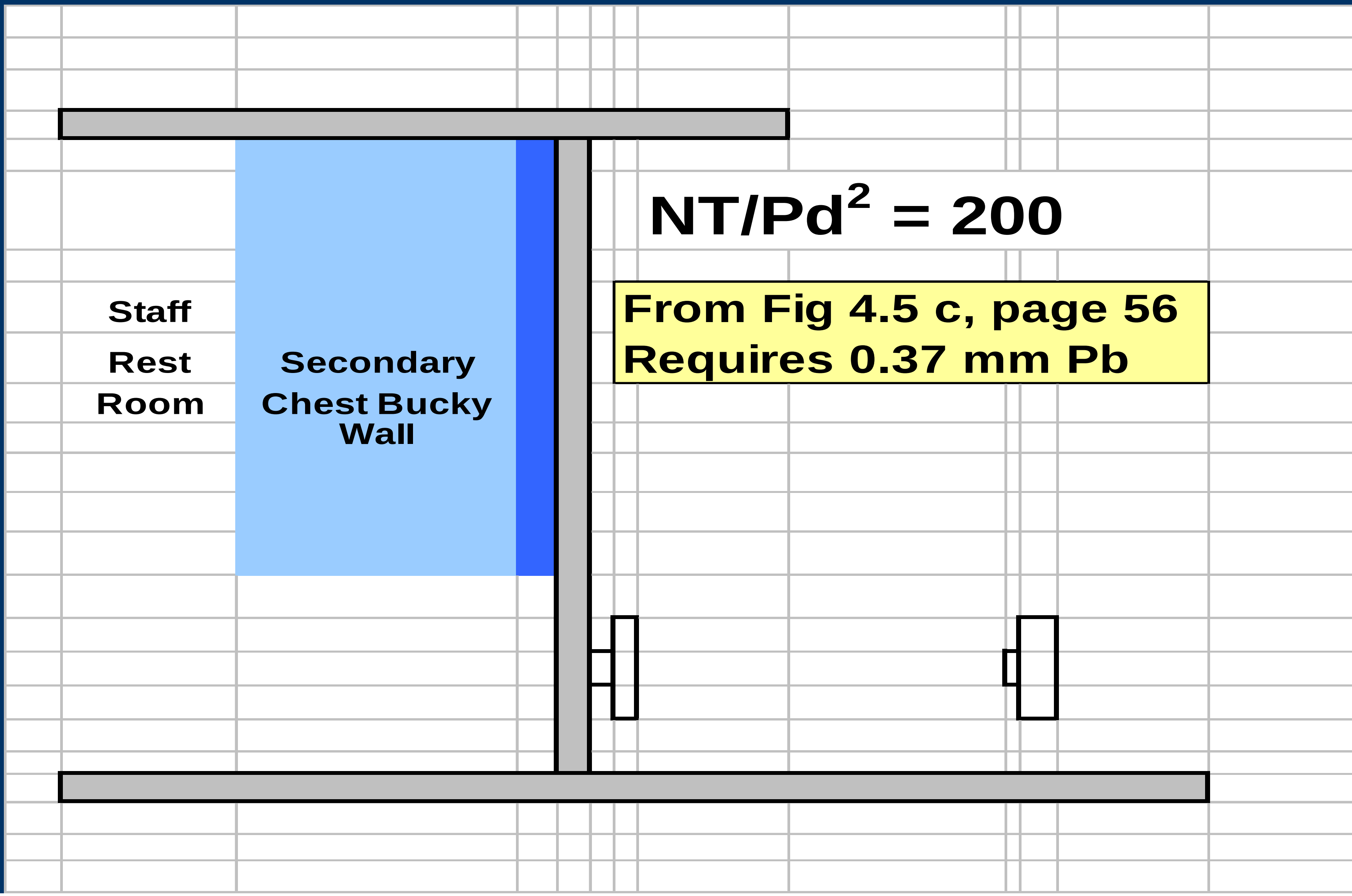
Primary Barrier- Chest Receptor Area

- From Fig 4.5 a, page 54
- (no pre-shielding)
- Requires 1.32 mm Pb

- From Fig 4.5 b, page 55
- (with pre-shielding)
- Requires 0.50 mm Pb

Wall Containing Chest Image Receptor

Secondary Barrier- Chest Receptor Wall



Wall Containing Chest Image Receptor

Shielding Required for Entire Wall

Since the primary shielding is greater than the secondary wall requirements, the entire wall can be shielded with the minimum primary requirement.

No Pre-shielding

Pb required = 1.32 mm

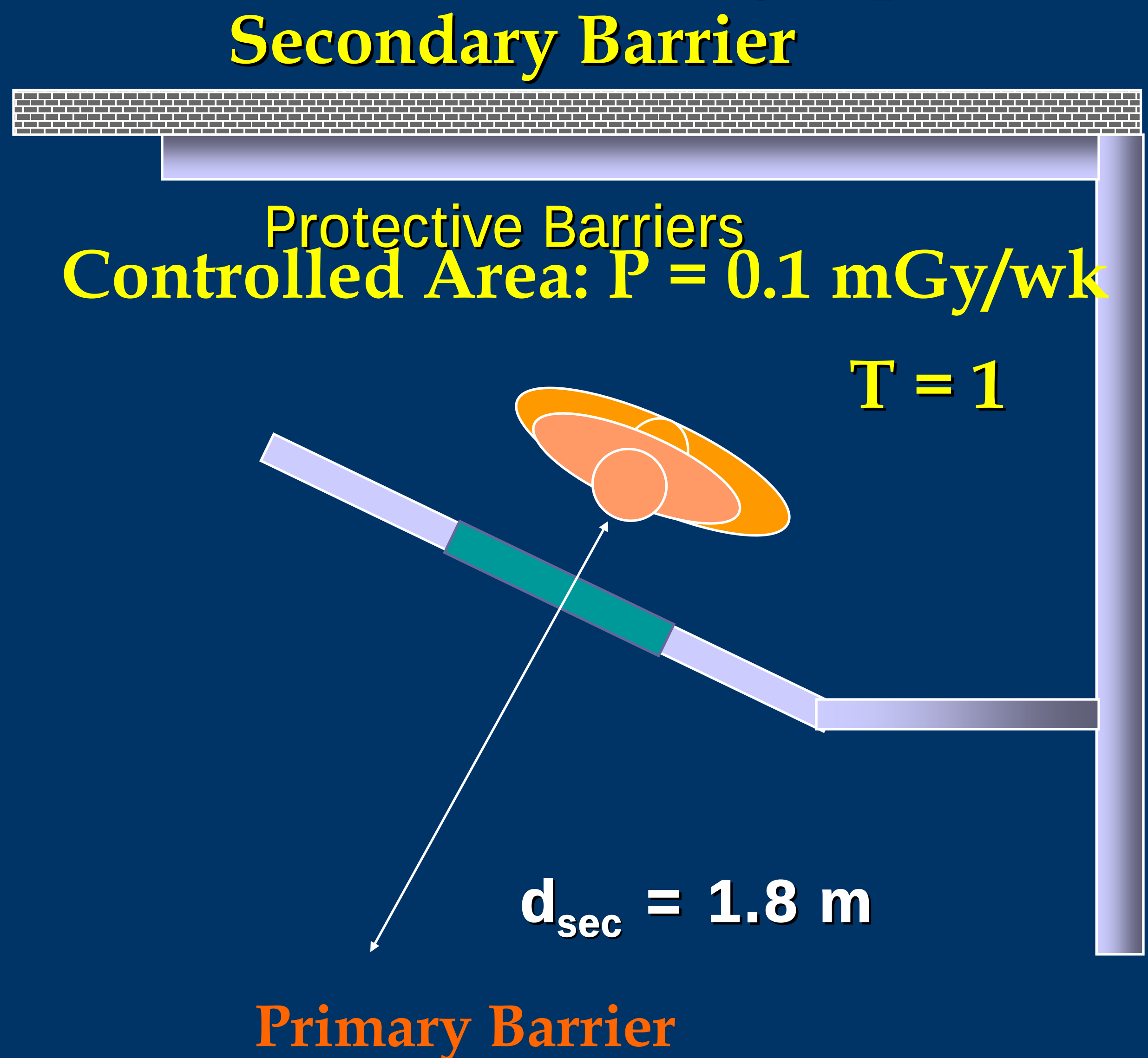
Specify: 1/16”; 4 lb/sqft

With Pre-shielding

Pb required = 0.50 mm

Specify: 1/32”; 2 lb/sqft

Control Wall in the Radiographic Room



Simplified Graphical Solution

Control Wall in the Radiographic Room

$NT/Pd^2 = 125x1 / 0.1x(1.8)^2 = 386$

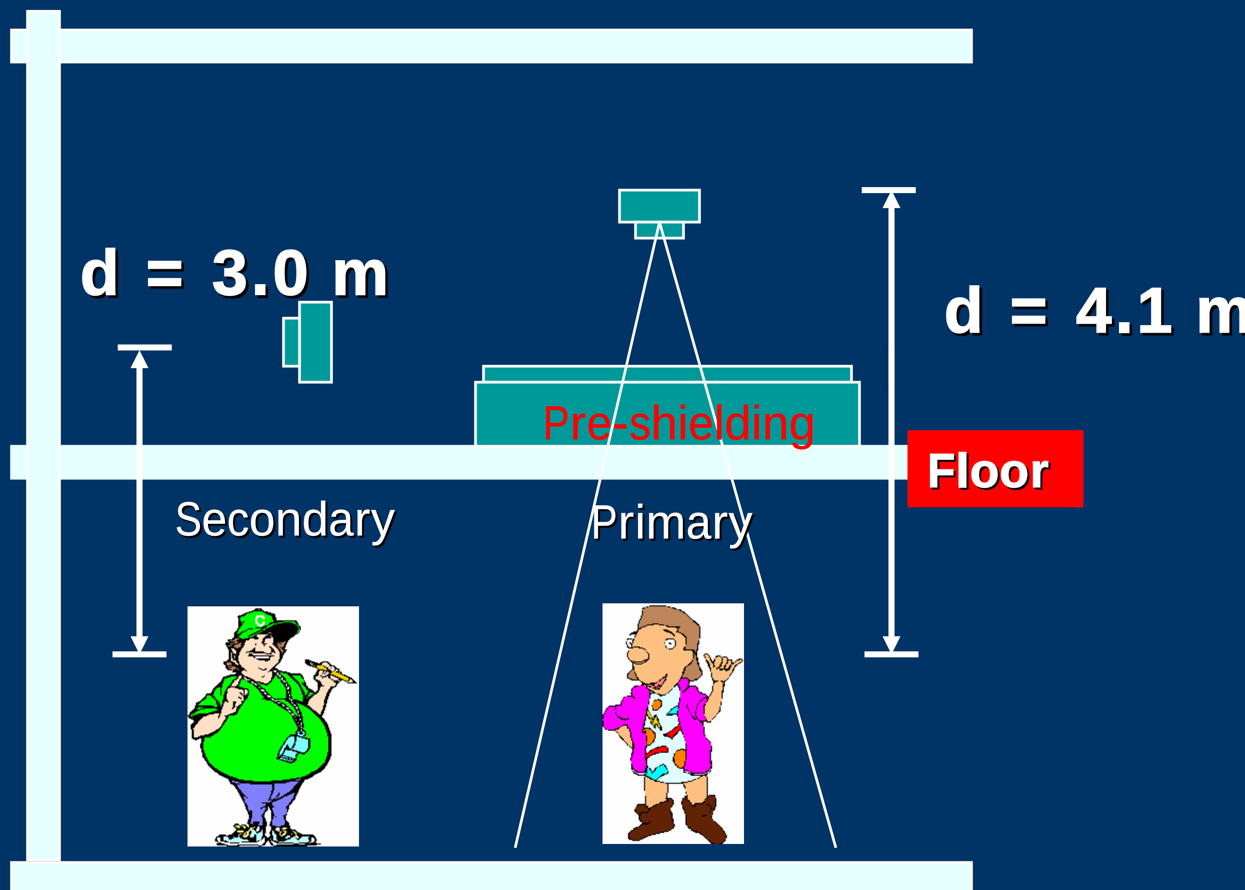
1. Go to page 56, Figure 4.5c "Secondary Wall" curve
2. Look up $NT/Pd^2 = 386$

Pb required = 0.27 mm

Specify: 1/32"; 2 lb/sqft (Minimum)

Recommended Specification: 1/16 inch lead in all control booth walls with lead equivalent windows of at least 1.5 mm.

Floor of the Rad Room



Floor of the Rad Room

Primary Barrier Beneath the Rad Table

- Required thickness ⇨ NT/Pd^2

  `   where:
- N = 125 patients/ week
- T = 1
- P = 0.02 mGy/wk
- d = 4.1 m

- $NT/Pd^2 = 372\ mGy^{-1}\ m^{-2}$

Floor of the Rad Room

Primary Barrier Beneath the Rad Table

1. Go to page 58, Fig. 4.6b (Primary, concrete, with pre-shielding)
2. Look up $NT/Pd^2 = 372$

If Specifying: Standard-Weight Concrete:

Minimum Concrete required = 37 mm = 1.5 in.

If Specifying: Light-Weight Concrete:

Minimum Concrete required = 37 mm x 1.3 = 48.1 mm = 1.9 in.

Floor of the Rad Room

Secondary Barrier Calculation for Floor

- Required thickness ⇨ NT/Pd^2
  ` where:
- N = 125 patients/ week
- T = 1
- P = 0.02 mGy/wk
- d = 3.0 m

- $NT/Pd^2 = 694\ mGy^{-1}\ m^{-2}$

Floor of the Rad Room

Secondary Barrier Calculation for Floor

1. Go to page 59, Fig. 4.6c (Secondary, concrete)
2. Look up $NT/Pd^2 = 694$

Minimum Concrete required = 33 mm = 1.3 in.

This is less than the 37 mm thickness required for the primary barrier. Thus 37 mm of standard-weight concrete will suffice for the entire floor.

Shielding References

- Simpkin, DJ, Transmission of scatter radiation from computed tomography (CT) scanners determined by a Monte Carlo calculation. Health Physics 58(3):363-367, 1990.
- Dixon, RL and Simpkin, DJ. New Concepts for Radiation Shielding of Medical Diagnostic X-ray Facilities. In Proceedings of the 1997 AAPM Summer School.
- NCRP (2005), National Council on Radiation Protection and Measurements. *Structural Shielding Design for Medical X-Ray Imaging Facilities*, NCRP Report #147 (National Council on Radiation Protection and Measurements, Bethesda, Maryland)

Acknowledgement

Multi Slice CT Shielding

Slides Courtesy of:

S. Jeff Shephard, M.S., DABR

M.D. Anderson Cancer Center, Houston, TX

Ben Archer, Ph.D, FACR

Baylor College of Medicine, Houston, TX

Multi-Slice Helical CT Shielding

- Larger collimator (slice thickness) settings generate more scatter
  - Offsets advantages of multiple slices per rotation
  - Environmental radiation levels typically increase
- Ceiling and floor deserve close scrutiny

Problem

Question:

Do I really need to put lead in the ceiling of a 16-slice CT scanner room?

Method

- Calculate the unshielded weekly exposure rate at area of interest
- Find the maximum weekly exposure at 1 m from isocenter and inverse-square this out to the occupied area beyond the barrier.
- Apply traditional barrier thickness calculations to arrive at an answer.
  - Occupancy, permissible dose, attenuation of concrete, etc.

NCRP 147 DLP Method

- Weekly Air Kerma at 1m (K^1_{sec})

K^1_{sec} (head) = κ_{head} * DLP
K^1_{sec} (body) = 1.2 * κ_{body} * DLP

$\kappa_{head} = 9\text{x}10^{-5}\ {}^1/_{cm}$
$\kappa_{body} = 3\text{x}10^{-4}\ {}^1/_{cm}$

Use inverse square to find unshielded weekly exposure at barrier from K^1_{sec}

NCRP 147 DLP Method

DLP (Dose-Length Product)

$= CTDI_{VOL} * L$

- $CTDI_{VOL} = CTDI_W/Pitch$
- $CTDI_W$ = 1/3 Center $CTDI_{100}$ + 2/3 Surface $CTDI_{100}$ (mGy)
- L = Scan length for average ***series*** in cm
- Units of mGy-cm

$= [{}^{1}/_{3}\ CTDI_{100,\ Center} + {}^{2}/_{3}\ CTDI_{100,\ Surface}] * L/p$

NCRP 147 DLP Method

Procedure	$CTDI_{Vol}$ (mGy)	Scan Length (L) (cm)	DLP* (mGy-cm)
Head	60	20	1200
Body	15	35	525
Abdomen	25	25	625
Pelvis	25	20	500
Body (Chest, Abdomen, or Pelvis)			550

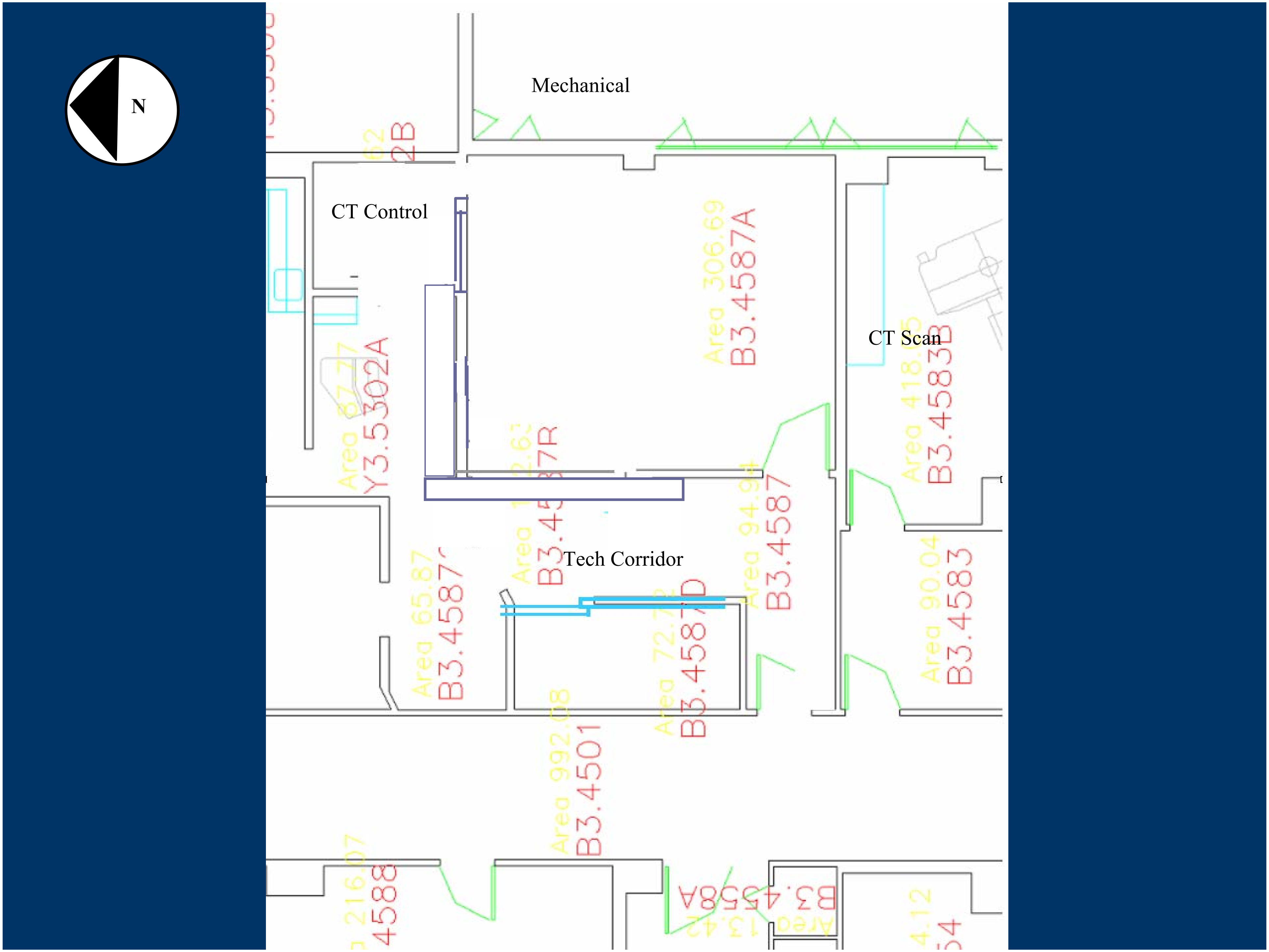
*** Double the value shown for w/wo contrast**

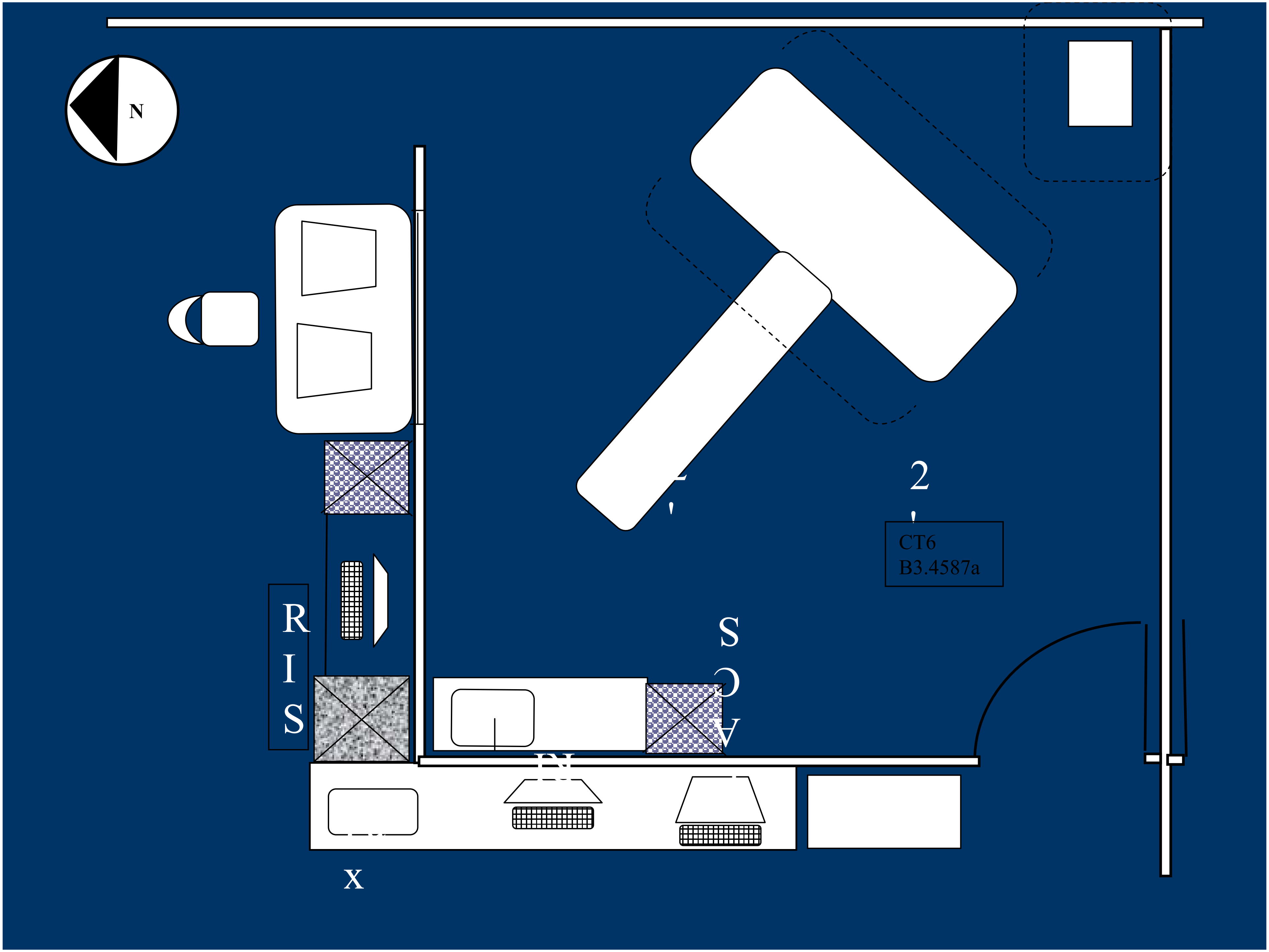
Example - Ceiling Calculation

- 180 Procedures/week
  - 150 Abdomen & Pelvis
  - 30 Head
- 40% w&w/o contrast
- 13’ (4.2 m) ceiling height (finished floor to finished floor)
- GE LightSpeed 16

Preliminary Information

- Architectural drawings (Plan view) of exam room, floor above, and floor below
  - Elevation sections through scanner location for floor and ceiling
  - Occupancy factors for floors above and below
  - Two rooms away for possibility that remote areas may be more sensitive than adjacent areas
- Composition of walls, ceilings and floors
  - Materials and thickness
- Scanner placement from vendor
  - Distance from scanner to protected areas beyond barriers


N
Mechanical
CT Control
CT Scan
Tech Corridor


N
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CT6
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R
I
S
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x

Unshielded Weekly Exposure at Barrier

- Air Kerma/procedure at 1m (K^1_{sec})
  - 40% w&w/o contrast

K^1_{sec} (head) = κ_{head} * DLP
= 1.4 * 9×10^{-5} cm^{-1} * 1200 mGy-cm
= 4.9 mGy

K^1_{sec} (body) = κ_{body} * DLP
= 1.4 * 1.2 * 3×10^{-4} cm^{-1} * 550 mGy-cm
= 41.6 mGy

Unshielded Weekly Exposure at Barrier

- Weekly Air Kerma (K_{sec}) at Ceiling:
  - 30 head procedures/wk
  - 150 body procedures/wk
  - D_{sec}= 4.2 m + 0.5 m – 1 m = 3.7 m

K_{sec} (head) = 30 * 4.9 mGy * $(1m/3.7m)^2$
= 0.36 mGy

K_{sec} (body) = 150 * 41.6 mGy * $(1m/3.7m)^2$
= 3.04 mGy

Unshielded Weekly Exposure at Barrier

- Weekly Air Kerma (K_{sec}) at Ceiling:

K_{sec} (Total) = K_{sec} (head) + K_{sec} (body)

K_{sec} (Total) = 0.36 mGy + 3.04 mGy

K_{sec} (Total) = 3.40 mGy

Required Transmission (B)

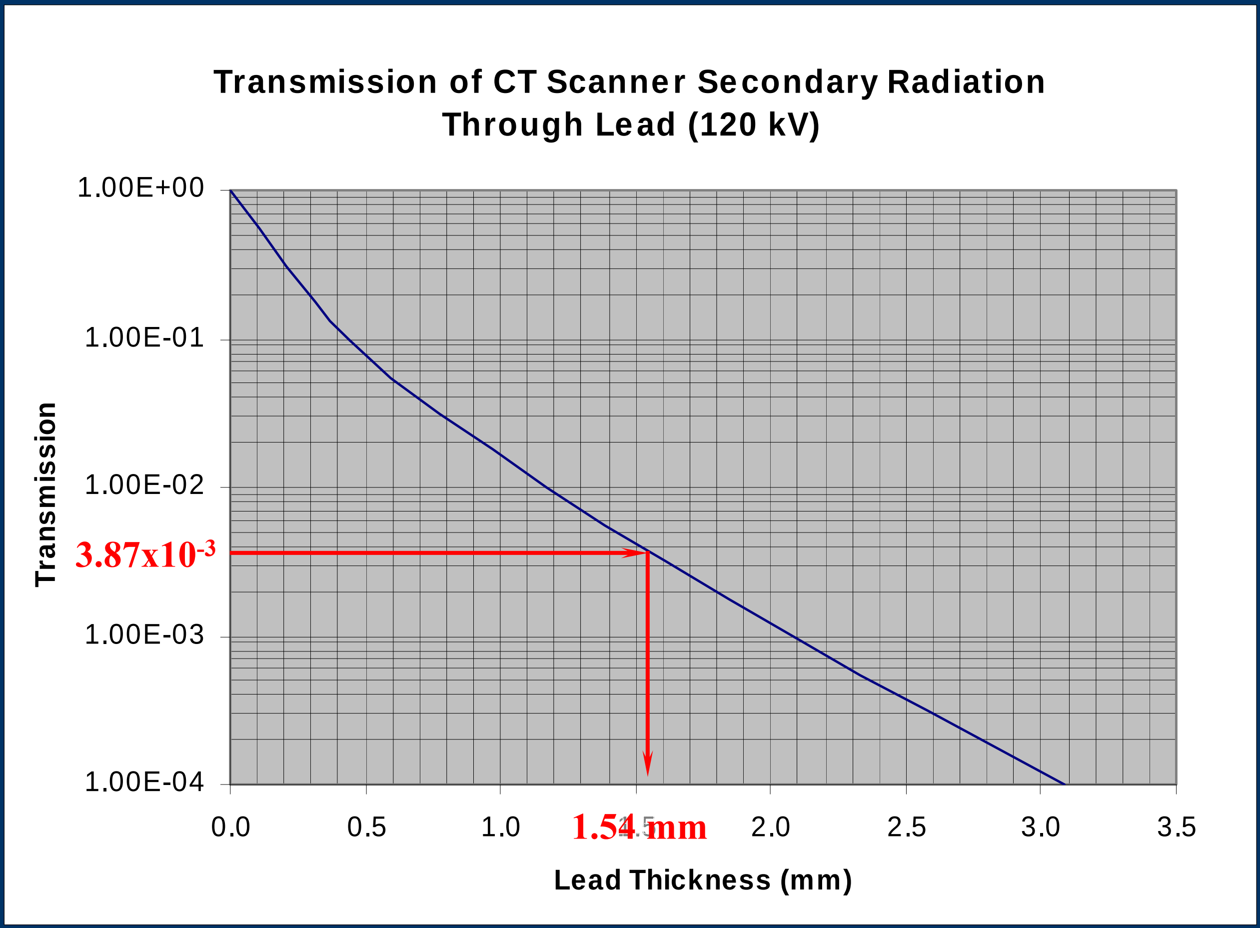
$$B = \frac{P}{K_{sec} * T}$$

P = Maximum permissible weekly exposure
T = Occupancy Factor

$$= \frac{0.02 \text{ mGy}}{3.40 \text{ mGy} * 1} = 3.87 \times 10^{-3}$$

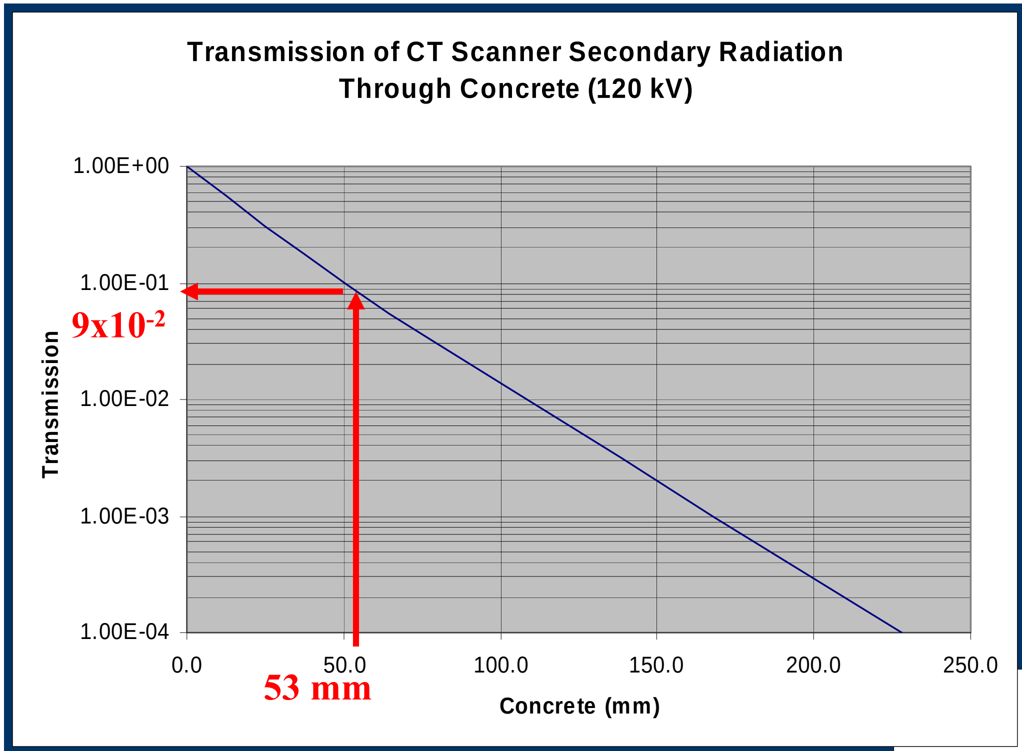
Total Shielding Required

Use Simpkin curve fit equations or look up on published attenuation diagrams (NCRP 147 Fig. A-2)



Existing Shielding

- Floors and ceilings
  - Find lead equivalence from documentation of concrete thickness.
  - Find thickness by drilling a test hole and measuring.
  - Always assume light weight concrete, unless proven otherwise (30% less dense than standard density, coefficients used in NCRP 147)

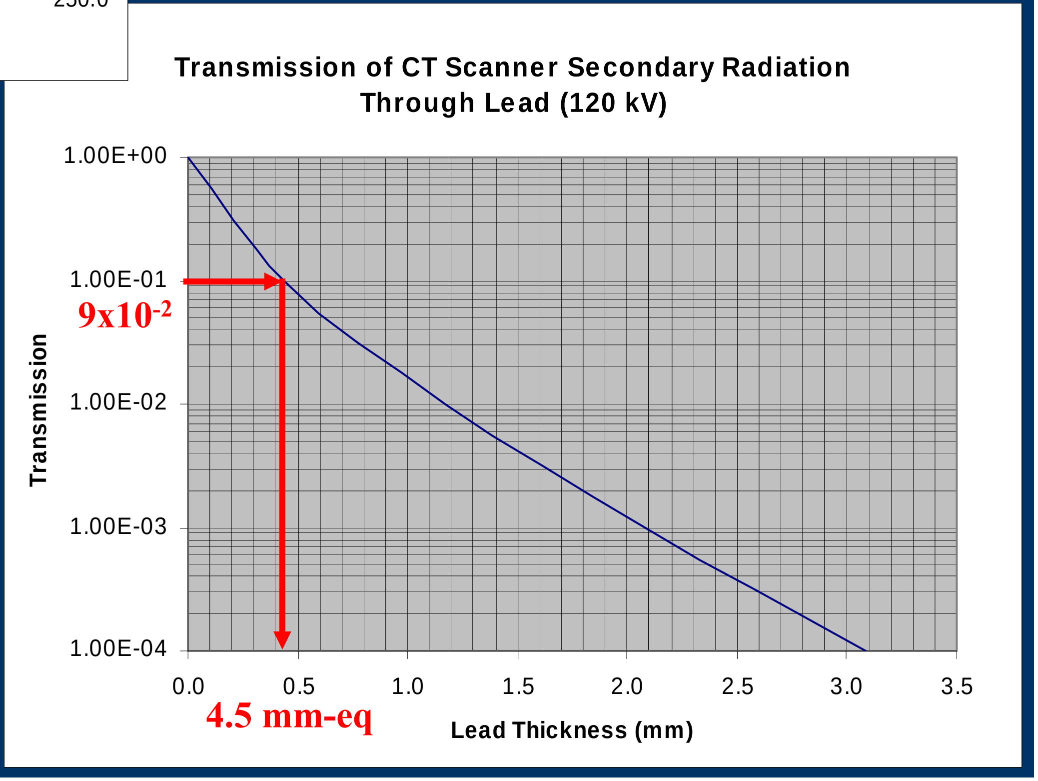


3” light concrete = 2.1” std concrete

= 53 mm std concrete

B = 9×10^{-2}

= 0.45 mm Pb-eqiv



Existing Shielding

- Subtract existing lead-equivalence from total required
- Convert to 1/32 inch multiples (round up)

Total lead to add = (Total required) – (Existing)

= 1.54 mm – 0.45 mm

= 1.1 mm

Round up to 1/16” Pb Additional Lead required

CTDI Method

Unshielded weekly exposure calculation:

Secondary exposure per procedure at one meter K_s^1

$$= \kappa \times \left[L/p \right] \times \left[\text{mAs/Rotation} \right] \times \left[\text{CTDI}_{100,\ \text{peripheral}} /\text{mAs} \right] \times \left[\frac{\text{Scan kV}}{\text{CTDI kV}} \right]^2$$

Where:

κ is the scatter fraction at one meter per cm scanned.

L is the length of the scanned volume.

p is pitch.

Κ (head)	9×10^{-5} cm^{-1}
Κ (body)	3×10^{-4} cm^{-1}

CTDI Method

- ImPACT (the UK's CT evaluation center) website has measured axial and peripheral $CTDI_{100}$ for most scanners on the market in Excel format.

Scanner	Scanner Group	kVp	CTDI (Head, mGy/100mAs) Air	Centre	Perip	CTDI (Body, mGy/100mAs) Air	Centre	Perip
CGR CE 10000,12000	CG.a	130						
Elscint Exel 2400 Elect	EL.a	120	18.8	13.2	14.5	18.5	3.5	6.2
Elscint Exel 2400 Elect	EL.a	140				25.8	5.2	8.6
Elscint CT Twin, Helicat	EL.b	120	18.6	12.9	13.9	19.0	3.8	6.5
GE 8800 / 9000 Series	GE.a	120	14.1	6.5	6.1	14.6	2.1	4.2
GE 9800 Series	GE.b	120	26.0	14.1	14.9	26.0	3.9	7.4
GE 9800 Series	GE.b	140	34.1	19.4	20.0	34.1	5.7	10.0
GE HiLight, HiSpeed, CT/i (No SmB)	GE.c	80	8.5	4.2	4.5	8.5	1.0	1.9
GE HiLight, HiSpeed, CT/i (No SmB)	GE.c	100	14.0	8.2	8.3	14.0	2.2	4.3
GE HiLight, HiSpeed, CT/i (No SmB)	GE.c	120	19.3	11.4	11.9	18.8	3.2	6.1
GE HiLight, HiSpeed, CT/i (No SmB)	GE.c	140	27.0	16.8	17.2	25.8	4.8	9.0
GE HiSpeed CT/i with SmartBeam	GE.d	80	8.5	4.2	4.5	8.5	1.0	2.7
GE HiSpeed CT/i with SmartBeam	GE.d	100	14.0	8.2	8.3	13.9	2.5	5.6
GE HiSpeed CT/i with SmartBeam	GE.d	120	19.3	11.4	11.9	20.4	3.8	7.3
GE HiSpeed CT/i with SmartBeam	GE.d	140	27.0	16.8	17.2	27.7	5.8	10.7
GE Max	GE.e	120	38.4	18.8	17.7	38.4	5.0	8.8
GE Pace, Sytec	GE.f	80	20.1	8.0	10.0	19.2	1.9	5.3
GE Pace, Sytec	GE.f	120	41.6	22.1	23.8	41.0	6.3	13.2
GE Pace, Sytec	GE.f	135	50.7	28.3	30.0	50.1	8.4	16.2
GE Pace, Sytec	GE.f	140	55.5	30.7	33.5	54.1	9.5	18.5
GE Prospeed	GE.g	120	36.6	20.7	22.3	36.6	5.7	11.8
GE Prospeed	GE.g	140	47.2	28.4	30.1	47.2	8.3	15.9
GE FX/i, LX/i	GE.h	80	16.3	6.8	8.2	16.3	1.5	4.2

www.impactscan.org

CTDI Method

Calculate K^1_{sec} for head and body separately, then combine with weighting factors depending on percentage of total workload.

$$K^1_s\,(\text{total}) = \frac{\%\ \text{heads} * K^1_s\,(\text{head}) + \%\ \text{body} * K^1_s\,(\text{body})}{100\%}$$

Finally, inverse-square this exposure out to each area to be protected.

Isodose Map Method

- Assume an isotropic exposure distribution based on the maximum exposure rate in the vendor-supplied exposure distribution plots (approx. 45^o to the scanner axis).
- Overestimates shielding needed in the gantry shadows and the shadows of the patient.

Sensation 64/ Cardiac 64

Scanning was performed using a maximum slice thickness of 20 x 1.2 mm (24 mm) at 140 kV through the system axis in the horizontal plane. A cylindrical PMMA phantom measuring 32 cm in diameter and 16 cm in length was used for the scatter radiation test. The phantom was centered in the tomographic plane.

	1,50m	1,00m	0,50m	0,00m	0,50m	1,00m	1,50m
1,50m	0,013	0,032	0,040	0,043	0,038	0,032	0,012
1,00m	0,003	0,025	0,080	0,098	0,077	0,027	0,003
0,50m	0,002	0,003	0,176	0,360	0,165	0,003	0,002
0,00m	0,002						0,002
0,50m	0,004	0,026	0,215	0,436	0,150	0,031	0,005
1,00m	0,031	0,054	0,087	0,106	0,085	0,057	0,028
1,50m	0,026	0,033	0,043	0,045	0,041	0,035	0,025
2,00m	0,019	0,021	0,025	0,026	0,024	0,023	0,019
2,50m	0,014	0,015	0,016	0,016	0,015	0,015	0,014
3,00m	0,010	0,010	0,012	0,011	0,011	0,011	0,010

2.2 m

Measurement values in µGy/1 mAs

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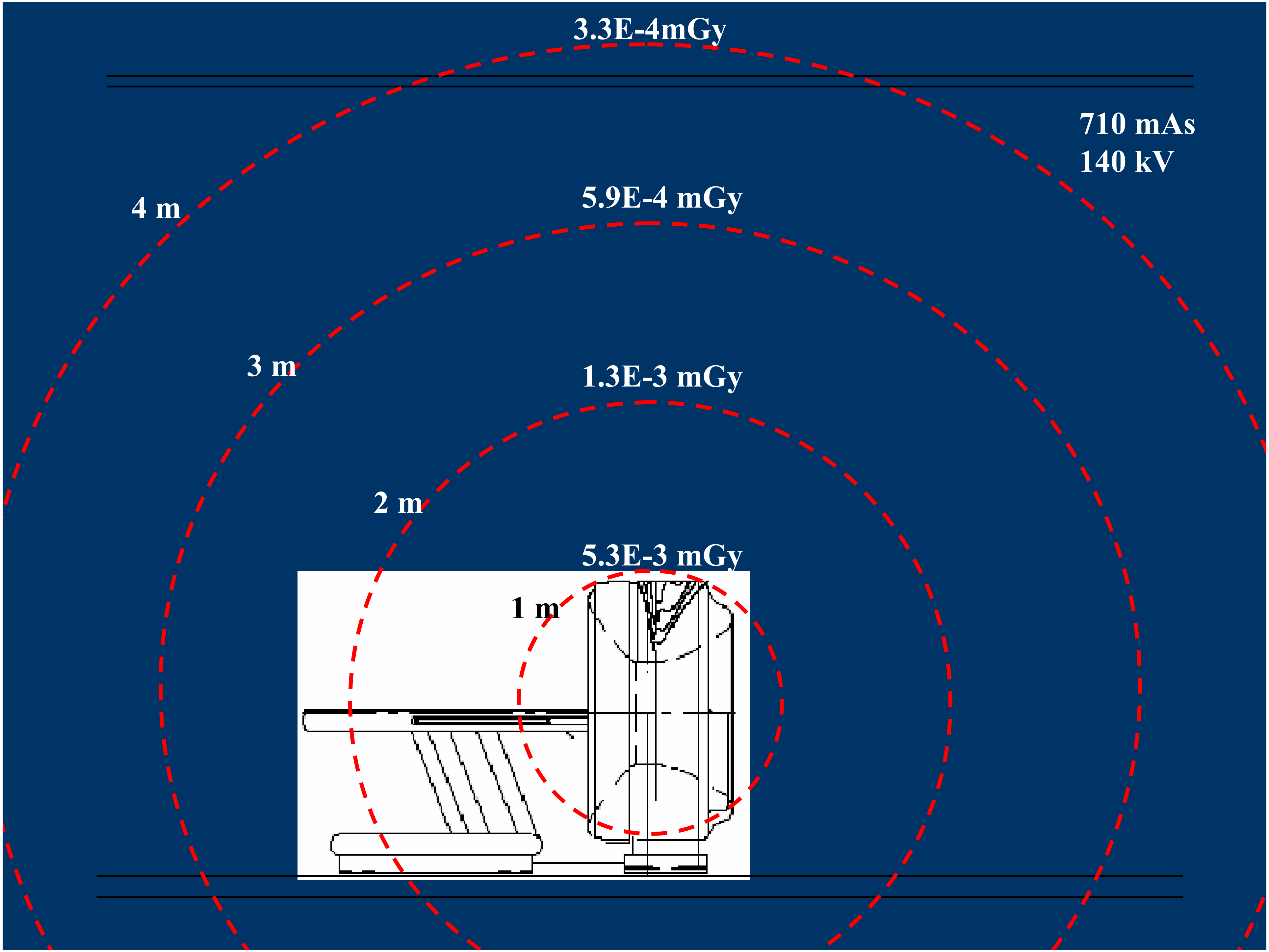
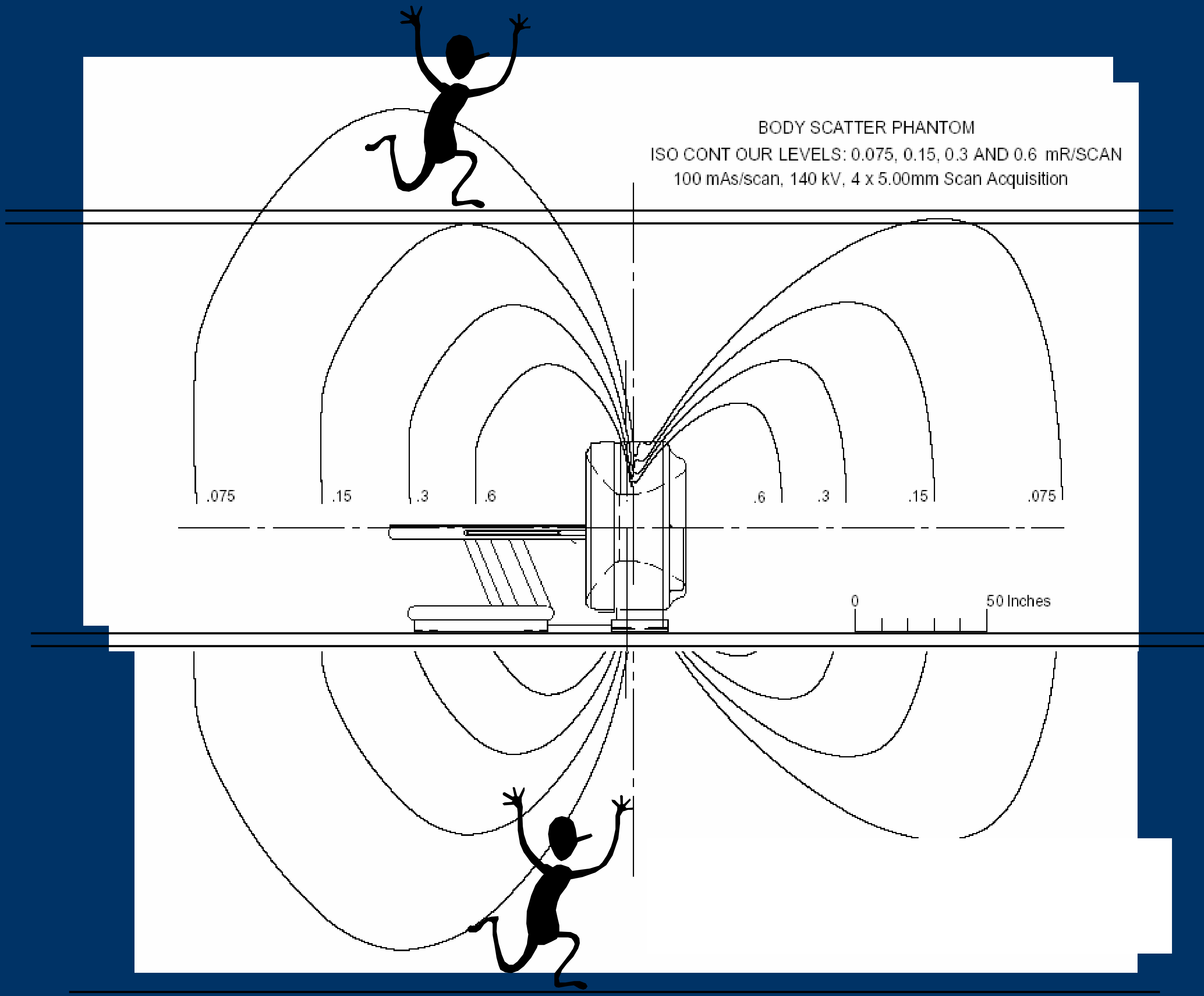

3.3E-4mGy
710 mAs
140 kV
4 m
5.9E-4 mGy
3 m
1.3E-3 mGy
2 m
5.3E-3 mGy
1 m


BODY SCATTER PHANTOM
ISO CONT OUR LEVELS: 0.075, 0.15, 0.3 AND 0.6 mR/SCAN
100 mAs/scan, 140 kV, 4 x 5.00mm Scan Acquisition
.075
.15
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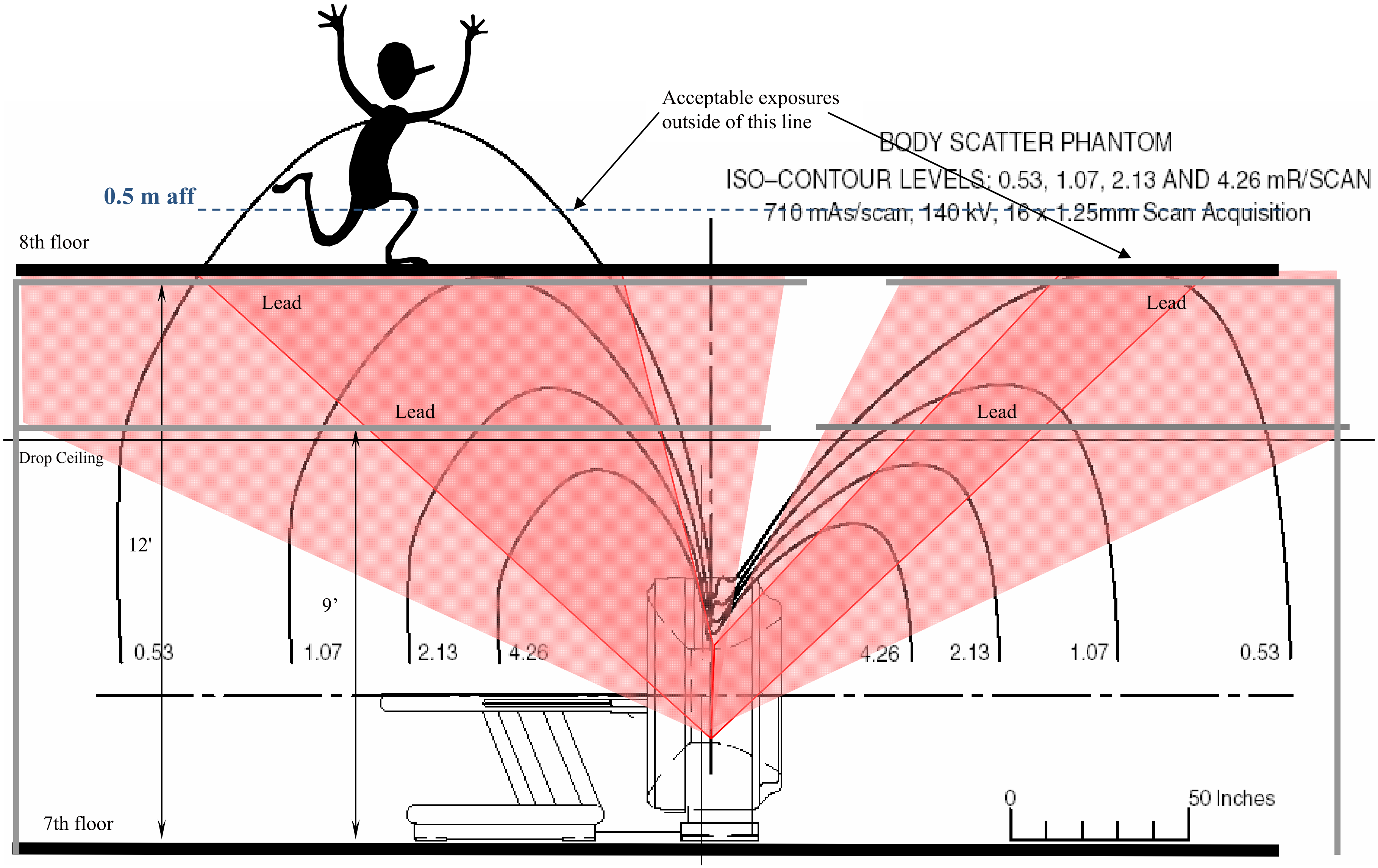
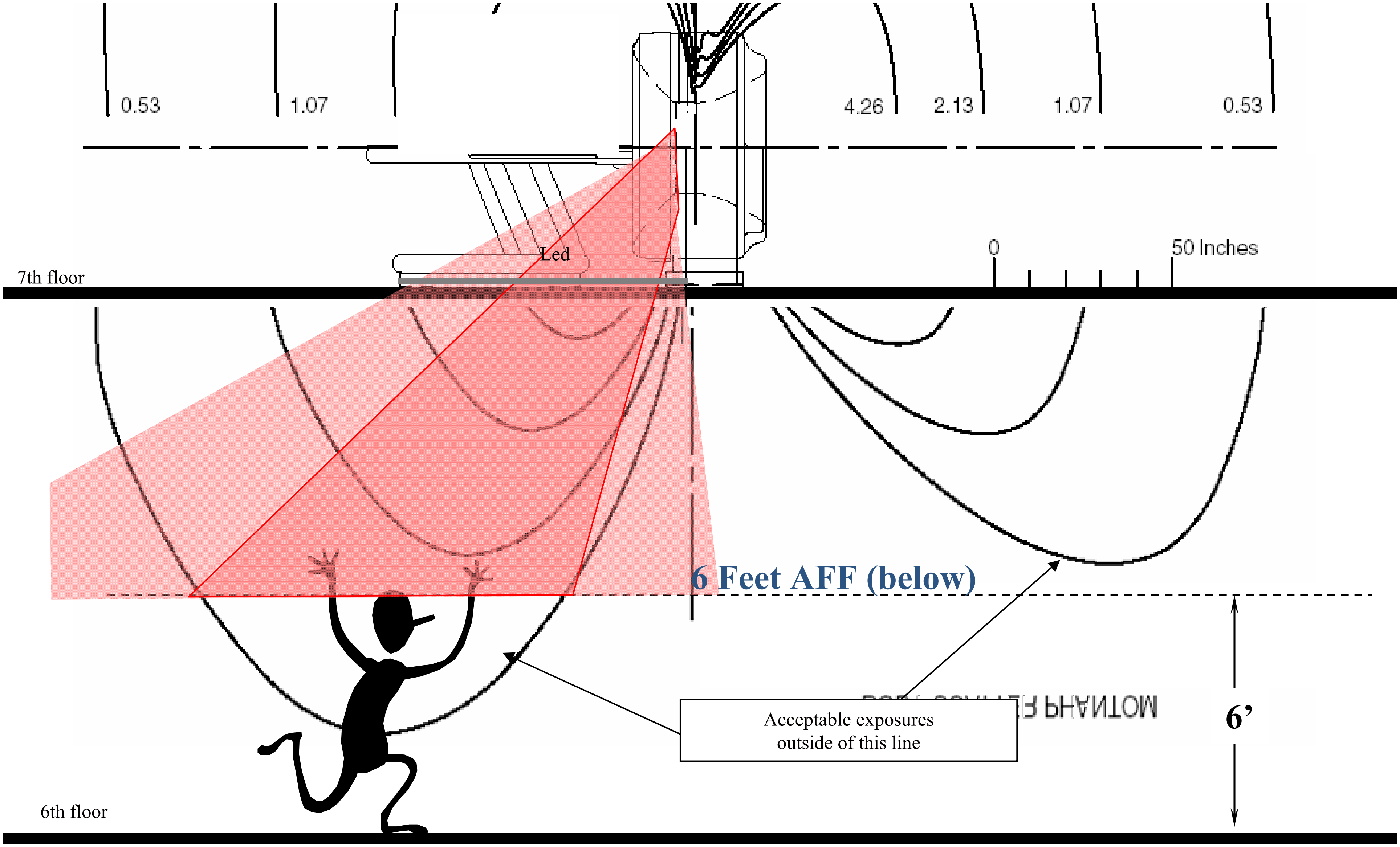
50 Inches



Acceptable exposures
outside of this line
BODY SCATTER PHANTOM
ISO–CONTOUR LEVELS: 0.53, 1.07, 2.13 AND 4.26 mR/SCAN
710 mAs/scan, 140 kV, 16 x 1.25mm Scan Acquisition
0.5 m aff
8th floor
Lead
Lead
Lead
Lead
Drop Ceiling
12'
9'
0.53
1.07
2.13
4.26
4.26
2.13
1.07
0.53
0
50 Inches
7th floor



0.53
1.07
4.26
2.13
1.07
0.53
Led
0
50 Inches
7th floor
6 Feet AFF (below)
Acceptable exposures outside of this line
6'
6th floor

Comparison of Methods

	DLP		$CTDI_{100}$		Isodose	
	Head	Body	Head	Body	Head	Body
K^1_{sec}	4.9	41.6	0.2	5.0	12	151
Combined Weekly Exposure at Ceiling	3.4 mGy		0.38 mGy		10 mGy	
Add Lead	1/16”		1/32”		3/32”	

Shielding References

- Simpkin, DJ, Transmission of scatter radiation from computed tomography (CT) scanners determined by a Monte Carlo calculation. Health Physics 58(3):363-367, 1990.
- Dixon, RL and Simpkin, DJ. New Concepts for Radiation Shielding of Medical Diagnostic X-ray Facilities. In Proceedings of the 1997 AAPM Summer School.
- NCRP (2005), National Council on Radiation Protection and Measurements. *Structural Shielding Design for Medical X-Ray Imaging Facilities*, NCRP Report #147 (National Council on Radiation Protection and Measurements, Bethesda, Maryland)