CT: Shielding and Radiation Protection

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Disclosures

Nothing to disclose

Learning Objectives

- **Understand approaches to specifying the shielding requirements for a CT scan room**
- **Review three acceptable methods for specs**
- **Review radiation protection methods for CT personnel**
- **Review patient shielding practices**

Shielding CT Scan Rooms

Shielding: NCRP Report 147

THE Reference


NCRP REPORT No. 147

Structural Shielding Design for Medical X-Ray Imaging Facilities

Recommendations of the NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

Issued November 19, 2004
Revised March 18, 2005

National Council on Radiation Protection and Measurements
7910 Woodmont Avenue, Suite 400 / Bethesda, MD 20814

Depending on the circumstances…

…both of these could be your best friend!

Shielding: Purpose

"To limit radiation exposure to employees and members of the general public to an acceptable level."

- Design Goals (P) *(in air kerma)*

Controlled Area: 0.1 mGy/week (5 mGy/yr)

Uncontrolled Area: 0.02 mGy/week (1 mGy/yr)

Shielding: Definitions

Controlled Area

Limited access area under supervision by an individual in charge of radiation protection.

Occupancy and working conditions are controlled for radiation protection purposes.

Uncontrolled Area

Not a controlled area.

Shielding: Definitions

Occupancy Factor

Average fraction of time that the maximally exposed individual is present while the x-ray beam is on.

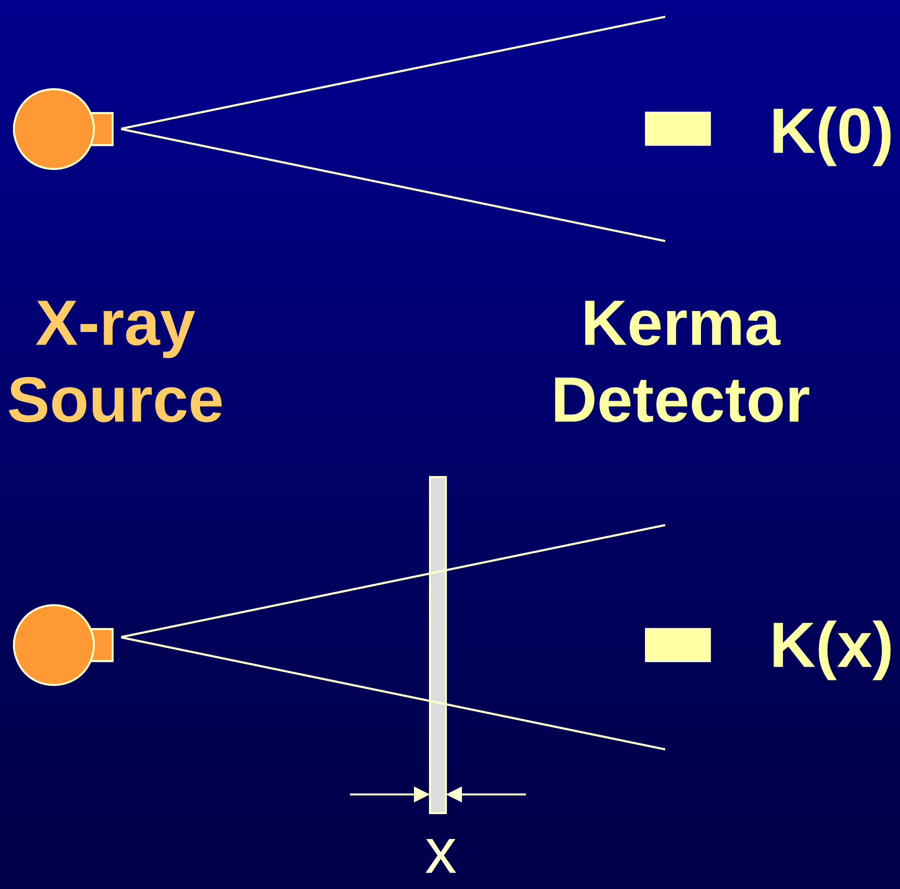
Not *any* person, but the *single* person who spends the most time there.

Suggested Occupancy Factors (T)

Location	T
Offices, labs, pharmacies, receptionist areas, attended waiting rooms, kid's play areas, x-ray rooms, nurse stations, reading rooms, control rooms	1
Exam and treatment rooms	1/2
Corridors, patient rooms, employee lounges & rest rooms	1/5
Corridor doors	1/8
Public toilets, vending areas, storage rooms, outdoor areas w/ seating, unattended waiting rooms, patient holding	1/20
Outdoors, unattended parking lots, attics, stairways, unattended elevators, janitor closets	1/40

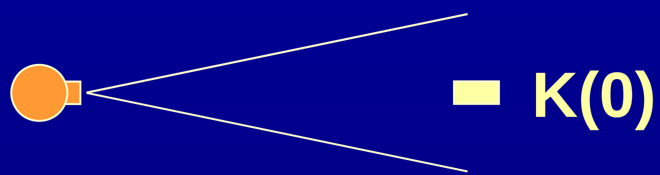
Shielding: Definitions

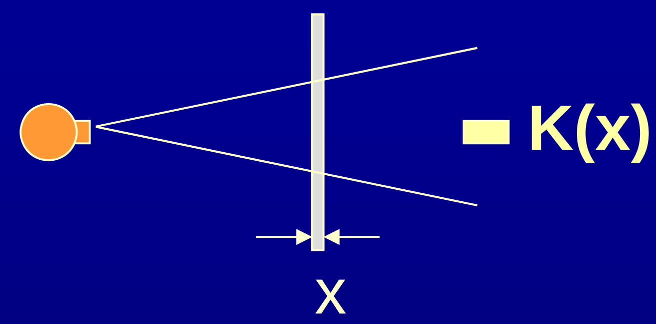
Barrier Transmission



$$B(x) = \frac{K(x)}{K(0)}$$

Barrier Transmission Usage





Design Goal (P)

$$B(x) = \frac{K(x)}{K(0)} \quad \Rightarrow \quad B(x) = \frac{P}{T \times K_{sec}}$$

CT: Only secondary

Occupancy Factor

Use B(x) to lookup barrier thickness

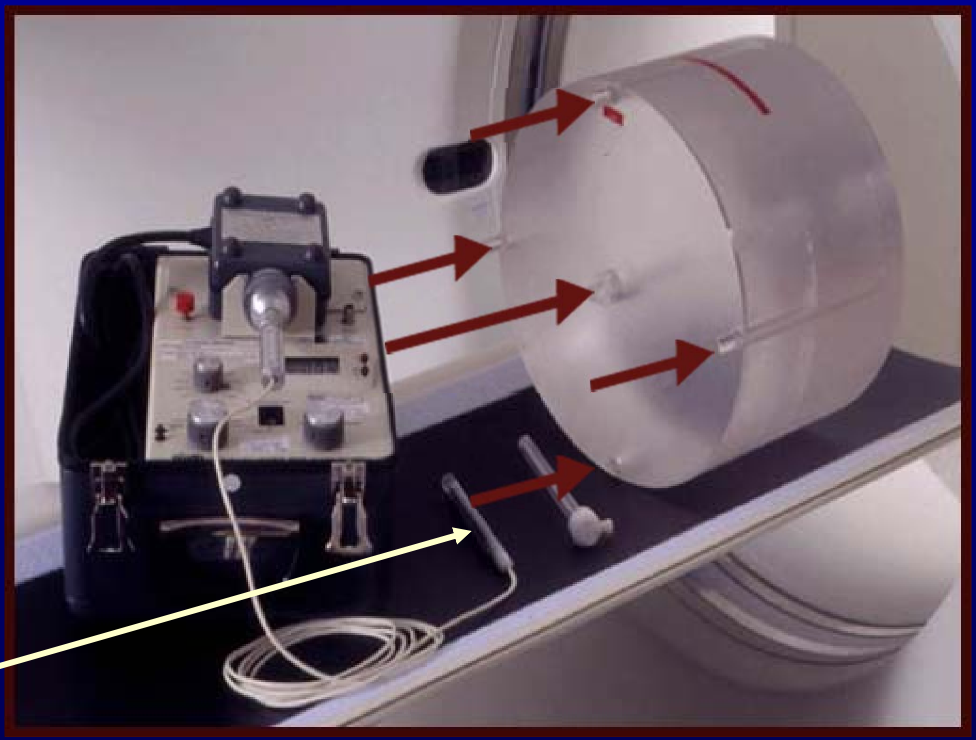
Shielding: General Scheme

1. Obtain tube output (at given distance) for given procedures
2. Estimate number of procedures per week
3. Decide usage of adjacent & nearby spaces (for occupancy factor & design goal)
4. Calculate barrier transmission factor
5. Look-up required shielding thickness

CT: Step 1. Obtain tube output

- Three Different Methods
  - CTDI-100
  - Dose Length Product (DLP)
  - Isodose Map

CTDI-100 Method



10 cm Pencil Chamber

Body Phantom (32 cm)

Head Phantom (16 cm)

CTDI-100 Method

Secondary air kerma per patient at 1 m

At 1 m ↓

$$K_{sec}^{1} = \mathrm{K}\,\frac{L}{p}\,CTDI_{100}$$

↑ Secondary

CTDI-100 Method

Secondary air kerma per patient at 1 m

Scatter fraction per cm (peripheral phantom axis)

$$K_{sec}^{1} = \kappa \frac{L}{p} CTDI_{100}$$

Kappa (κ): Head = 9×10^{-5} cm^{-1}

Body = 3×10^{-4} cm^{-1}

Considers leakage too!

CTDI-100 Method

Secondary air kerma per patient at 1 m

Length of scan (cm) ↓

$$K^{1}_{sec} = K \frac{L}{p} CTDI_{100}$$

↑ Pitch

CTDI-100 Method

Secondary air kerma per patient at 1 m

$$K_{sec}^{1} = \kappa \frac{L}{p} \, CTDI_{100}$$

↑ At "typical" technique

CTDI-100 Method

Secondary air kerma per patient at 1 m

$$K^{1}_{sec} = \mathrm{K} \frac{L}{p} \, mAs \; {}_{n}CTDI_{100}$$

↑ Normalized per unit mAs*

*From measured or published values

CTDI-100 Method

Secondary air kerma per patient at "D" m

Inverse square law

$$K_{sec} = \left(\frac{1\ m}{D\ m}\right)^2 \kappa \frac{L}{p}\ mAs\ {}_nCTDI_{100}$$

CTDI-100 Method

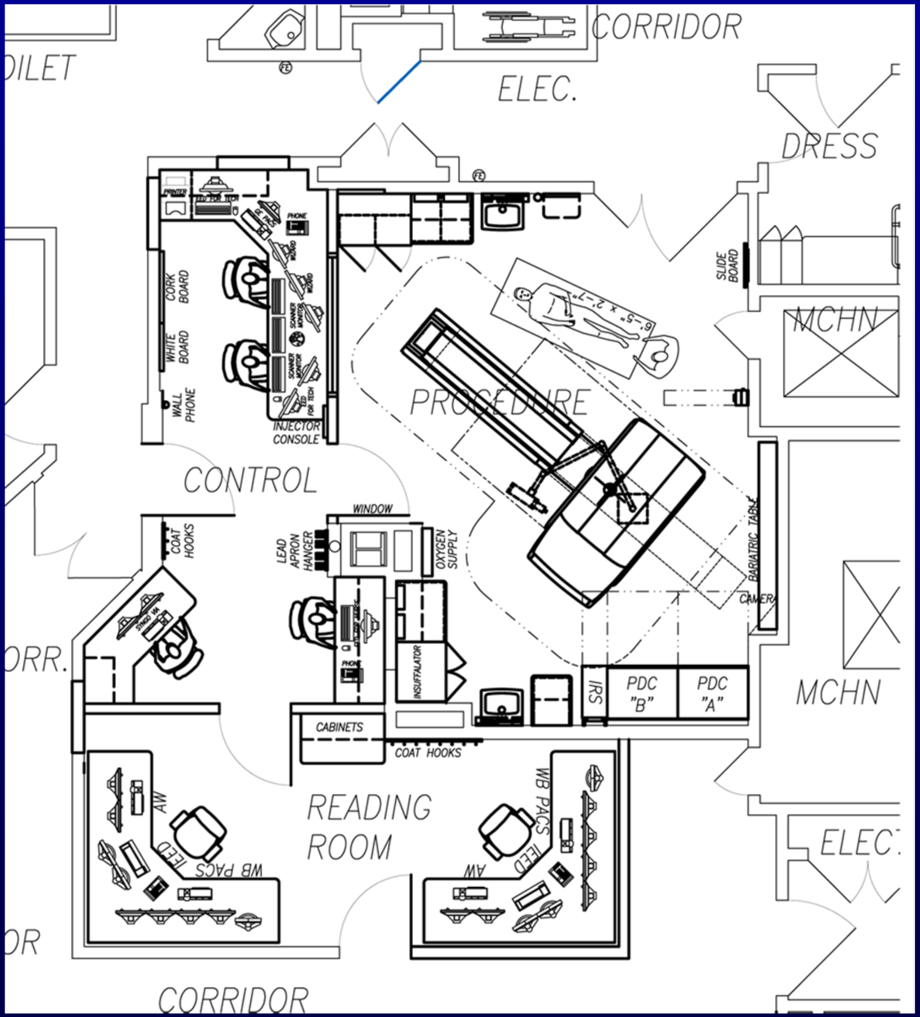
Secondary air kerma per week at "D" m

Number of patients/week ↓

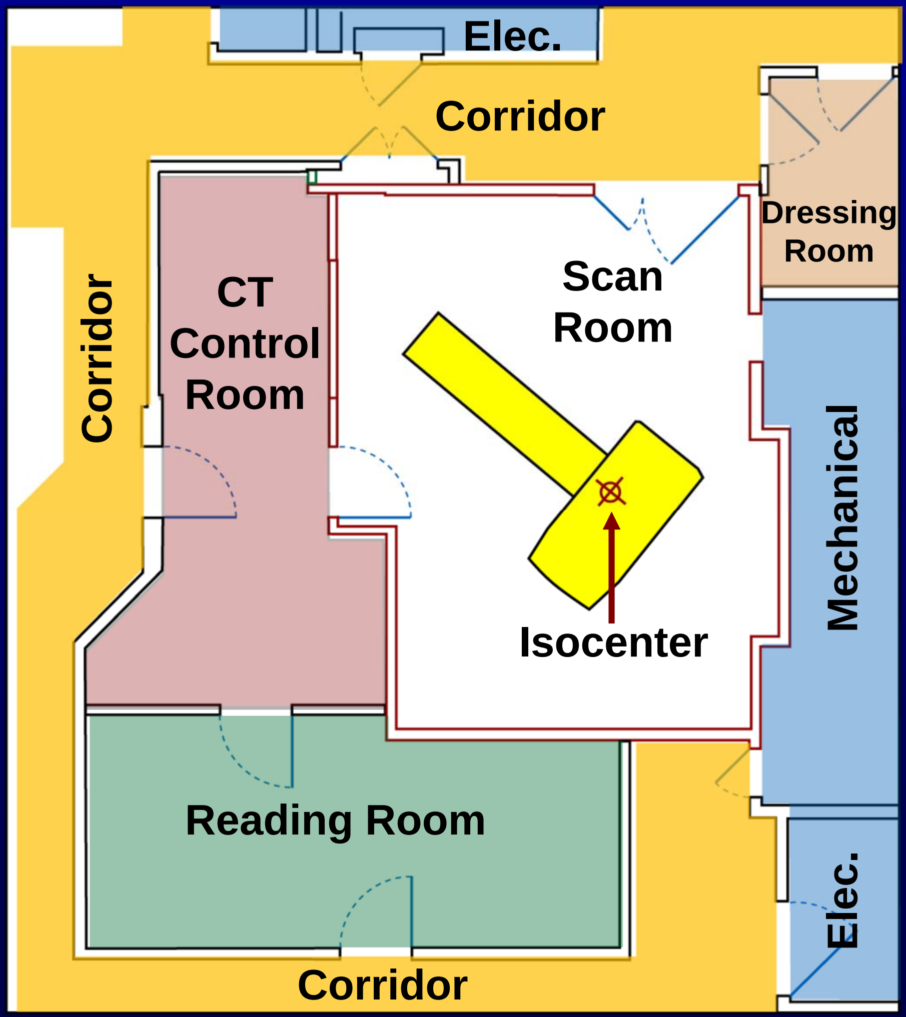
$$K_{sec} = N \left(\frac{1\ \mathrm{m}}{D\ \mathrm{m}} \right)^2 \mathrm{K} \ \frac{L}{p} \ \mathrm{mAs}\ {}_{n}\mathrm{CTDI}_{100}$$

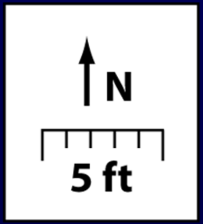
Units of mGy/week

CT Shielding: EXAMPLE

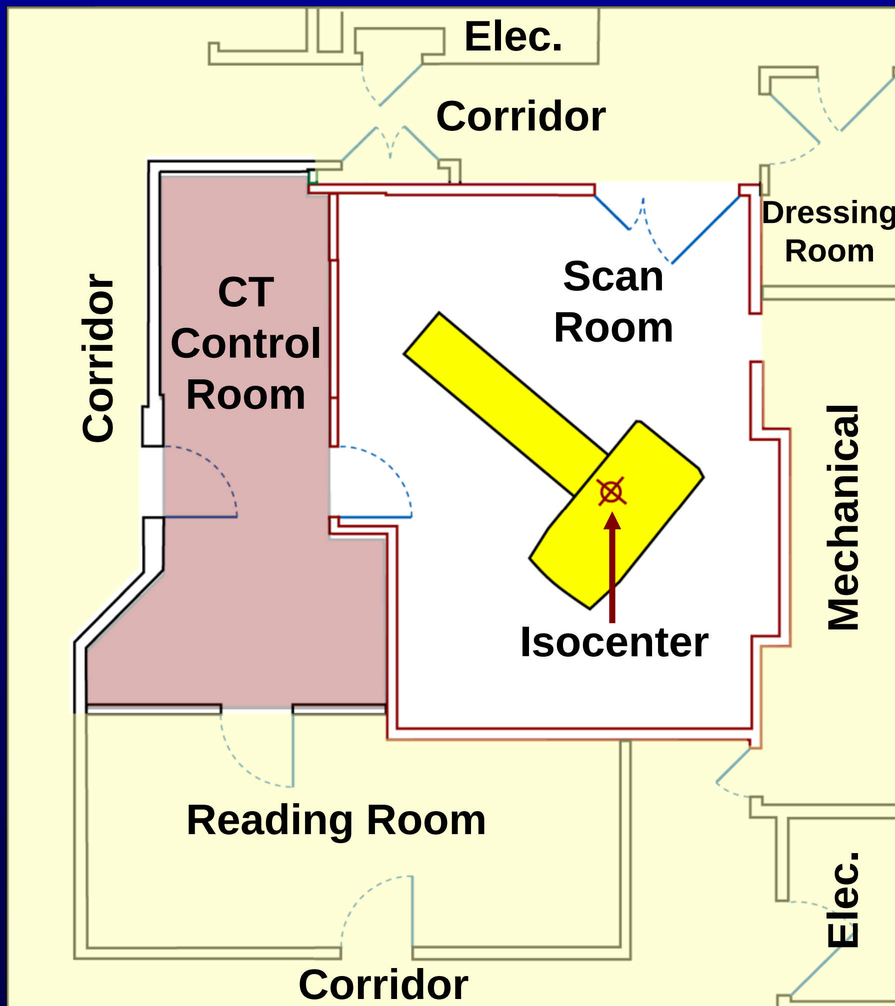


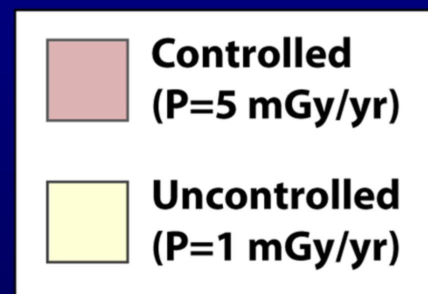
CT Shielding: EXAMPLE

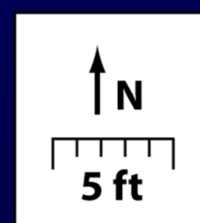




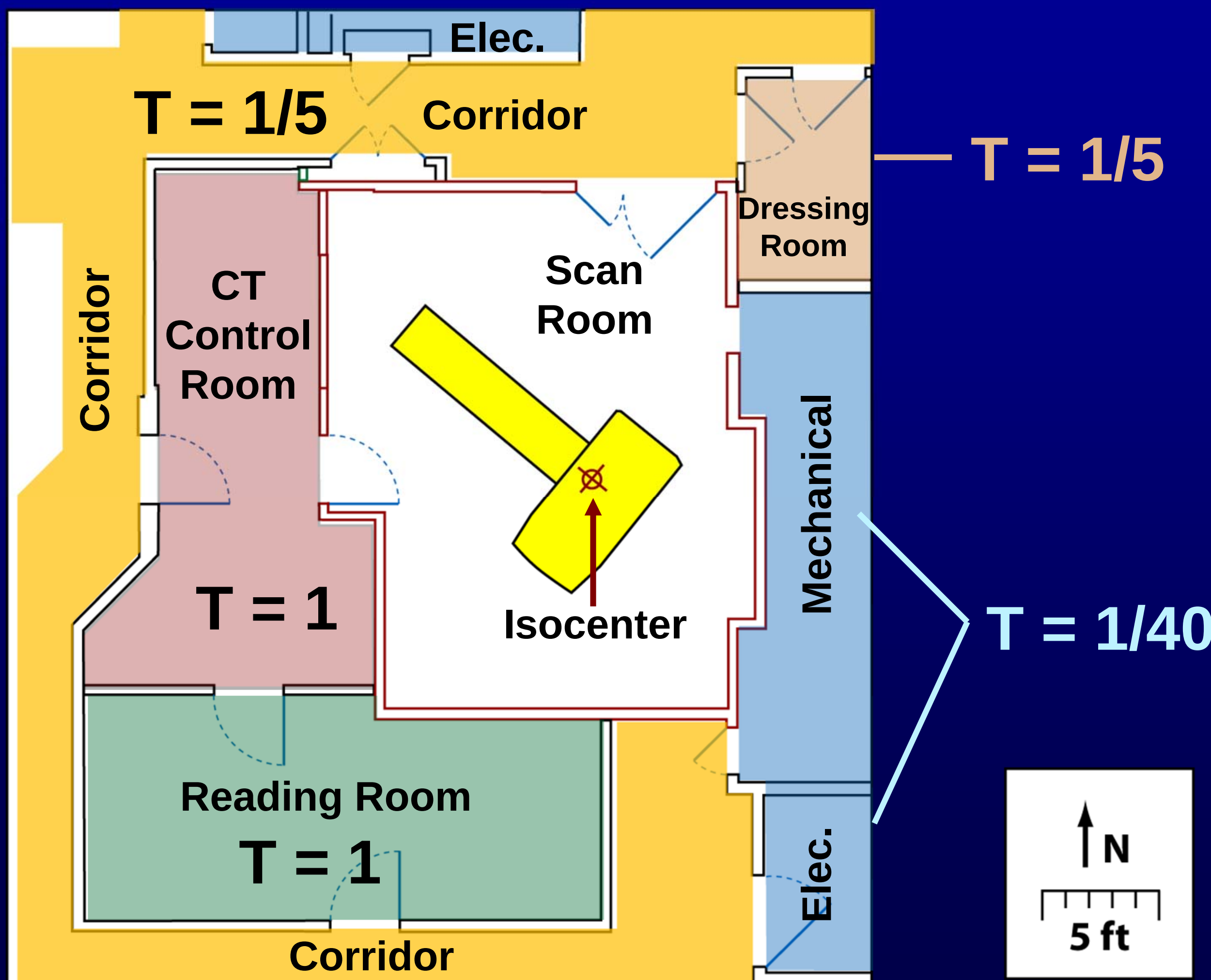
CT Shielding: EXAMPLE







CT Shielding: EXAMPLE

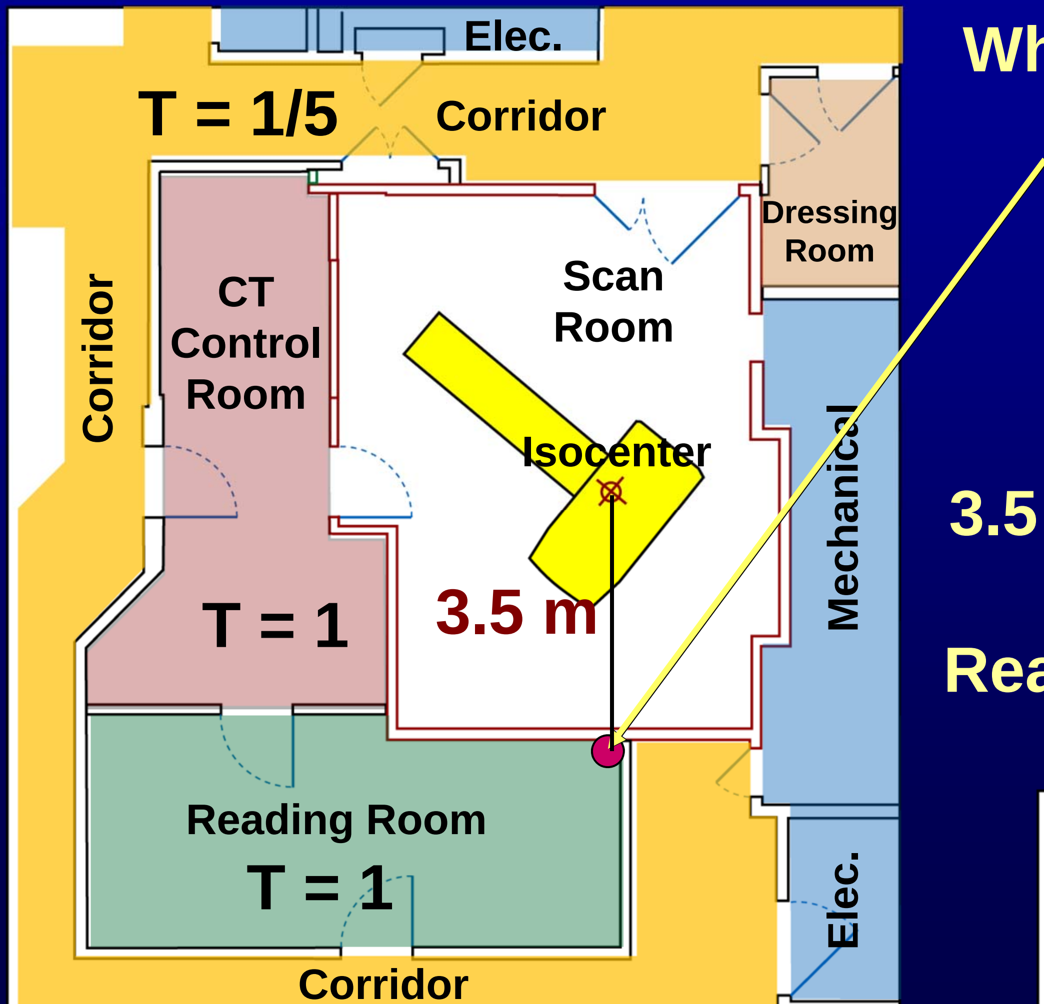


CT Shielding: EXAMPLE

- **Workload (Body scanner)**

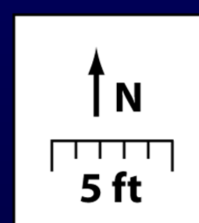
175	Patients/work week (35 Patients/day)
1.25	Scans/patient (pre- & post-contrast)
60	Average scan length (cm)
0.5	Gantry rotation time (s)
120	kVp
300	Average effective mAs (Implies 300 mAs at pitch of 1.0)
7.8	Average total scan time (s)
0.08	${}_{n}CTDI_{100}$ (mGy/mAs)

CT Shielding: EXAMPLE



What shielding is required here?

3.5 m from isocenter (0.3 m inside Reading Room wall)



CTDI-100 Method

Secondary air kerma per week at 3.5 m

$$K_{sec} = N \left(\frac{1\ \text{m}}{D\ \text{m}} \right)^2 \kappa \frac{L}{p}\ \text{mAs}\ {}_nCTDI_{100}$$

$$K_{sec} = 218.75 \left(\frac{1\ \text{m}}{3.5\ \text{m}} \right)^2 3\text{x}10^{-4}\ \text{cm-1}\ \frac{60\ \text{cm}}{1}\ 300\ \text{mAs}\ 0.08\ \text{mGy/mAs}$$

Scans/week

$$K_{sec} = 7.71\ \text{mGy/wk}$$

CTDI-100 Method

- **Design Goal (P)** ***(in air kerma)***
  - **- Uncontrolled Area: 0.02 mGy/week (1 mGy/yr)**
- **So Transmission factor is:**

$$B(x) = \frac{P}{T\,K_{sec}} = \frac{0.02\ \text{mGy/wk}}{(1)\ 7.71\ \text{mGy/wk}}$$

$$= 2.6 \times 10^{-3}$$

Note: Occupancy factor was “1”

CT Shielding: EXAMPLE

$B(x) = 2.6 \times 10^{-3}$

Look to Fig. 2.3 to see what to specify

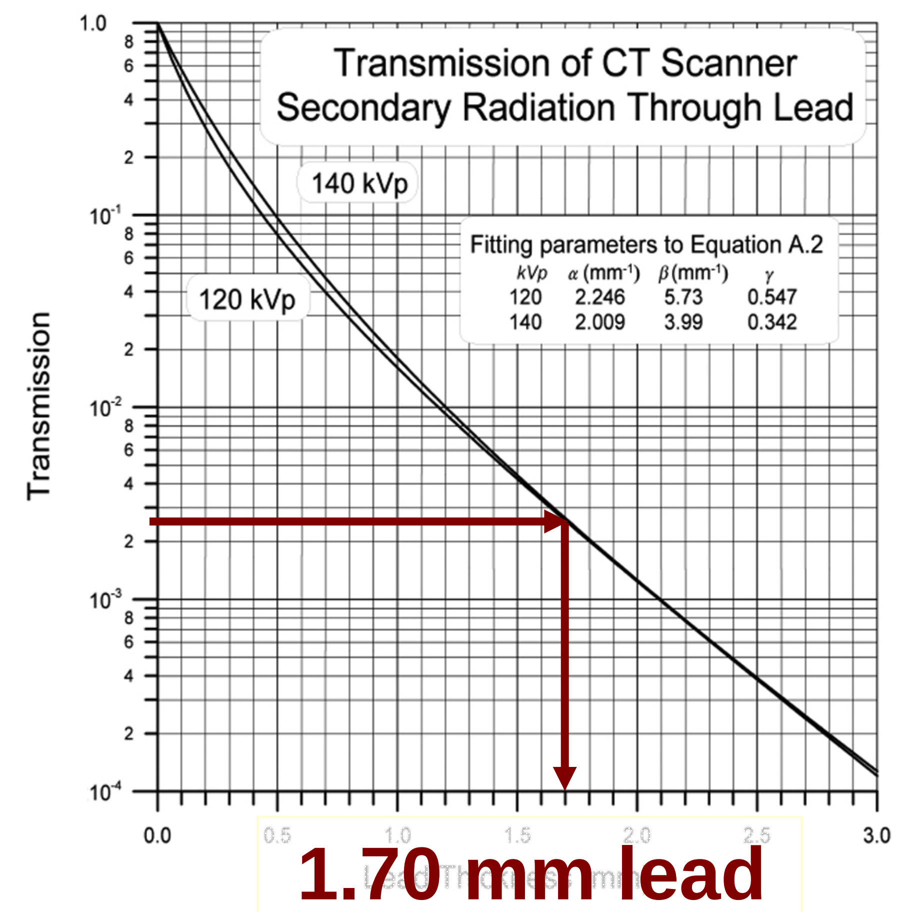


Fig. A.2. Transmission through lead of secondary radiation from CT scanners [data of Simpkin (1991) fitted to Equation A.2].

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CT Shielding: EXAMPLE

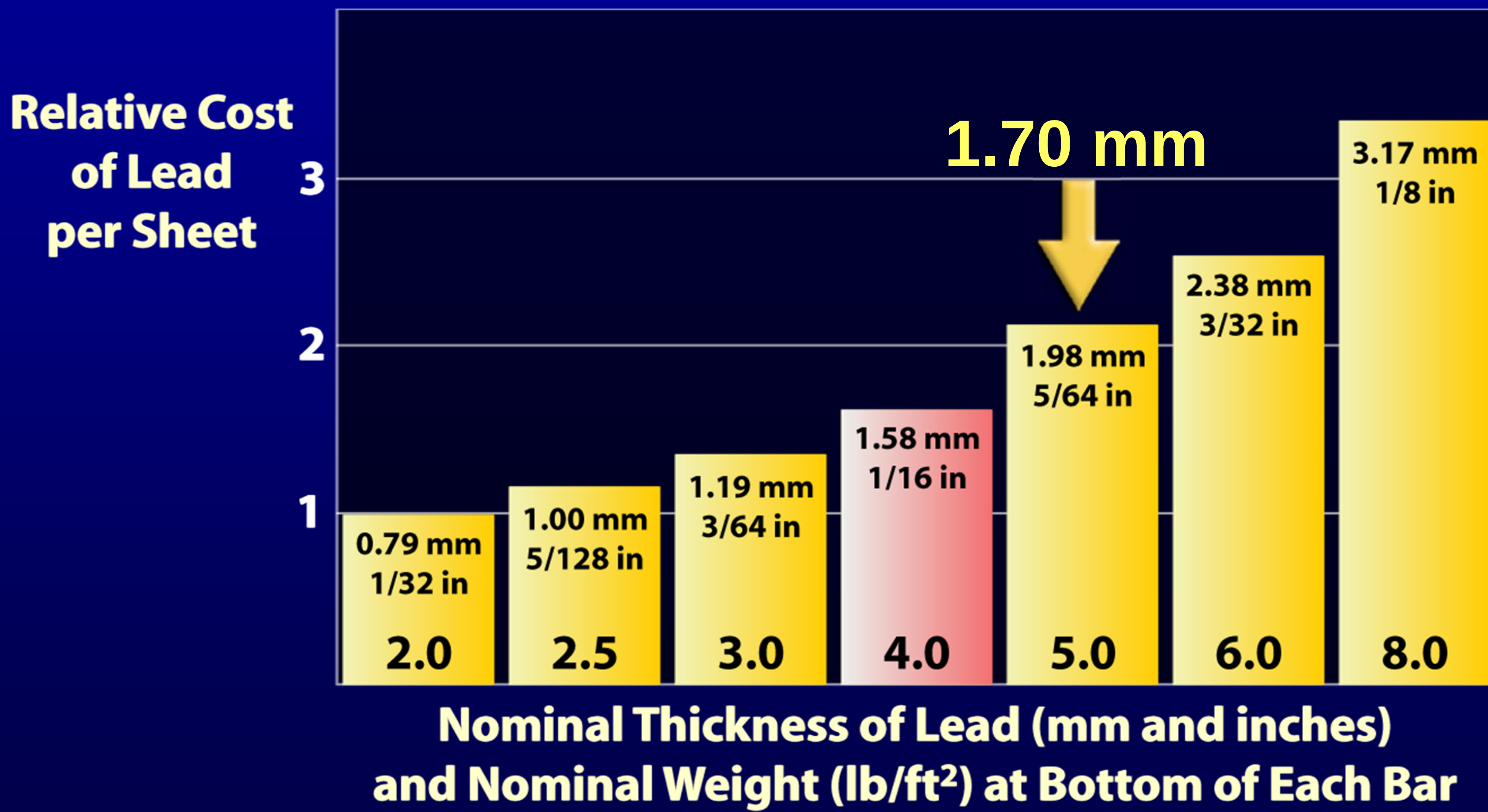

Figure 2.3 NCRP Report No. 147

CT Shielding: EXAMPLE

$B(x) = 2.6 \times 10^{-3}$

Could use:
5 lb lead
(1.98 mm,
5/64 inch)

But wait!!

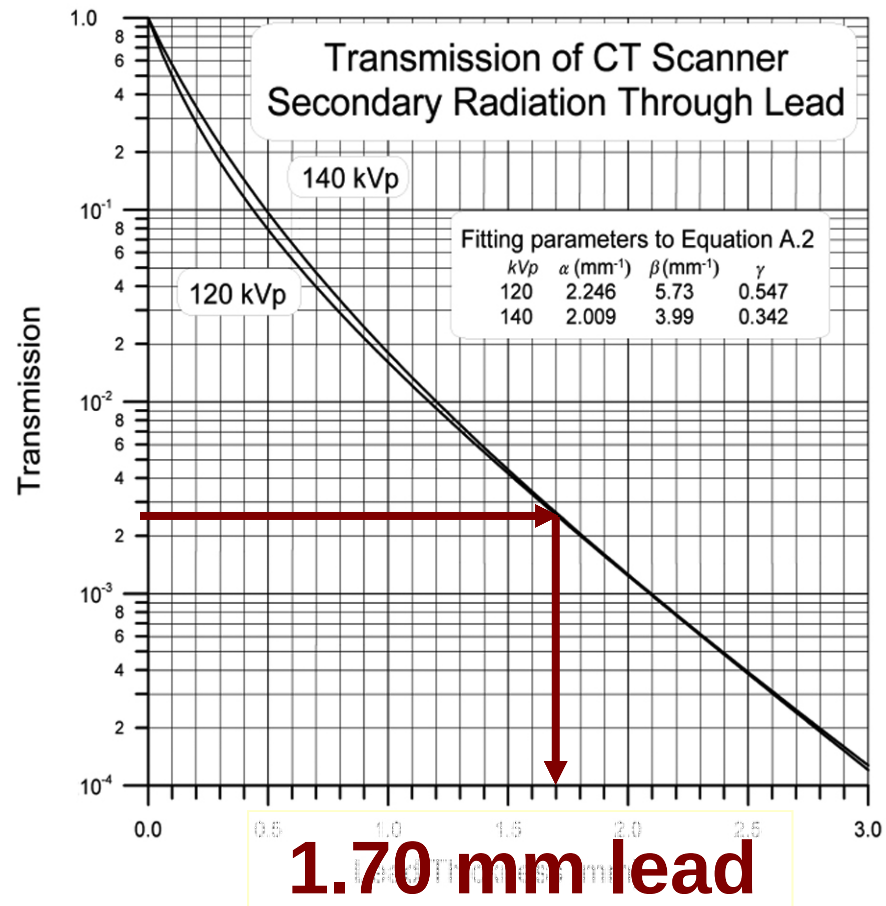

Fig. A.2. Transmission through lead of secondary radiation from CT scanners [data of Simpkin (1991) fitted to Equation A.2].

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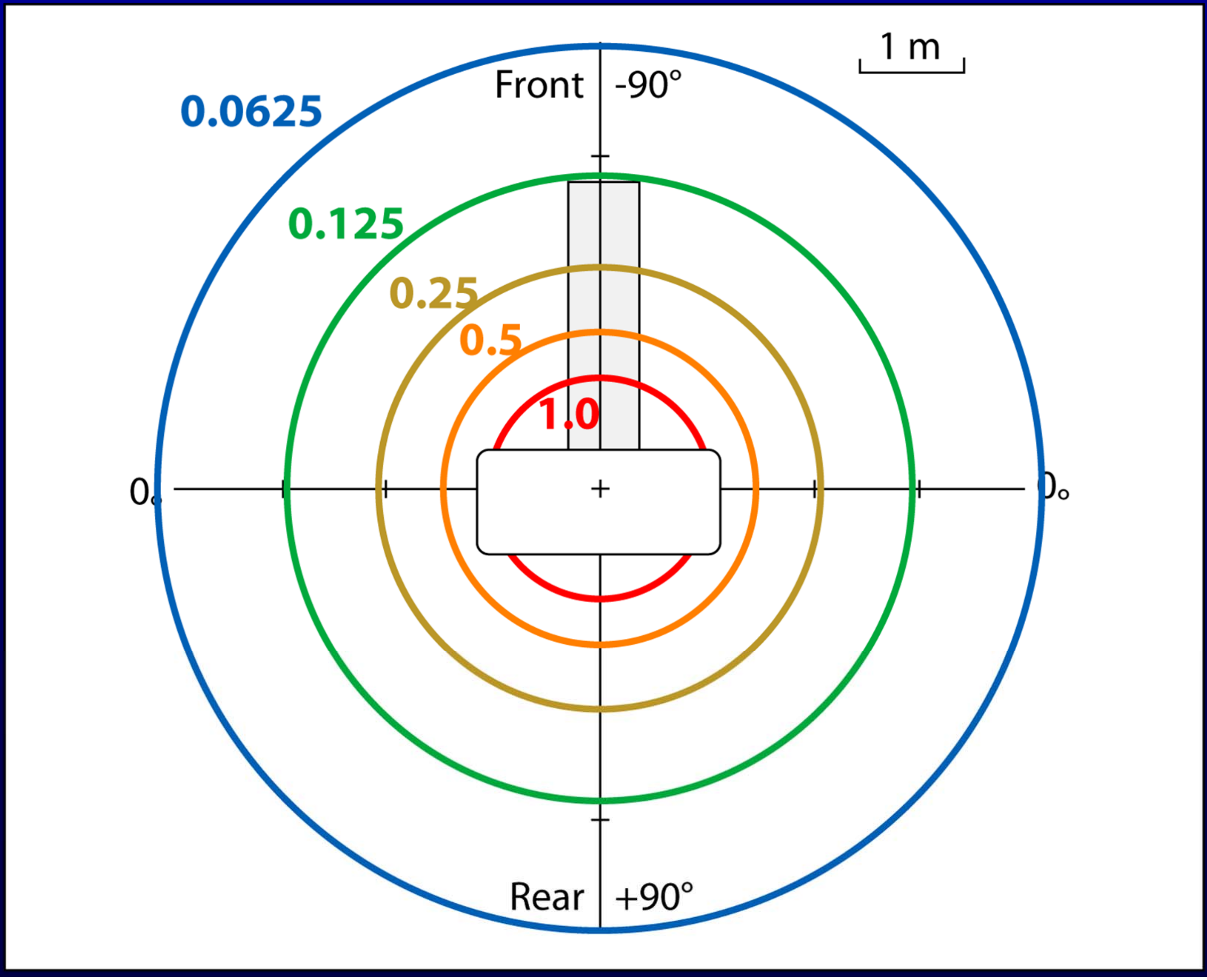
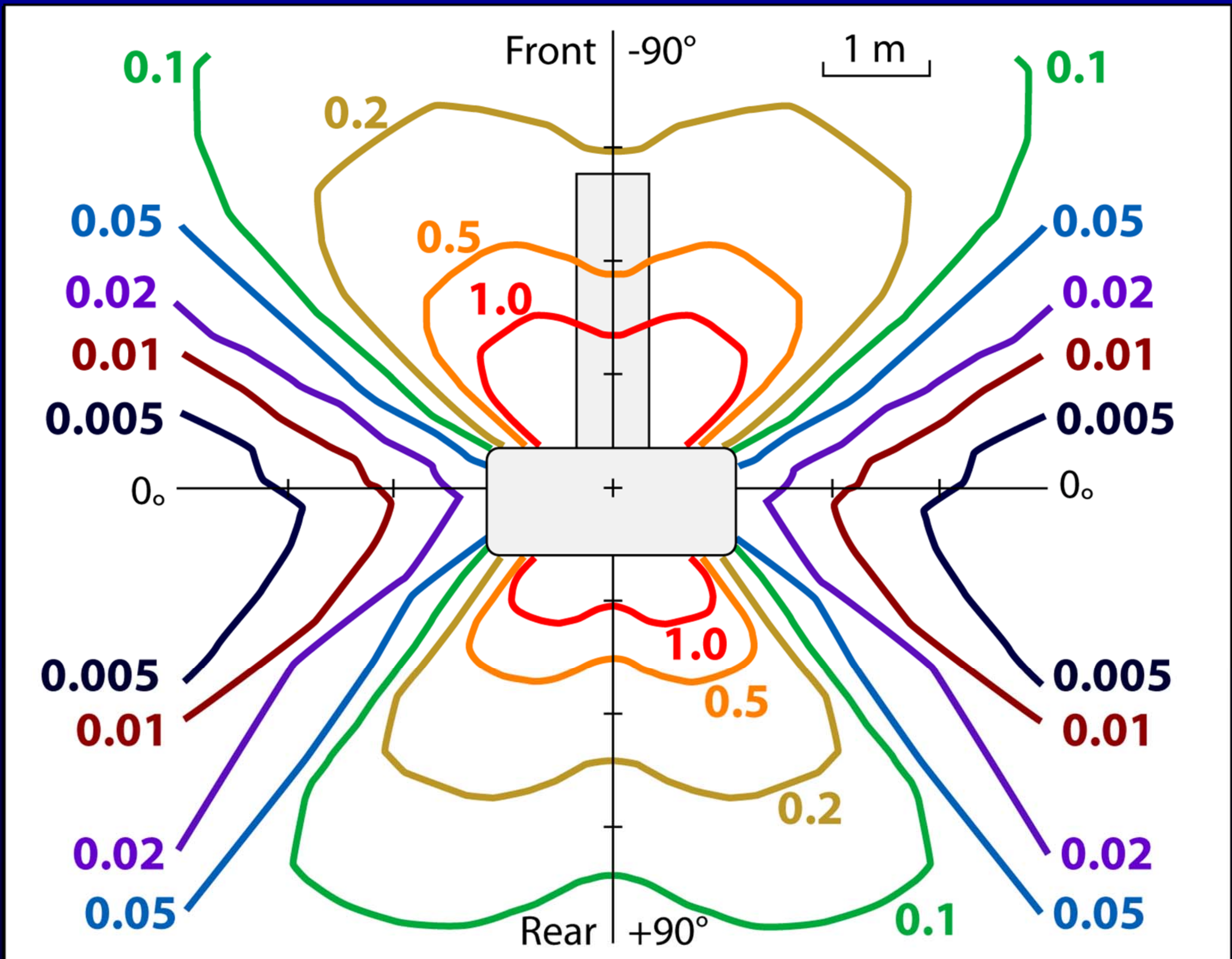
CTDI-100 Method: Isotropic Assumption

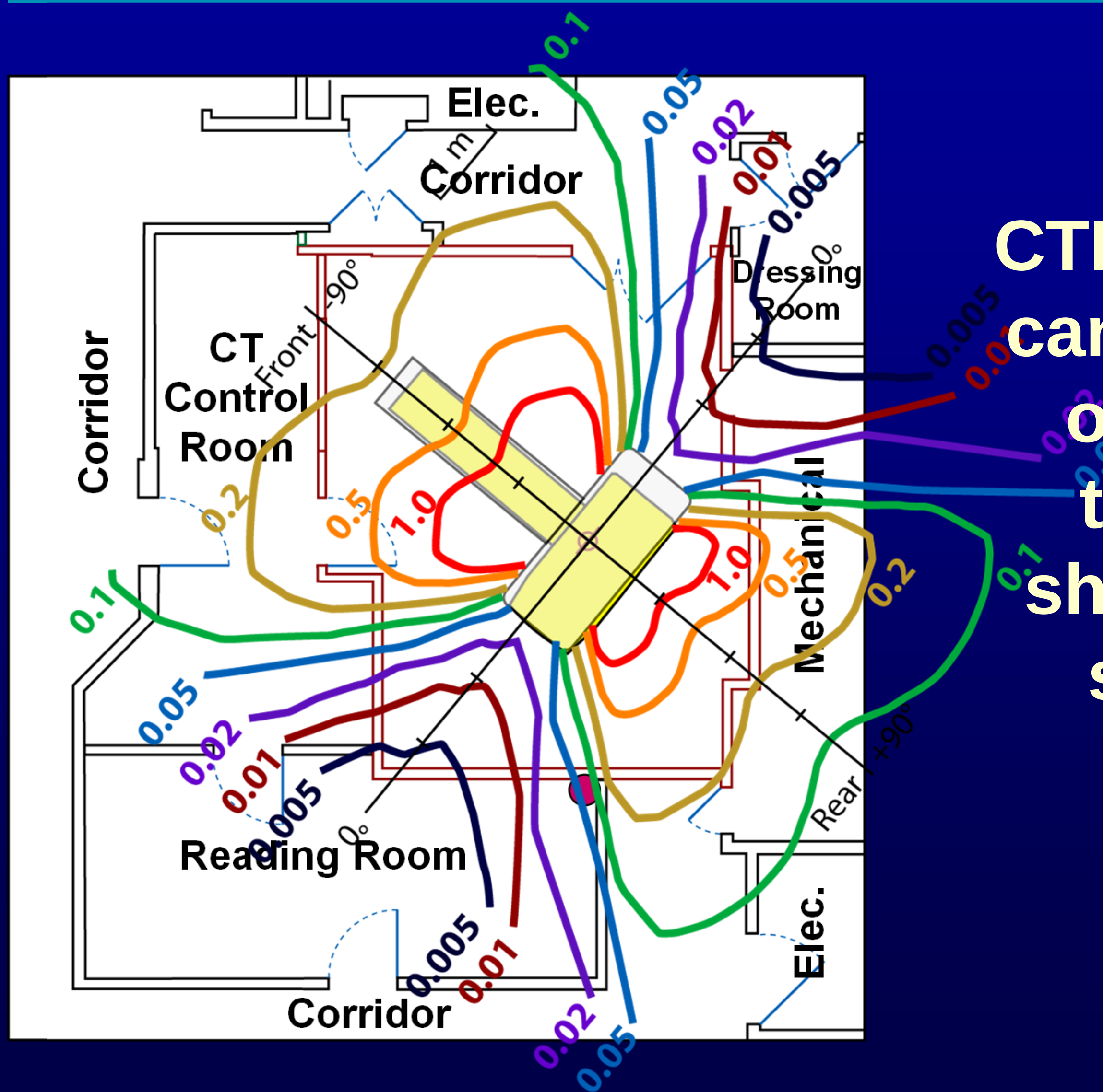


CTDI-100 Method: Measured Scatter



Adapted from Wallace, et. al, J. Radiol. Prot. 32 (2012) 39-50

CT Shielding: EXAMPLE

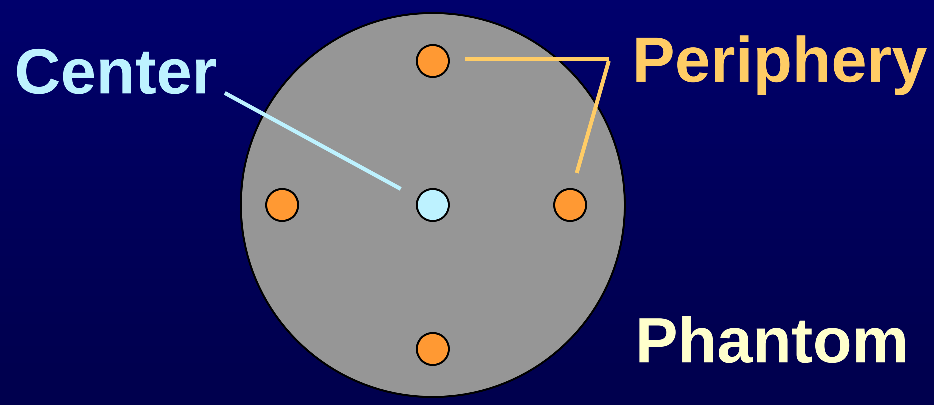


CTDI-100 Method can significantly overestimate the required shielding along sides of the scanner!

Dose-Length Product (DLP) Method

$$DLP = CTDI_{vol} \times \text{Scan Length}$$

$$CTDI_{vol} = \frac{1/3\ CTDI_{100,\ center} + 2/3\ CTDI_{100,\ periphery}}{Pitch}$$



DLP (and $CTDI_{vol}$) are displayed on scanner console

Dose-Length Product (DLP) Method

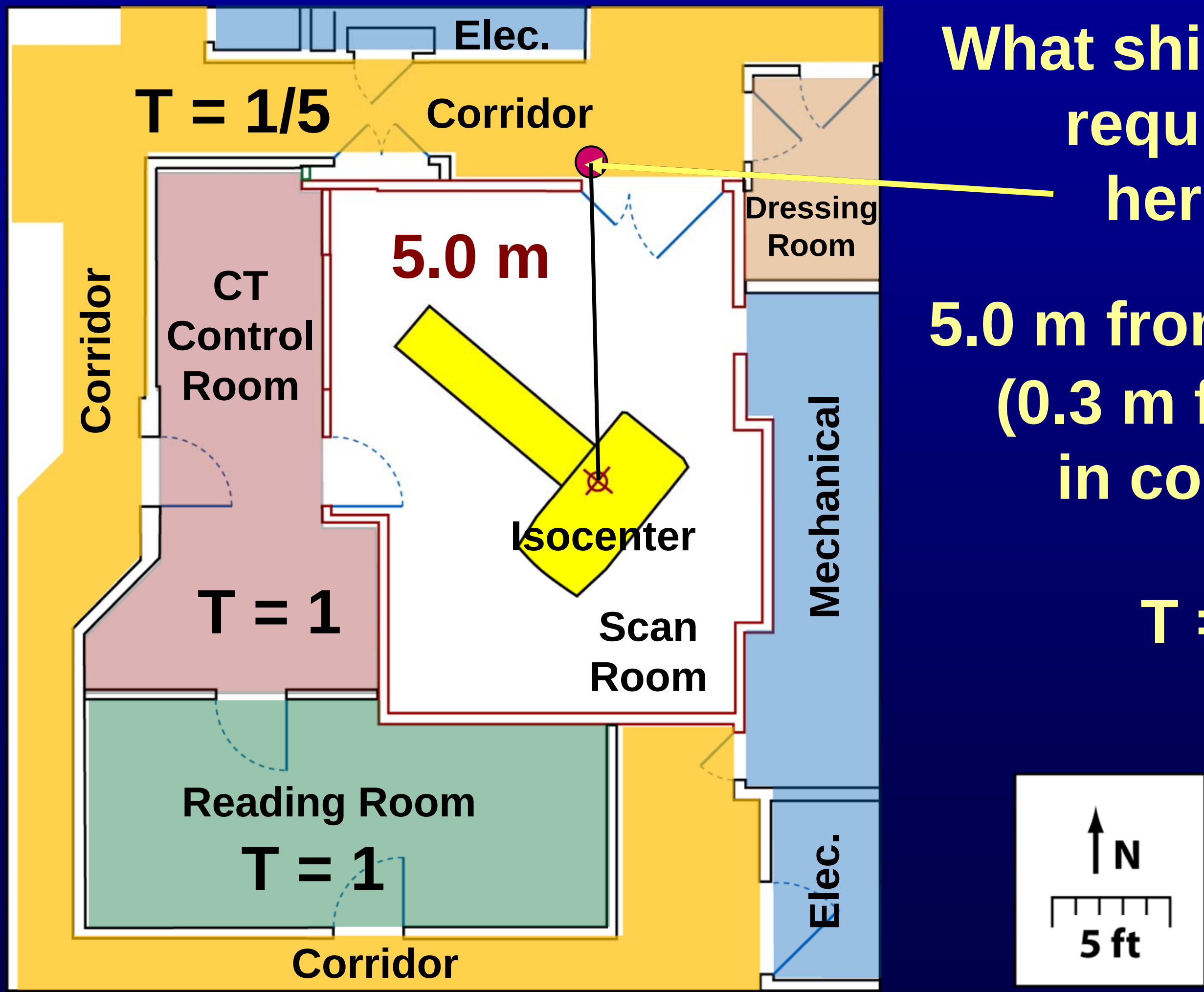
Secondary air kerma per procedure at 1 m

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

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

As before, multiply by the number of procedures and inverse-square for the wall distance.

CT Shielding: EXAMPLE



What shielding is required here?

5.0 m from isocenter (0.3 m from wall in corridor)

T = 1/5

DLP Method: EXAMPLE

- **Workload (Body scanner)**

175 Patients/work week

1.25 Scans/patient (pre- & post-contrast)

= 218.75 procedures per week

All are chest, abdomen, pelvis or combo

Need DLP values!

DLP Method: EXAMPLE

- Typical DLPs from Table 5.2 (NCRP 147)

Procedure	DLP (mGy cm)
Head	1,200
Chest	525
Abdomen	625
Pelvis	500
Body Average (chest, abdomen, or pelvis)	550

DLP Method: EXAMPLE

CAUTION

Be careful about using published "typical" values

Estimates should be based on site-specific data, when possible

DLP Method: EXAMPLE

Secondary air kerma per procedure at 1 m

$$K^{1}_{sec}\text{ (body)} = 1.2 \times 3\times10^{-4}\ \text{cm}^{-1} \times 550\ \text{mGy-cm}$$

$$= 0.198\ \text{mGy/procedure}$$

Secondary air kerma per week at 5.0 m

$$K_{sec} = \left(\frac{1\ \text{m}}{5.0\ \text{m}}\right)^{2} 218.75\ \text{procs} \times 0.198\ \text{mGy/proc}$$

$$= 1.73\ \text{mGy/week}$$

DLP Method: EXAMPLE

- Design Goal (P) *(in air kerma)*
  - Uncontrolled Area: 0.02 mGy/week (1 mGy/yr)
- So Transmission factor is:

$$B(x) = \frac{P}{T\,K_{sec}} = \frac{0.02\ \text{mGy/wk}}{(1/5)\ 1.73\ \text{mGy/wk}}$$

$$= 5.7 \times 10^{-2}$$

CT Shielding: EXAMPLE

B(x) = 5.7 x 10^{-2}

Could use:
2 lb lead
(0.79 mm,
1/32 inch)

But wait!!

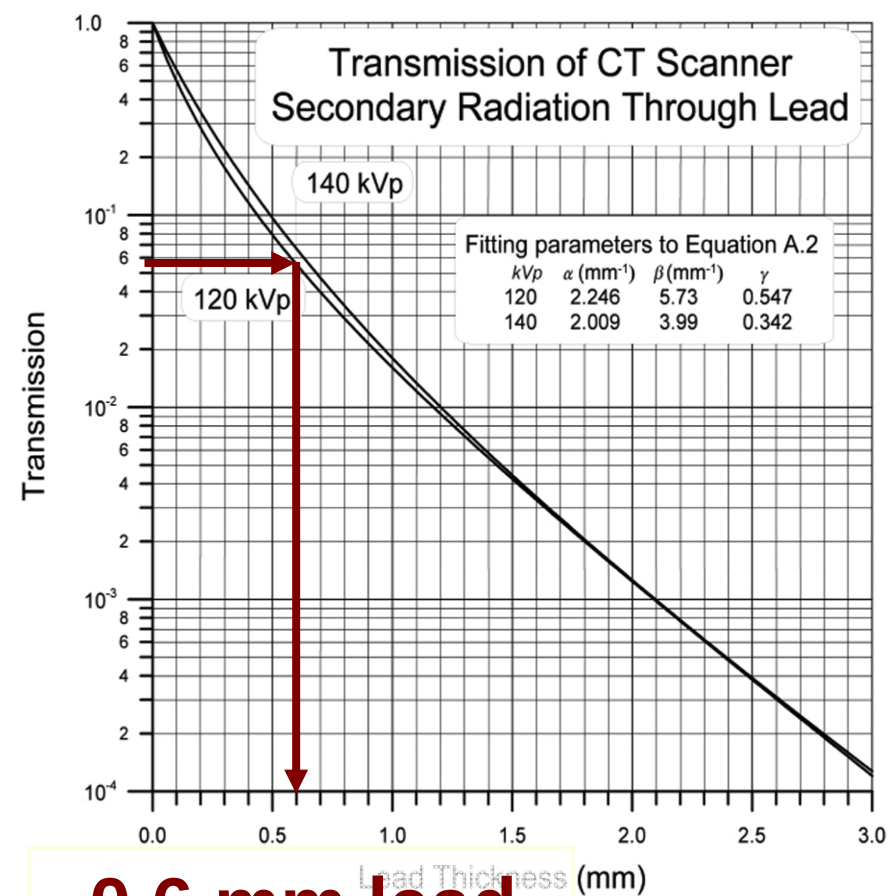


Fig. A.2. Transmission through lead of secondary radiation from CT scanners [data of Simpkin (1991) fitted to Equation A.2].

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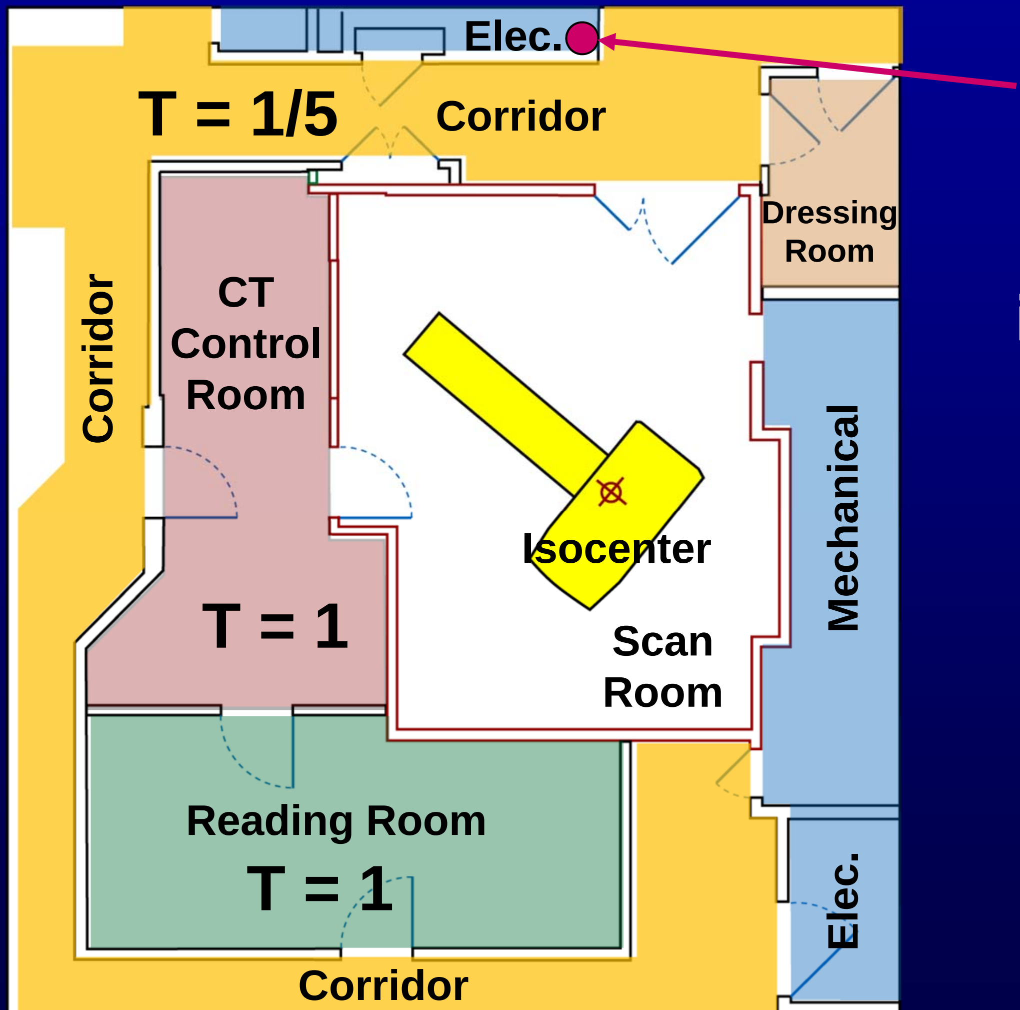
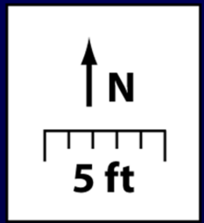
Consistency in lead thickness

- Must document lead in walls (so always know), but…
- Having consistency with all walls
  - Easier for carpenters
  - Easier if scanner changes
  - Easier if room use changes
  - Doors and windows often re-used in remodeling projects (these must be same as in walls)
- Exception may be if one wall needs more lead

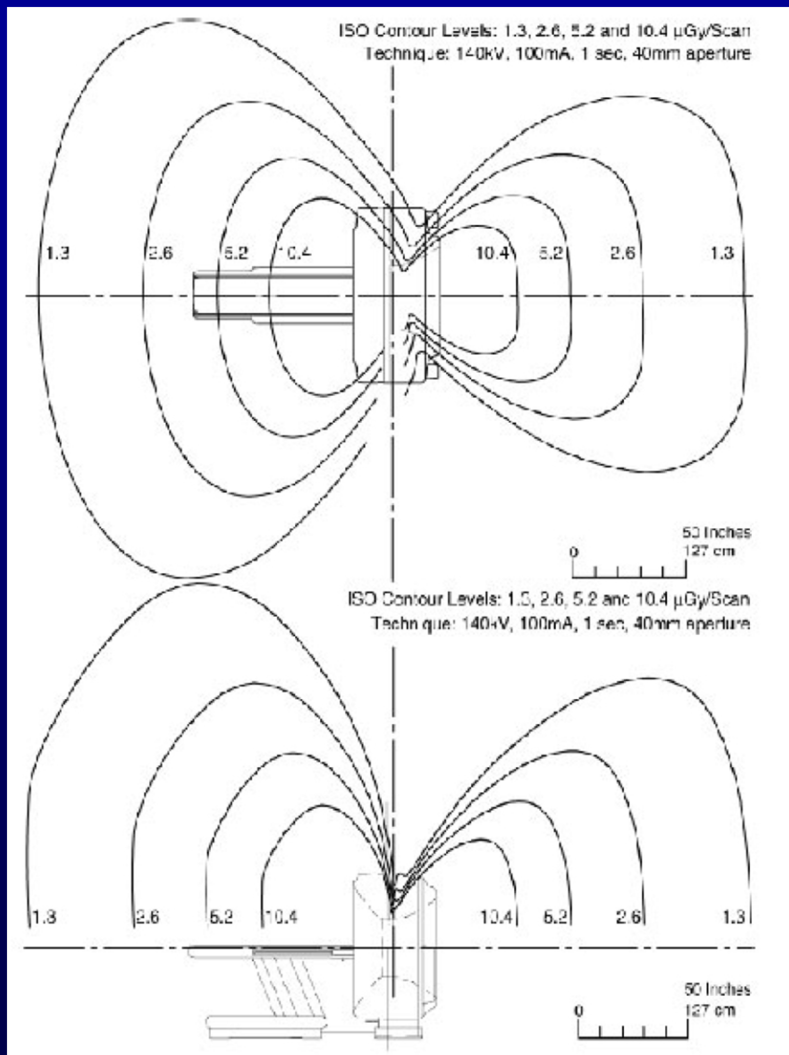
CT Shielding: EXAMPLE



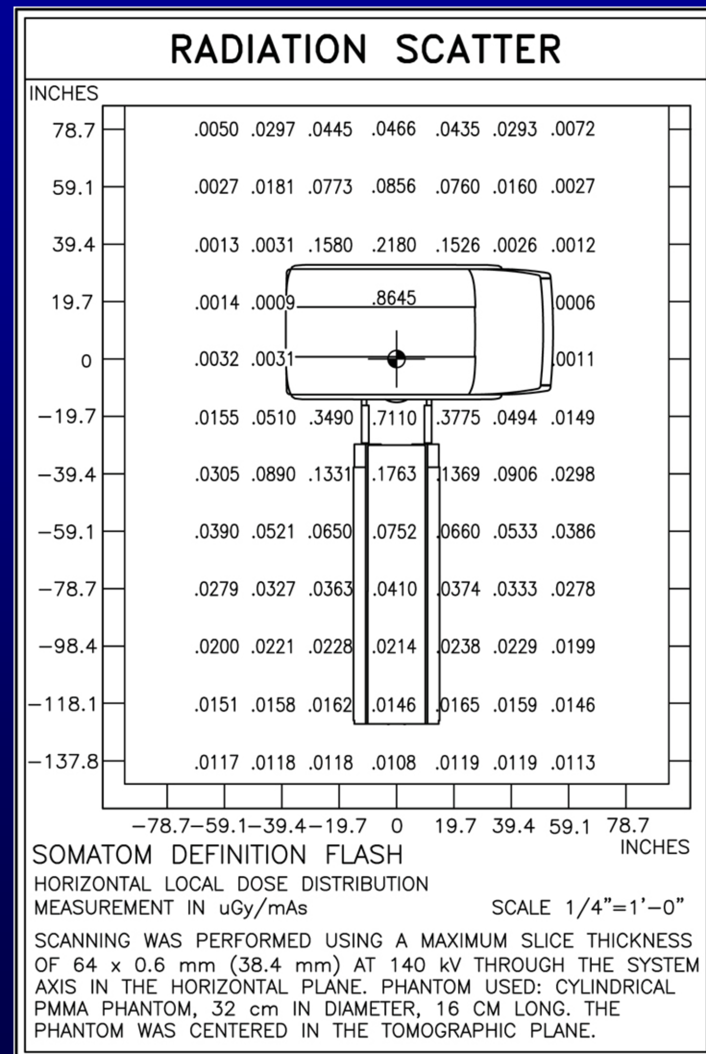
If this were an occupied space (office, etc.) it may dominate the shielding requirements!



Isodose Method

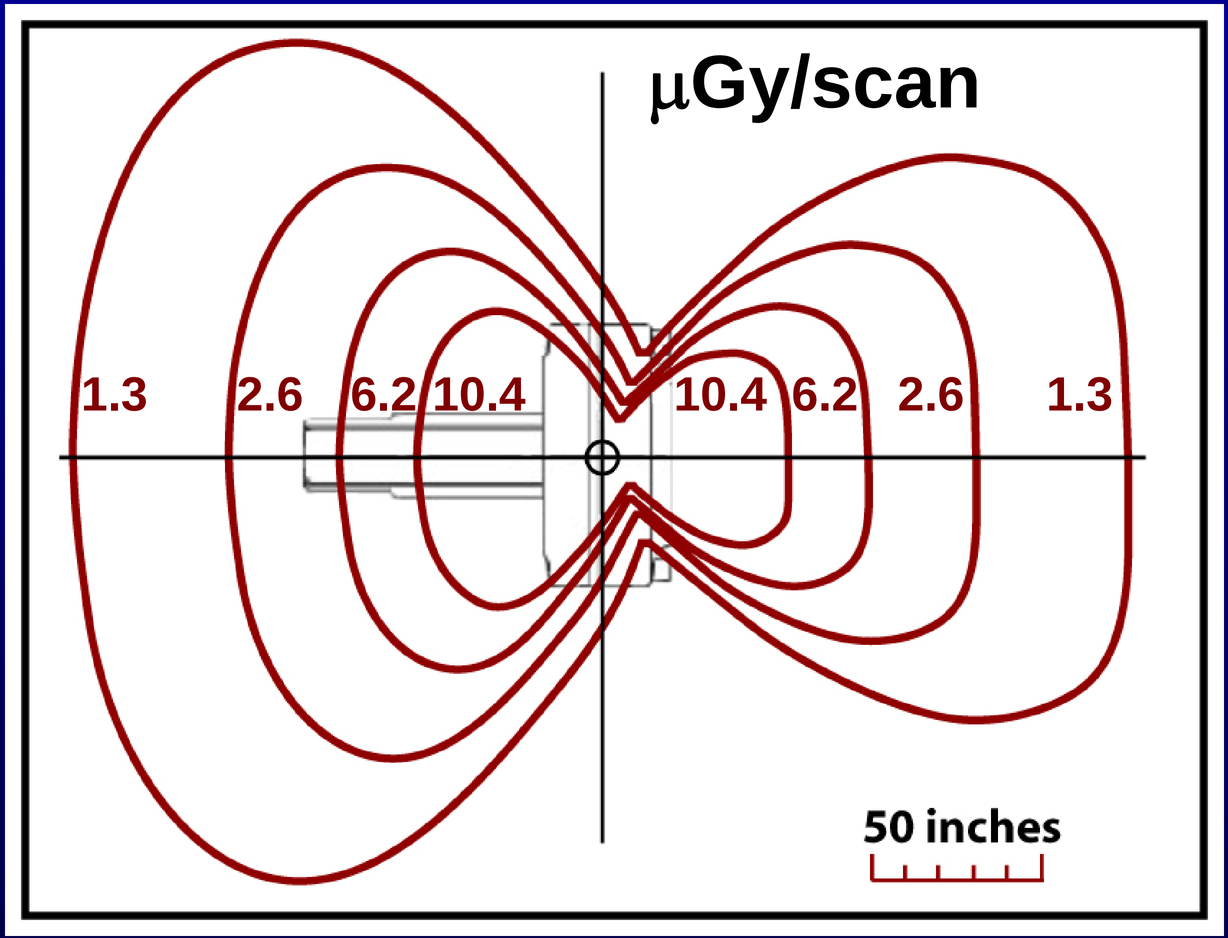


GE



Siemens

Scatter Distribution from Manufacturer

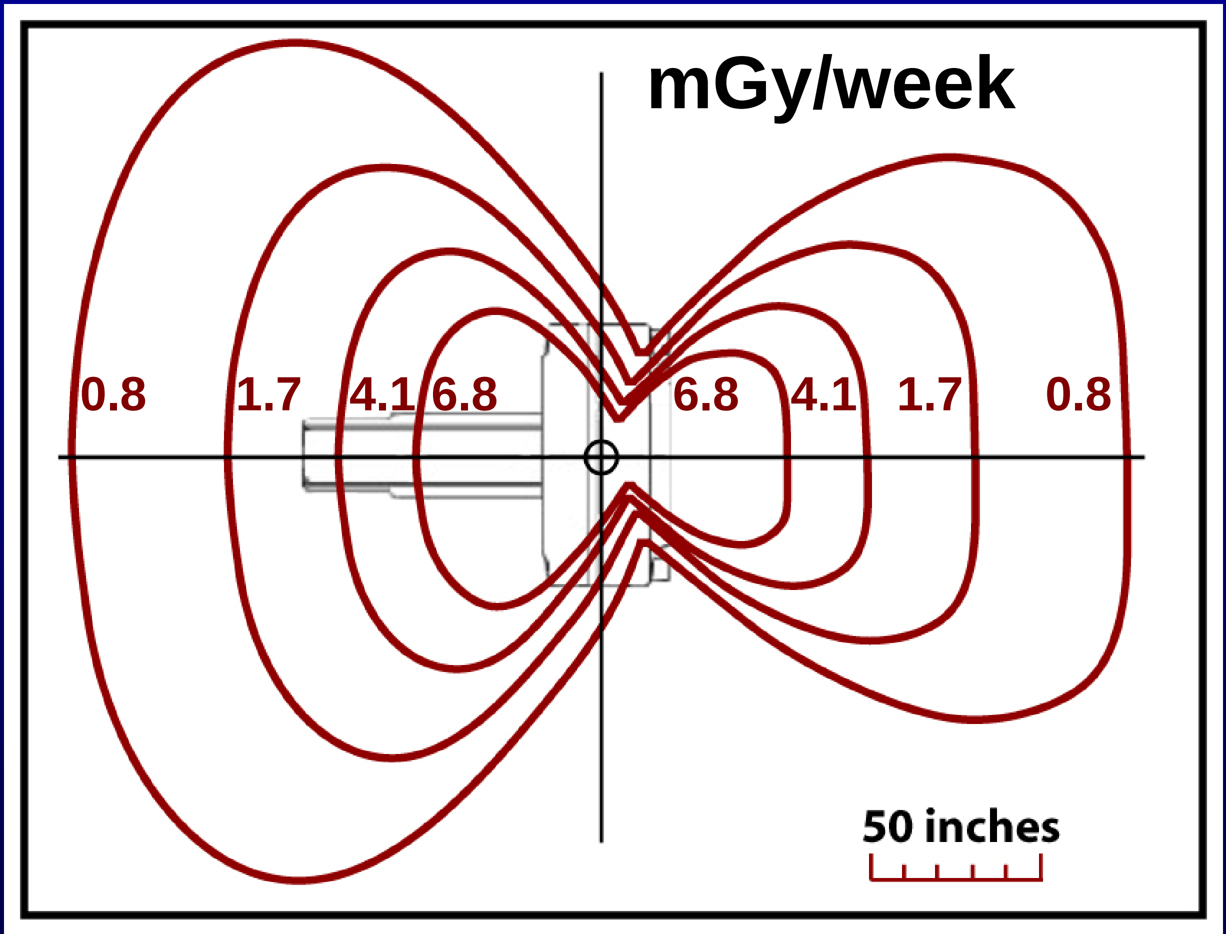


Technique:

140 kV,
100 mAs,
40 mm coll.

Need to scale to weekly site usage

Scatter Distribution from Manufacturer

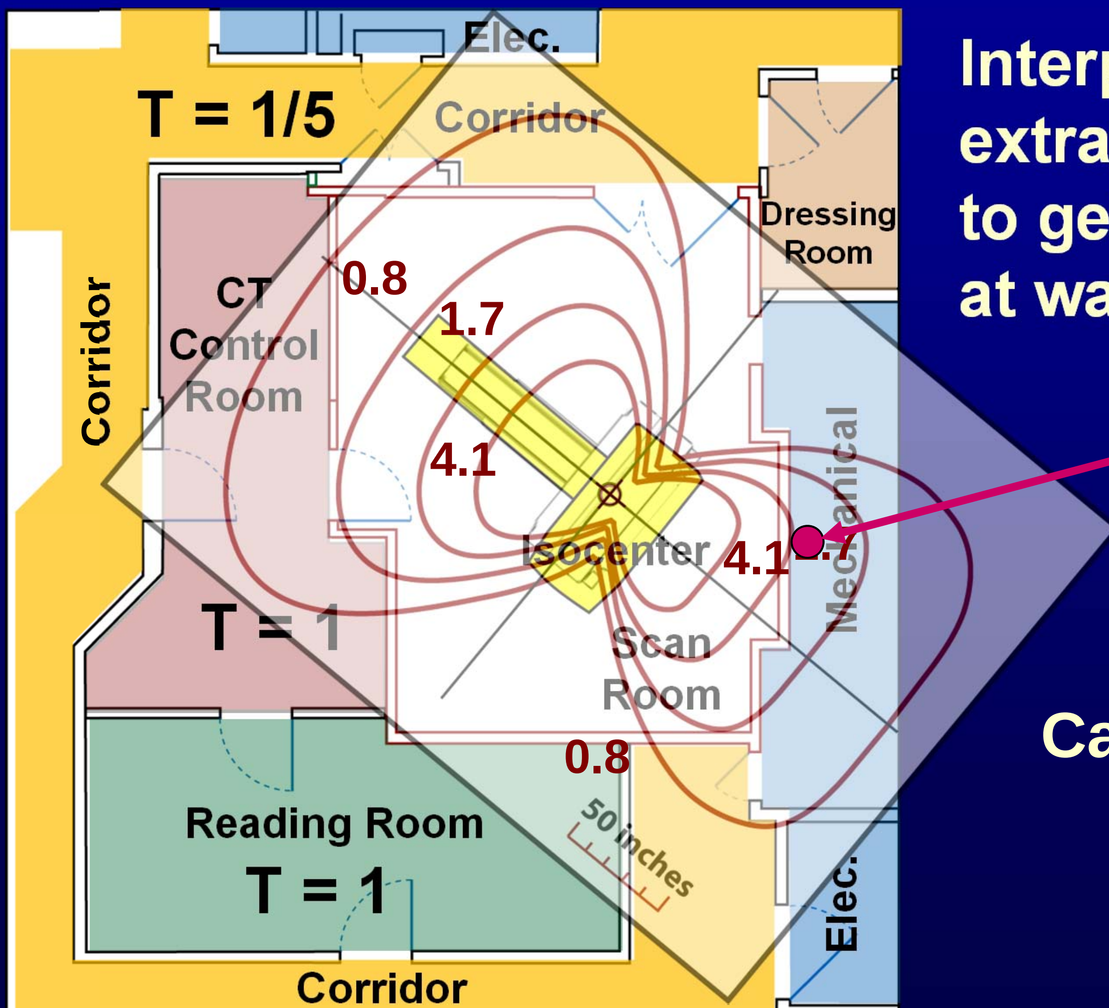


Technique:

120 kV,
300 mAs/proc,
218.75 procs,
40 mm coll.

Need to scale and overlay on blueprint

Scatter Distribution from Manufacturer



Interpolate, extrapolate (r-squared) to get unshielded kerma at walls

What shielding is needed here?

Call it 4.1 mGy/wk

Isodose Method: EXAMPLE

- **Design Goal (P)** ***(in air kerma)***
  - **- Uncontrolled Area: 0.02 mGy/week (1 mGy/yr)**
- **So Transmission factor is:**

$$B(x) = \frac{P}{T\,K_{sec}} = \frac{0.02\ \text{mGy/wk}}{(1/40)\ 4.1\ \text{mGy/wk}}$$

$$= 1.9 \times 10^{-1}$$

CT Shielding: EXAMPLE

B(x) = 1.9 x 10^{-1}

Could use:
2 lb lead
(0.79 mm,
1/32 inch)

But recall consistency!

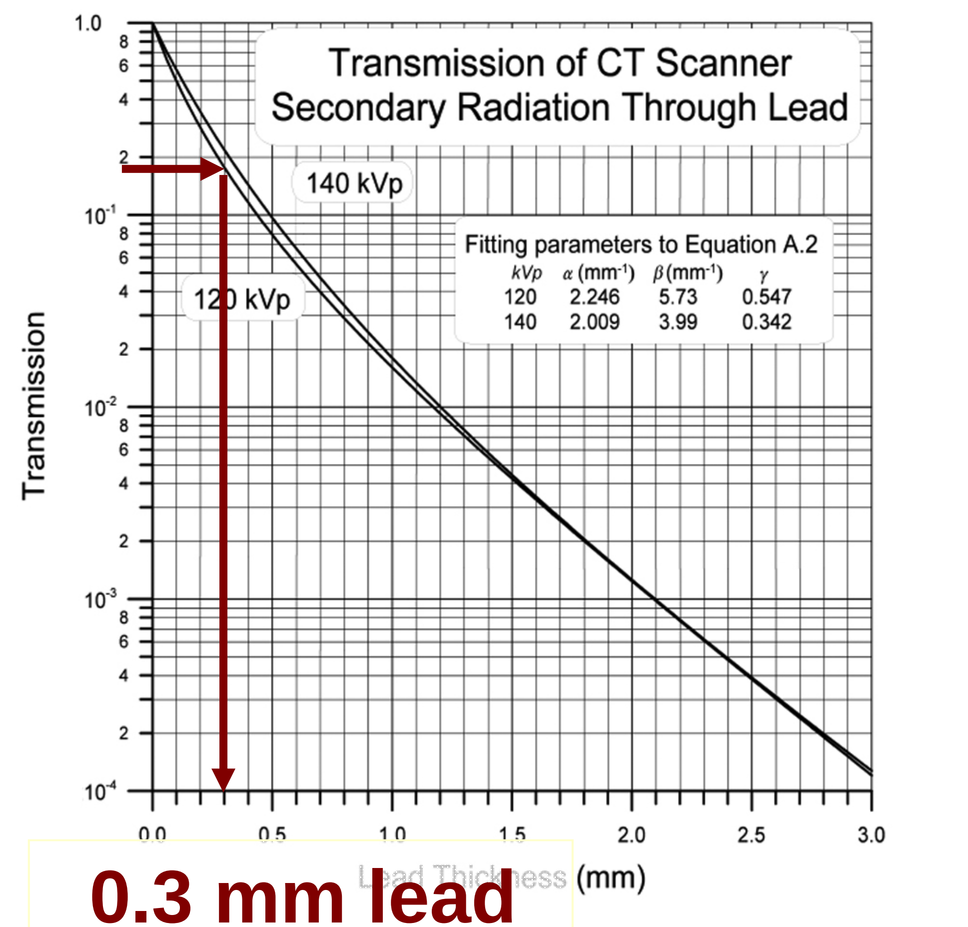


Fig. A.2. Transmission through lead of secondary radiation from CT scanners [data of Simpkin (1991) fitted to Equation A.2].

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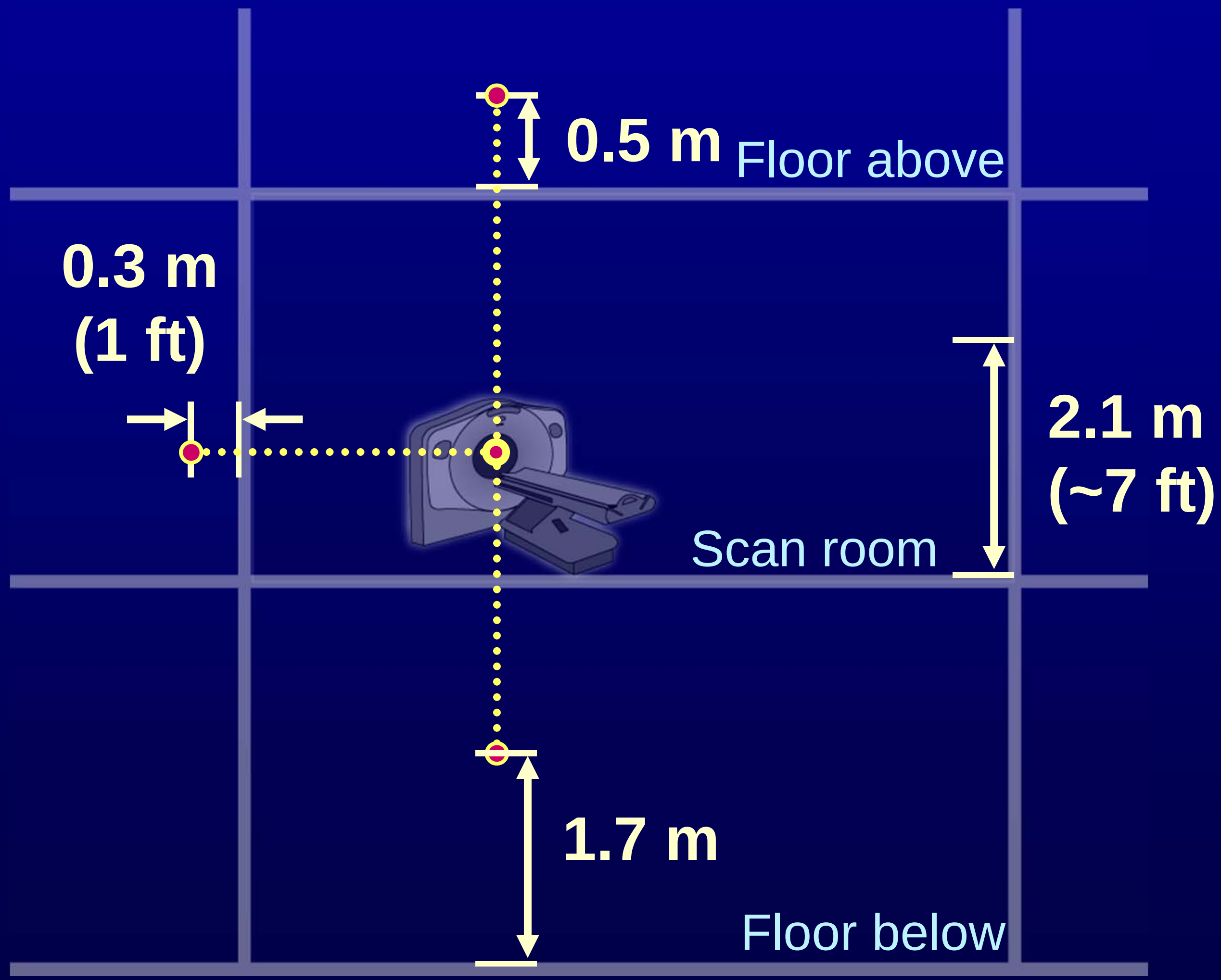
CT Shielding: Three Methods

- $CTDI_{100}$
  - Neglects scanner shielding
    - Over-estimates shielding on sides
  - Most variables easy to find
- Dose Length Product
  - Neglects scanner shielding
    - Over-estimates shielding on sides
  - Easy to use
- Isodose
  - Can be very cumbersome (errors)
  - Accounts for scanner shielding

CT Shielding: Other Considerations

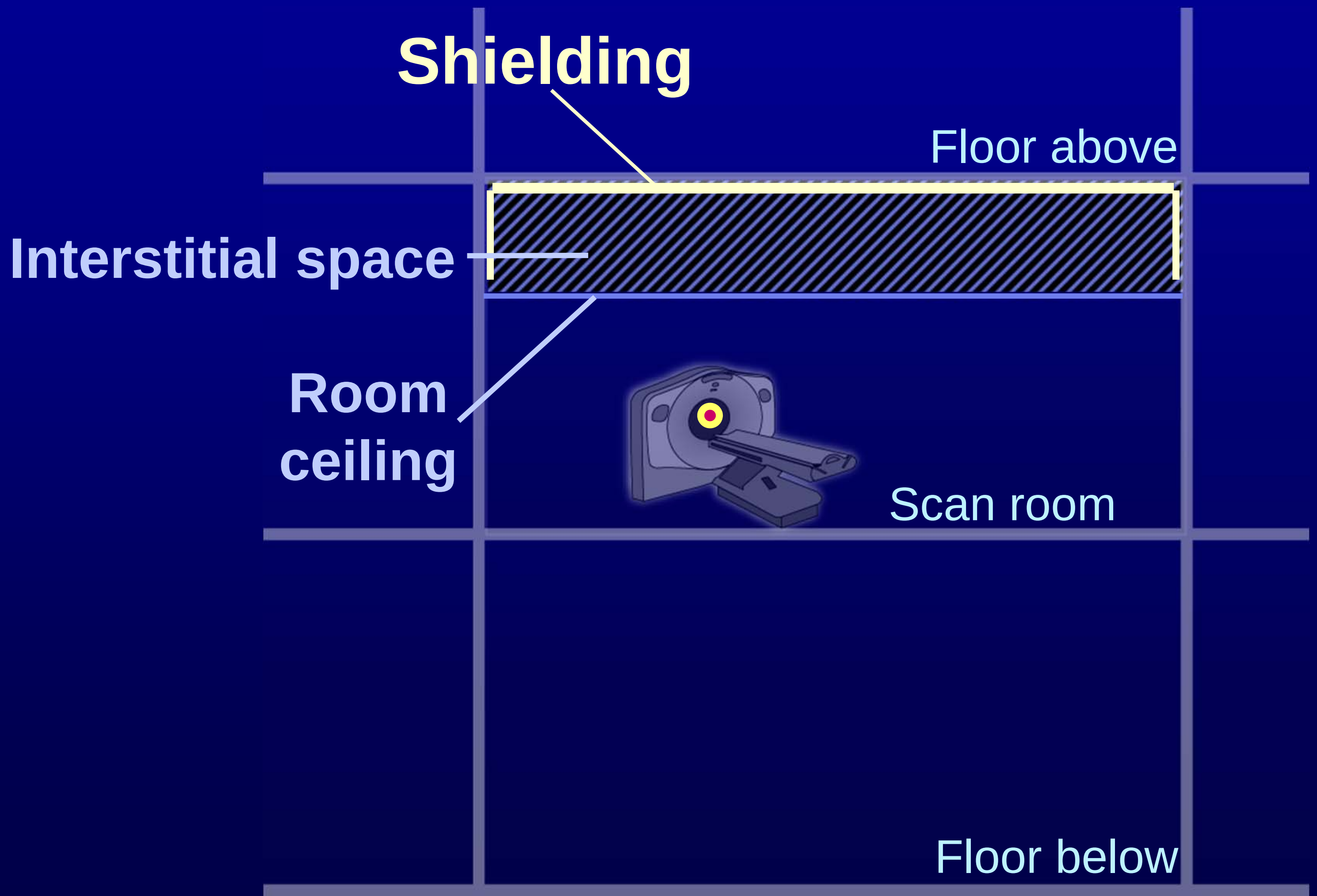
- **Penetrations (plumbing, electrical, etc.)**
  - **Wrap, overlap, get creative if necessary**
  - **No "line of sight" to isocenter**
- **Floors and ceilings**
  - **For $CTDI_{100}$ and DLP methods:**
    Calculate requirements same way
  - **For isodose method:**
    "Spin" plot to vertical orientation
  - **Different types of concrete slabs and decking**

Floors and Ceilings



Not drawn to scale

Floors and Ceilings



Not drawn to scale

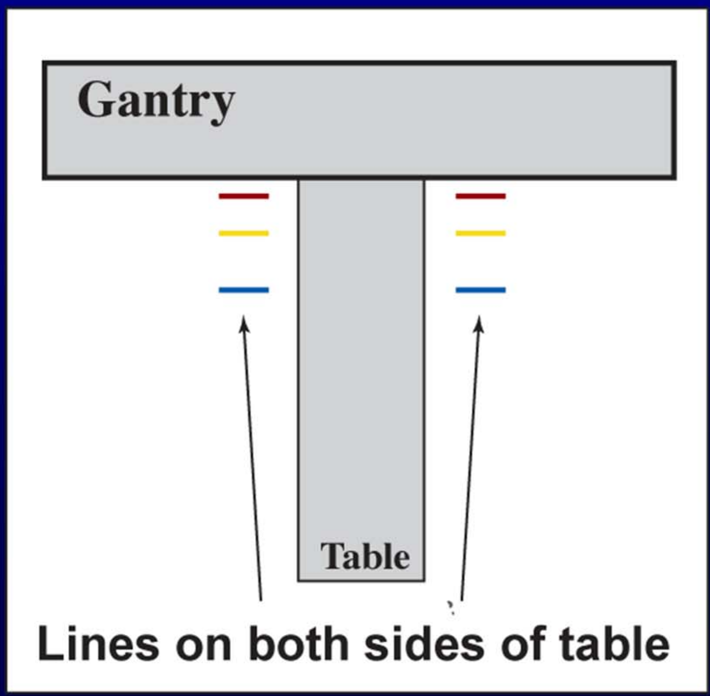
Radiation Protection for CT Personnel

Shielding Personnel

- **Time**
  - Minimize time in room while x-ray ON
- **Distance**
  - Maximize distance from scanner while ON
- **Shielding**
  - Personal protective shielding should be available
    - Aprons, eyewear, gloves, etc. as appropriate
  - Moveable shields if practical

Shielding Personnel

At Mayo - Relative exposure lines
“Step back one line to halve exposure”



Patient Shielding in CT

Bismuth and Other Patient Shields

AAPM Position Statement on the Use of Bismuth Shielding for the Purpose of Dose Reduction in CT Scanning

"… Other techniques exist that can provide the same level of anterior dose reduction at equivalent or superior image quality that do not have these disadvantages. The AAPM recommends that these alternatives to bismuth shielding be carefully considered, and implemented when possible."

http://www.aapm.org/publicgeneral/BismuthShielding.pdf

Bismuth and Other Patient Shields

- Can reduce anterior dose, but…
- Can fool auto exposure controls
- Can cause streaks and incorrect CT numbers
- Waste photons from other side of patient
- Can get same benefit and image quality by reducing mA

From Oak Ridge National Laboratory (1947)

Lots more cool stuff at the Health Physics Museum (Google it!)

(toys, movie posters, brands, comics, quack cures, antique instruments, more…)