Radiation Oncology treatment facility design

Simulators, CT scanners,

HDR Brachytherapy

McGill

MDPH 613 Fall 2004

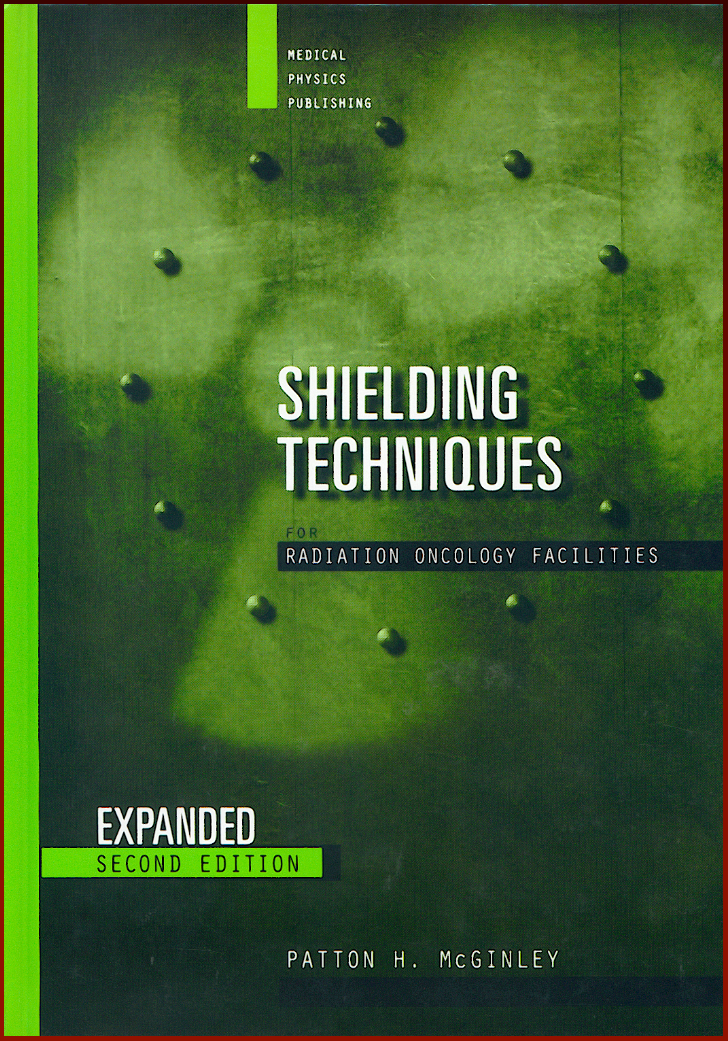
UNITS

For this class only:

1 R = 1 cGy = 1 cSv = 10 mSv

Reference book

- McGinley
- NCRP 49
- NCRP 51
- *Health Physics notes*, Robert Corns
- *Safety code 20A*, Health Canada



Radiation Oncology

- Linear accelerator
- Brachytherapy
- CT simulator
- simulator

Basic shielding concepts

- Establish a target dose-rate at a certain point behind a barrier
- Calculate barrier thickness necessary to achieve the target dose rate

Shielding considerations

- Machine workload
- Type of person to protect
  - NEW
  - Public
- Type of space to protect
  - Public access area
  - Restricted access

Shielding considerations

- Type of radiation
- Primary beam incidence
- Primary beam scatter
- Patient scatter
- Leakage radiation

Simulator

- Operates with same geometry as LINAC
- Radiation source is diagnostic x-ray tube
- Capable of radiographic and fluoroscopic functions

Simulator

- Most exposures made in fluoroscopy mode
- X-ray beam collimated, always incident on image intensifier (II)
- Primary beam significantly attenuated by patient and II

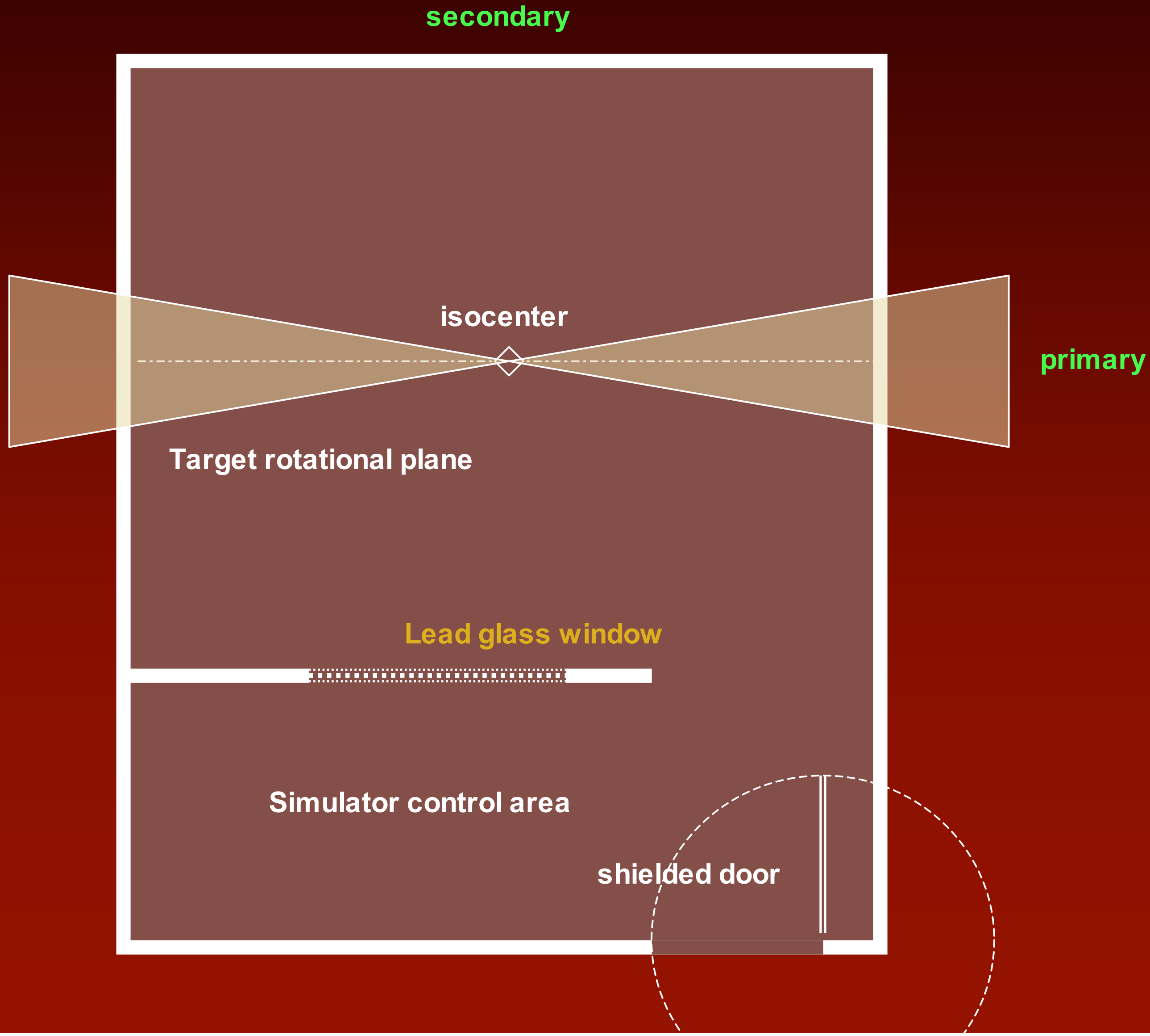
Shielding materials

- Lead (Pb) backed gypsum board (dry wall)
- Shielding provided to height of 7 feet unless space above is occupied
- Viewing window with lead glass is used at console area

Types of barriers

- Primary barriers
  - Attenuate primary (direct) beam
- Secondary barriers
  - Leakage
  - Patient scatter
  - Wall scatter

Simulator room

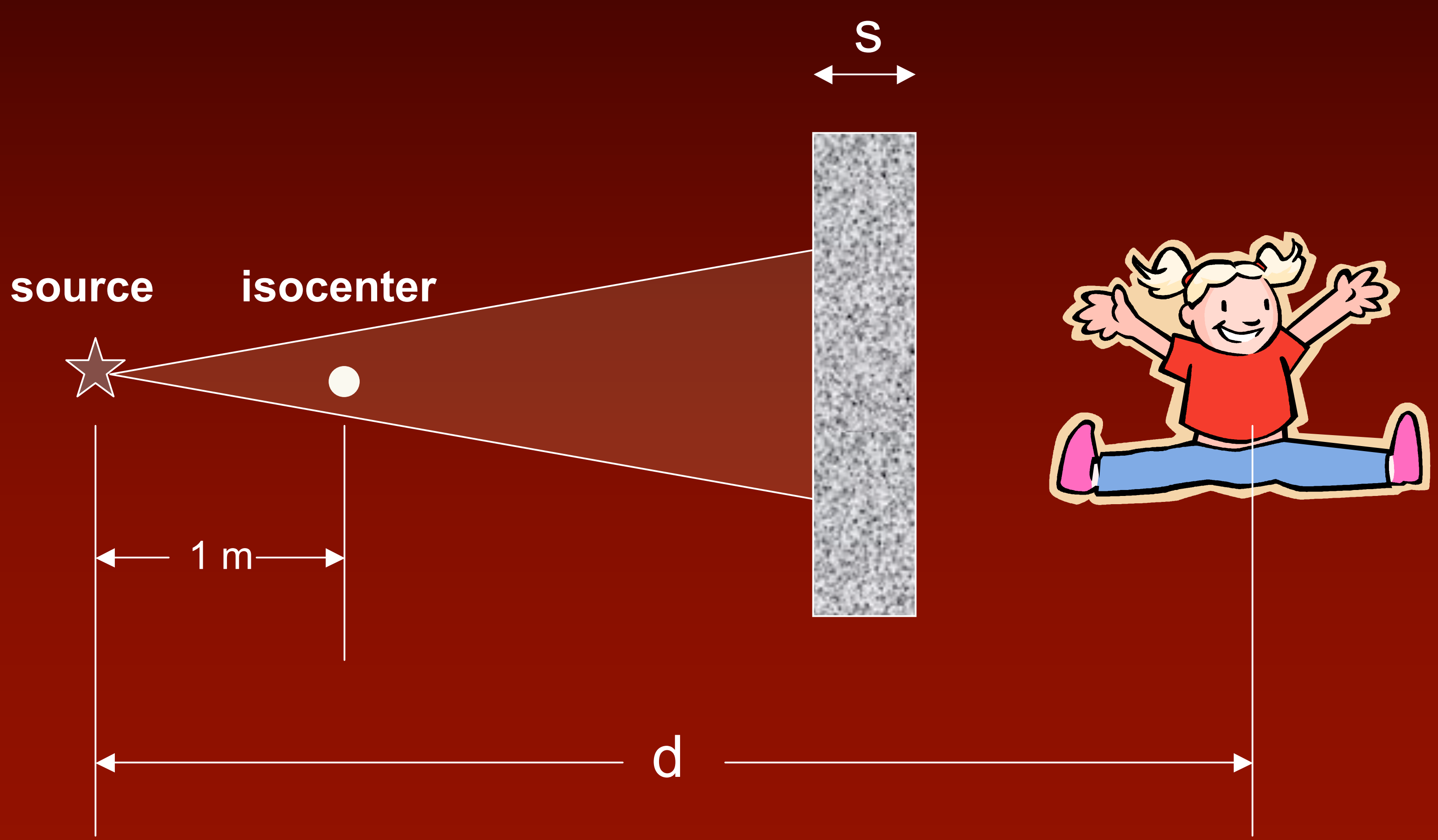


Primary beam

- Barrier thickness depends on:
  - Distance to POI from source (d)
  - Target dose rate (P)
  - Workload (W)
  - Occupancy (T)
  - Usage (U)

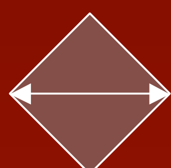
*Patient and table attenuation not taken into account

Basic situation

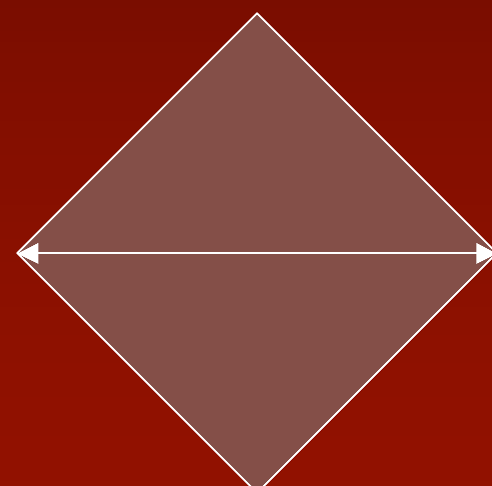


Primary barrier

- At isocenter max FS is 40 x 40 cm^2
- Largest dimension is diagonal (56 cm)
- At barrier this will project to larger size



at iso ~ 56 cm



at barrier ~ 200 cm

Simulators: Primary beam

- $\mathbf{K_{ux}}$ is transmission factor
- Expressed in (R/mA min) at 1m
- NCRP 49 (1976)

$$K_{ux} = \frac{Pd^2}{WUT}$$

Target dose rate P

Group	ICRP 60 Dose limit (mSv/y)	Exposure rate (R/week)	Exposure rate (R/y)
NEW	20	**0.04**	~ 2
Public	1	**0.002**	~ 0.1

*1 year has 50 weeks of 40 hrs/week or 2000 hr/year
** diagnostic X-ray installations are not licensed by CNSC but may fall under provincial regulations

Workload

- **W** workload expressed in mA-min/wk:

- Radiography
  - 50 patient/wk x 500 mAs/patient x 1 s/60 min = 400 mA min/wk

- Fluoroscopy
  - 50 patient/wk x 5 mA/patient x 1 min = 250 mA min/wk

$$K_{ux} = \frac{Pd^2}{W\,UT}$$

W = 1000 mA-min/wk

Typical workload

Table 3
Typical Workloads (W) For Busy Department

	Daily Patient Load	Workload mA-min/week		
		#100 kVp	125 kVp	150 kVp
Chest (36 cm × 43 cm) (14" × 17")	60	150	—	—
Cystoscopy	8	600	—	—
Fluoroscopy including spot filming	24	1500	600	300
Fluoroscopy without spot filming	24	1000	400	200
Fluoroscopy with image intensification including spot filming	24	750	300	150
General Radiography	24	1000	400	200
Special Procedures	8	700	280	140

Usage factor U

- **U** Accounts for beam orientation
- Isocentric units have same usage for floors, ceiling, and walls.
- **U = 0.25**

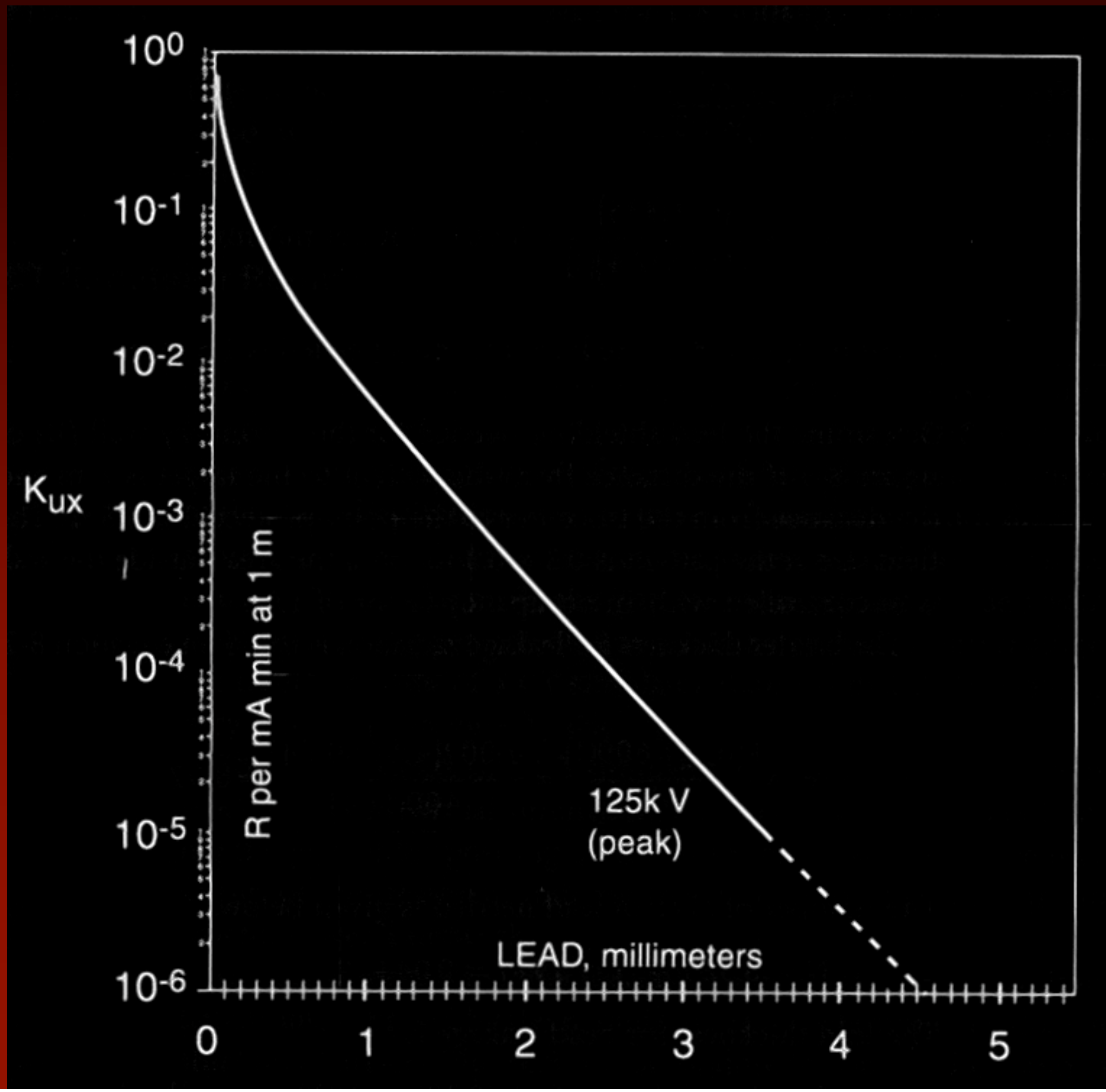
$$K_{ux} = \frac{Pd^2}{W\,U\,T}$$

Occupancy factor T

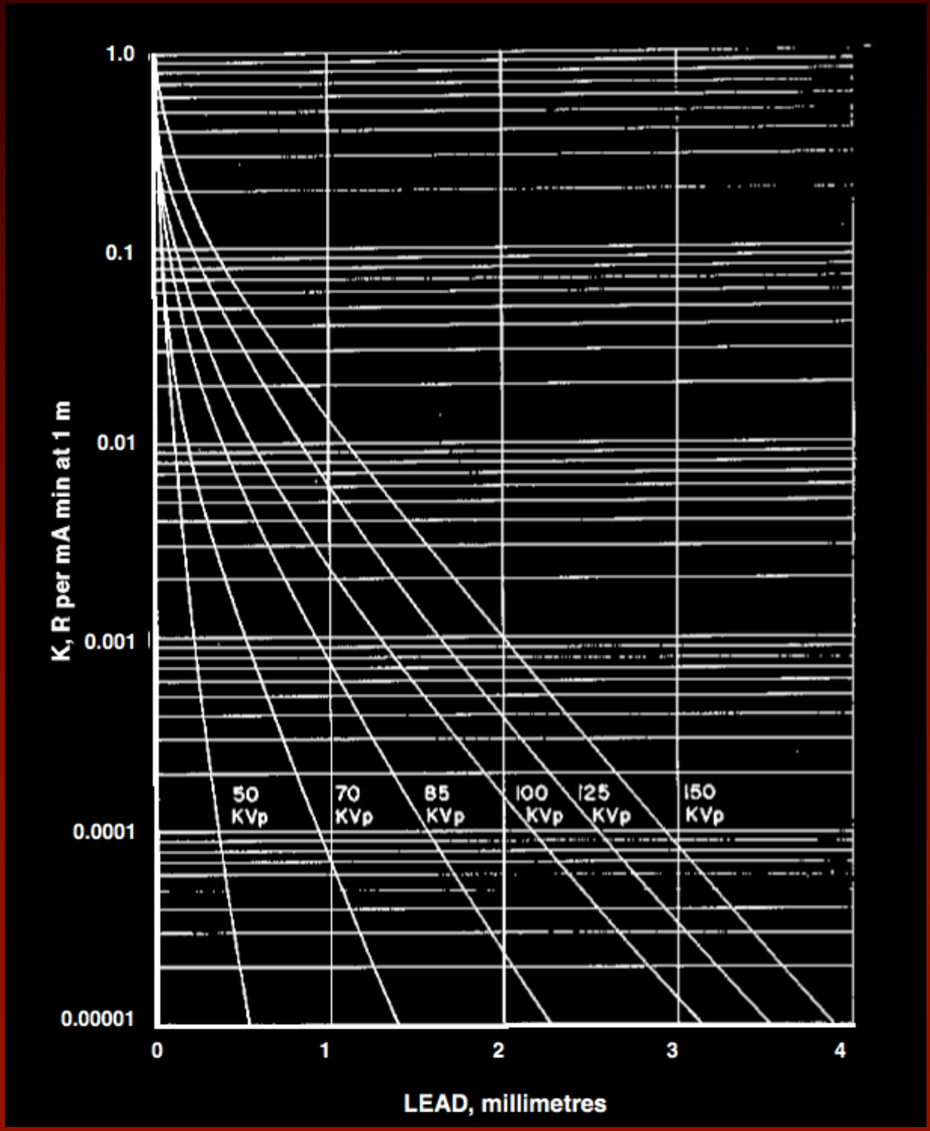
T	Type of area
1	Full Offices, shops, labs, living area
1/4	Partial Corridors, restrooms, parking
1/16	Occasional Waiting room, stairway, janitor closet

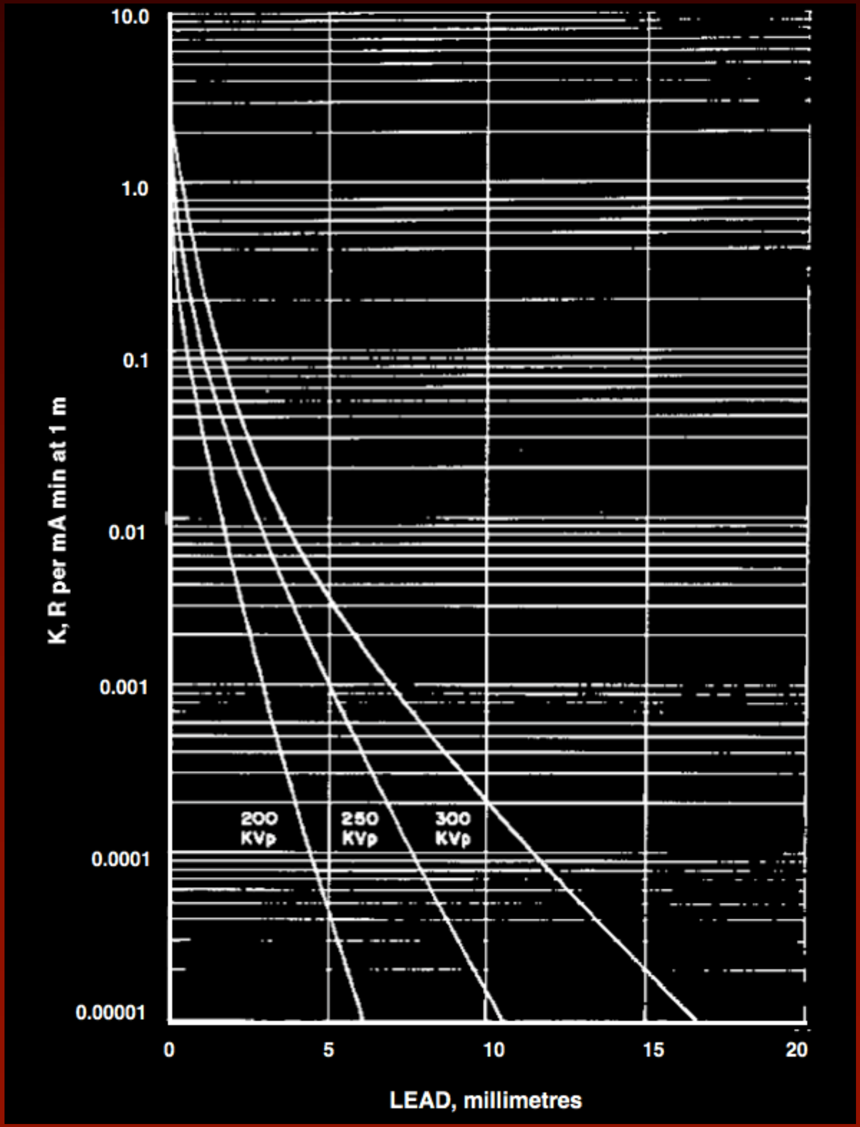
$$K_{ux} = \frac{Pd^2}{W\,U\,T}$$

Transmission factor K_{ux}

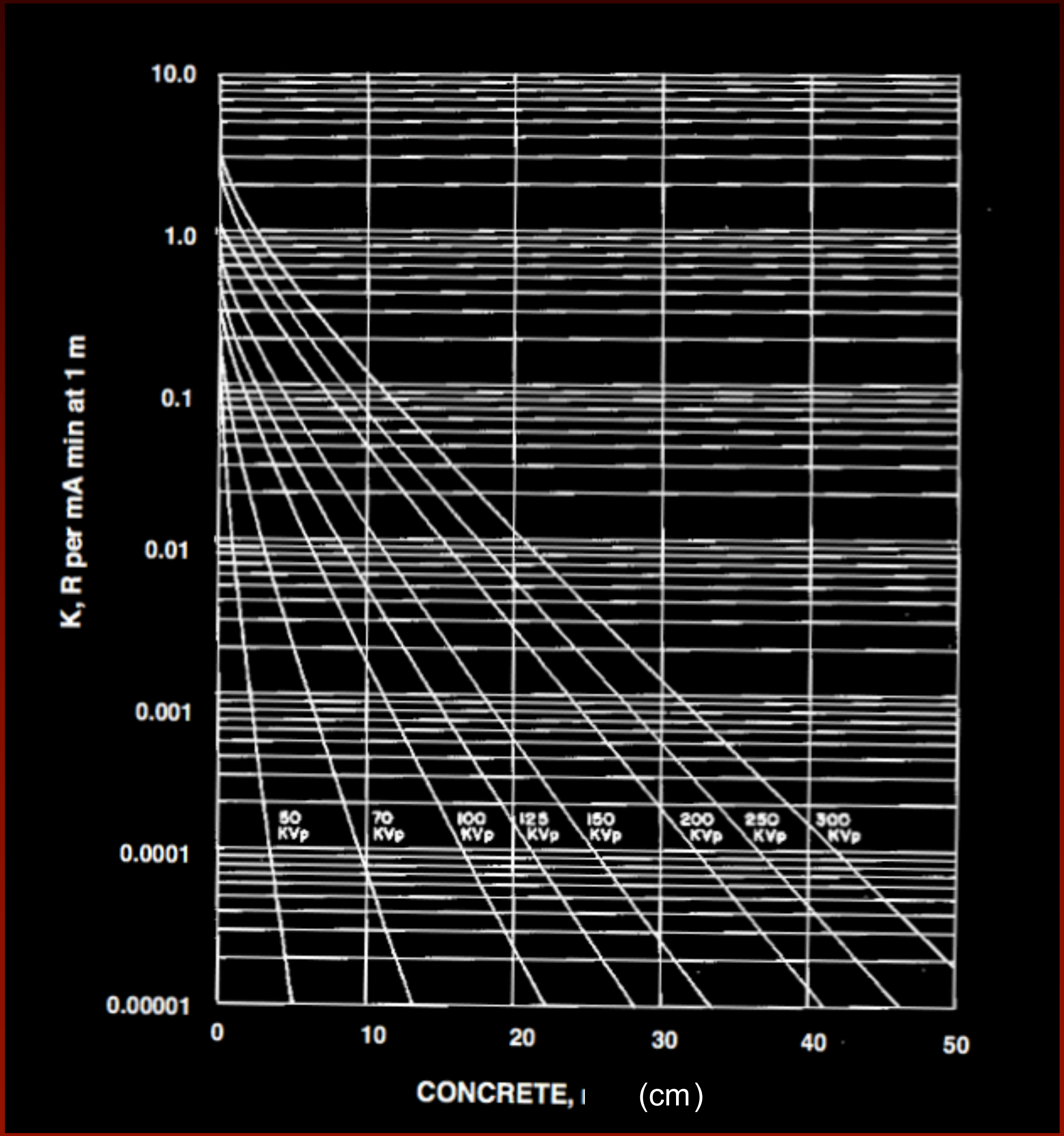


Transmission - lead





Transmission - concrete



Simulators: Leakage

- Assumption leakage is 0.1 R/hr at 1m
- Shielded to a factor of 600 per minute

$$B = \frac{600\ I\ P d_s^2}{WT}$$

Simulators: Leakage

- **B** is the factor by which the intensity of radiation (P_o) must be reduced to achieve the target dose rate **P**

$$\mathbf{B} = \frac{P}{P_o} \qquad \mathbf{B} = \frac{600\ I\ P d_s^2}{WT}$$

Simulators: Leakage

- **I** is the tube current (mA)
- $\mathbf{d_s}$ is the distance from source to POI

$$B = \frac{600\, \mathbf{I}\, P \mathbf{d_s}^2}{WT}$$

TVL - Tenth Value Layer

$$n = \log\left(\frac{1}{B}\right)$$

HVL - Half Value Layer

1 TVL = 3.32 HVL

TVL and HVL

$$\frac{1}{2^x} = \frac{1}{10}$$

$$2^x = 10$$

$$x \log 2 = \log 10$$

$$x = 3.32$$

Table 4
Half-Value Layers and Tenth-Value Layers for Heavily Filtered X-Radiation Under Broad-Beam Conditions

Tube Potential	Attenuation Material			
	Lead (mm)		Concrete (cm)	
kVp	HVL	TVL	HVL	TVL
50	0.06	0.17	0.43	1.5
70	0.17	0.52	0.84	2.8
85	0.22	0.73	1.25	4.5
100	0.27	0.88	1.60	5.3
125	0.28	0.93	2.00	6.6
150	0.30	0.99	2.24	7.4
200	0.52	1.70	2.50	8.4
250	0.88	2.90	2.80	9.4
300	1.47	4.80	3.10	10.4

Simulators: Scatter

- Scattered x-rays have same barrier penetration as primary beam
- NCRP 49 (1976)

$$K = \frac{400\ P\ D^2\ d^2}{F \quad aWT}$$

Simulators: Scatter

- D is the distance from the source to scatterer
- d is the distance from scatterer to POI
- F is the field area on patient
- a is the scatter fraction

$$K = \frac{400\ P\ D^2\ d^2}{F \quad aWT}$$

Scatter fraction

Table 6
Ratio, a, of Scattered to Incident Exposure

Tube Potential KvP	Scattering Angle (from Central Axis of Beam) 30°	45°	60°	90°	120°	135°
50	0.0005	0.0002	0.00025	0.00035	0.0008	0.0010
70	0.00065	0.00035	0.00035	0.0005	0.0010	0.0013
85	0.0012	0.0007	0.0007	0.0009	0.0015	0.0017
100	0.0015	0.0012	0.0012	0.0013	0.0020	0.0022
125	0.0018	0.0015	0.0015	0.0015	0.0023	0.0025
150	0.0020	0.0016	0.0016	0.0016	0.0024	0.0026
200	0.0024	0.0020	0.0019	0.0019	0.0027	0.0028
250	0.0025	0.0021	0.0019	0.0019	0.0027	0.0028
300	0.0026	0.0022	0.0020	0.0019	0.0026	0.0028

Lead Glass

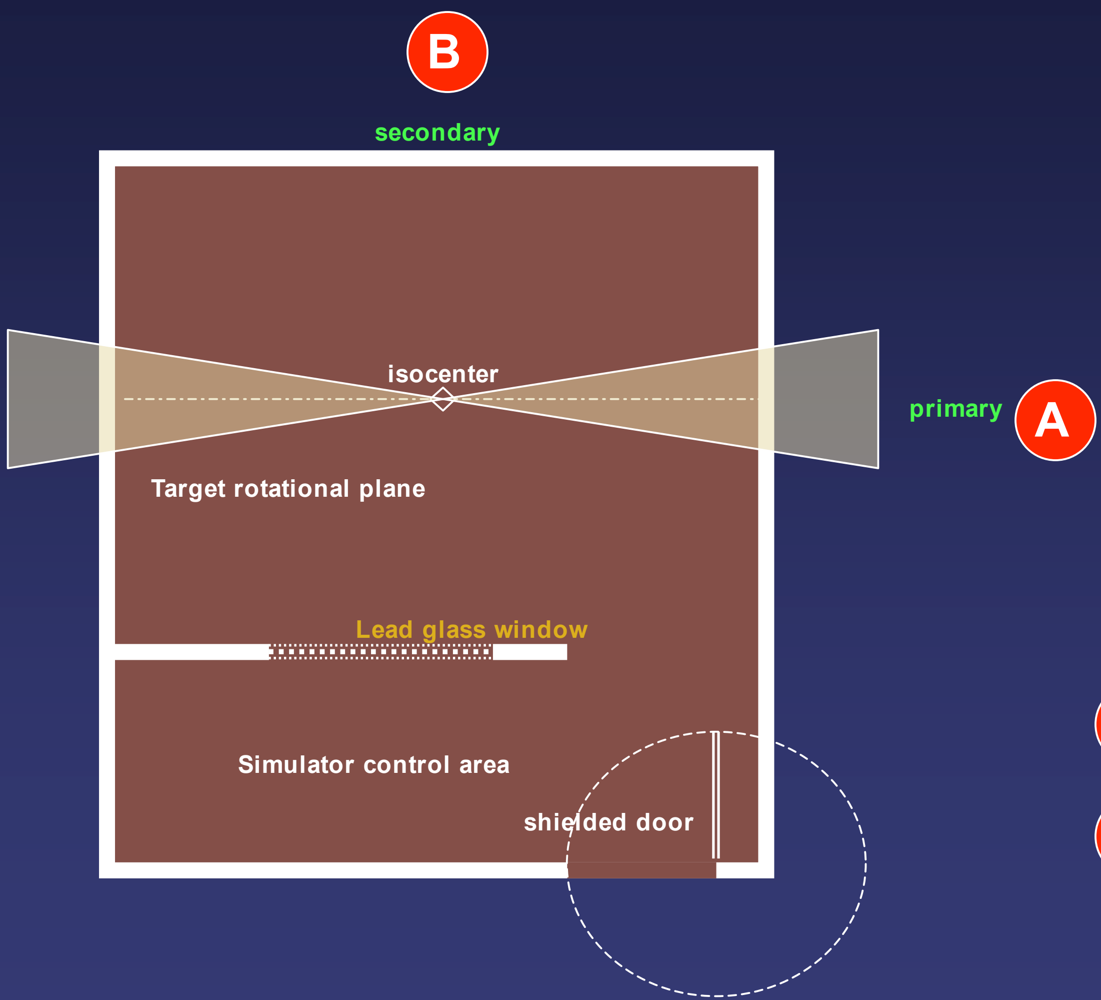
- Leaded glass may be used for patient observation window

	thickness (mm)		
Lead	1.9 (1/16”)	2.6 (3/32”)	3.1 (1/8”)
Glass	8	11	14
X-ray kV_p	150	150	200
Cost/m^2	145	190	220

Doors

- Doors contain the lead equivalent thickness required for secondary barrier shielding
- 1 - 2 mm Pb in wood
- Make sure door is not in primary beam

Simulator (125 kV_p) room



Determine wall thickness (concrete and Pb) required for POI A and B. What would be the thickness of the lead glass required for the console area?

d iso to POI is 4m

A is an office T =1

B is a waiting room T = 1/16

U = 0.25 for simulators

W = 1000 mA min/week

Simulator room

- **Determine target P**
  - At Ⓐ , office with NEW (+ALARA ?)
  - 20 mSv/year (ICRP 60)
  - Target dose rate is 20 mSv/yr = 2 R/yr = 0.04 R/wk

Simulator room

- P = 0.04 R/week
- d = 4m
- W = 1000 mA min/week
- U = 0.25, T = 1

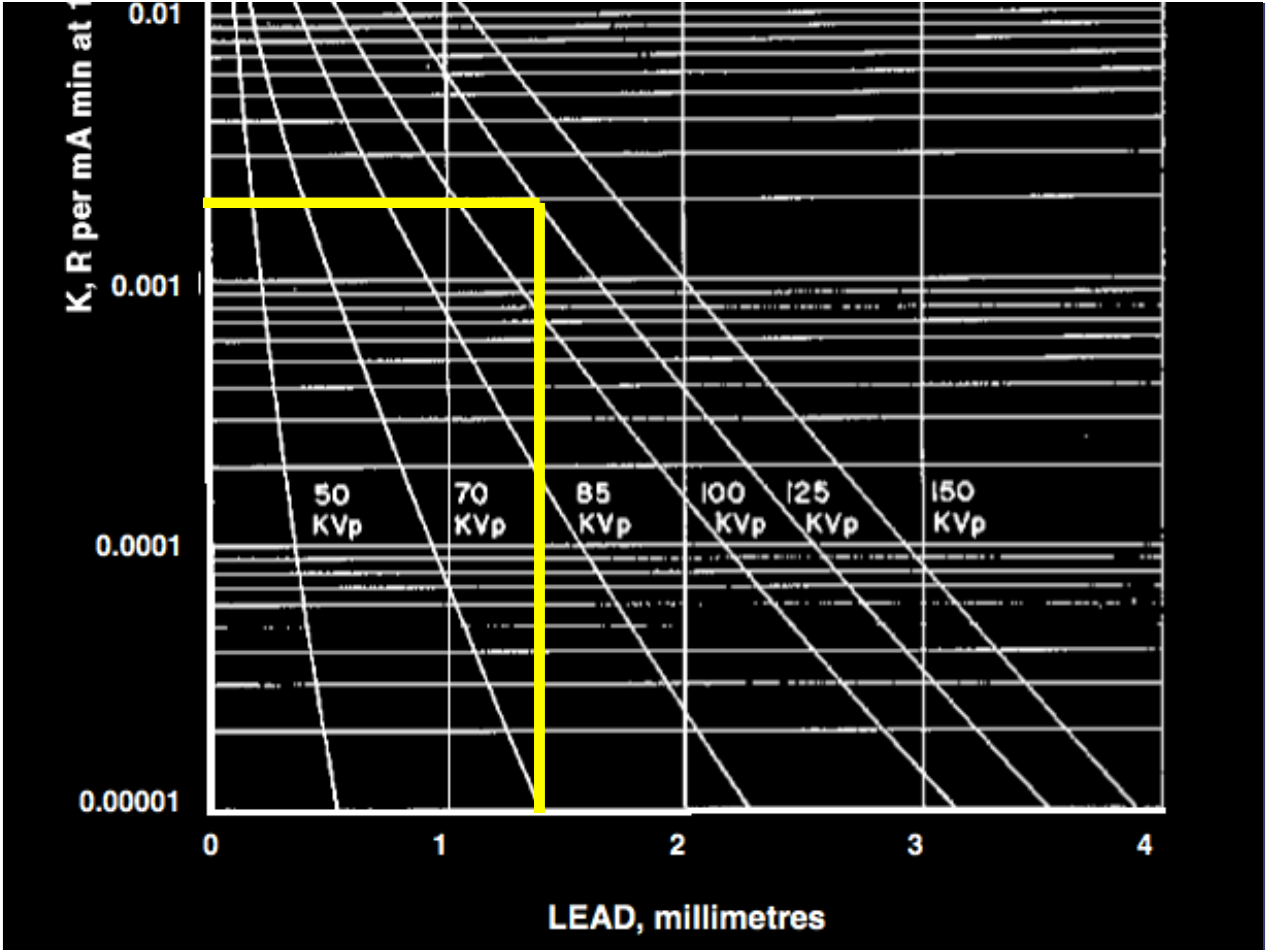
$$K_{ux} = \frac{Pd^2}{WUT} = 0.00256$$

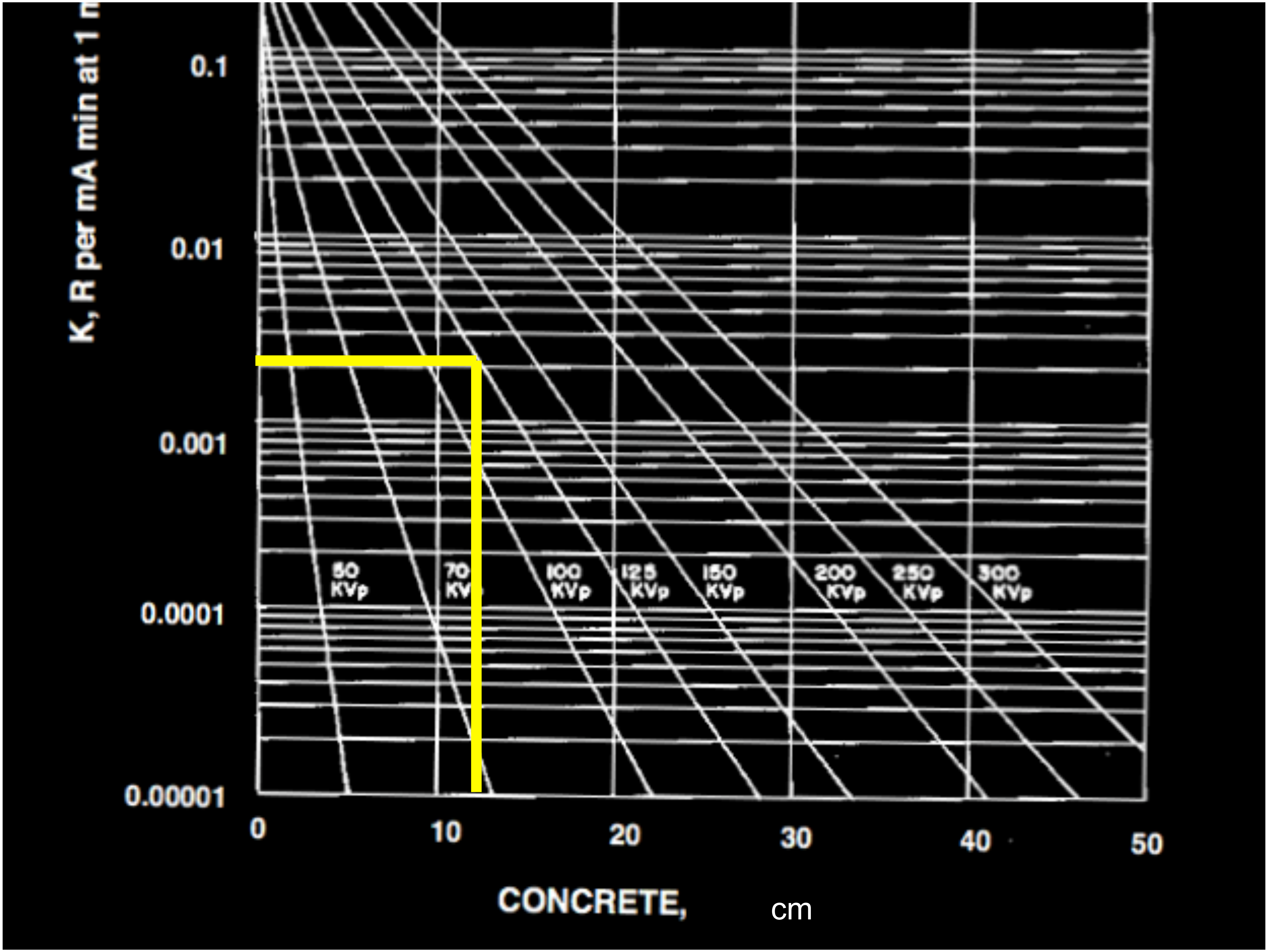
Simulator room

$$K_{ux} = \frac{0.04 \text{ R/wk} \times 4^2}{1000 \text{ mA min/wk} \times 0.25 \times 1}$$

K_{ux} = 0.00256 R/mA min at 1m

~ 12 cm concrete or 1 - 2 mm Pb


K, R per mA min at 1
0.01
0.001
0.0001
0.00001
50 KVp
70 KVp
85 KVp
100 KVp
125 KVp
150 KVp
0
1
2
3
4
LEAD, millimetres



K, R per mA min at 1 m
0.1
0.01
0.001
0.0001
0.00001
50 KVp
70 KVp
100 KVp
125 KVp
150 KVp
200 KVp
250 KVp
300 KVp
0
10
20
30
40
50
CONCRETE, cm

Leakage barrier

- Leakage barrier (at B)
  - I = 5 mA, T = 1/16, d_s = 4m

$$B = \frac{600\ I\ P d_s^2}{WT}$$

Simulator room

- Leakage barrier (at B)

$$B = \frac{600\ I\ Pd_s^2}{WT}$$

$$= \frac{600 \times (5) \times 0.002\ R/wk \times 4^2}{1000 \times 1/16} = 1.536$$

= 0.186 TVLs or 0.618 HVLs

Simulator room

– Concrete @ 125 kVp = 0.186 x 6.6 cm = 1.2 cm
– Lead @ 125 kVp = 0.186 x 0.93 = 1.7 mm
– Lead glass equivalent = 8 mm

Half-Value Layers and Tenth-Value Layers for Heavily Filtered X-Radiation Under Broad-Beam Conditions

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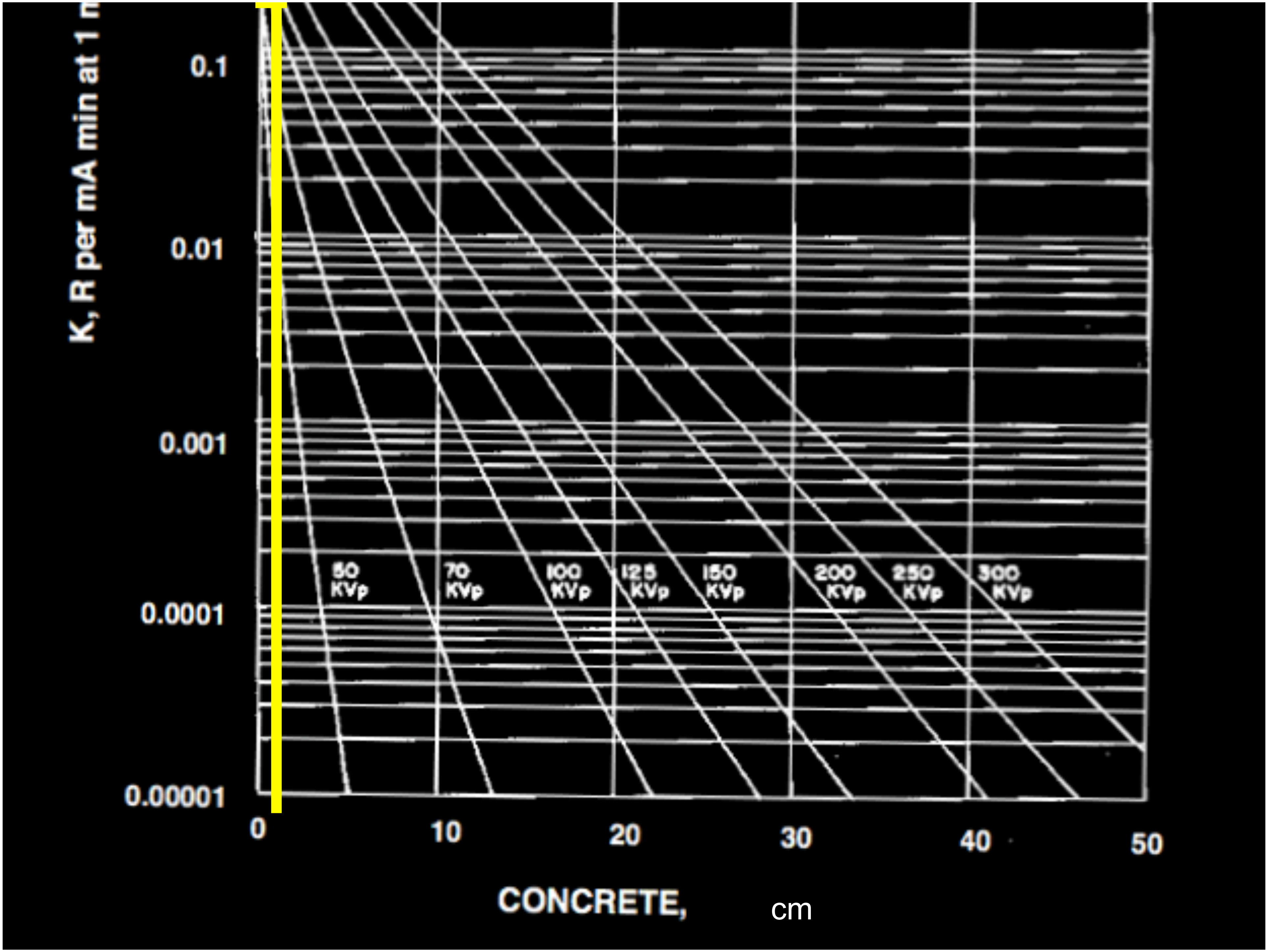
85	0.22	0.73	1.25	4.5
100	0.27	0.88	1.60	5.3
125	0.28	0.93	2.00	6.6

Scatter barrier

- Scatter barrier (at B)
  - $F = 20^2$ cm^2, T = 1/16, D = 1m, d = 4m
  - a = 0.002

$$K = \frac{400\ P\ D^2\ d^2}{F \quad aWT} = 0.256$$

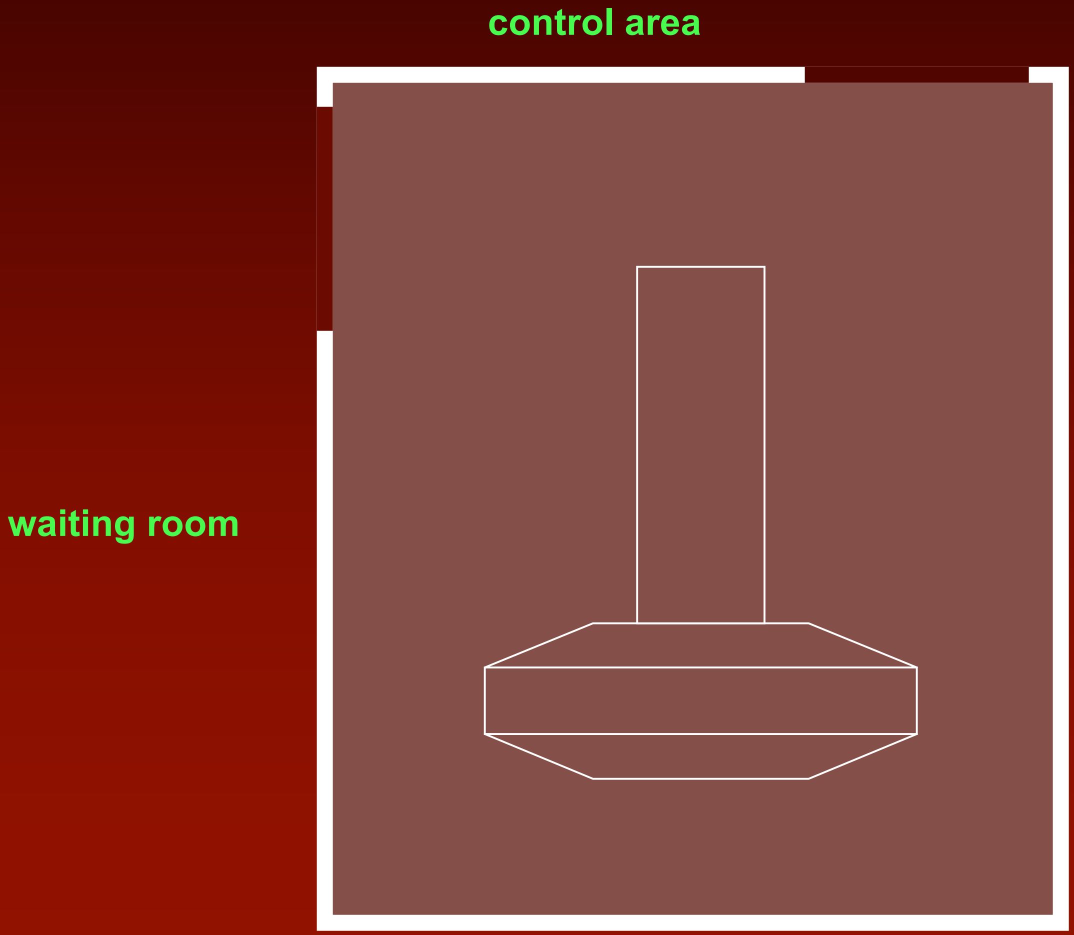
  - Equivalent to about 1 cm concrete so use leakage calculation


K, R per mA min at 1 m
0.1
0.01
0.001
0.0001
0.00001
50 KVp
70 KVp
100 KVp
125 KVp
150 KVp
200 KVp
250 KVp
300 KVp
0
10
20
30
40
50
CONCRETE, cm

CT simulator room

- Dedicated CT scanner for radiotherapy
- Flat table, lasers, big bore
- X-ray tube operating at 125 kVp and 250 mAs
- Primary beam is inherently shielded and U = 1

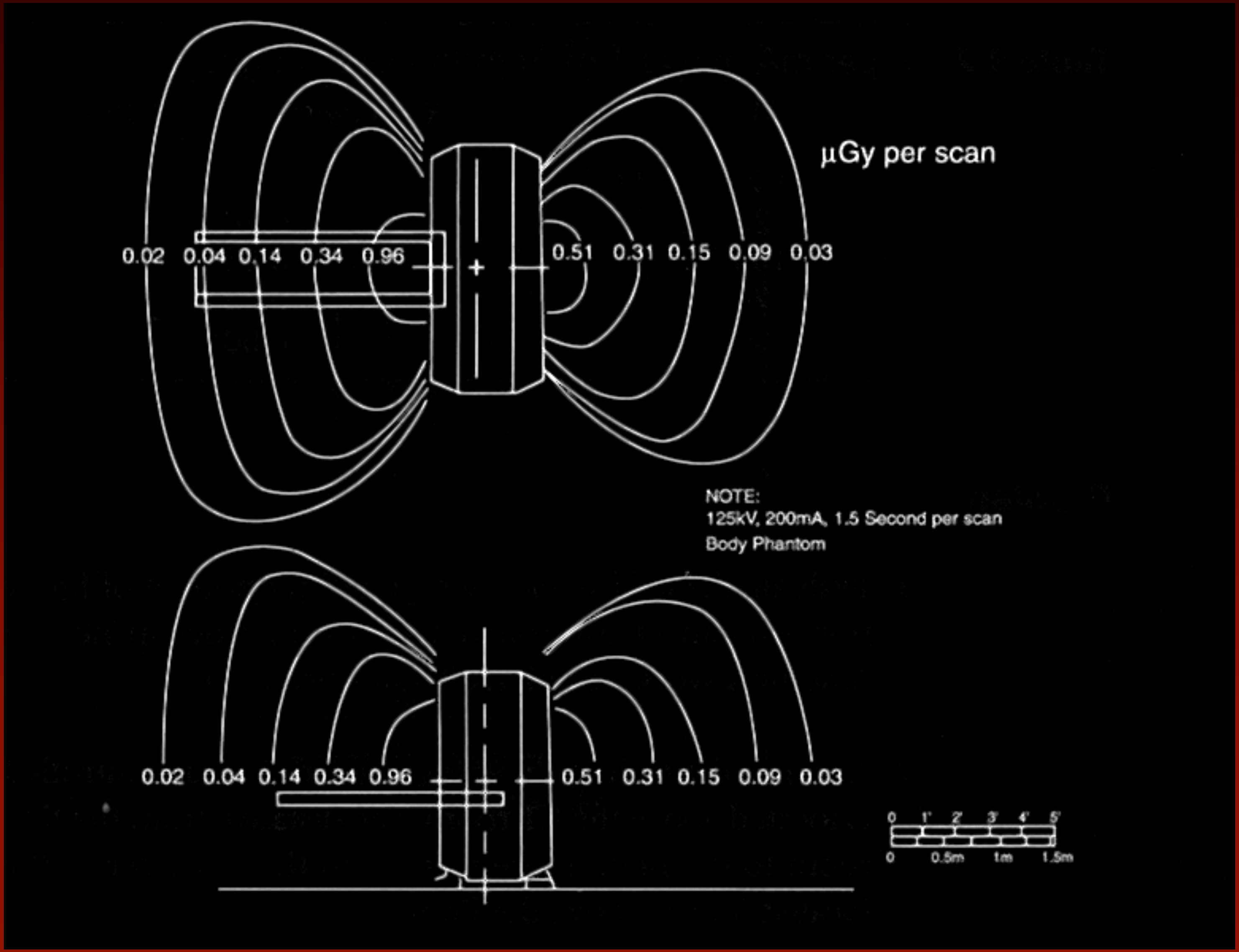
CT simulator room



CT simulator

- Workload
  - W = 50 pt/wk x 100 slices/pt = 5000 slices/wk
- Isodose plots are provided from the manufacturer to estimate the dose rate in different parts of the room

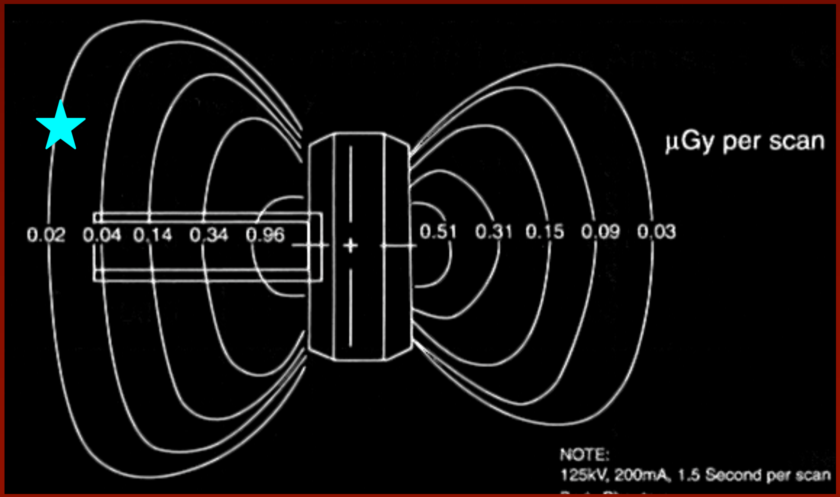
CT scanner dose



CT scanner dose

- The workload at any unprotected point in the room:

$$D = W\,D_o\,T$$



- D_o is the isodose value, T is the occupancy

CT simulator room

- The required transmission is:

$$TR = P / D = P / W D_o T$$

$$\text{and } TR = X_s/X_o$$

$$X_s = X_o TR$$

$$X_s = X_o P / W D_o T$$

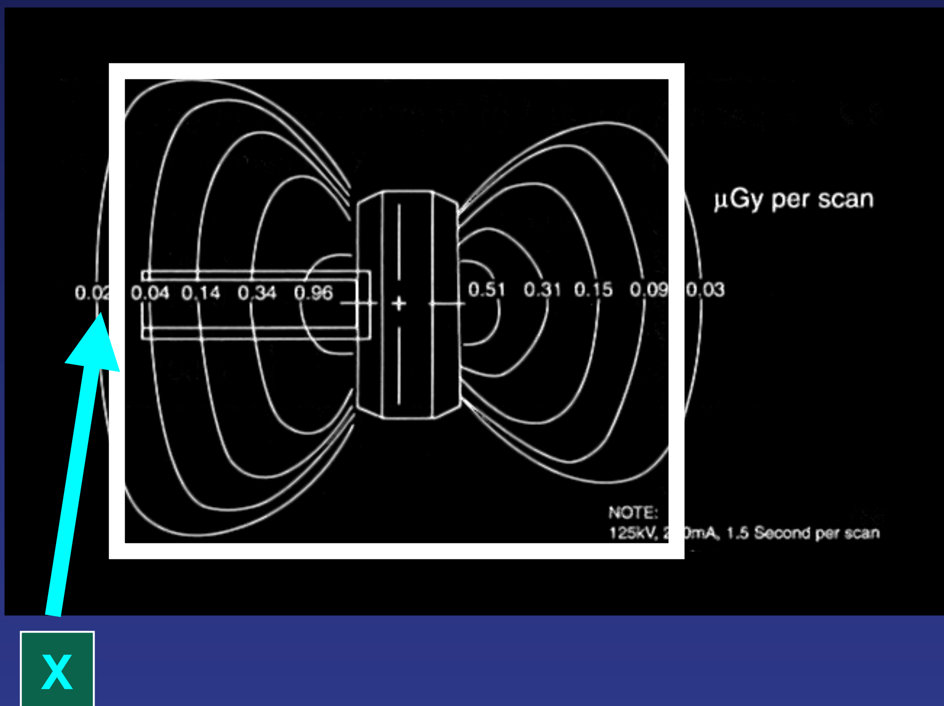
- $\mathbf{X_s}$ is the shielded intensity
- $\mathbf{X_o}$ is conversion R per mA min at 1m

CT simulator room

- R per mA min at 1 m from the x-ray target

kV	Xo
150	0.95
125	0.90
100	0.86
70	0.73
50	0.50

CT simulator room



Calculate the barrier thickness required at point X.

10 patients are scanned a day, 100 slices each patient.

The area to be protected is a public access area with occupancy T=1.

The scanner operates at 125 kV and 200 mA for 1.5s per slice.

a) Calculate the Workload
b) Calculate the P
c) Determine the thickness of lead required

$X_s = X_o P / W D_o T$

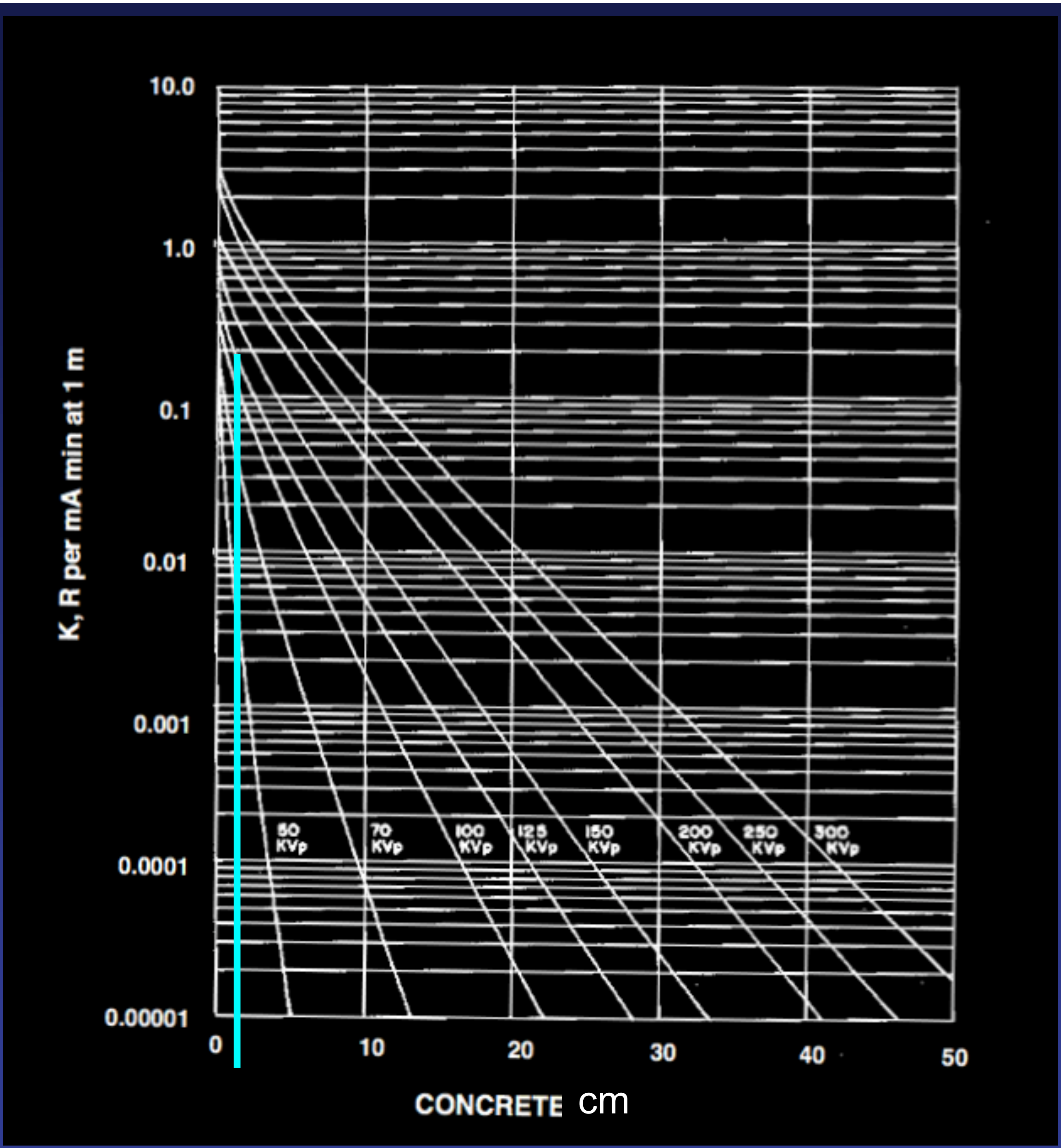
- Workload W
  - 10 pt/day x 100 slices/pt x 5 day/wk = 5000 slices/wk
- Target dose rate P
  - Public limit 1 mSv/year is 0.02 mSv/wk
- Dose from isodoses D_o
  - $D_o = 0.03$
- R per mA min conversion X_o
  - $X_o = 0.95$

CT simulator room

$$X_s = X_o\, P \,/\, W\, D_o\, T$$

$$= \frac{(0.95 \times\ 0.02\ \text{mSv/wk})}{5000\ \text{slices/wk} \times 0.02 \times 10^{-3}\ \text{mGy}}$$

$$X_s = 0.19$$



K, R per mA min at 1 m
10.0
1.0
0.1
0.01
0.001
0.0001
0.00001
0
10
20
30
40
50
50 KVp
70 KVp
100 KVp
125 KVp
150 KVp
200 KVp
250 KVp
300 KVp
CONCRETE cm

HDR brachytherapy

- Ir-192
- 10 Ci, welded to flexible steel cable
- Remotely controlled
- Source driven out of safe through a catheter to patient
- Typical room ~ 60 cm concrete

HDR brachytherapy

- Shielding calculations based on transmission factor B, where:

$$B = \frac{Pd^2}{WT}$$

- d is distance from source to POI

HDR brachytherapy

- Workload based on the total dose delivered to all patients to be treated per week
- W is also function of source activity and treatment time
- $W = \Gamma f A t$

HDR brachytherapy

$$W = \Gamma f A t$$

- Γ exposure rate constant
  - Relates exposure rate to activity at 1m
  - For Ir-192 Γ = 0.48 m^2 R/hr Ci
- F factor
  - relates cGy to R and is 0.96 cGy/R for Ir-192
- t treatment time per week
  - T = dose x #patients / doserate @ 1cm

HDR brachytherapy

- Calculate thickness of concrete required for a 10 Ci Ir-192 installation that treats 25 pt/wk to a dose of 10 Gy per patient. The dose is delivered at 1 Gy per minute. d = 2 m, and the POI is a control area T = 1, we want to protect NEWs.

- Workload
- Target dose rate

HDR brachytherapy

$$W = \Gamma \, f \, A \, t$$

- Workload
  - Time = dose / doserate
    = 25 patients x 10 Gy / 1 Gy/min
    = 250 min = 4.16 hr/wk

W = 0.48 R/hr Ci x 0.96 cGy/R x 10 Ci x 4.16 hr/wk = 19.2 cGy/wk @1m

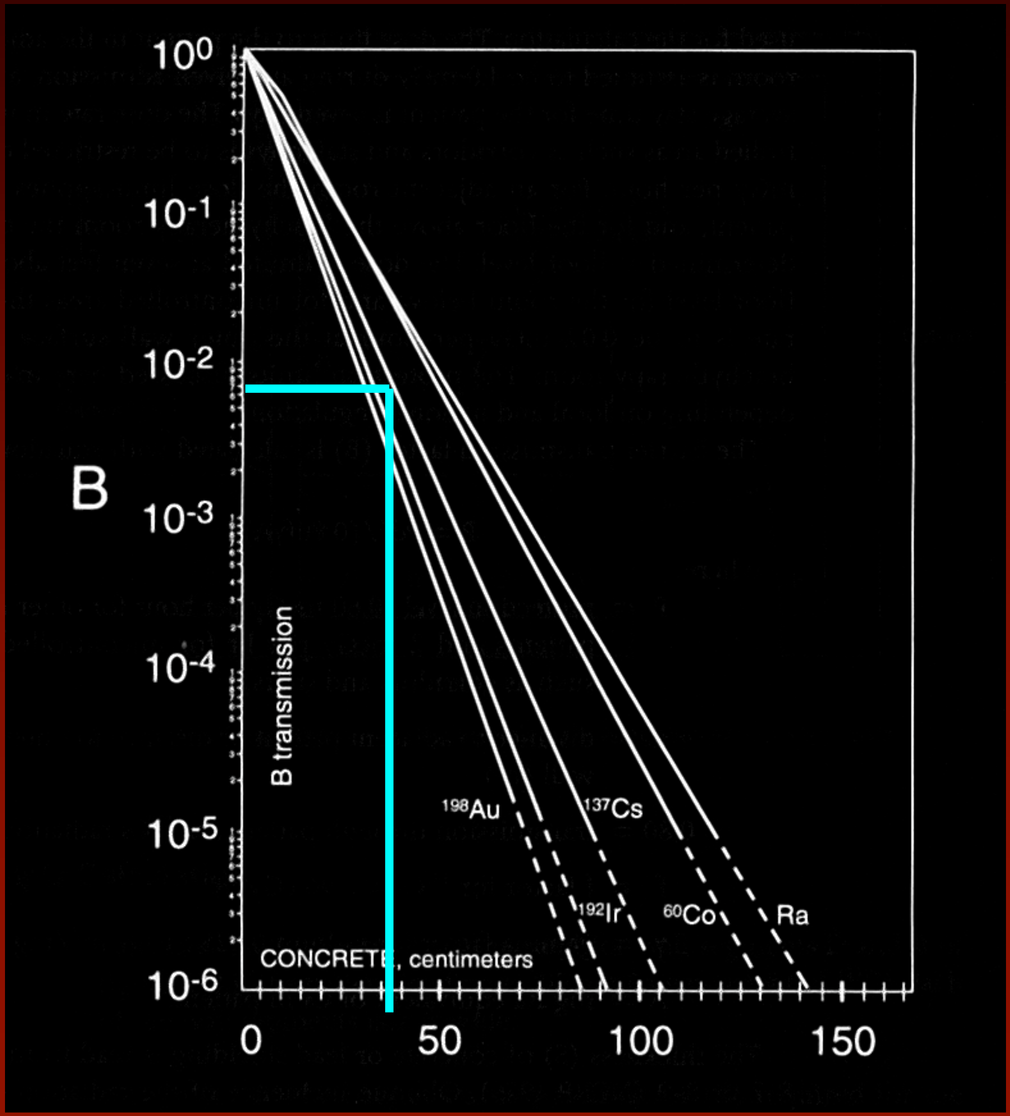
- Target dose rate
  - NEW 0.04 cGy/wk (or cSv)

HDR brachytherapy

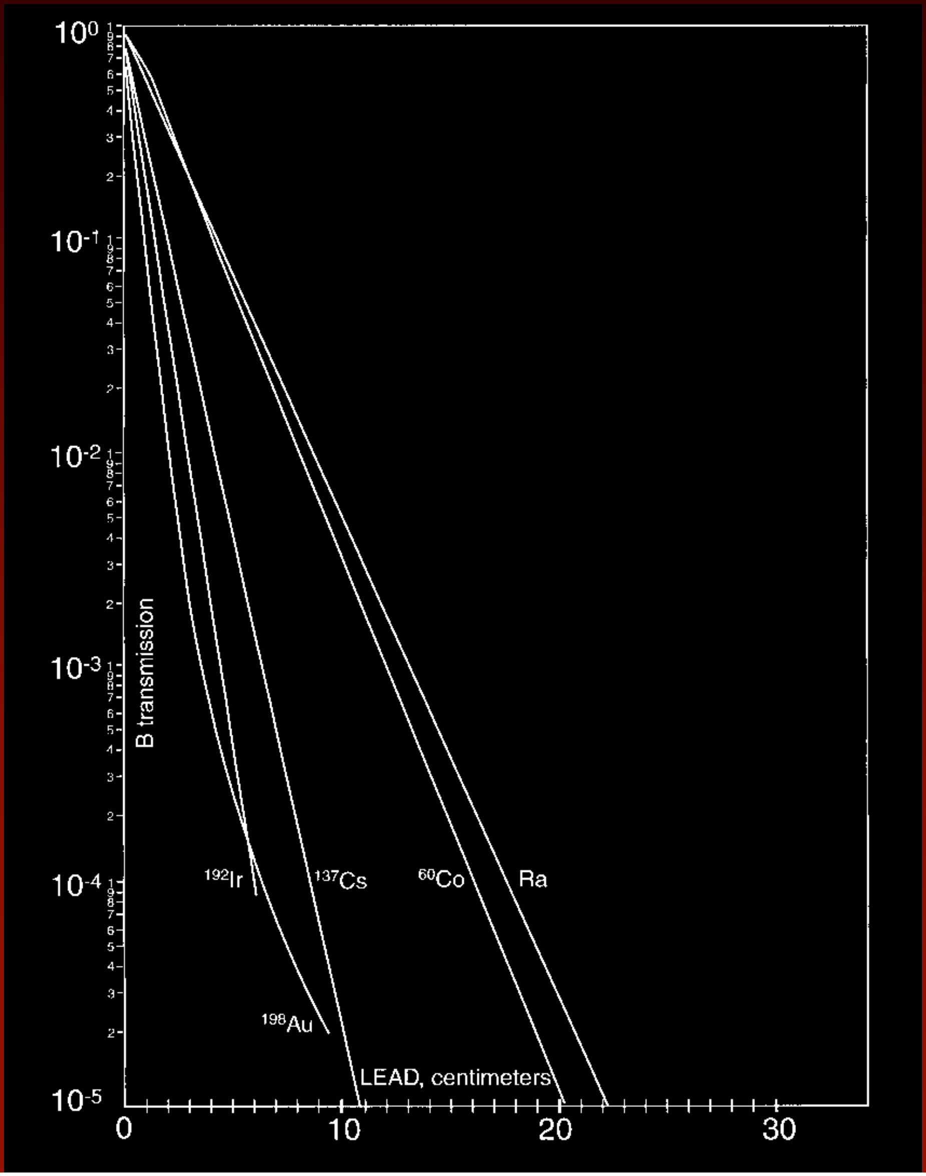
$$B = \frac{Pd^2}{WT} = 0.008$$

- From graph ~ 48 cm concrete

Brachytherapy - concrete



Brachytherapy - lead



Lead underwear

Radiation Guard

for prostate cancer patients

Direct Scientific now offers the Radiation Guard designed specifically for patients who have undergone permanent radioactive seed implantation for prostate cancer. The radioactive seeds are either Iodine-125 or Palladium-103. The Radiation Guard stops more than 99% of the Palladium radiation and 95% of the Iodine radiation. Loved ones will now be able to spend unrestricted time near you while you are wearing the Radiation Guard. The Radiation Guard is comfortable">

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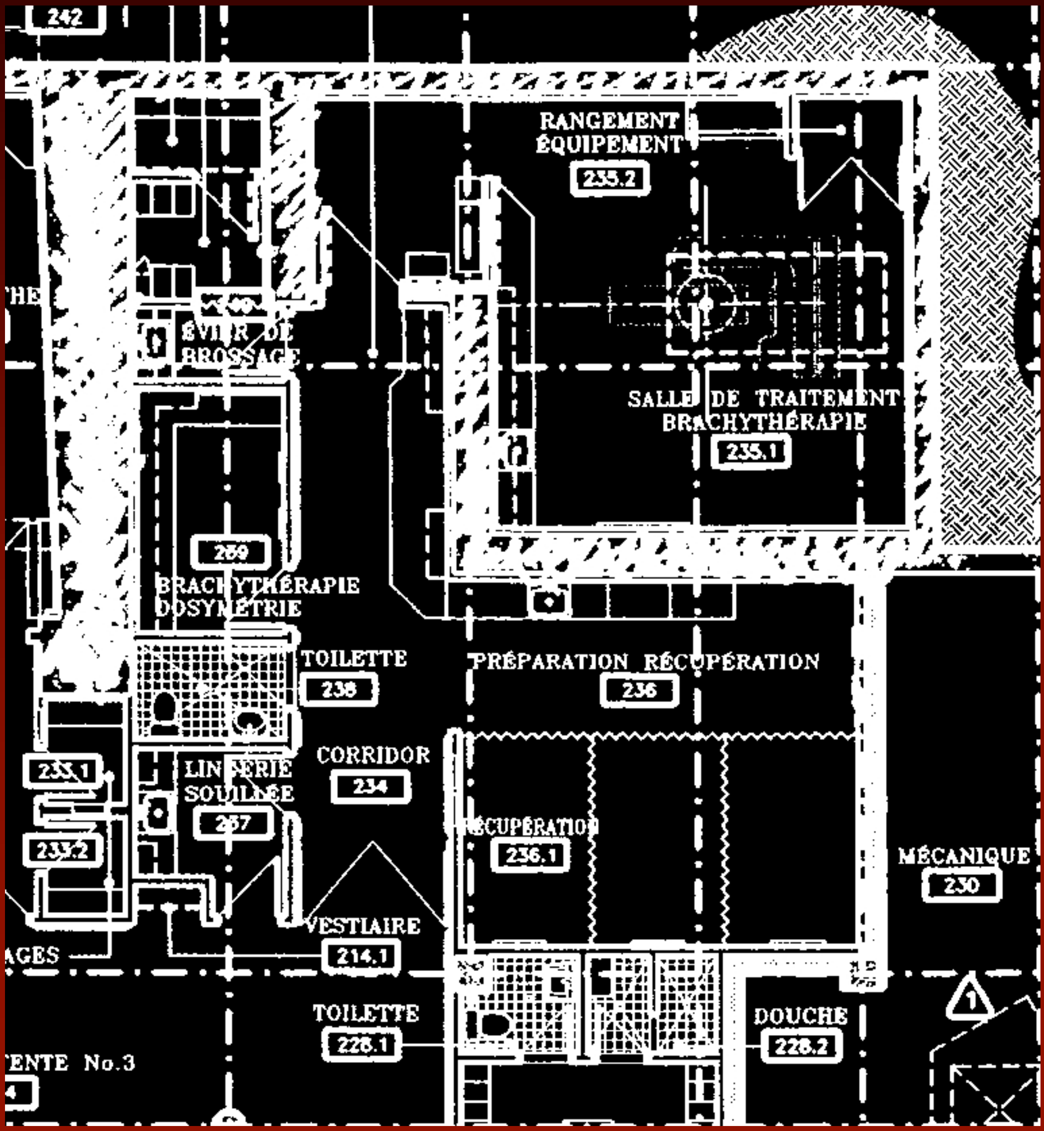
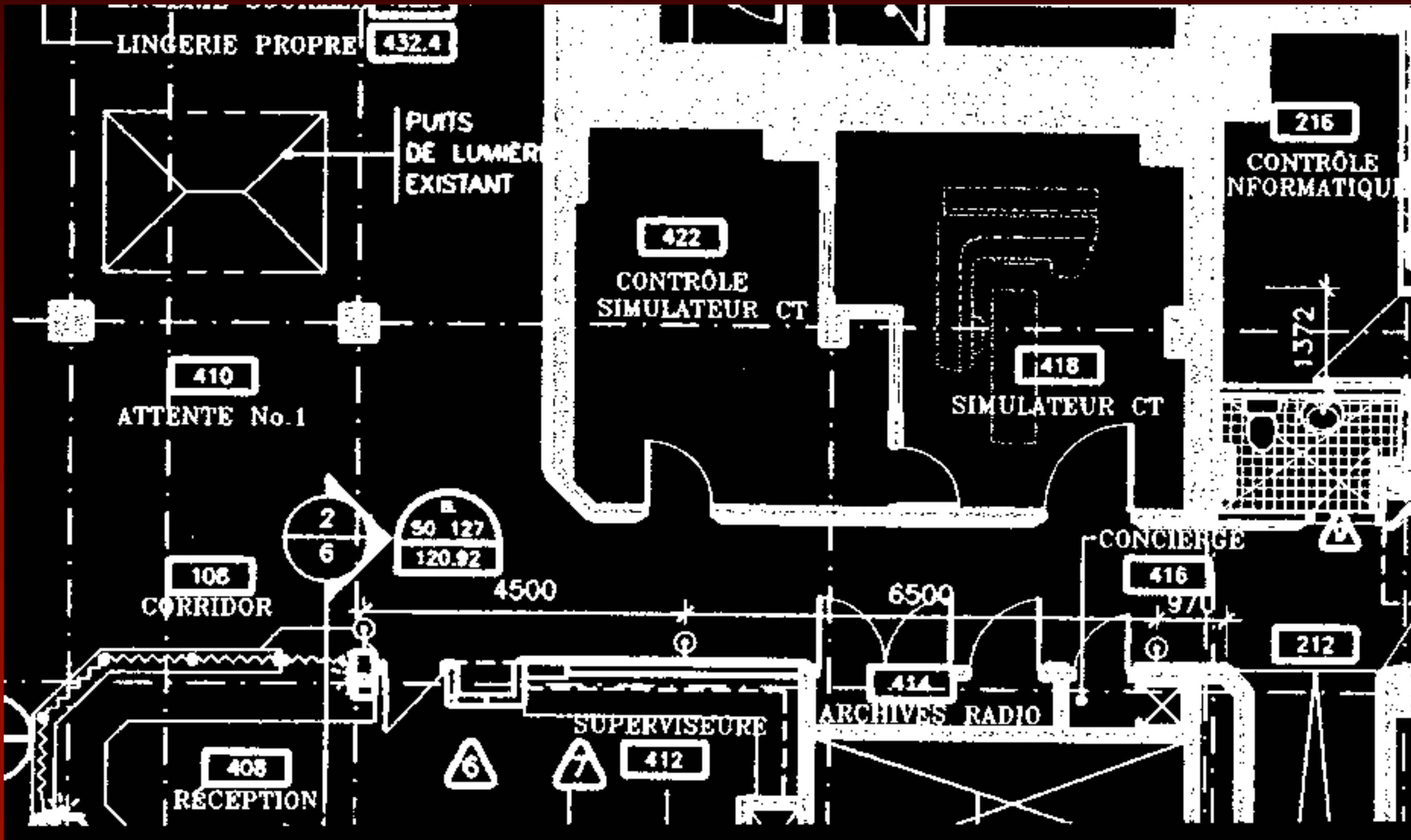
Shipping-UPS	
ground	$10.00
orange 3 day	$13.00
blue 2 day	$18.00
red next day	$30.00

Radiation Guard	$120.00
Radiation Guard w/ extension straps	$125.00
Visa and MasterCard accepted	

MGH brachytherapy/SIM



MGH CT simulators 1



MGH CT simulators 2