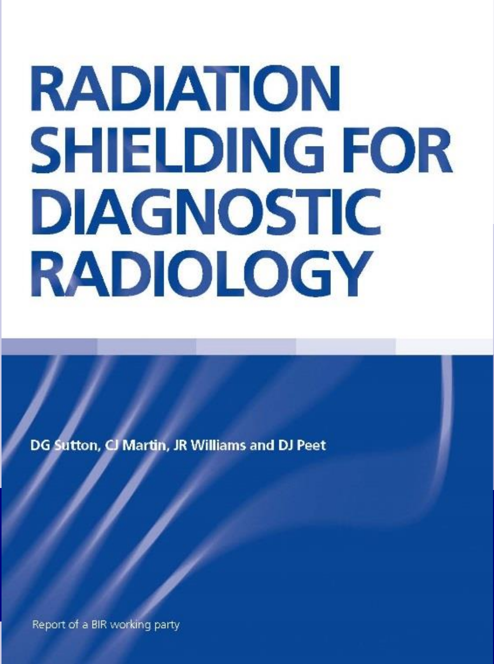
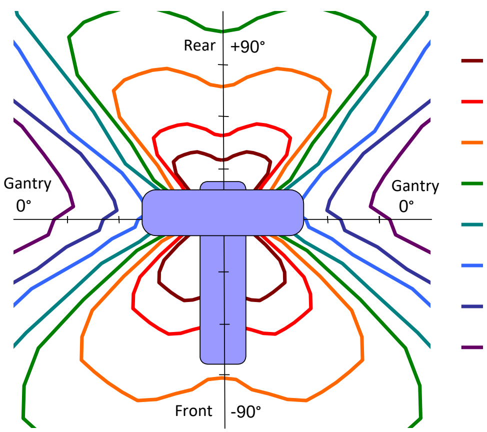


The UK approach to shielding x-ray rooms



Colin Martin
University of Glasgow
Scotland, UK

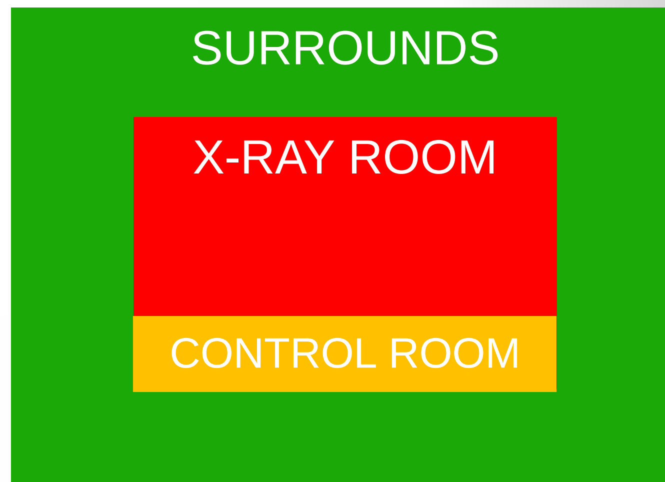
The UK approach to shielding x-ray rooms

- Dose limits and constraints
  - Occupancy
- Radiation sources
  - Predicting scatter levels from kerma-area product (KAP)
- Shielding radiography and fluoroscopy rooms
  - Primary for radiography
  - Simplifications for mammography and dental
- CT
  - Scatter from DLP
  - Tertiary scatter

Dose Limits and Constraints

Dose Limits

- X-ray room - Employees - 20 mSv y^{-1}
- Surrounding area - Public dose limit - 1 mSv y^{-1}



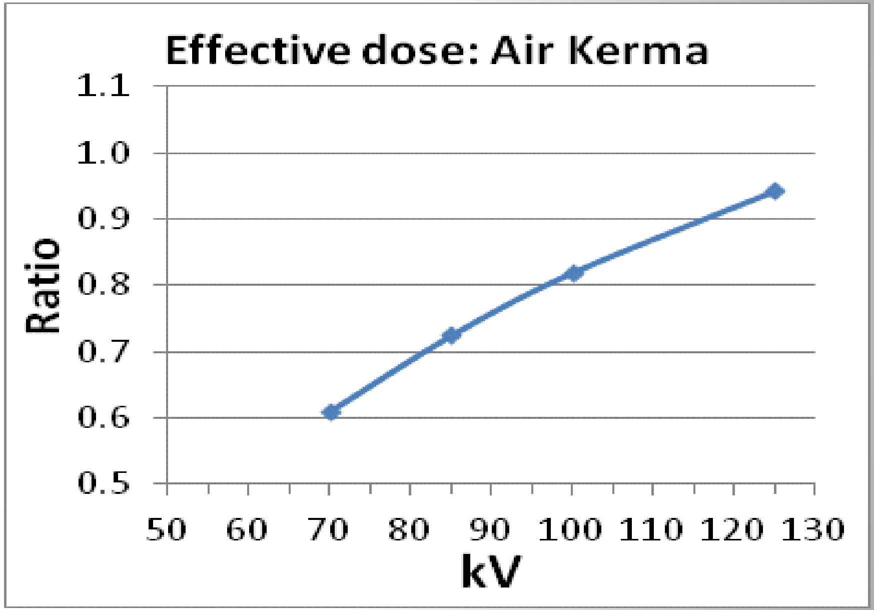
Dose Constraints

- ALARP solution (As Low As Reasonably Practicable)
- Control Room & Surrounds - 0.3 mSv y^{-1}

Air Kerma and effective dose

Easier to measure or calculate

Ratio: $\frac{\text{Effective Dose}}{\text{Air Kerma}}$



Air kerma is greater than E for X-rays, so this is a conservative approach

Use an Air Kerma Constraint

0.3 mGy y^{-1} (300 µGy y^{-1})

Occupancy

For how long are people exposed

- Constraint: 300 μGy y^{-1}
- Dose to individual

Design limit

- Air kerma constraint / Occupancy factor (T)
- 300/ T μSv y^{-1}

Occupancy Factors

Full Occupancy **Factor: 1**

- Control room
- Reception area
- Nursing station
- Offices
- Shops
- Living quarters
- Adjacent buildings

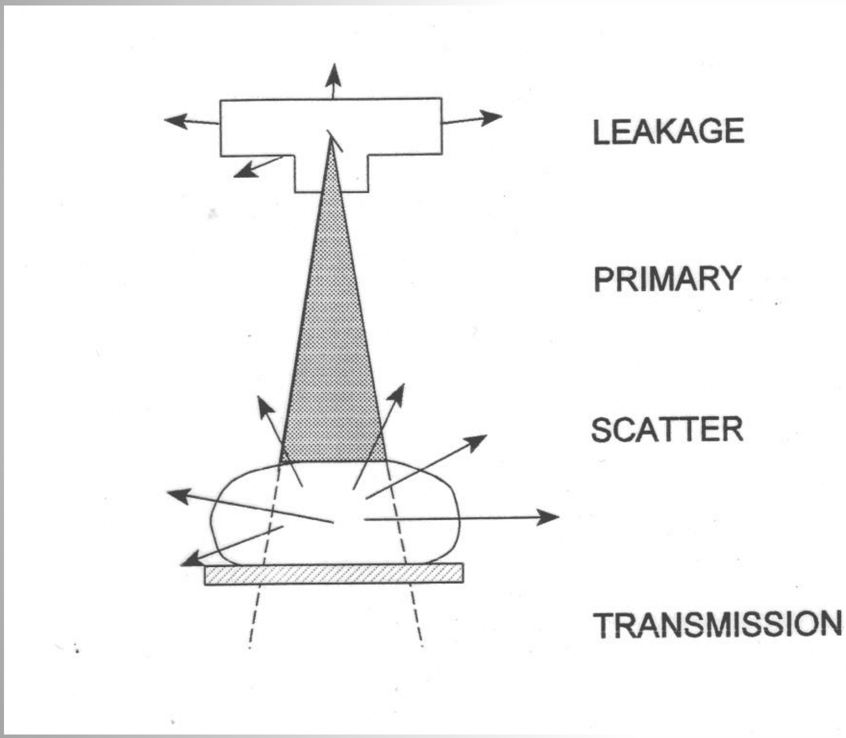
Partial Occupancy **Factor: 0.2 – 0.5**

- Staff rooms
- Wards
- Clinics
- Reporting room

Occasional Occupancy **Factor: 0.05 – 0.125**

- Corridors,
- Stairways
- Store rooms
- Changing rooms
- Toilets
- Gardens
- Unattended waiting rooms
- Unattended car park

Radiation sources



- **Secondary scatter**
  - All modalities
- Leakage
  - Minimal significance
- **Primary**
  - Radiography
- Tertiary scatter
  - Consider for CT

Scatter air kerma: source of most radiation

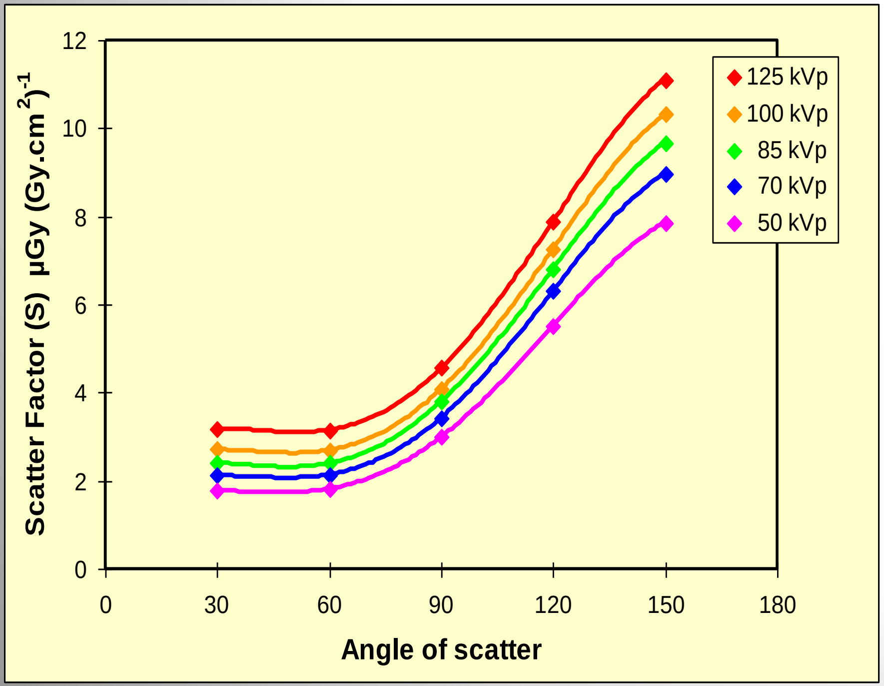
- Varies with primary beam air kerma and beam size
- Varies with angle and kV
- Dependent on beam position, patient size
- Scatter α Kerma-Area Product (KAP)
- Equation used to determine scatter air kerma K_s is:

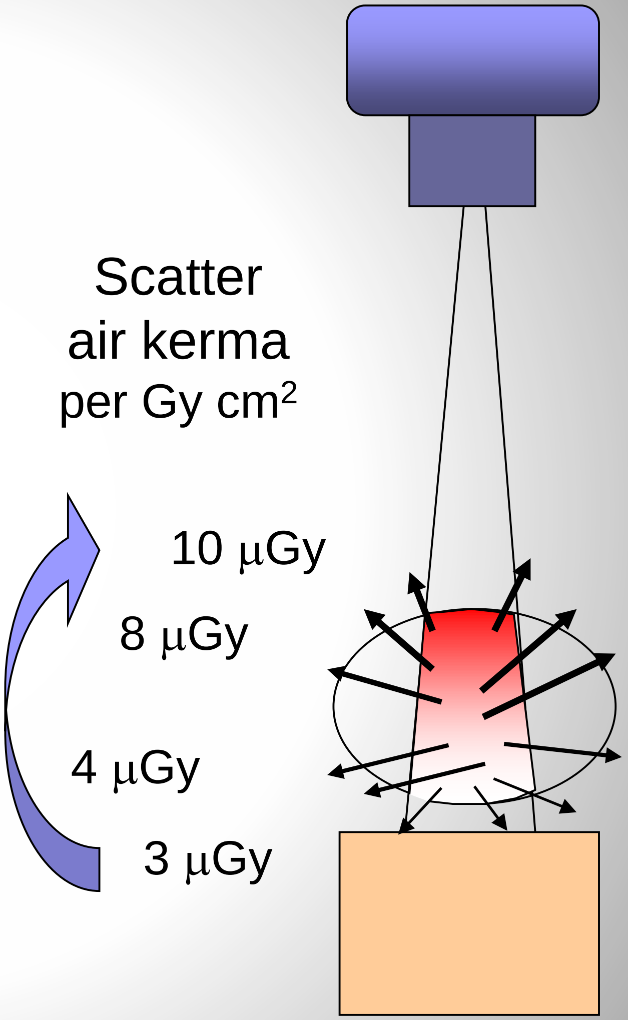
$$K_s = S \times KAP$$

- S is a scatter factor

Scatter

- Varies with angle and kV
- Scatter factor $S = K_s / KAP$

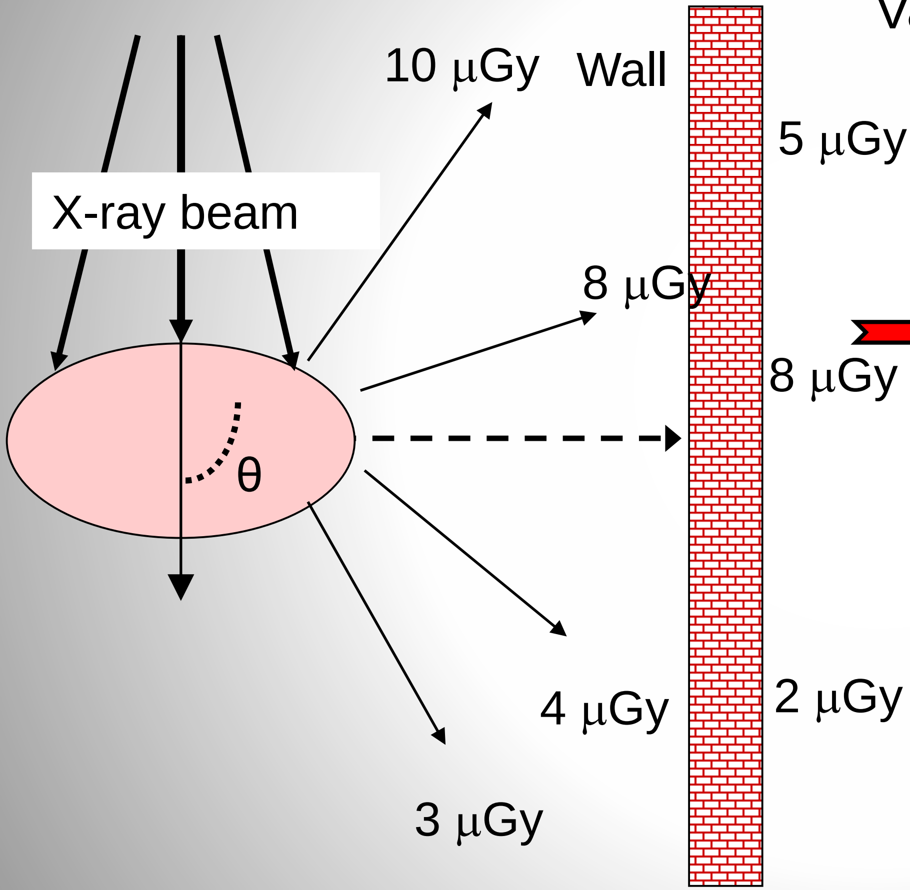




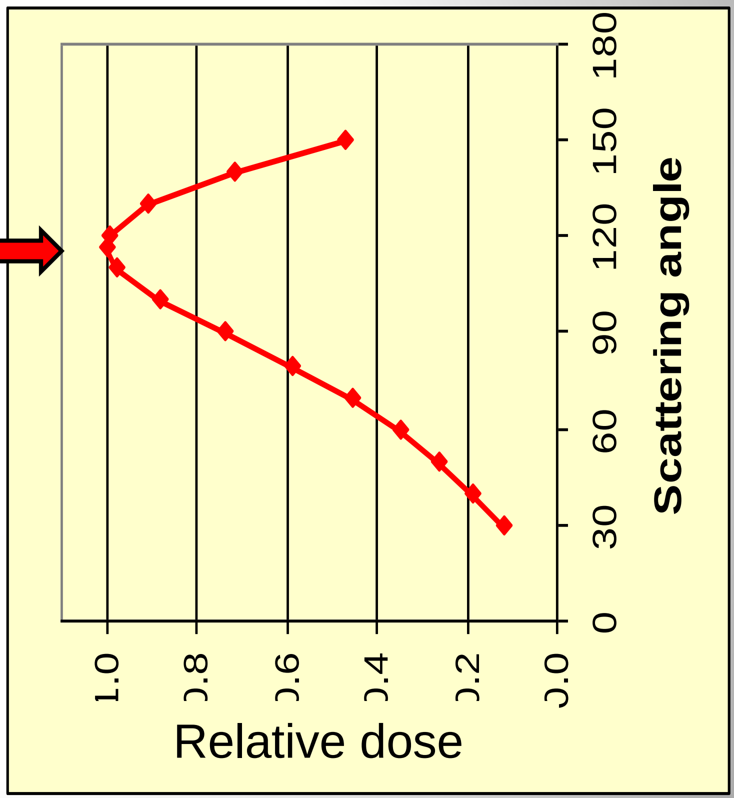
Williams JR (1996) Br J Radiol, 69,1032

Incident beam parallel to barrier

Distance to barrier shortest at an angle of 90º



Variation in dose at barrier with angle



Taking into account variation with angle and distance to barrier: Maximum air kerma occurs at 117º

Scatter factors (S)

for fluoroscopy and radiography from measurement and calculation

$S = K_s / KAP$

$S_{max} = 0.031 \times kV + 2.5$ µGy (Gy cm^2)$^{-1}$ @ 1 m

85 kV: $S_{max} = 5.1$ µGy (Gy cm^2)$^{-1}$

For interventional beams with copper filtration

85 kV: $S_{max} = 8$ µGy (Gy cm^2)$^{-1}$

Workload – in terms of KAP

(At least) Two approaches:

1. Predict clinical usage

- Typical KAP values per exam

2. Assume typical total KAP values

- **Exceptional workload** with 800 patients/wk
  KAP: 500 Gy cm^2
- **Typical workload** with 180 patients / wk
  KAP: 150 Gy cm^2

Scatter Calculation

$$\text{Scatter air kerma } (K_s) = \frac{S \times KAP_{Ann}}{d^2}$$

S = Scatter factor

KAP_{Ann} = Annual workload

d = Distance to barrier

$$\text{Design criterion (C)} = \frac{\text{Dose constraint}}{\text{Occupancy (T)}}$$

Annual dose constraint = 300 µGy, T = 0.05 – 1.0

$$\text{Transmission (B)} = \frac{C}{K_s}$$

Empirical equations can be used to link shielding thickness to broad beam transmission

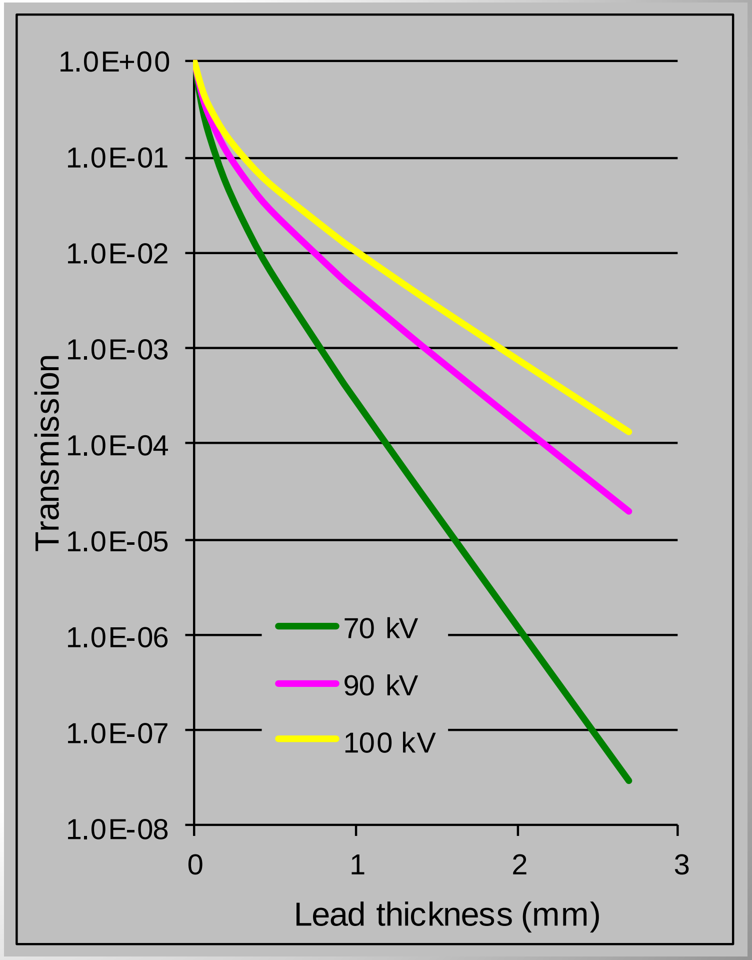
$$B = [(1+\beta/\alpha).\exp.(\alpha\gamma x)-\beta/\alpha]^{-1/\gamma}$$

B = broad beam transmission

x = thickness of material

$$x = \frac{1}{\alpha\gamma} \ln \left[\frac{B^{-\gamma} + \beta/\alpha}{1 + \beta/\alpha}\right]$$

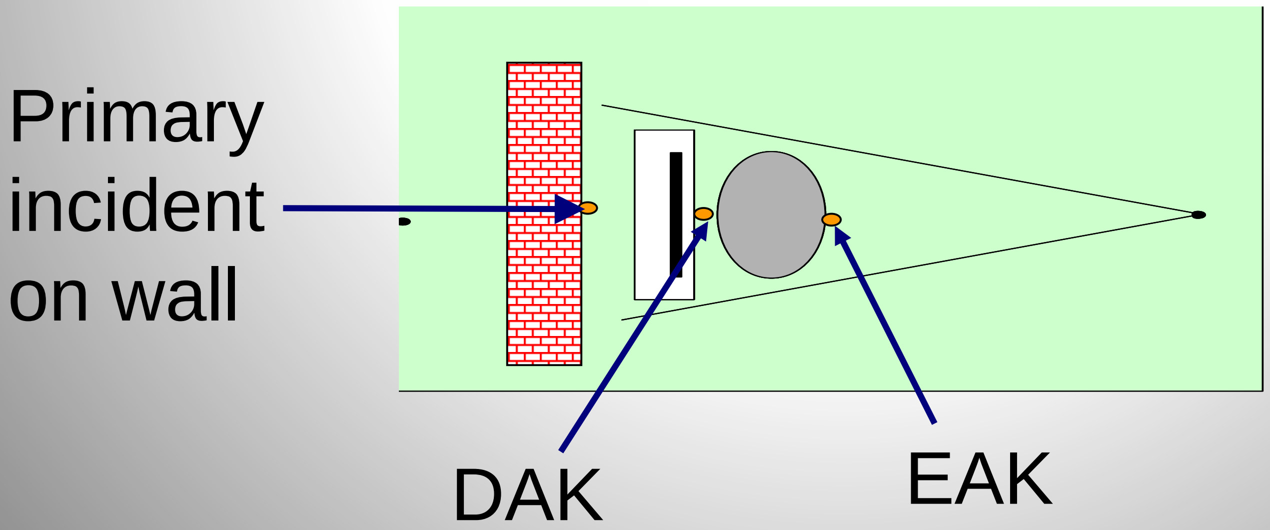
Archer, Thornby & Bushong (1983)
Health Physics, 44, 507-17

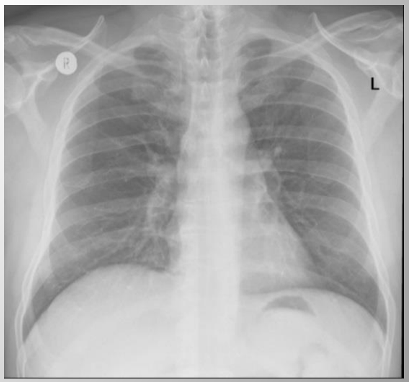


Primary beam

<u>Two approaches</u>

- Detector Air Kerma (DAK) Method ~ 10 µGy
  and allow for lead equivalence of cassette/bucky/table
- Entrance Air Kerma (EAK) method
  Adjust for inverse square law





Modalities where scatter per image or exam can be used

- Mammography 7.6 µGy per image
- Intra-oral dental 0.5 µGy per image
- Panoramic dental 0.65 µGy per exam
- Dental cone beam 6-20 µGy per image

Intra-ora dental clinics

Gypsum Wallboard (plaster board) – 10-15 mm thick

Transmission of 40 mm is 0.1 (120 X-rays per week at 1 m)

Protecting a CT scanner room

Scatter factors S_{CT} linked to Dose Length Product (DLP)

Coefficients provide links between scatter air kerma and DLP derived from measurements on CT scans of anthropomorphic phantom.

Scatter factors of the form: $S_{CT} = K_s / DLP$

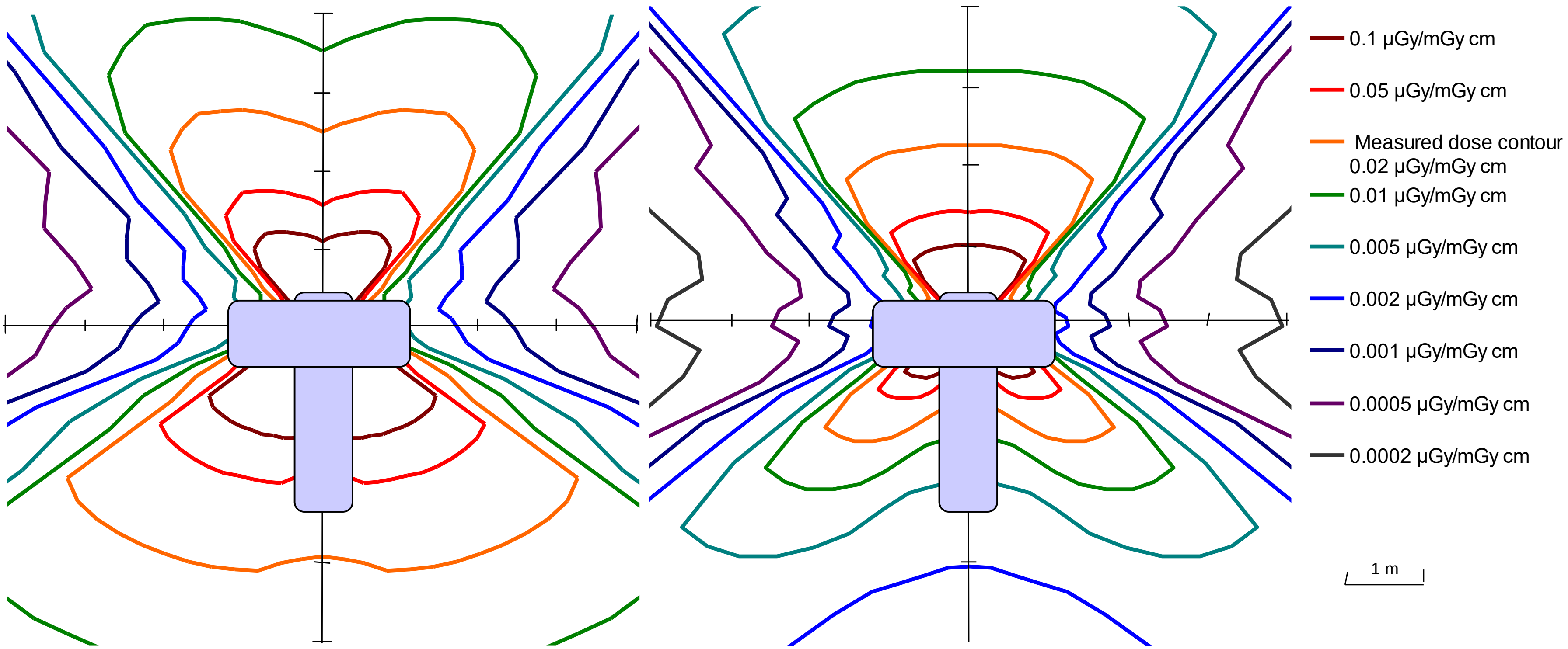
where values of K_s represent the scatter air kerma at 1 m from the iso-centre for a particular direction.

Factors based on scatter measurements on CT scanners for 4 major vendors

CT scanner dose distributions

Scatter from body scan
with Philips MX8000

Scatter from head scan
with GE Lightspeed 16



Central region shielded by gantry

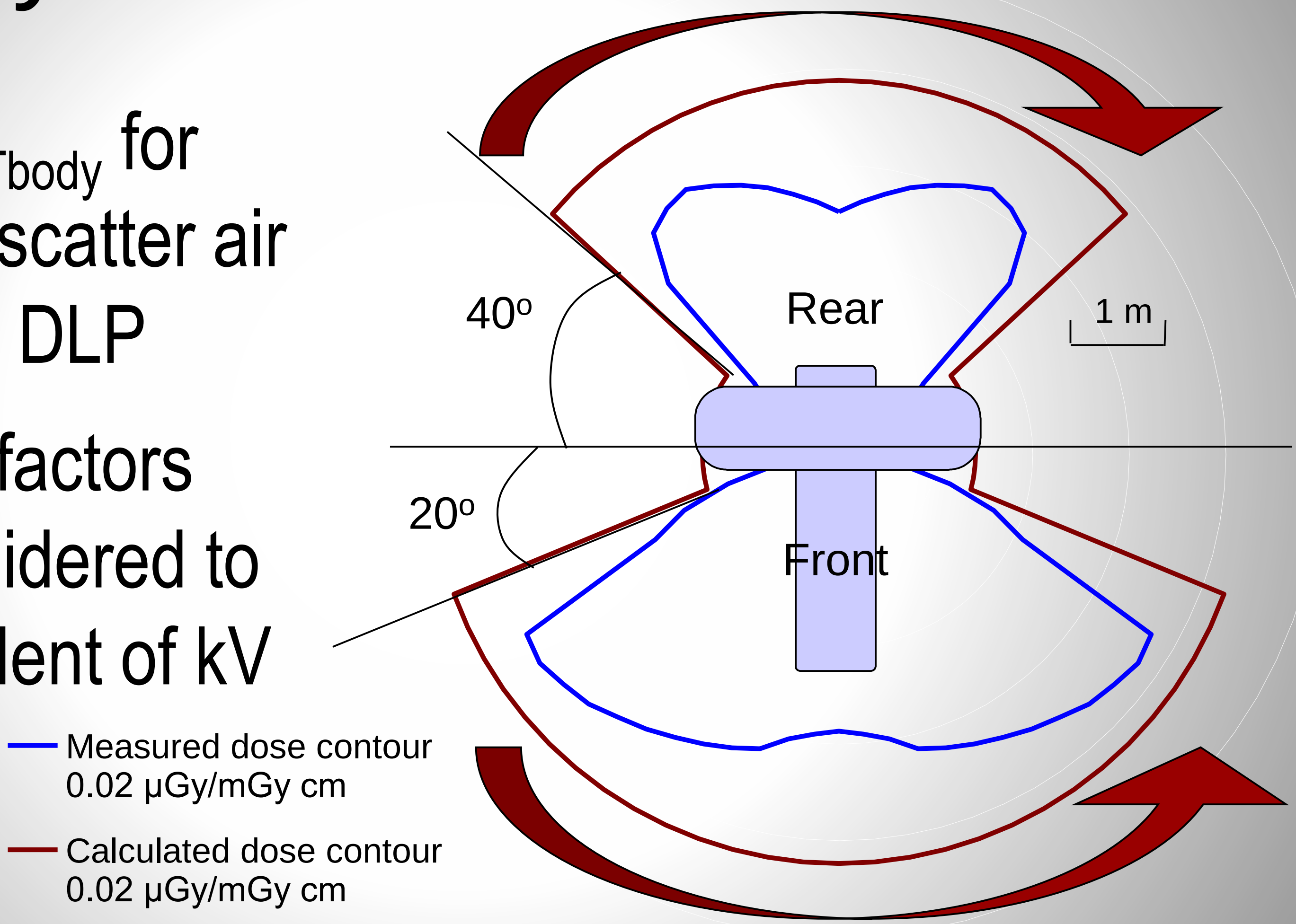
Dose per DLP higher for body than head scans

CT body scans

Factors S_{CTbody} for calculating scatter air kerma from DLP

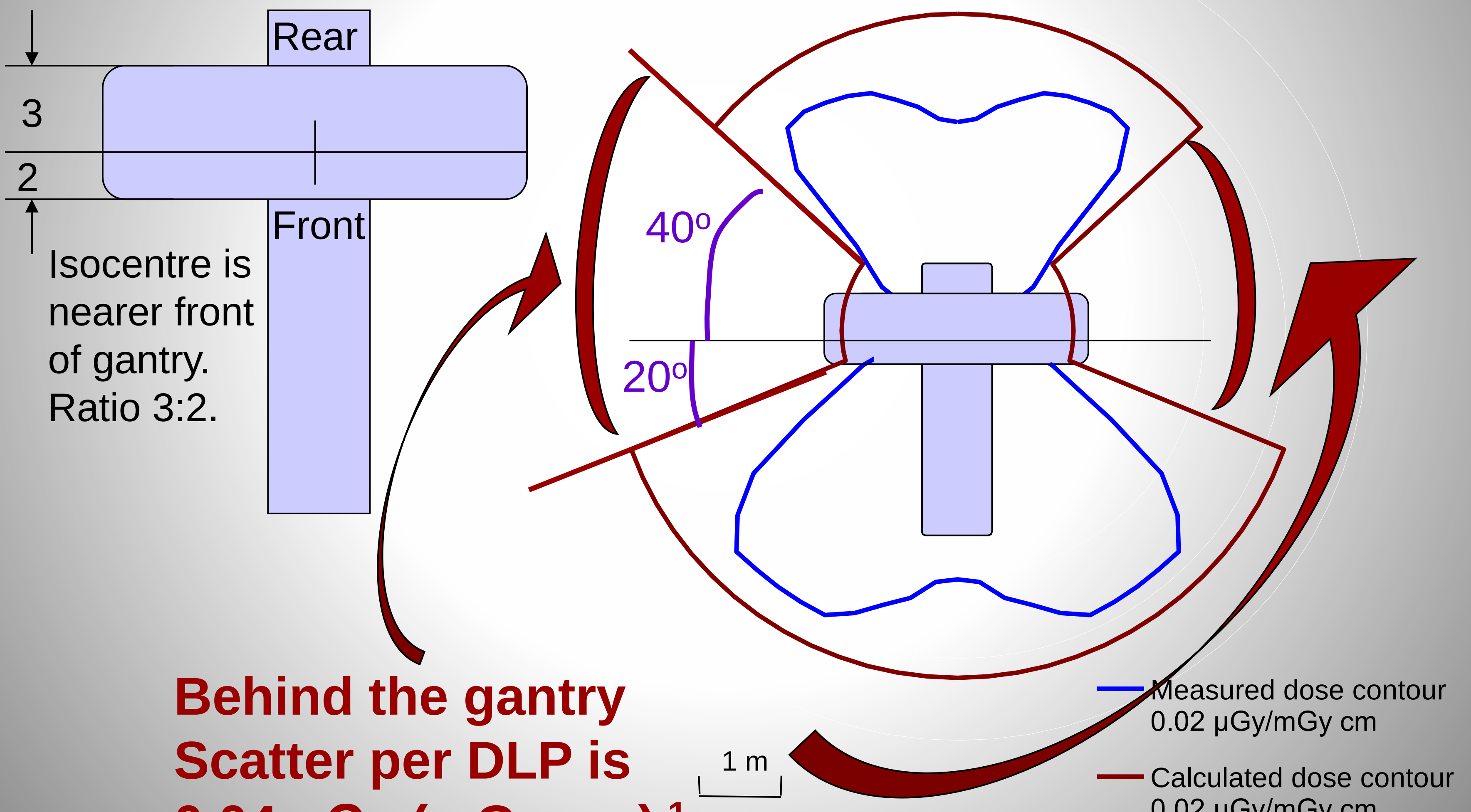
The scatter factors can be considered to be independent of kV

Scatter per DLP
0.3 µGy (mGy cm)$^{-1}$



Scatter per DLP
0.36 µGy (mGy cm)$^{-1}$

CT gantry provides protection equivalent to a factor of 10



Behind the gantry Scatter per DLP is $0.04\ \mu Gy\ (mGy\ cm)^{-1}$

Scatter factors

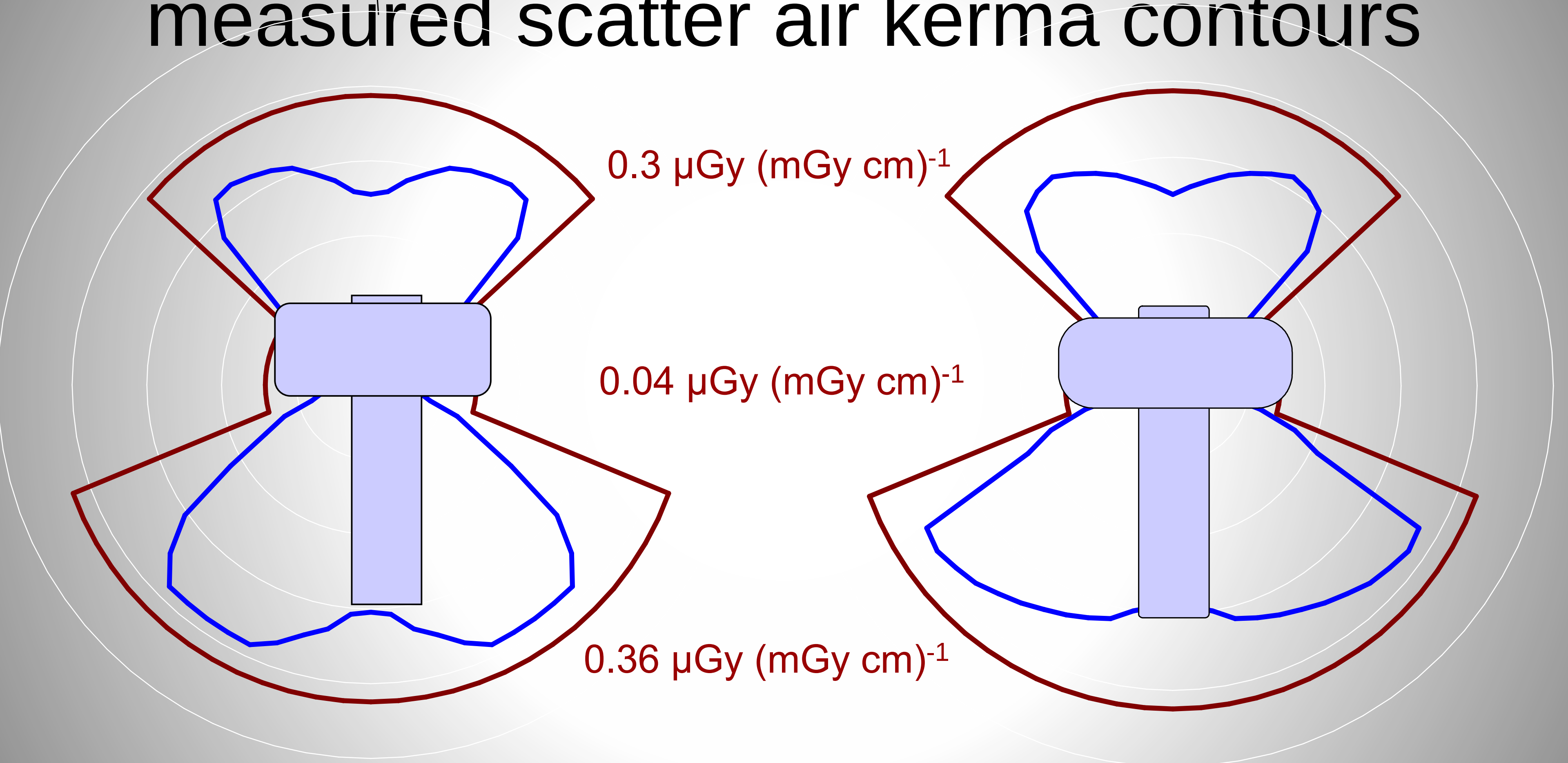
Air kerma at 1 m from scanner isocentre at different angles with respect to the scan plain

Negative angles - front of the gantry; positive angles - rear

Exam	Sector of CT scanner	Angular range per unit DLP	Scatter factor μGy (mGy cm)$^{-1}$
Body	Front	-90º - -20º	**0.36**
Body	Rear	40º - 90º	**0.3**
Body	Gantry	-20º - 40º	**0.04**
Head	Front and rear	-90º - -20º & 40º - 90º	**0.14**
Head	Gantry	-20º - 40º	**0.014**

Apply inverse square law to air kerma value at 1 m

Comparison of calculated and measured scatter air kerma contours



Calculated contours --- are compared with measurements of scatter air kerma ---.

No significant difference found between 120 kV and 140 kV

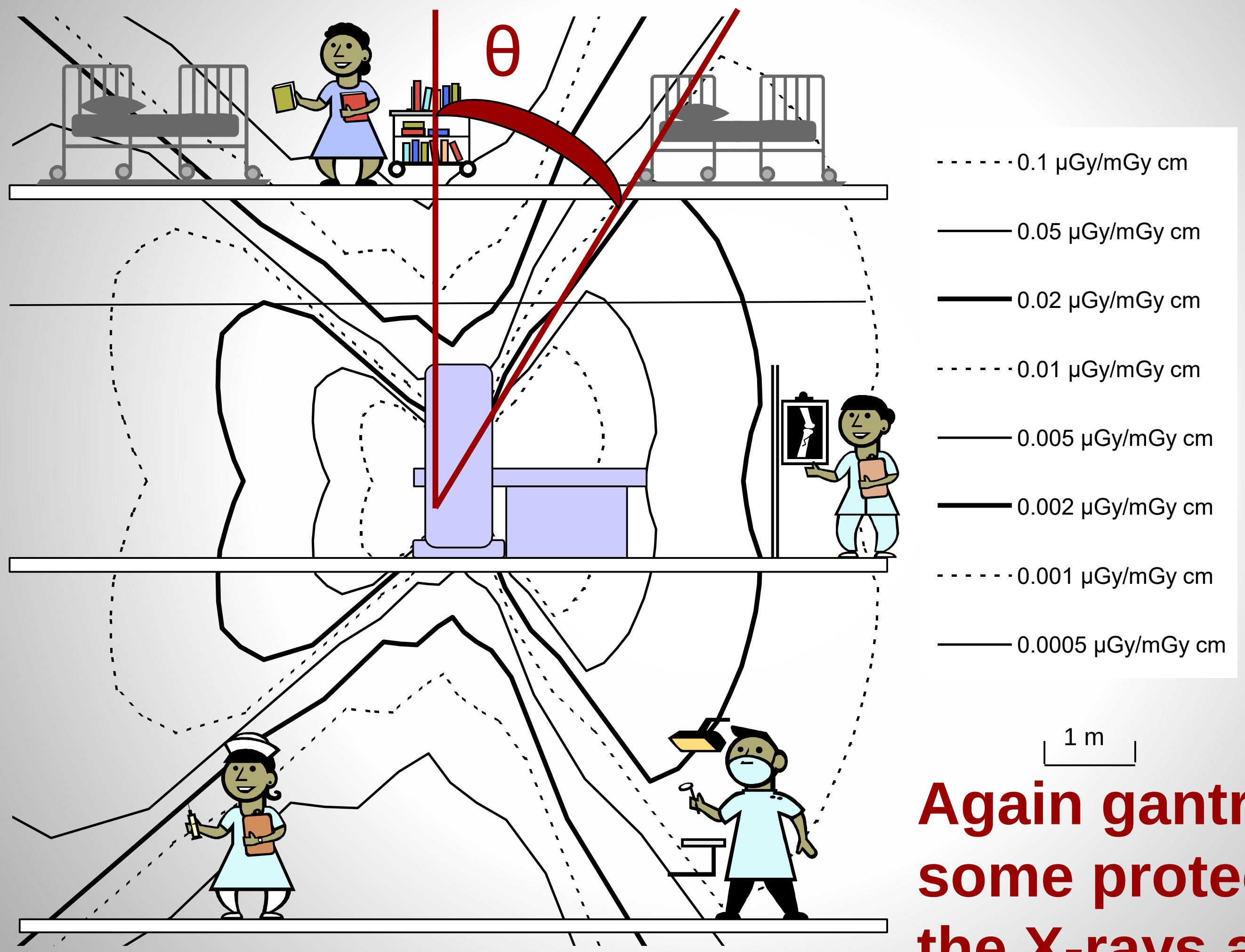
Prediction of workload

- Workload obtained from audit of local practice ideally.
- Consider body and head separately
- Head group - all exams using a small field of view
- Mean exam DLPs provide an indication of likely values.
- Mean – 850 mGy cm; 3rd quartile - 900-1,000 mGy cm

Annual Workloads for 38 CT scanners - body & head scans

	Mean DLP per annum (Gy cm)	3rd Quartile DLP per annum (Gy cm)	Maximum DLP per annum (Gy cm)
Body	1,900	3,400	5,000
Head	1,300	2,500	3,600
Total	3,200	5,500	8,600

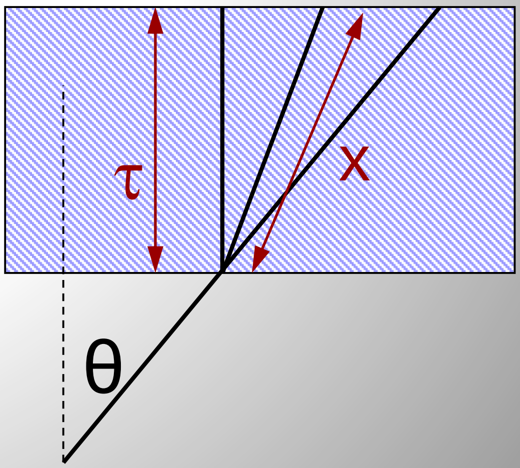
Protecting the floors above and below



Again gantry provides some protection, so the X-rays are incident at angle θ = 30^{o}.

Protecting the ceiling and floor

- Calculated for persons at vertical distance 0.5 m above the next floor level and 1.0 m above floor below.
- Protection afforded by gantry means that only angles of incidence (θ) > 30^{o} need be considered.
- If vertical distance is d, then distance from isocentre for calculation = **$d / \cos\theta$**
- Oblique incidence, so use an equivalent barrier thickness equal to mean of actual thickness and that in direction of scatter

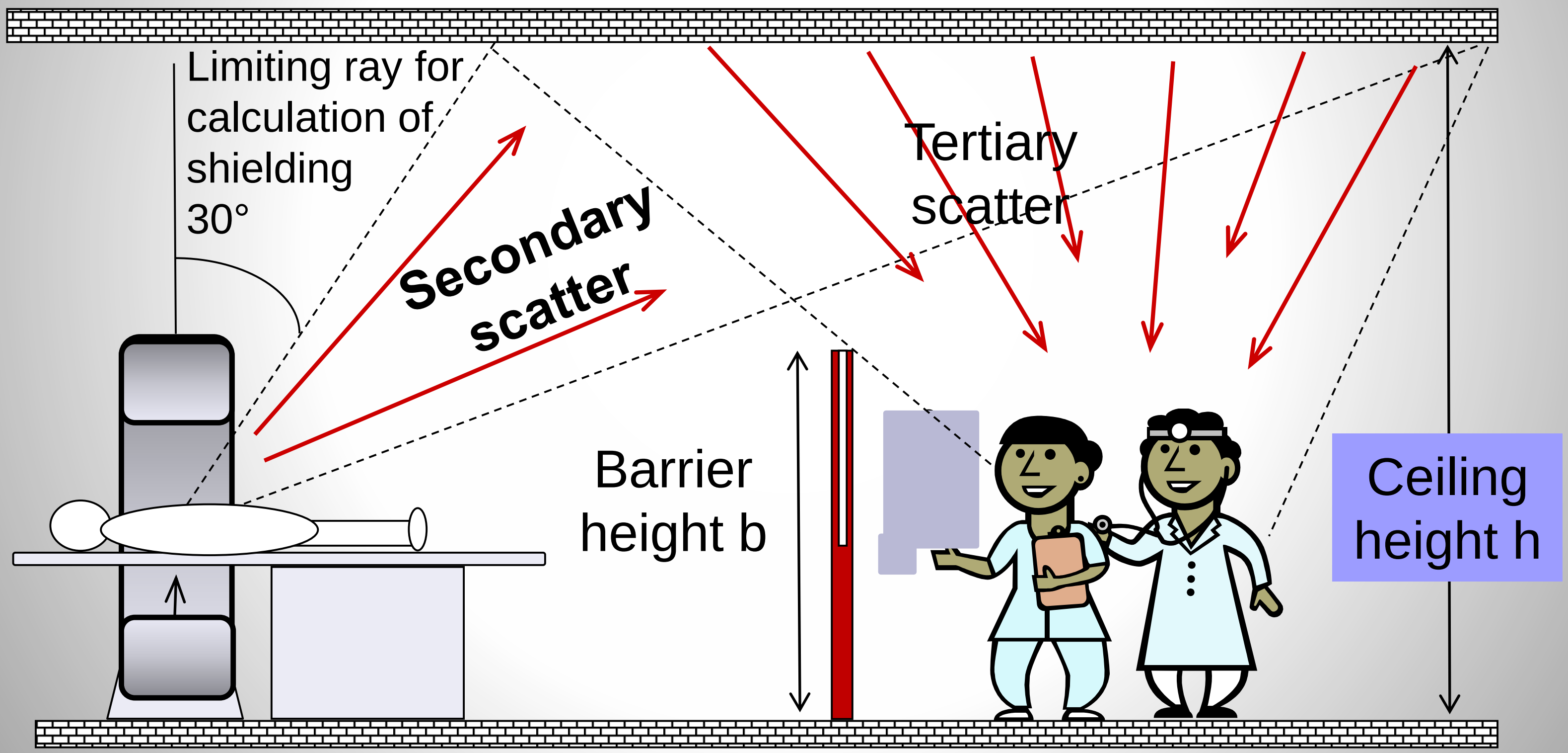


- Calculated thickness =x
- Barrier thickness required

$\tau = x\,(1 + \cos\theta) / 2$

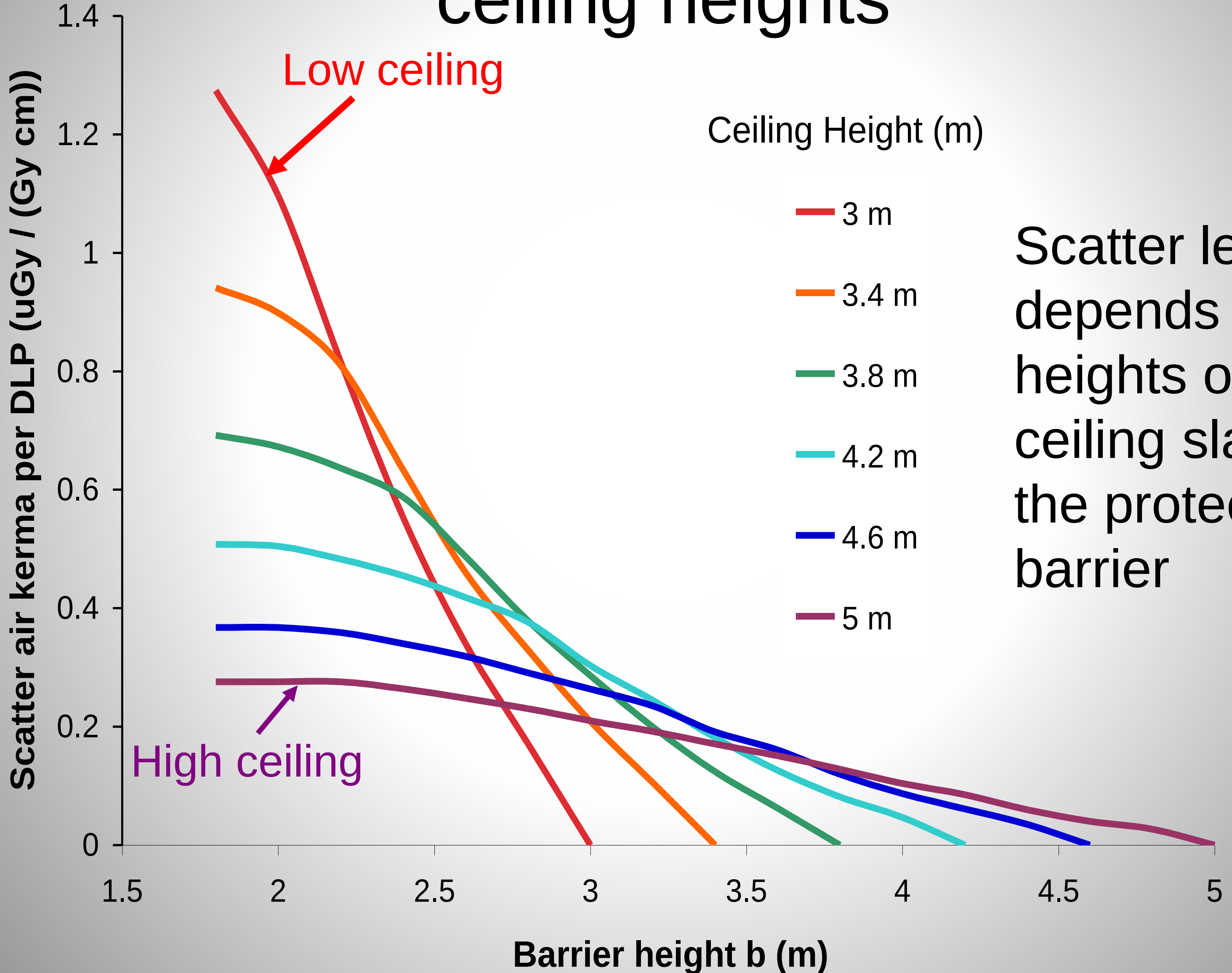
The problem of tertiary scatter

The scatter of X-rays from the ceiling over short barriers is high enough to give staff a radiation dose



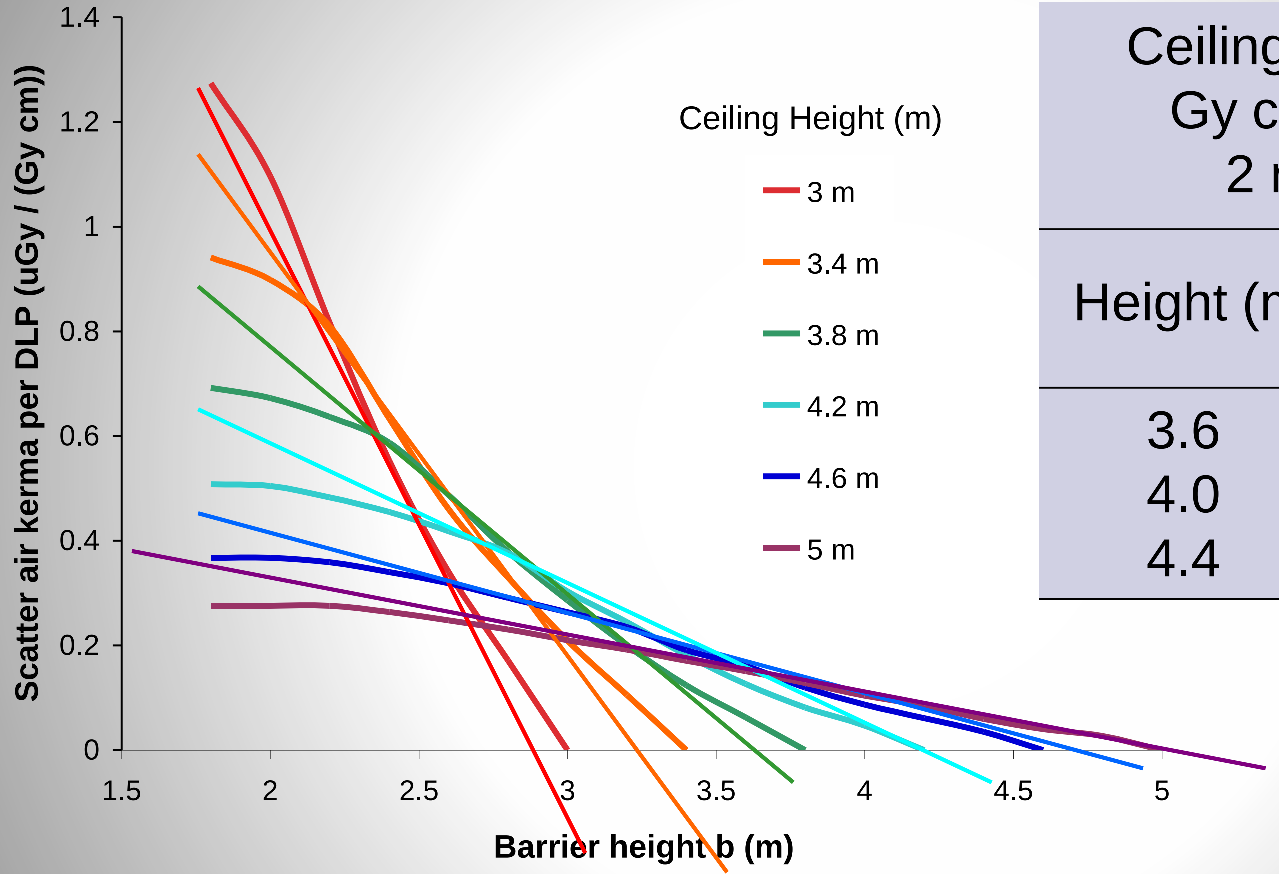
How do we calculate this dose?

Variation of tertiary scatter with barrier and ceiling heights



Scatter level depends on the heights of the ceiling slab and the protective barrier

Calculation of tertiary scatter levels



Ceiling Scatter for 5,000 Gy cm workload and 2 m high barrier	
Height (m)	(mGy)
3.6	4.0
4.0	3.0
4.4	2.2

- Equation: $K_{sec} = (C - m.b) \times (DLP_{body} + DLP_{head}/2)$
- Where b is the height of the barrier and C and m are constants dependent on the height of the ceiling.

Summary

- Set dose constraint and include occupancy
- Scatter is the main component of stray radiation
- Scatter levels can be calculated from the KAP
- Predict KAP based on clinical workload or data in literature
- Radiography requires shielding for both scatter and primary
- Calculation of CT shielding based on DLP workload
- Separate scatter factors for body and head
- Attenuation afforded by gantry can be taken into account
- Obliquity of scatter on ceiling can be taken into account
- Tertiary scatter from ceiling slabs can be calculated

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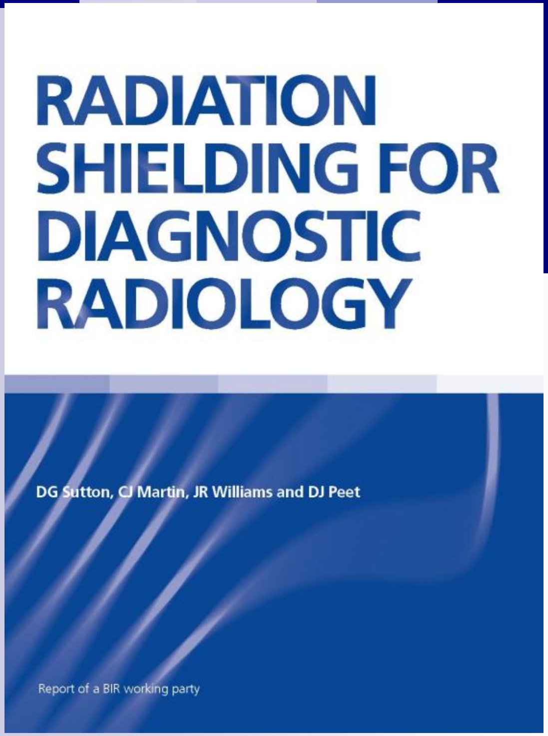
Thank you for your attention

Radiation Shielding for Diagnostic Radiology BIR - 2nd Edition



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