Design and Evaluation of Shielding for CT Facilities

Multi-Slice CT Scanners
Using NCRP 147 Methodology

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Acknowledgement

Slides Courtesy of:

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Baylor College of Medicine, Houston, TX

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

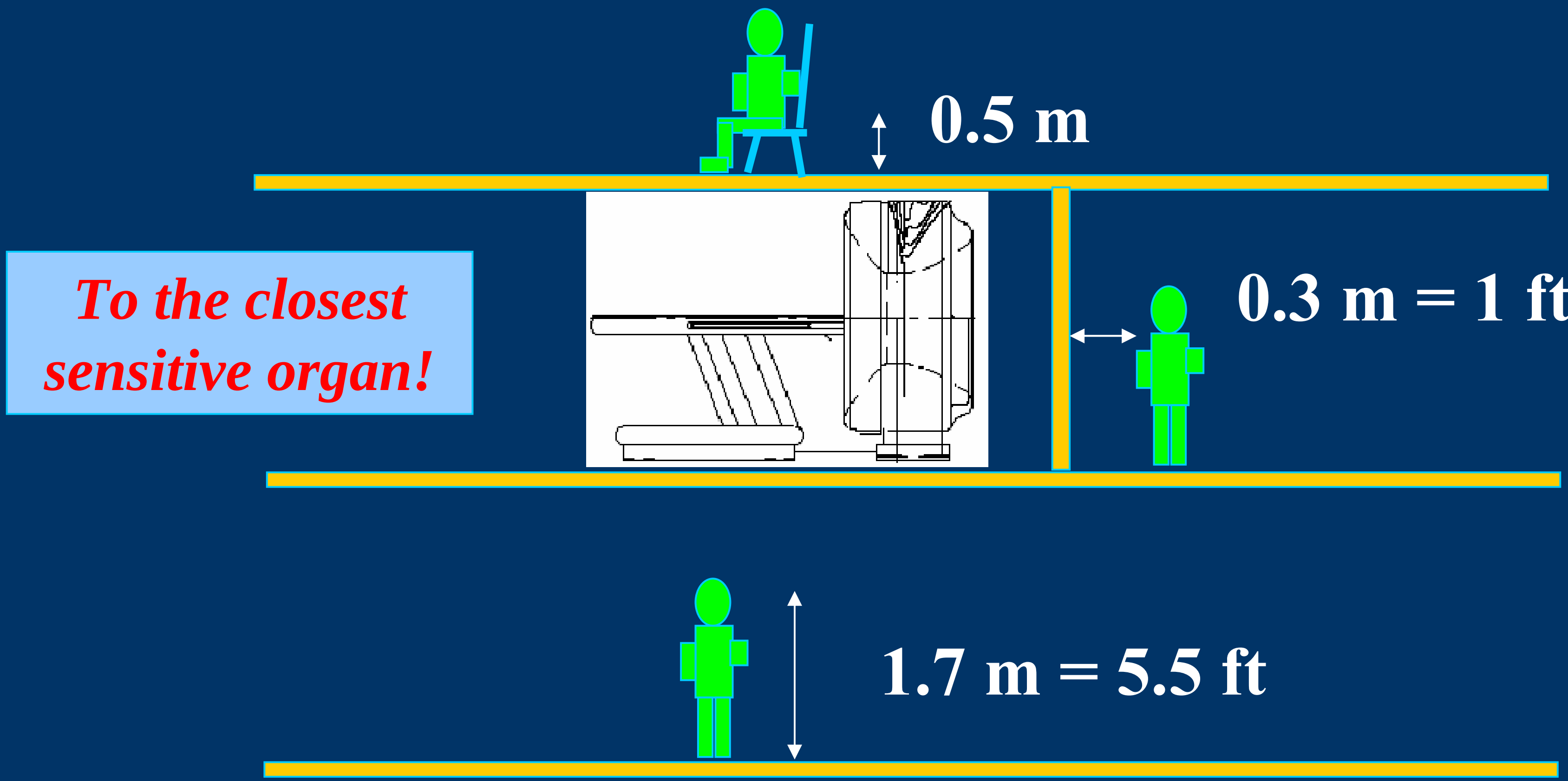
Annual: P = 5 mGy per year
Weekly: P = 0.1 mGy per week

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

Equivalency of Shielding Materials

Table 4.8 Page 67

Steel thickness requirement:

8 × Pb thickness requirement

Gypsum wallboard thickness requirement:

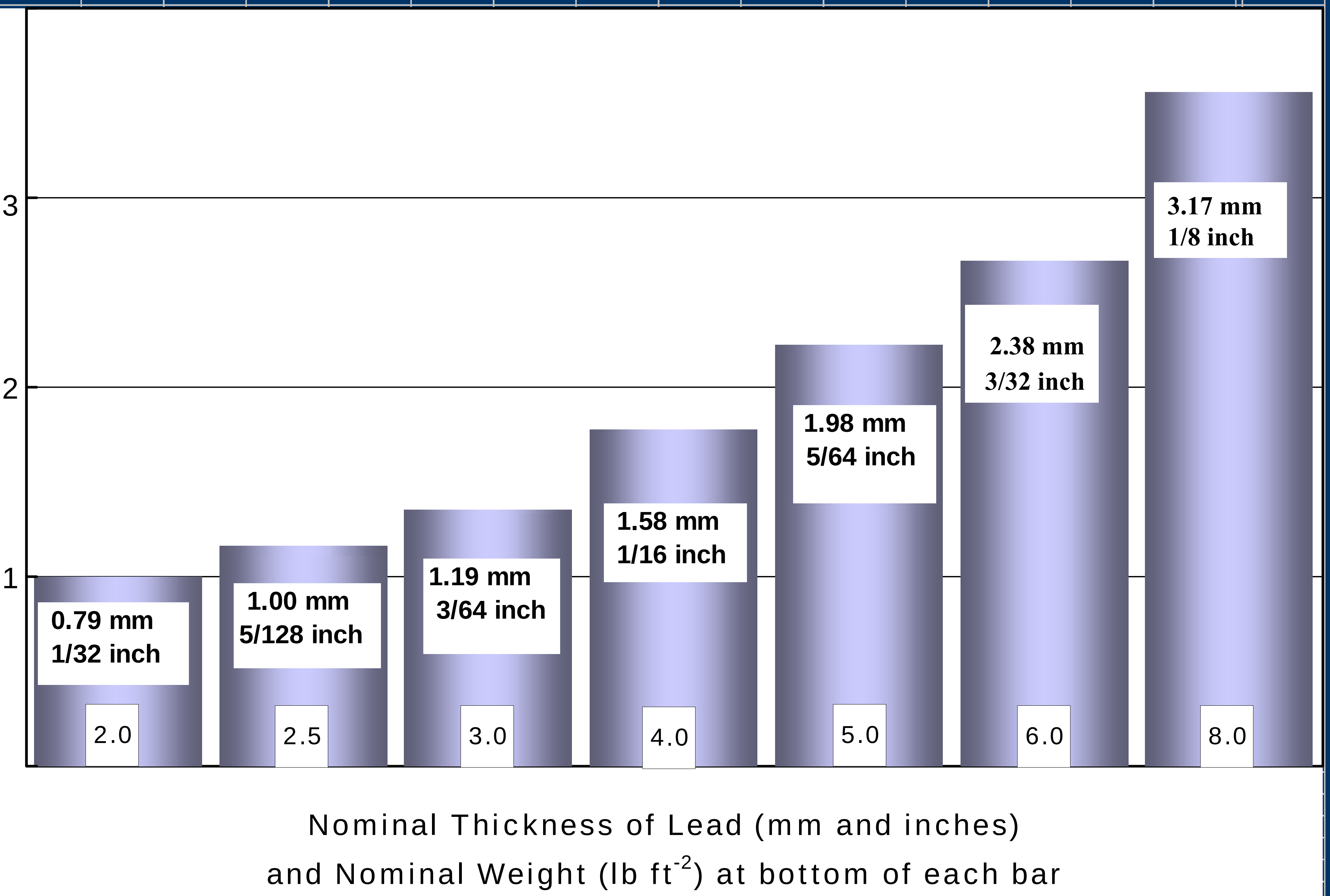
3.2 × concrete thickness requirement

Plate Glass thickness requirement:

1.2 × concrete thickness requirement

Light-weight concrete thickness requirement:

1.3 × std-weight concrete thickness requirement


3
2
1
0.79 mm
1/32 inch
2.0
1.00 mm
5/128 inch
2.5
1.19 mm
3/64 inch
3.0
1.58 mm
1/16 inch
4.0
1.98 mm
5/64 inch
5.0
2.38 mm
3/32 inch
6.0
3.17 mm
1/8 inch
8.0
Nominal Thickness of Lead (mm and inches)
and Nominal Weight (lb ft-2) at bottom of each bar

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 0.5 m beyond the floor above.
  - 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})

$$K^1_{sec}\ (head) = \kappa_{head} * DLP$$

$$K^1_{sec}\ (body) = 1.2 * \kappa_{body} * DLP$$

$$\kappa_{head} = 9x10^{-5}\ {}^{1}/_{cm}$$

$$\kappa_{body} = 3x10^{-4}\ {}^{1}/_{cm}$$

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

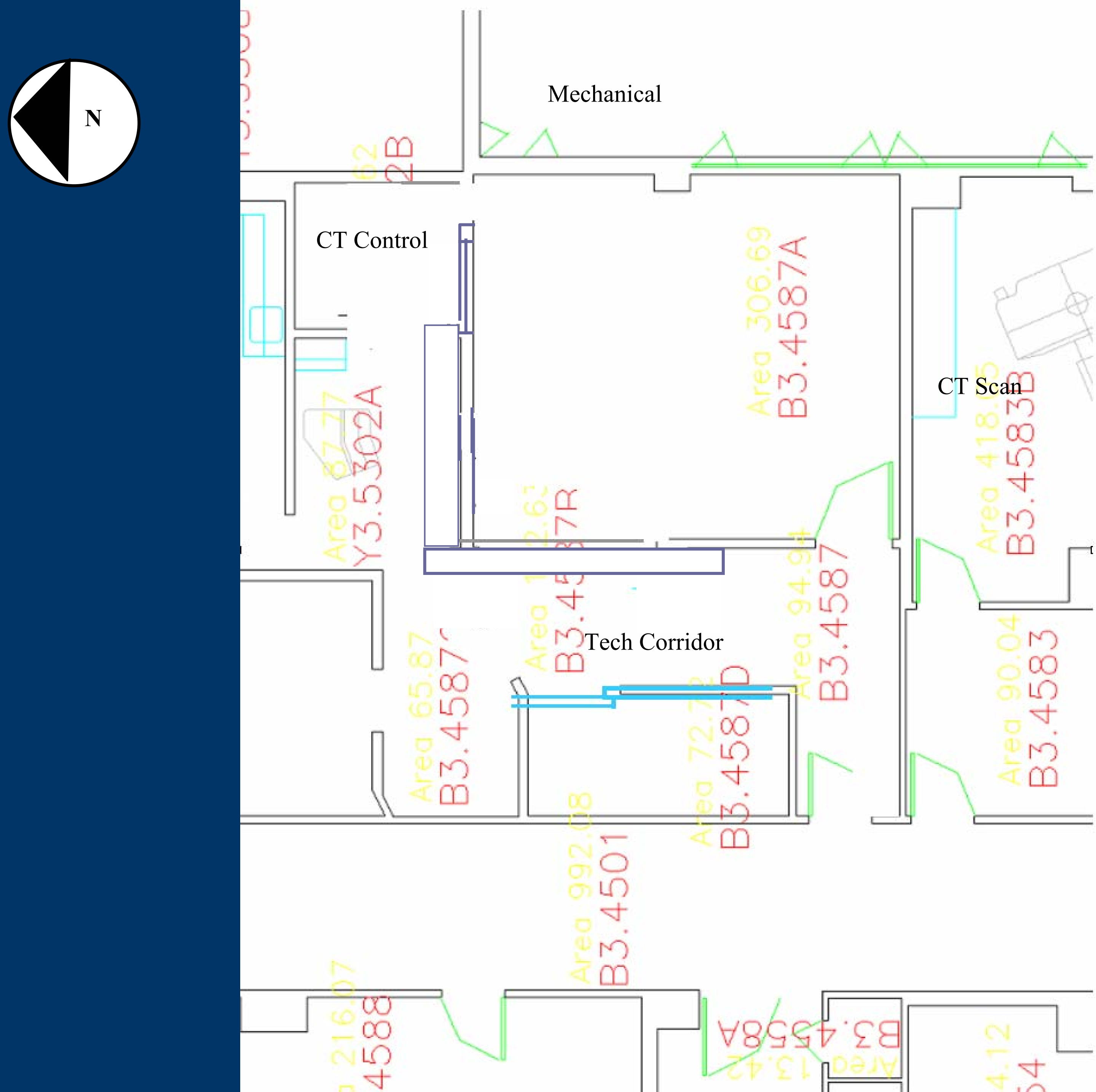
*** Double the value shown for w/wo contrast**

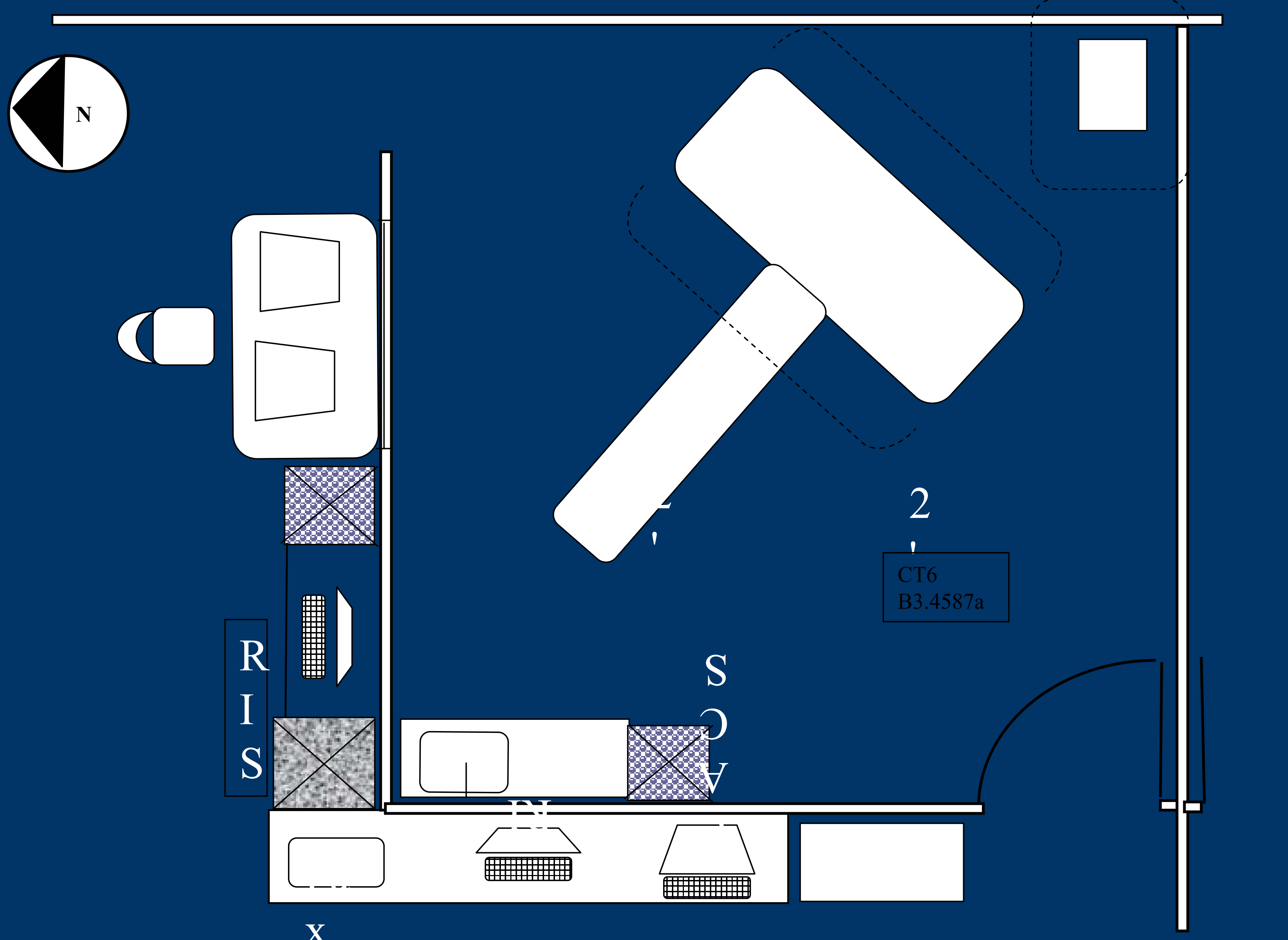
Example

- 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
Area 306.69
B3.4587A
Area 418.05
B3.4583B
Area 94.94
B3.4587
Area 90.04
B3.4583
Area 65.87
Area 992.08
B3.4501
B3.4558A


N
2
CT6
B3.4587a
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I
S
S
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)

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

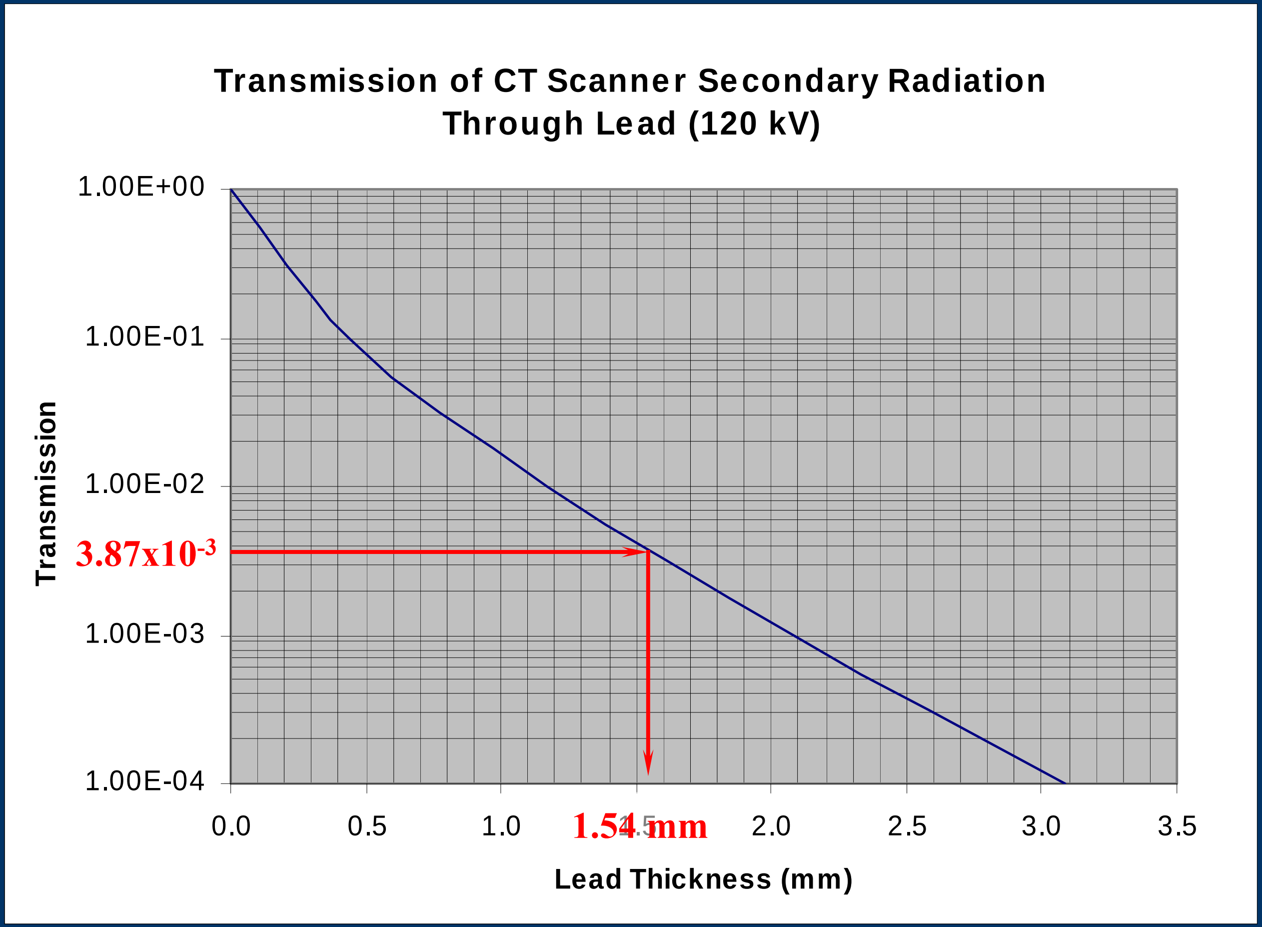
P = Maximum permissible weekly exposure

T = Occupancy Factor

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

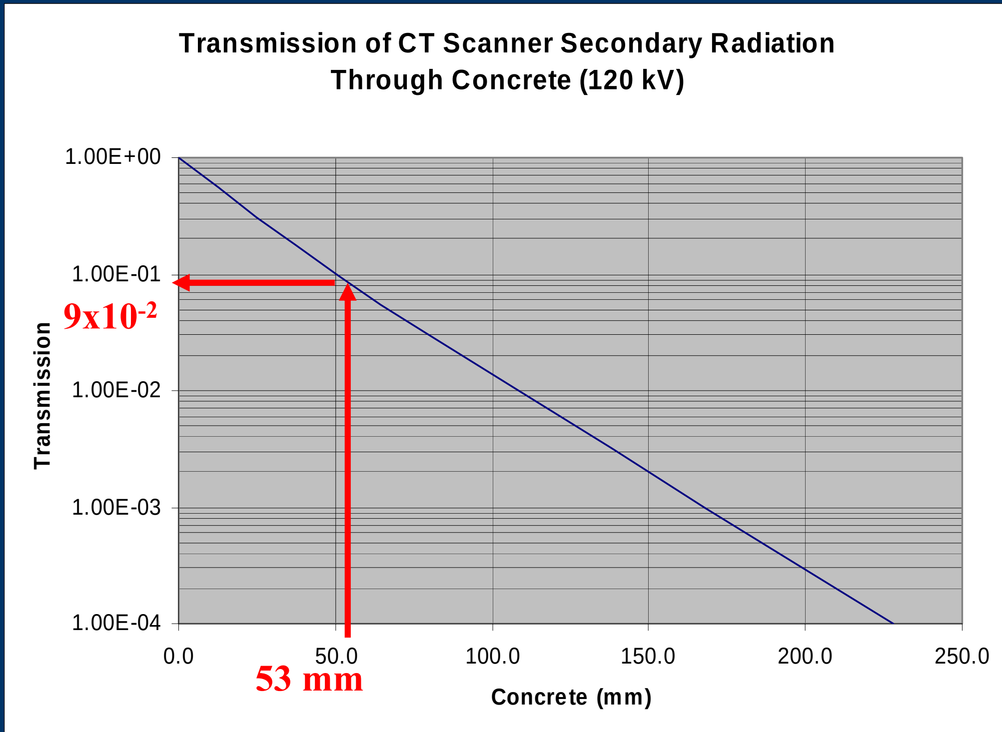
Total Shielding Required

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



Existing Shielding

- Measure existing attenuation in walls with Tc-99m source and Na-I detector (determine lead-equivalence – usually 0.1 mm Pb-eq)
- 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)

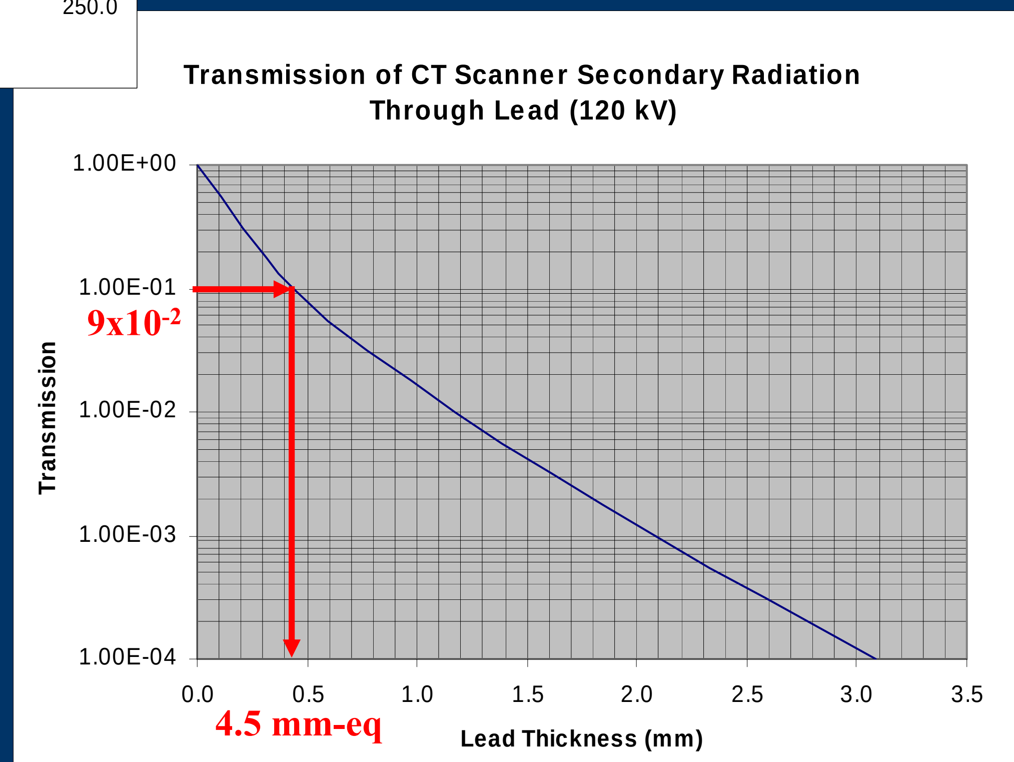


3” light concrete = 2.1” std concrete

= 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)	$9 \times 10^{-5}\ cm^{-1}$
κ (body)	$3 \times 10^{-4}\ cm^{-1}$

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. 45º to the scanner axis).
- Overestimates shielding needed in the gantry shadows and the shadows of the patient.

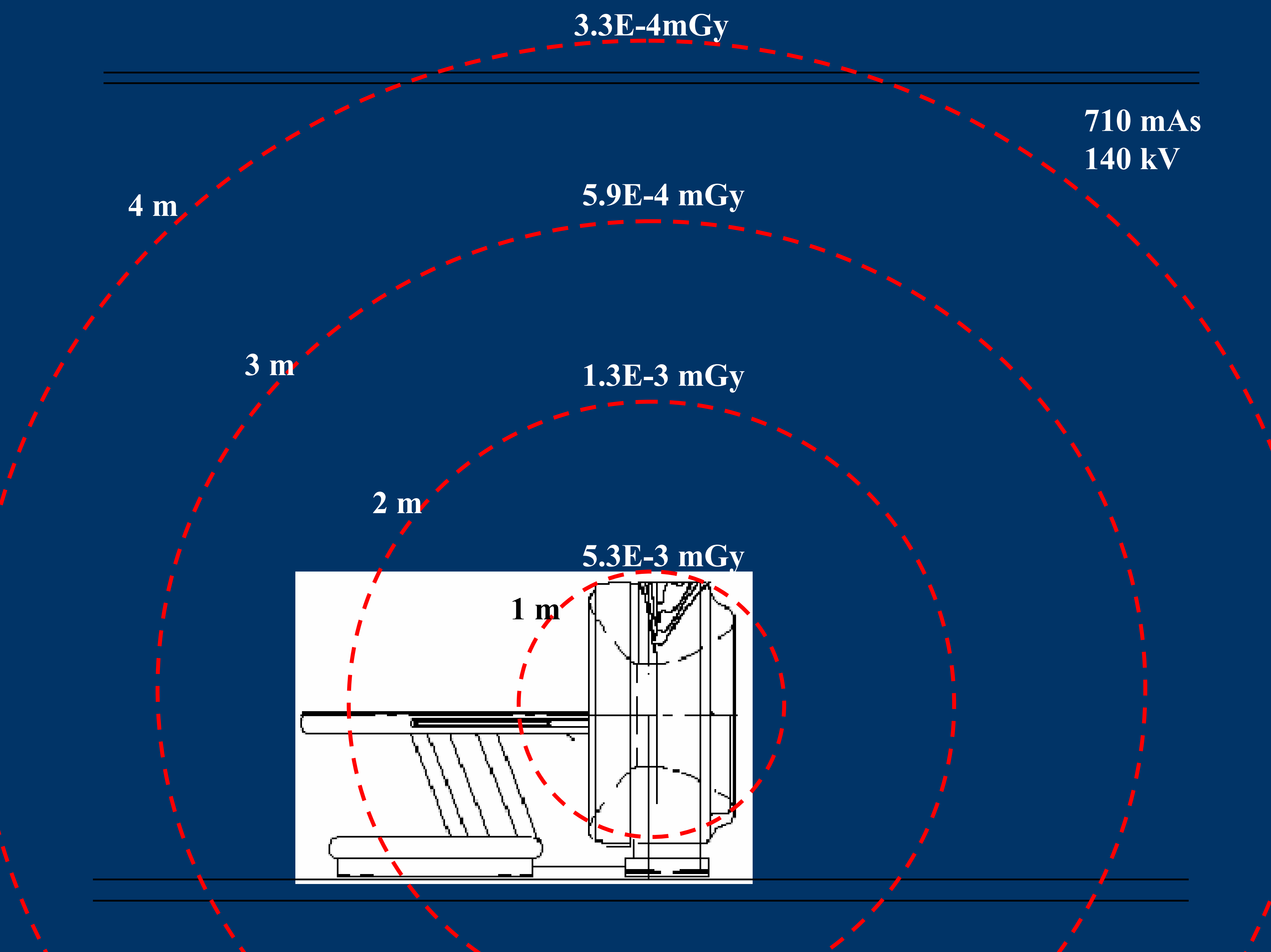
Sensation 64/ Cardiac 64

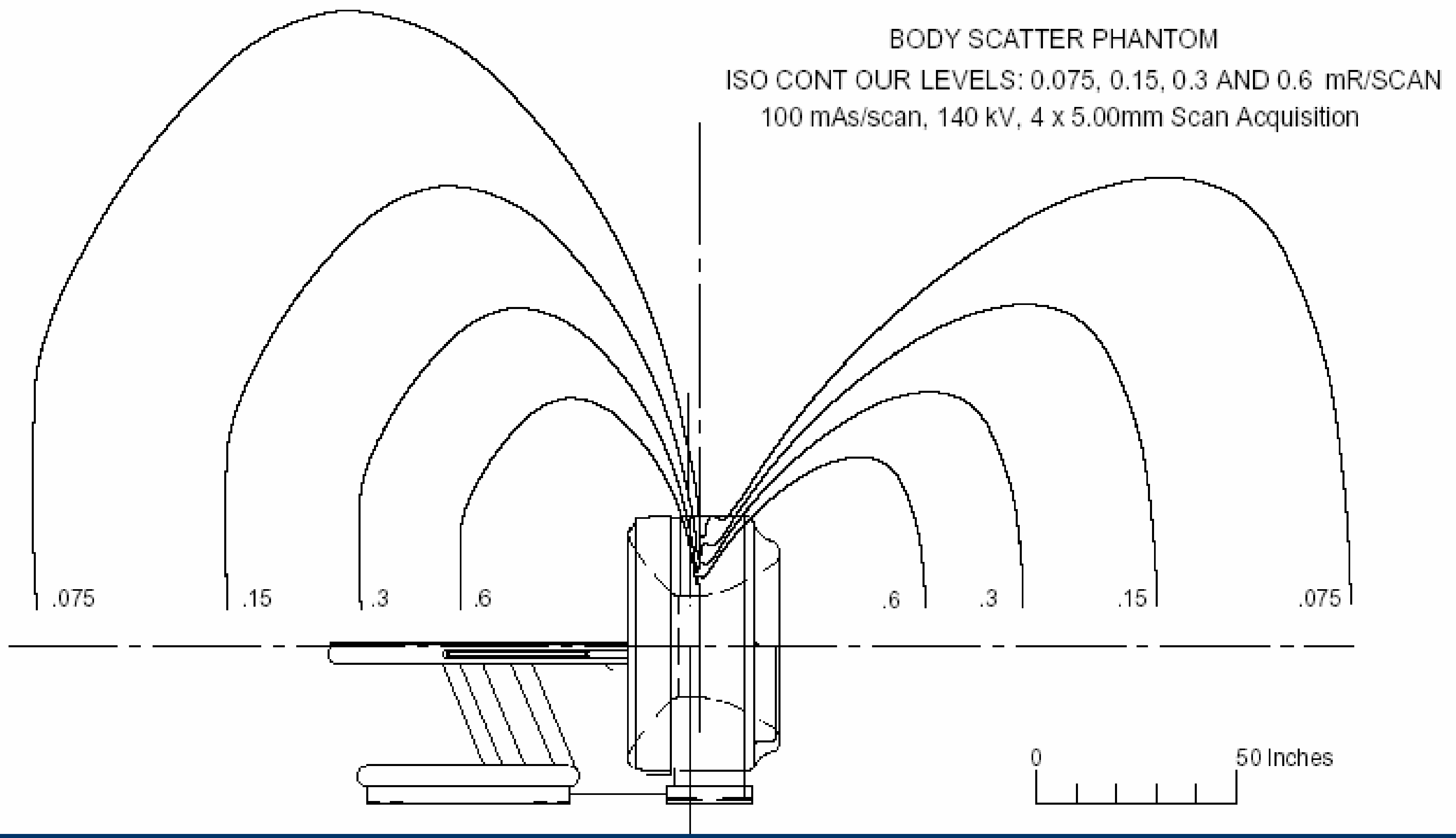
Scanning was performed using a maximum slice thickness of 20 x 1.2 mm (24 mm) at 140 kV through the system axis in the horizontal plane. A cylindrical PMMA phantom measuring 32 cm in diameter and 16 cm in length was used for the scatter radiation test. The phantom was centered in the tomographic plane.

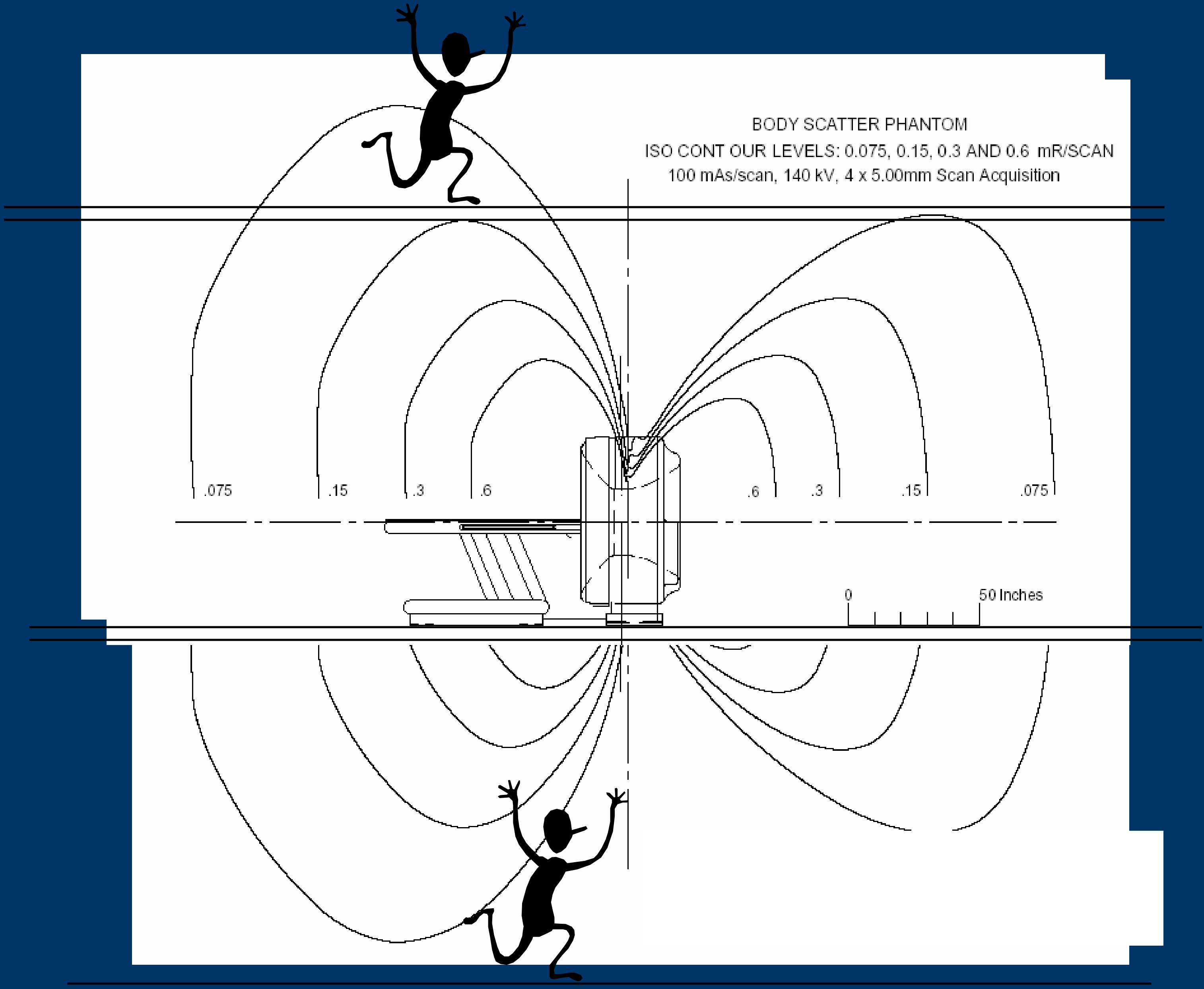
	1,50m	1,00m	0,50m	0,00m	0,50m	1,00m	1,50m
1,50m	0,013	0,032	0,040	0,043	0,038	0,032	0,012
1,00m	0,003	0,025	0,080	0,098	0,077	0,027	0,003
0,50m	0,002	0,003	0,176	0,360	0,165	0,003	0,002
0,00m	0,002						0,002
0,50m	0,004	0,026	0,215	0,436	0,150	0,031	0,005
1,00m	0,031	0,054	0,087	0,106	0,085	0,057	0,028
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


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
.3
.6
.6
.3
.15
.075
0
50 Inches


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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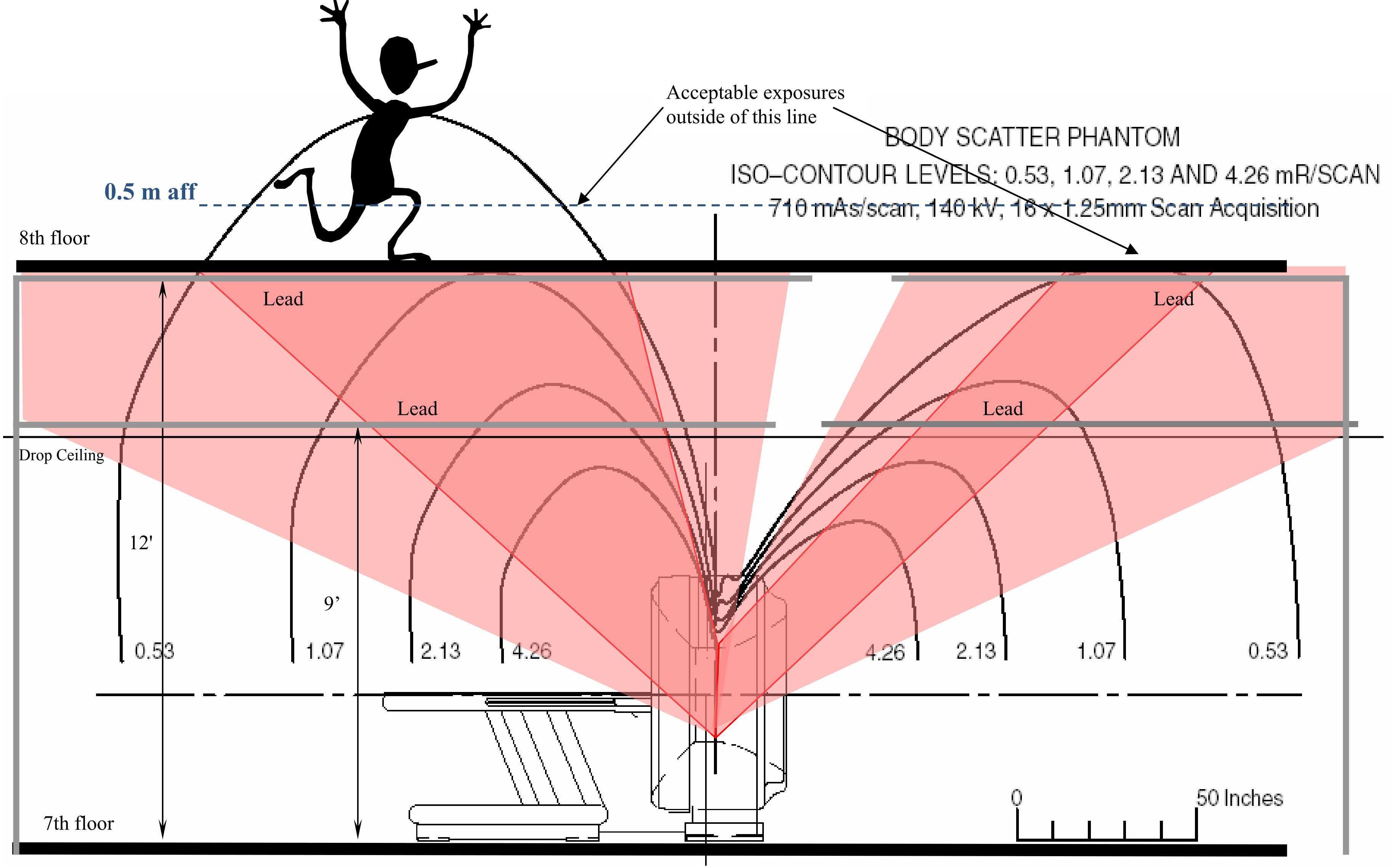
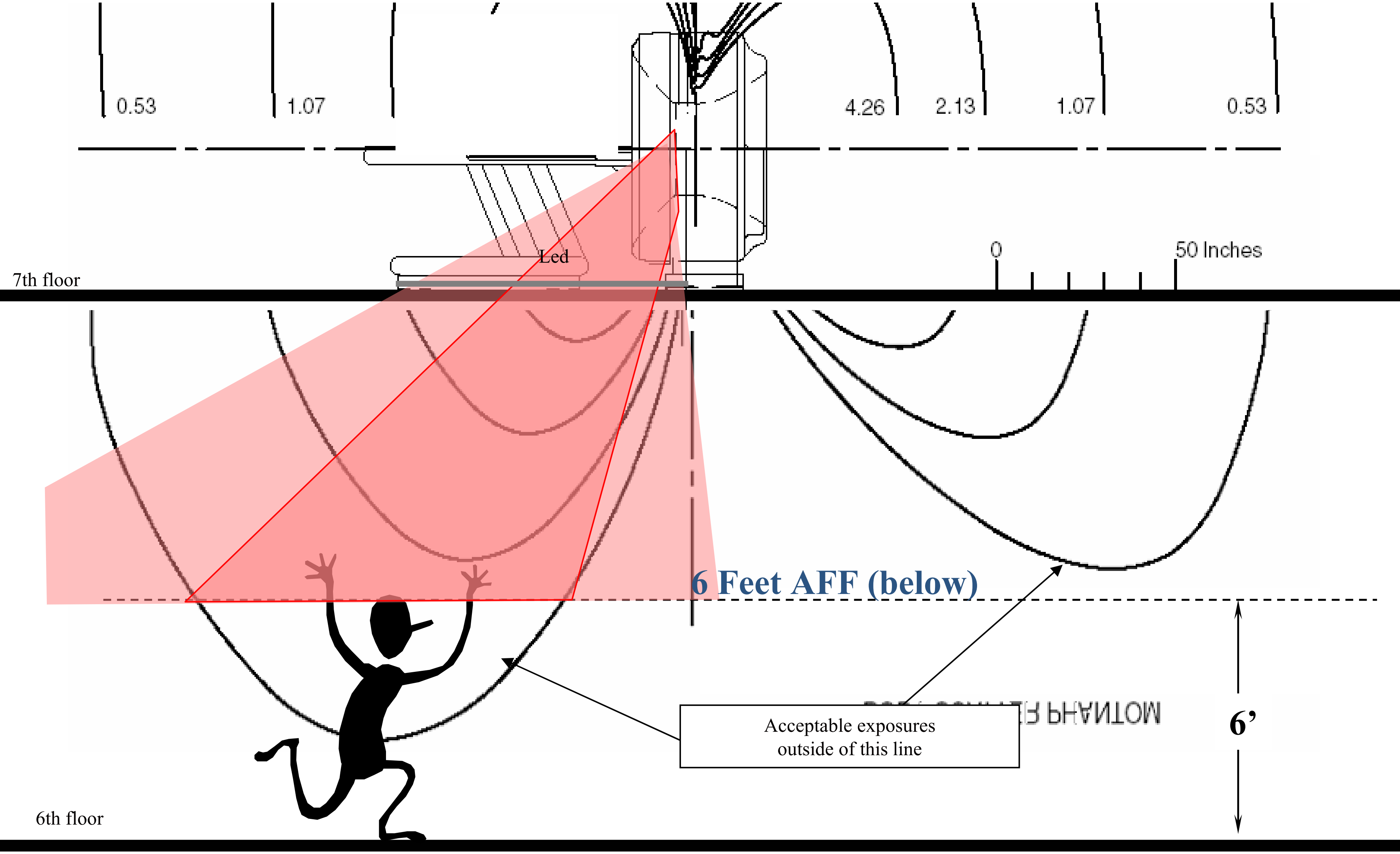
.15
.075
0
50 Inches


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
0
50 Inches
Led
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”	


Celotex

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)

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