Shielding Calculations

Controlled Area – Radiation Workers only

NCRP 49 - 100 mrem/wk
NCRP 116 - 10 mrem/wk
- 5 rem/yr

Uncontrolled Area – Non-radiation workers & general population

NCRP 49 - 10 mrem/wk
NCRP 116 - 2 mrem/wk = 0.02 mSv/week
- 0.1 rem /year, 100 mrem/yr
  - 0.1 rem/yr = 0.1 cGy/yr (in therapy no Quality Factor)

- Uncharged ionizing radiation has no specific range (average number of x-ray interactions in diagnostic range is 40 before full absorption) only a probability of interacting.

- **Transmission** B(x) - $\frac{\textit{Dose}\text{ Shielded}}{\textit{Dose}\text{ Unshielded}}$
  - $B(x) = \left[\left(1 + \beta/\alpha\right)e^{-\beta\gamma x} - \beta/\alpha\right]^{-1/\gamma}$
    - where x is the thickness of shielding, and α is $^{0.693}/_{HVL}$
- Occupancy Factor ≡ T

Uncontrolled Areas	T
Offices	1.0
Nurses Station	½
Film Reading Area	1/5
Corridor	1/8
Toilets, Outside seating	1/20
Traffic, sidewalks	1/40

- Workload ≡ W
  Diagnostic
  - Total intensity of photons
  - Time integral of tube current
  - Proportional to number of electrons incident on anode.

  - W average = 275 mA min
  - W conservative = 1000 mA min / wk
  - W special procedures > 3000 mA min

Therapy

- (# of patients per day) x (# days during week) x (Average dose at 1 meter from isocenter)
    - EX: 40 pts/day x 5 days x 200 cGy/m
    - **Average dose at a point 1 meter away from isocenter ≅ 200 cGy**

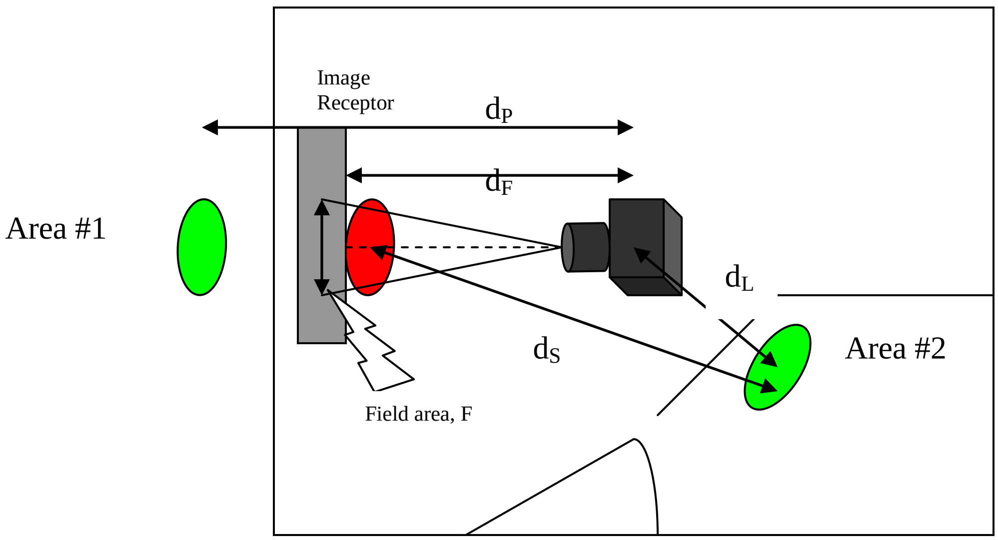
- Use Factor ≡ U
    - Fraction of primary radiation stopped by barrier
    - Floor = 1
    - Walls = ¼
    - Ceiling = 0
    - Radiographic Room
        - Total
            - 22% Chest Bucky Wall
            - 7% Cross Table Lateral
            - 2% Another Wall
        - Directed at Walls and Floor
            - 89% Floor
            - 9% Cross Table Lateral
            - 2% Another Wall
- ***a***

    Scatter Fraction ≡ Scatter Dose @ 1 meter / Primary Dose @ 1 meter

    Scatter Dose ≡ Generated in the patient and other things hit by primary radiation.

Calculation Scheme

1. Estimate Unshielded dose acceptable – Max Permissible Dose – Uncontrolled Area
2. Know P/T allowed in occupied area
3. Plug into Fraction Transmitted at distance $k = B(x)D = \frac{Pd^2}{WUT}$
4. X-ray transmission for a given type of radiation then determine necessary barrier thickness.



SIMPLIFY. . .

- Primary Unshielded Radiation
  - ➢ Dose unshielded $D_{UNSHIELDED} = \frac{D'UN}{d^2} = \frac{D'UW_{TOTAL}}{d^2 W_{normal}}$

    Where D' is the dose per patient at 1 meter, N number of patients per week

    Primary

    ➢ $D_p = \frac{Pd_p^2}{WUT}$

    Secondary @1 meter < 1%

    ➢ $D_L = \frac{1000Pd_p^2}{WT}$

- Therefore the barrier transmission required to decrease D' to acceptable level P/T is

$$B(x) = \frac{P/T}{D_{unshielded}} = \frac{P}{T}\frac{d^2}{D'UN} = \frac{P}{T}\frac{d^2 W_{normal}}{D'UW_{TOTAL}}$$

For secondary radiation just get rid of the Use Factor

$$B(x) = \frac{P/T}{D_{unshielded}} = \frac{P}{T}\frac{d^2}{D'N} = \frac{P}{T}\frac{d^2 W_{normal}}{D'W_{TOTAL}}$$

- LINAC Calc
  1. Estimate Unshielded dose acceptable – Max Permissible Dose – Uncontrolled Area
  2. Know P/T allowed in occupied areas
  3. Plug into Fraction Transmitted at distance $k = B(x)D = \frac{Pd^2}{WUT}$
  4. Leakage
     a. Get value from manufacturer
     b. Check with survey before TXT
     c. U=1
  5. Scattered
     a. RULE of Thumb: 0.1% Primary at 1 meter from isocenter
        i. That assumes 90 degree scattering
        ii. 40 x 40 F.S.

     b. **DOOR** $Dose_{DOOR} = \frac{W \cdot d_{DOOR}^2 \cdot 1000(mrem)}{d_{MAZE}^2 \cdot (0.1\%)}$
        i. Longer Maze less neutrons at door.
        ii. 2.2 MeV Energy threshold for neutron production (Head).
        iii. 6 – 8 MeV for neutron production from x-ray interactions.
  6. X-ray transmission for a given type of radiation then determine necessary barrier thickness.

HVL

- For shielding $HVL_{PRIMARY} = \frac{\ln(FractionTransmitted)}{\ln(0.5)}$

Neutrons

- Mainly created in the head – primary collimators, beam filters.
- Door
  - Need Maze for beams over 10 MeV
  - 3 materials
    1. Layer to slow down fast neutrons

2. Layer Polyethylene to stop thermal neutrons
3. Last layer, Lead or equivalent to stop 2.22 Mev gammas created from thermal neutron capture.

IMRT

- Primary *WORKLOAD* same because same number of patients.
- Leakage *WORKLOAD* different because more output and less of it used. We're throwing away most of the useful beam which contributes to leakage dose.

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1. Cath Lab

a. No PRIMARY radiation barrier needed. Only secondary radiations!

12" I.I. at 90 cm SID acting like beam stop

Assume: d = 4 m; T = 1
P = 0.02 mSv/week; uncontrolled area
90° scatter; N = 25 patients/week
Workload from NCRP 49

Calculate . . .

D'=2.7 mSv per patient from 90° scatter from Secondary dose table

W_{norm} = 160 mA minute per patient

$W_{\textbf{total}}$ = (W_{norm})(number patients per week)
= (160 mA minute)(25)
= 3990 (mA minute)/week

Therefore,

$$D_{UNSHIELDED} = \frac{D'N}{d^2} = \frac{\left(2.7\, {}^{mSv}\!/_{patient}\right)\left(25\, {}^{patietns}\!/_{week}\right)}{(4m)^2} = 4.2\, {}^{mSv}\!/_{week}$$

and then the barrier transmission must be

$$B(x) = \frac{{}^{P}\!/_{T}}{D_{UNSHIELDED}} = \frac{0.02\, {}^{mSv}\!/_{week}}{4.2\, {}^{mSv}\!/_{week}} = 4.7\times10^{-3}$$

For Lead (Pb) read value from graph and then it will be a shielding of 1.2 mm of Pb

NOTE: NCRP same calc would be 1.9 mm lead. The difference is due to the realistic workload kVp distribution and assume a more accurate leakage model.

2. CT Scanner

a. No PRIMARY radiation barrier needed. Only secondary radiations!

Assume:

There are head scans	$N_H \equiv$ # of head scans/week $M_H \equiv$ # slices per scan $a_{\text{CT head}} = 9 \times 10^{-4}$
There are Body scans	$N_B \equiv$ # of body scans/week $M_B \equiv$ # of slices per scan $a_{\text{CT Body}} = 5 \times 10^{-4}$

Where:

40 slices non-helical   50-60 slices helical

$a_{CT} \equiv$ Shearer's Scatter Fraction Values

Energy = 120 kVp

Calculate . . .

Ambient dose per scan is defined as. . . .

$$D'_{CT} = \frac{\text{CTDIcGy}}{0.78\,{}^{\text{cGy}}\!/_{\text{R}}} \cdot a_{CT} \cdot \frac{mAs_{CLINICAL}}{mAs_{CTDI}} \cdot 0.876\,{}^{cGy}\!/_{R} \cdot \frac{10mGy}{1cGy} \cdot \frac{d(mm)}{d_{CTDI}(mm)} \cdot \frac{1mSv}{1mGy}$$

$$D'_{CT} = 11.2 \cdot (\text{CTDI}(cGY)) \cdot a_{CT} \cdot \frac{mAs_{CLINICAL}}{mAs_{CTDI}} \cdot \frac{d(mm)}{d_{CTDI}(mm)}$$

Dose per type of scan for unshielded secondary dose is . . .

$$D'_{CTHead} = 11.2 \cdot 9 \times 10^{-5} \cdot 4m = 0.00403mSv$$

$$D'_{CTBody} = 11.2 \cdot 5 \times 10^{-4} \cdot 4m = 0.011mSv$$

So, the total unshielded dose at a distance of 3 meters from the scanner is

$$D'_{CTTOTAL} = \frac{0.00403mSv}{3m^2} + \frac{0.011mSv}{3m^2} = 3.8mSv$$

Therefore, the barrier with uncontrolled area behind it needs to be

$$B(x) = \frac{{}^{P}\!/_{T}}{D'_{unshielded}} = \frac{0.02mSv}{3.8mSv} = 5.3 \times 10^{-3}$$

- So from the curves the barrier will need to be a thickness of 1.4 mm Pb or 125 mm of concrete for a 125 kVp beam.

Backup Info . . .

- Primary
  - Primary dose $D_P = \frac{P}{T} = \frac{\dot{D}_0 WU}{d_p^2} = B(x)$
  - P/T is the condition that needs to be met behind barrier.

    $$\frac{P}{T} = \dot{D}_0 B(x) = \frac{Pd_p^2}{WUT}$$

    Where P ≡ permissible Dose

    d ≡ is the distance from isocenter to calc point
  - Multiple kVp's then sum each energy component
    - $D_p = \frac{1}{d_p^2} \sum_{kVp} \dot{D}_0 UTB(x)$ where $B(x) = \left[\left(1 + \beta/\alpha\right)e^{-\beta\gamma x} - \beta/\alpha\right]^{-1/\gamma}$

- Scatter
  - Scatter is equal to primary dose distribution.
  - Scatter dose $D_s = \frac{P}{T} = \frac{a\dot{D}_0 W}{d_s^2} \frac{F}{(400cm^2)d_f^2} = B(x)$
    - where a is the scatter fraction

      F is the irradiated area on the I.I.

      d_f is the distance from source to I.I. (SID)
  - $\frac{P}{T} = \dot{D}_0 B(x) = \frac{Pd_S^2}{WT} \frac{(400cm^2)d_f^2}{F}$
  - Multiple kVp's take sum of Scatter Doses.

- Leakage
  - Leakage is radiation emanating from the x-ray tube but not from tube portal. Another words not primary beam or scatter from primary beam.
  - Workload $_{leakage}$ = I_{max} x Beam-on-Time
  - $D_L = \frac{P}{T} = \frac{LW}{I_{max} d_L^2} B(x)$

  where L is the leakage factor at one meter

  $$L \le 100\, mR/hr \text{ at } 1 \text{ meter} = 0.1\, \mathrm{R/hr} = 0.1\, rem/hr$$

  - If you know what dose you want on the other side of the barrier then

    $$D_L = \frac{P}{T} = B(x) = \frac{PI_{max} d_L^2}{TLW} = \frac{1000Pd^2}{WT}$$

    Therefore,

$$B(x) = \frac{P I_{\max} d_L^2}{TW\left(0.1 \, {}^{R}\!/_{hr}\right)}$$

- **Total Dose**

$$D_{X_{\text{THROUGH ACCEPTABLE BARRIER THICKNESS}}} = \frac{P}{T} = \sum_{\text{ALL TUBES}} D_{PRIMARY} + D_{SCATTER} + D_{LEAKAGE}$$

References

1. NBS Handbook 60 (1955) & Braestrup & Wykoff Health Physics text

2. NCRP Reports 34 (1972) & 49 (1976)
3. AAPM Task Group 9, 1989, then the new one in 1992 Draft report only.
   a. New report addresses diagnostic rooms only, not dental or therapy or radionuclides.