Mobile CT: Novel shielding and quantification of tertiary scatter

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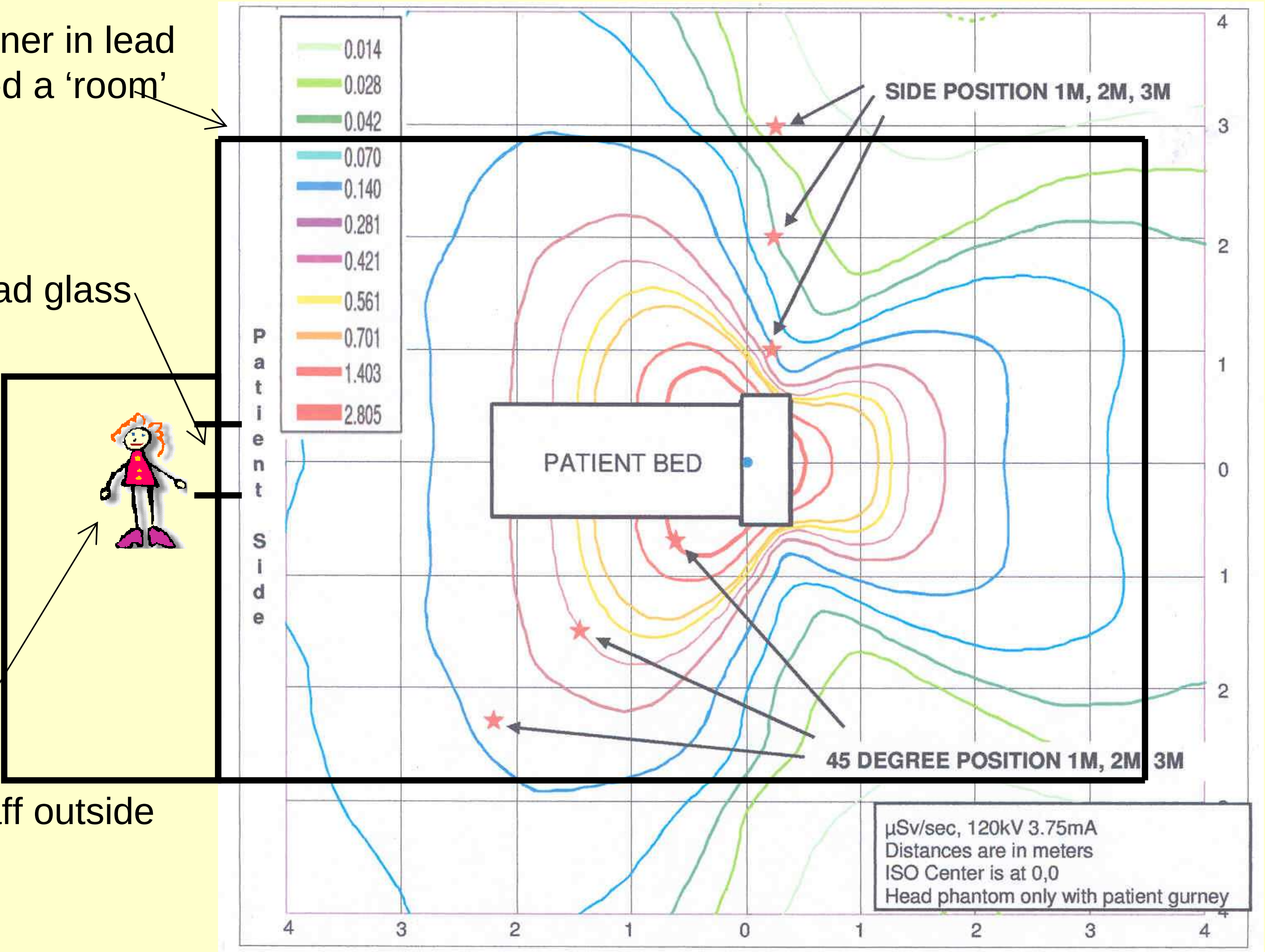
About the Neurologica CereTom Scanner:

- The CereTom is an 8-row multislice scanner with a 25 cm field of view, optimised for head and neck scanning.

- During scanning, the patient is located on a radiolucent headboard attached to their normal hospital bed and the gantry is translated over the required scan volume via a caterpillar track drive.

- The device is charged from a standard mains outlet and transfers DICOM images via wireless 802.11g secure transfer protocols.

Initial Assessment – a conventional scanner:

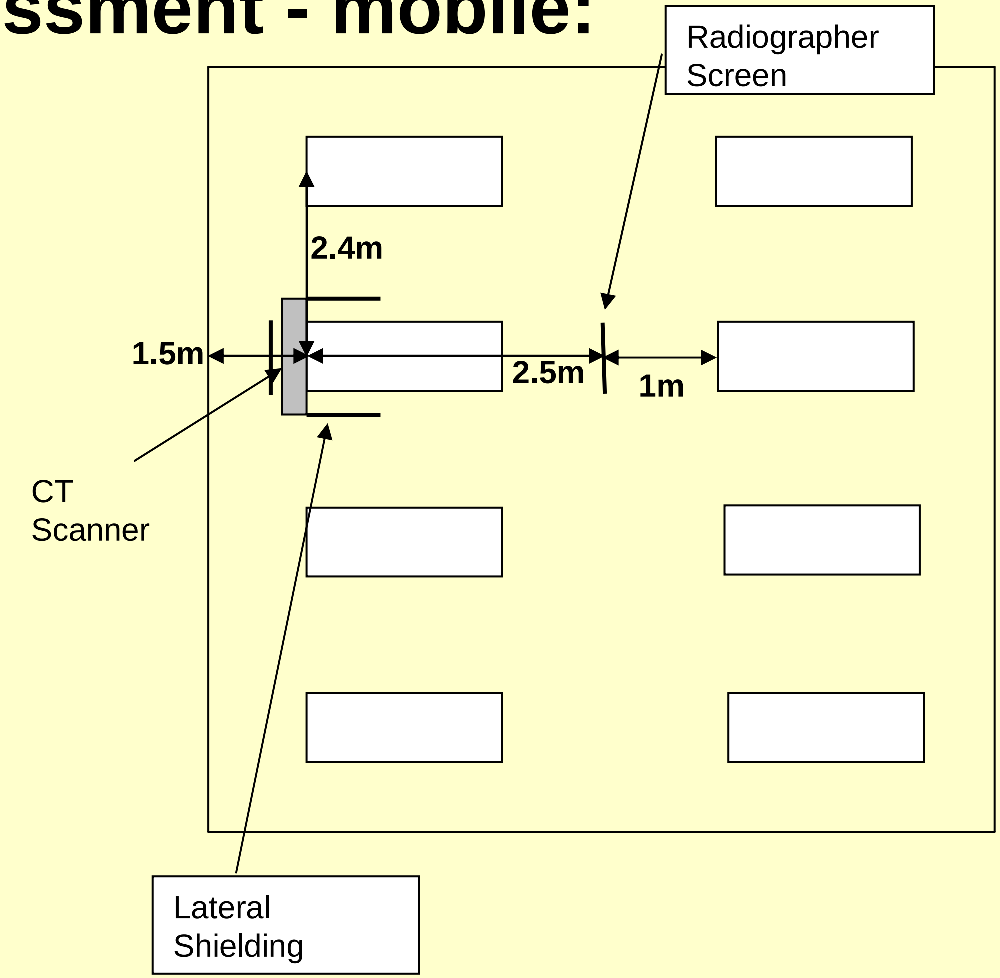


Put scanner in lead box called a ‘room’

Add a lead glass window

Keep staff outside the box

Initial Assessment - mobile:



- Thinking inside the box.
- Perform calculation using existing methodology (BIR/IPEM 2000)
- Pragmatically, make the shields as thick as possible (ALARP)

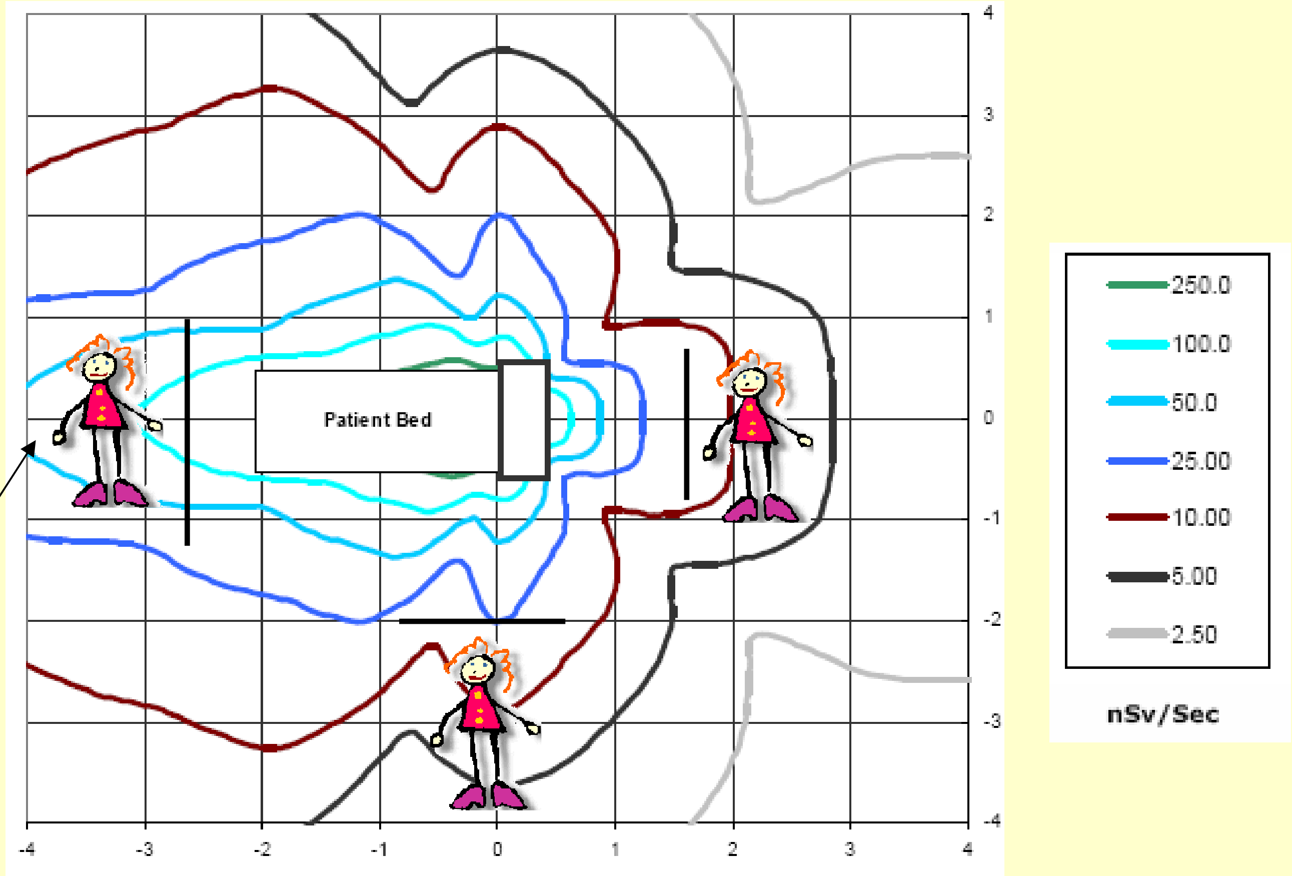
Results:

‘Shadow shields’

‘Such shields are placed in the path of the primary beam, particularly if it is a collimated beam; they are placed as close to the source as possible so that a shield of relatively small size can cast a much larger shadow of lower exposure rate’

BS 4094 (BSI 1971, p78)

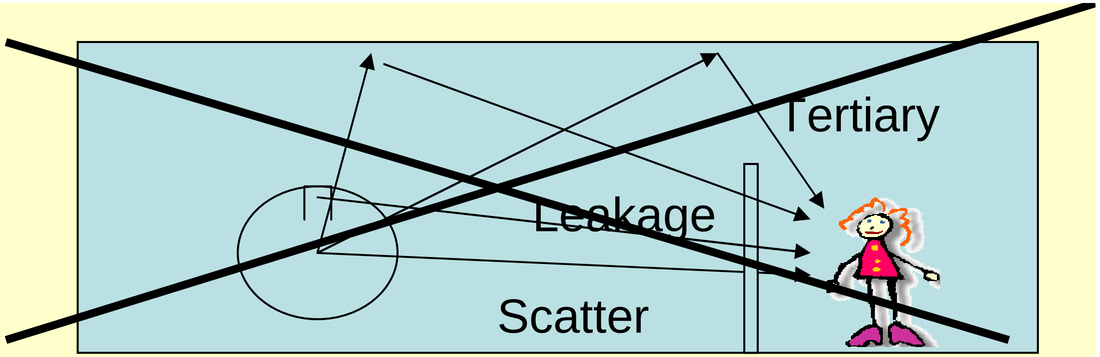
Results:



- **Q:**How do we use this map?
- **Q:**Could we consider attenuation by the patient? Should we?
- **Q:**Should we worry about scatter from the roof?

Barrier Sums

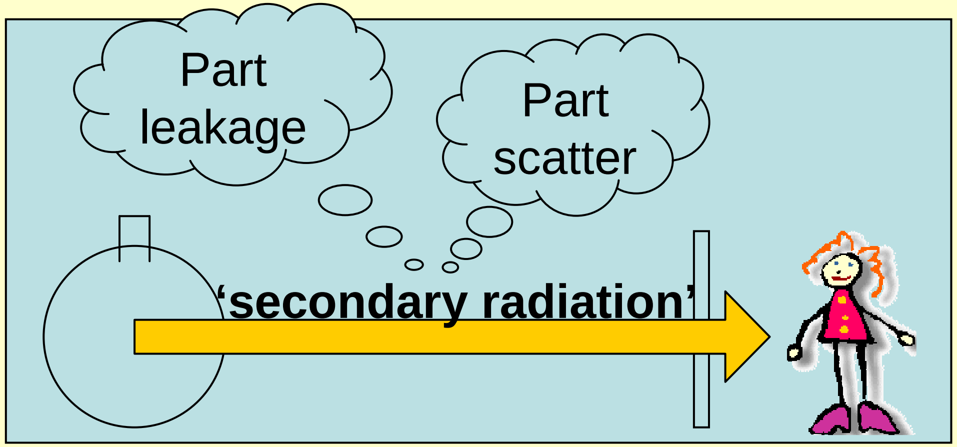
-Conventional model:



- …applies the ‘secondary radiation’ parameters of Simpkin and Dixon (1998) to the broad-beam attenuation model of Archer *et al.* (1983).

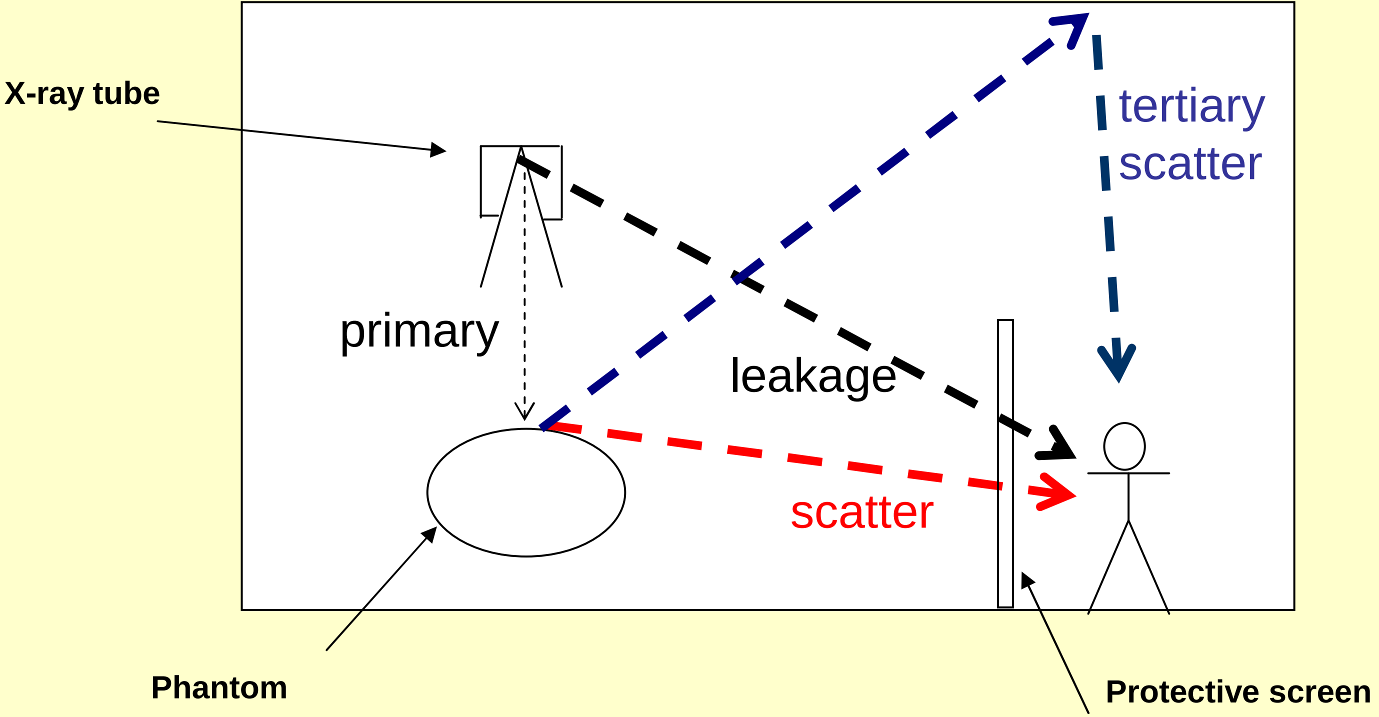
- It is assumed:
-scatter radiation has the same attenuation properties as the primary beam.
-leakage radiation is hardened and transmission is described by limiting HVL.
-the proportion of leakage to scatter radiation occurs in accordance with a simple model they provide (dependent upon kV_p).

- It is inadvertently assumed that tertiary is negligible (i.e. it is grouped together with scatter, none sneaks around the screen).



Potential (kV_p)	Leakage Fraction	Side Scatter Fraction	Leakage as a percentage of total (%)
50	1.23×10^{-11}	4.24×10^{-3}	2.9×10^{-7}
70	4.7×10^{-7}	9.44×10^{-3}	0.005
100	9.90×10^{-4}	2.24×10^{-2}	4.23
125	2.56×10^{-3}	3.73×10^{-2}	6.42
150	4.42×10^{-3}	5.44×10^{-2}	7.51

The three components:



X-ray tube

primary

leakage

tertiary scatter

scatter

Phantom

Protective screen

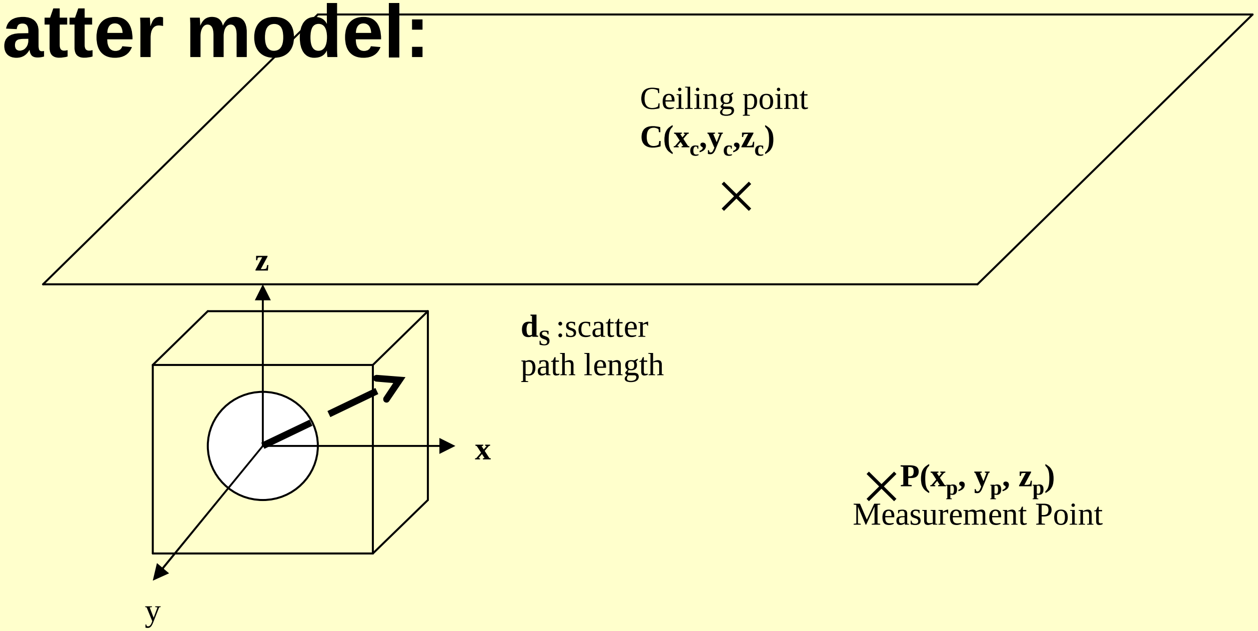
- 3 principal radiation sources to consider: scatter, leakage and tertiary scatter
- The survey map contains contributions from all three sources
- In normal CT installations the barrier blocks all three sources

?

‘The process of scattering from a concrete barrier will reduce the dose rate to about 1% of that incident on the ceiling slab’ (BIR/IPEM 2000)

‘The scattered air kerma at a distance of 1m from a wall would typically be of the order of 5% of the incident beam’ (BIR/IPEM 2000)

An empirical scatter model:



Ceiling point
C(x_c,y_c,z_c)

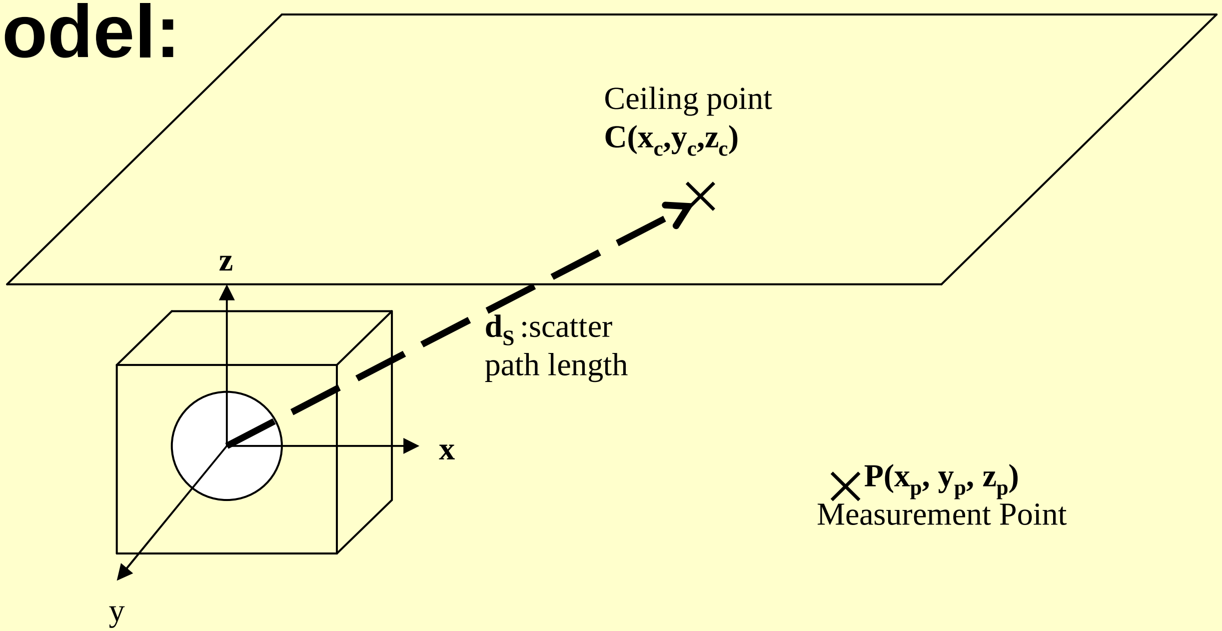
d_S :scatter
path length

P(x_p, y_p, z_p)
Measurement Point

Assuming:

- The scatter dose rate at 1m may be described as a function of emission angle θ

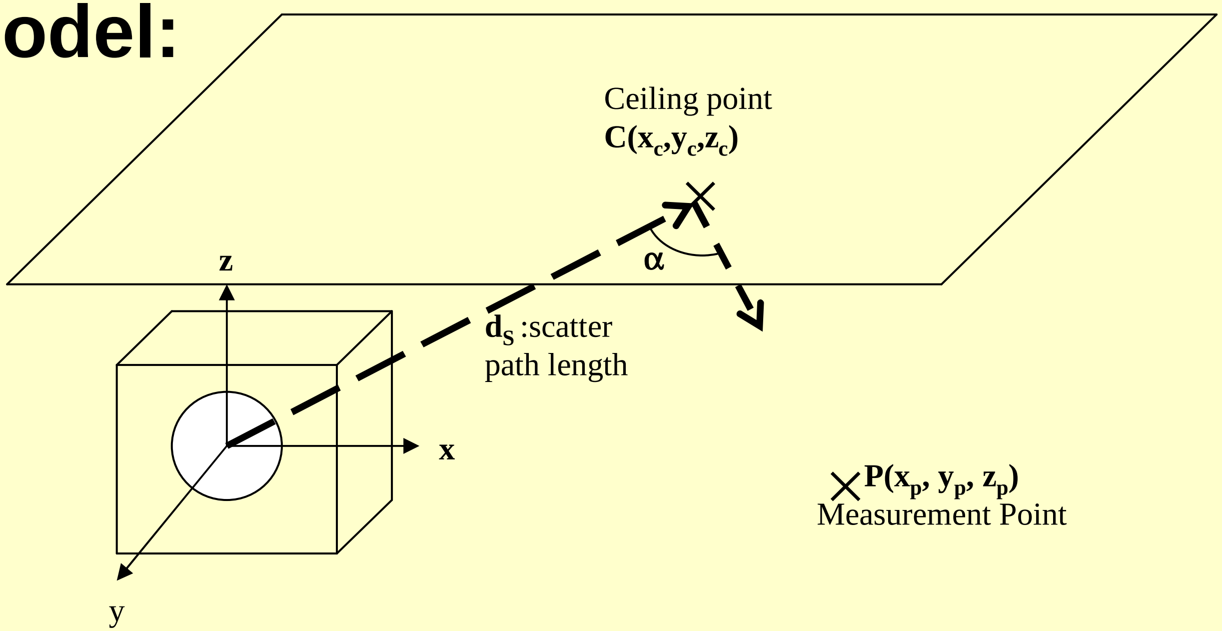
An empirical model:



Assuming:

- The scatter dose rate at 1m may be described as a function of emission angle θ
- The scatter dose rate incident on the ceiling is proportional to the inverse square of the scatter path length from source, d_s

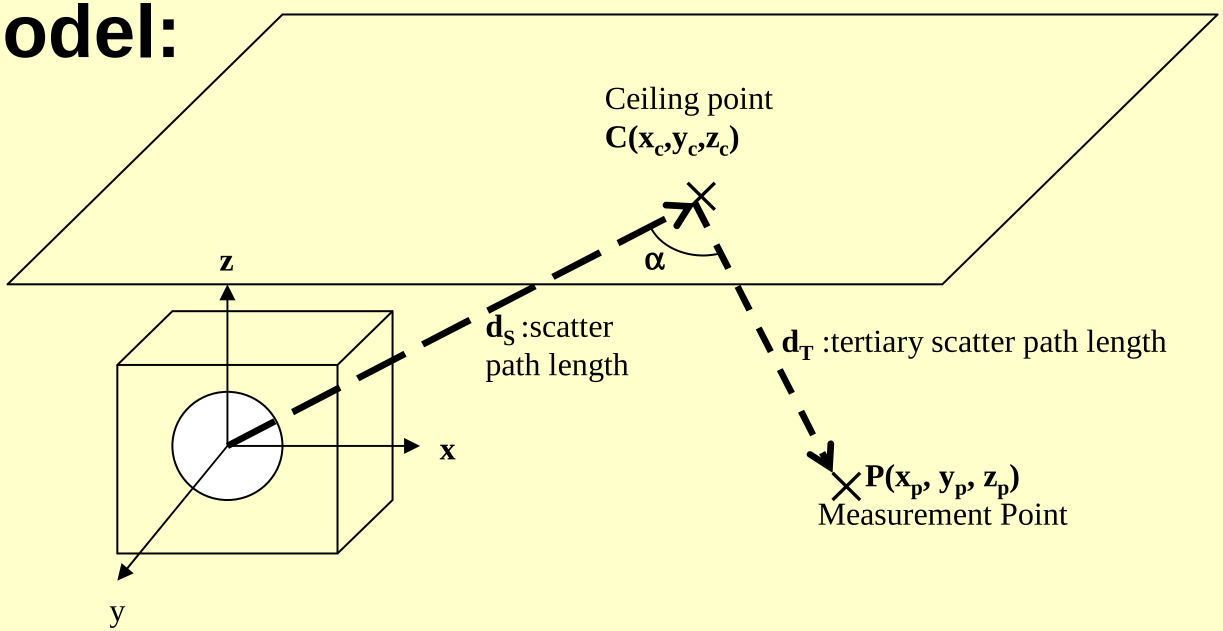
An empirical model:



Assuming:

- The scatter dose rate at 1m may be described as a function of emission angle θ
- The scatter dose rate incident on the ceiling is proportional to the inverse square of the scatter path length from source, d_s
- The ratio of tertiary scattered dose rate at 1m to incident scatter dose rate is given by k(α), where α is the tertiary scattering angle

An empirical model:



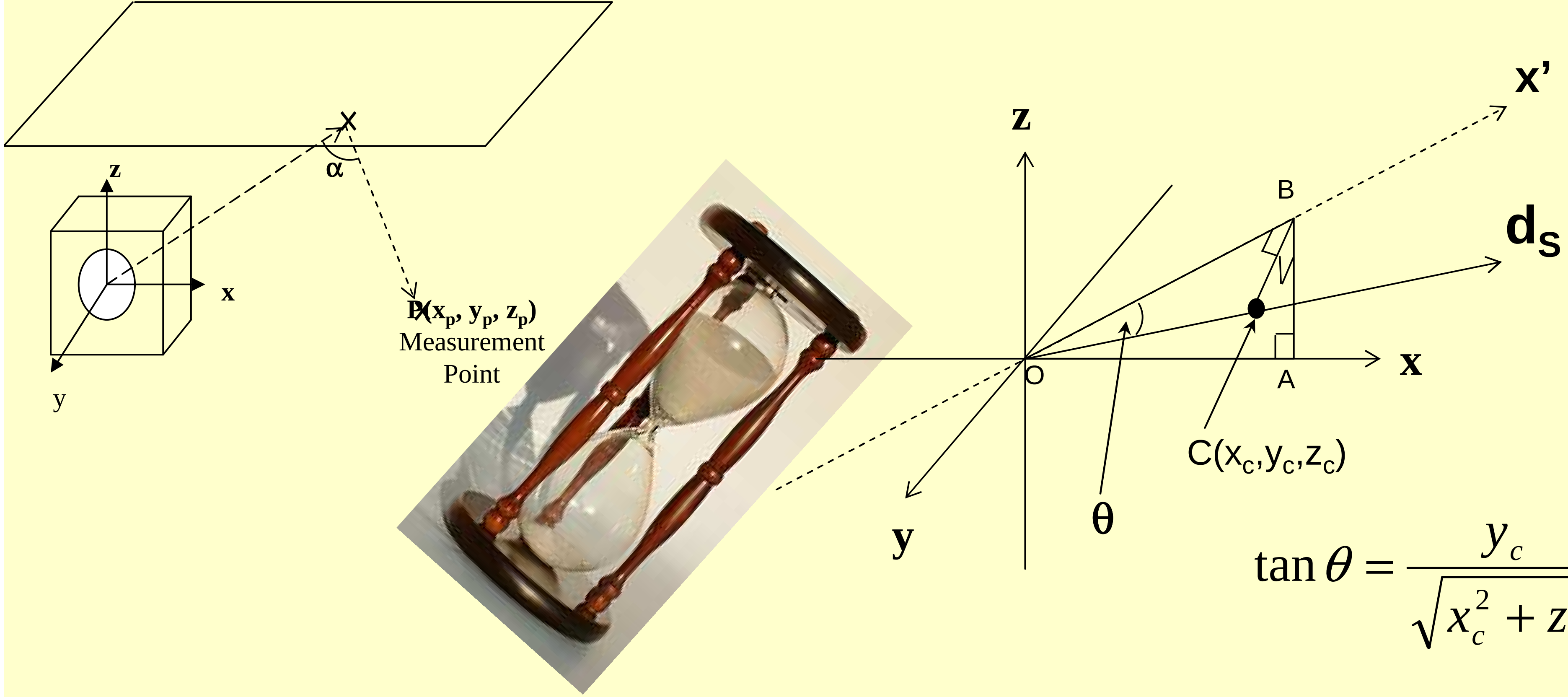
Assuming:

- The scatter dose rate at 1m may be described as a function of emission angle θ
- The scatter dose rate incident on the ceiling is proportional to the inverse square of the scatter path length from source, d_s
- The ratio of tertiary scattered dose rate at 1m to incident scatter dose rate is given by k(α), where α is the tertiary scattering angle
- The tertiary dose rate at the measurement point is proportional to the inverse square of the tertiary scatter path length, d_T

The tertiary scatter dose rate at point P from point C is:

$$T_P = D_{1m,\theta} \times \frac{1}{d_S^2} \times k(\alpha) \times \frac{1}{d_T^2}$$

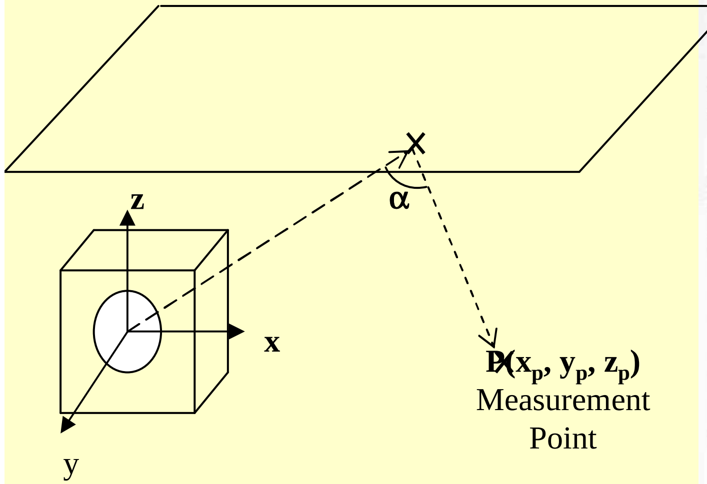
Implementation:
Angular scatter distribution of source



$$\tan\theta = \frac{y_c}{\sqrt{x_c^2 + z_c^2}}$$

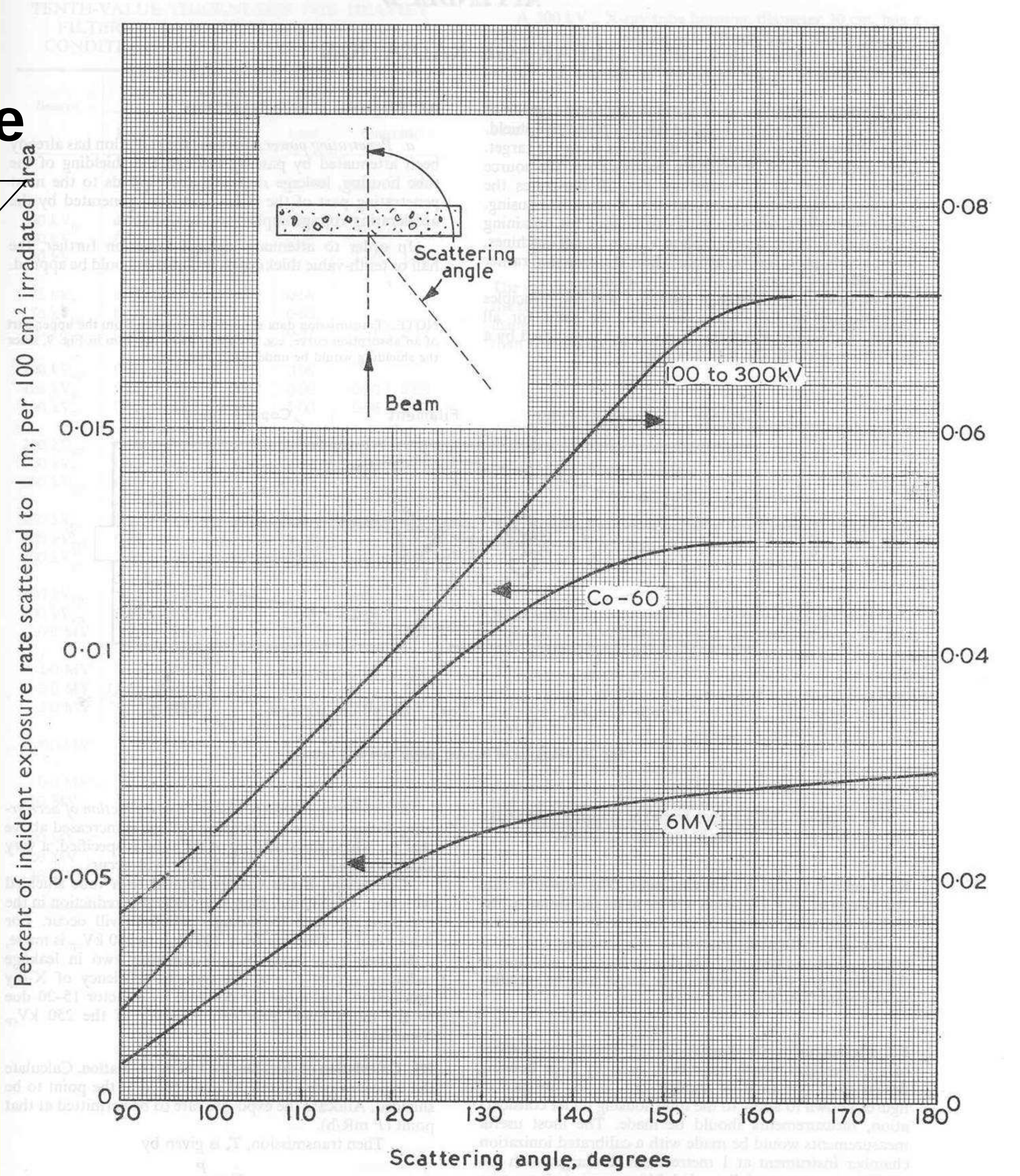
- Assume the scatter map is rotationally symmetric about the y-axis (patient head-foot direction) (BIR/IPEM 200) →Can rotate hour-glass shaped scatter map from x-y plane to x'-y plane.
- angle θ is of interest
- Trace outermost complete isodose, measure at 5° angles, extrapolate back to 1m using an inverse square relationship

Implementation: Roof scatter angle

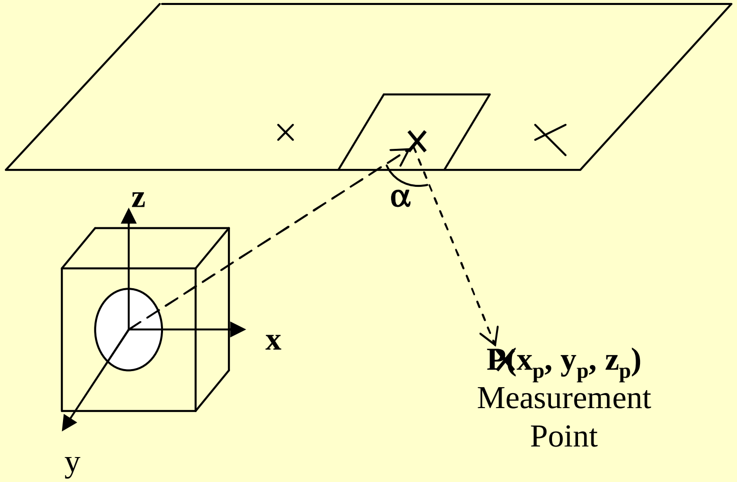


- k(α) is a problem
- Limited data in BS4094
- Insufficient data to describe variation with full range angle α
- ISL corrections will dominate anyway

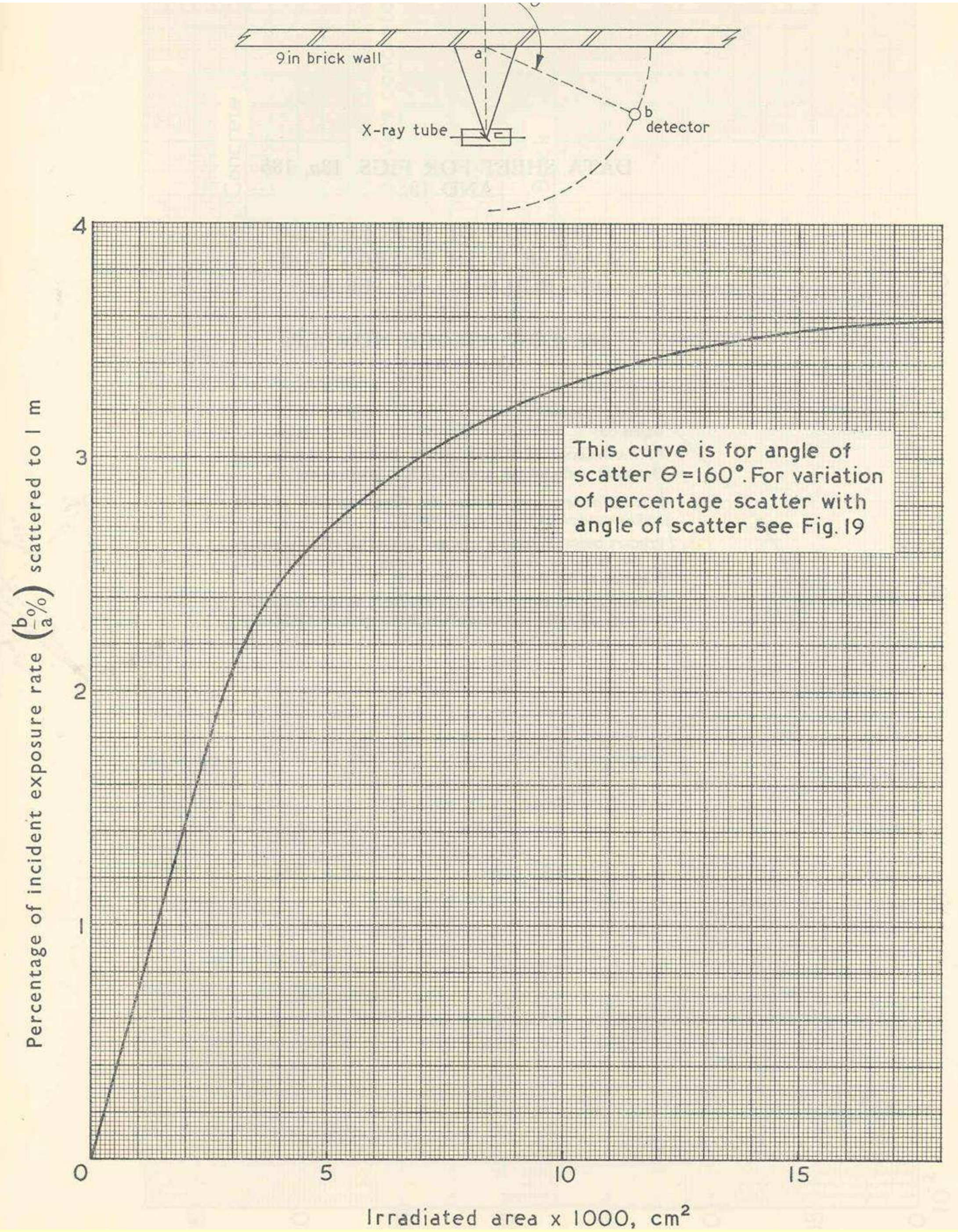
- ~~k(α)~~ k



Implementation:
Area of roof element



- Scale k dependent upon roof element area
- Roof element area dependent numerical integration step size
- Nice linear behaviour in ‘narrower’ beam conditions
- Simple to scale k when performing numerical integration over square elements of the roof



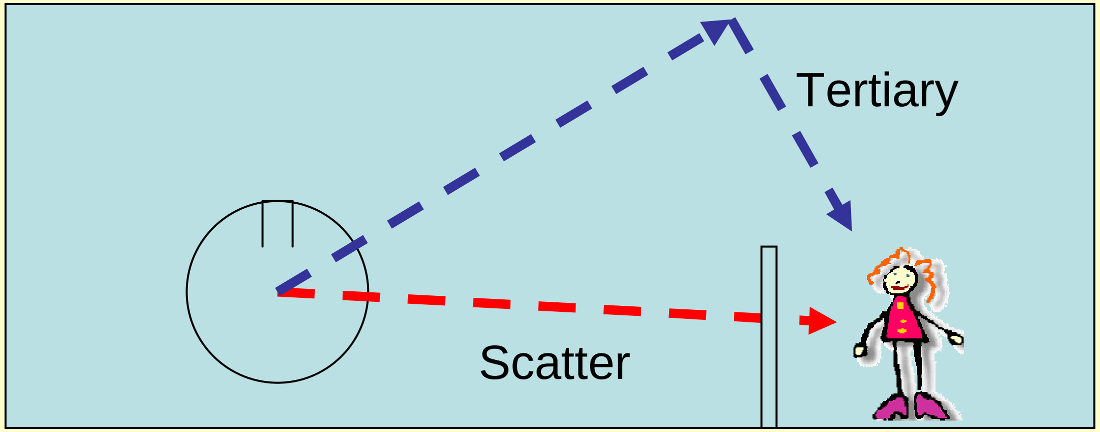
This curve is for angle of scatter Θ =160°. For variation of percentage scatter with angle of scatter see Fig. 19

Results:

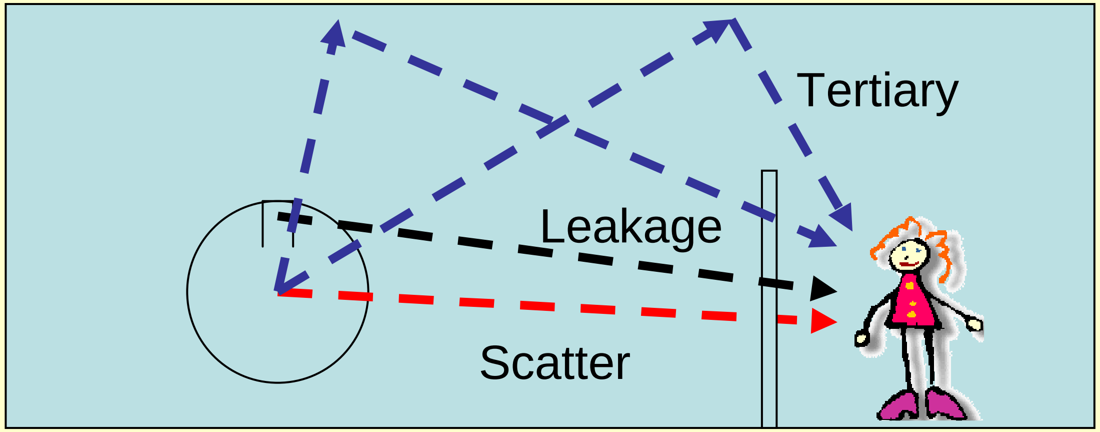
- Numerical integration model built using MS Visual Basic for Applications within Excel .
- Suggests tertiary scatter is significant
- Particularly so at larger distances or in the ‘radiation shadow’ of the gantry.

	-1	-0.5	0	0.5	1	1.5	2	2.5
-2	6	5	5	5	6	10	24	72
-1.5	4	3	3	3	5	16	64	183
-1	5	2	1	2	8	61	166	210
-0.5	50	1		2	52	80	92	108
0						33	53	75
0.5	3	1		1	3	11	22	32
1	3	2	2	2	3	6	12	21
1.5	5	5	4	5	6	7	10	14
2	9	8	8	8	9	10	12	14
2.5	13	12	12	12	13	13	14	16
3	16	16	16	16	17	17	18	18
3.5	20	19	20	20	20	20	20	21

Theoretical ratio of tertiary dose rate to scatter dose rate (expressed as a percentage)



Barrier Sums - Three component model:



- Consider the three components separately. The dose behind the mobile screen is given by:

$$D_{total} = aD_{leakage} + bD_{scatter} + cD_{tertiary}$$

- The leakage transmission factor *a* is calculated by limiting HVL

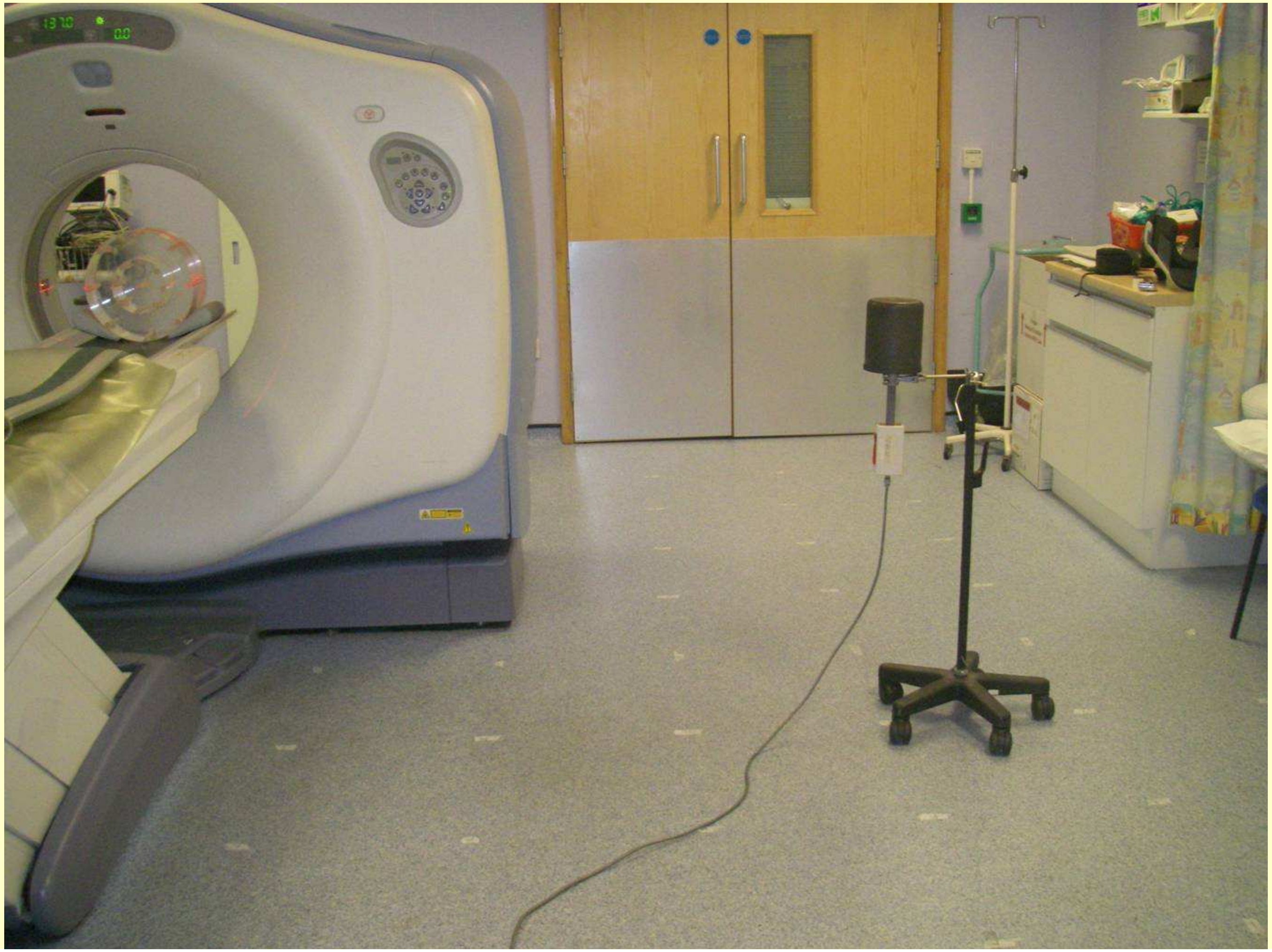
- The scatter transmission factor *b* is calculated by use of primary radiation parameters (Simpkin 1995) and the broad beam model (Archer *et al.* 1983)

- The tertiary transmission factor *c* is difficult to determine since the ceiling/walls represent an extended source of radiation – conservatively assume c=1.

Measurement methodology:

Leakage:

- Mapped by closing the tube port in service mode and setting LARGE exposures. 600mA 4 seconds worked nicely.
- Do not blow up your scanner. Not even slightly.

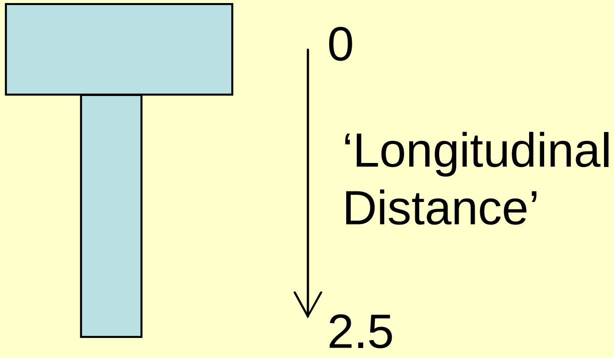


Results:

Leakage:

Leakage radiation expressed as a percentage of (leakage + scatter) at 140 kVp on a GE Lightspeed VCT at a number of collimations

Longitudinal distance (m)	20mm	10mm	5mm	1.5mm
0	0.87	1.72	3.38	10.45
0.5	0.41	0.82	1.62	5.21
1.0	0.17	0.34	0.68	2.22
1.5	0.05	0.10	0.20	0.67
2.0	0.10	0.20	0.39	1.30
2.5	0.10	0.20	0.40	1.32



Data of Simpkin and Dixon for a plane film x-ray set

Potential (kVp)	Leakage expressed as a percentage of (leakage + scatter)
50	2.9×10^{-7}
70	0.005
100	4.23
125	6.42
150	7.51

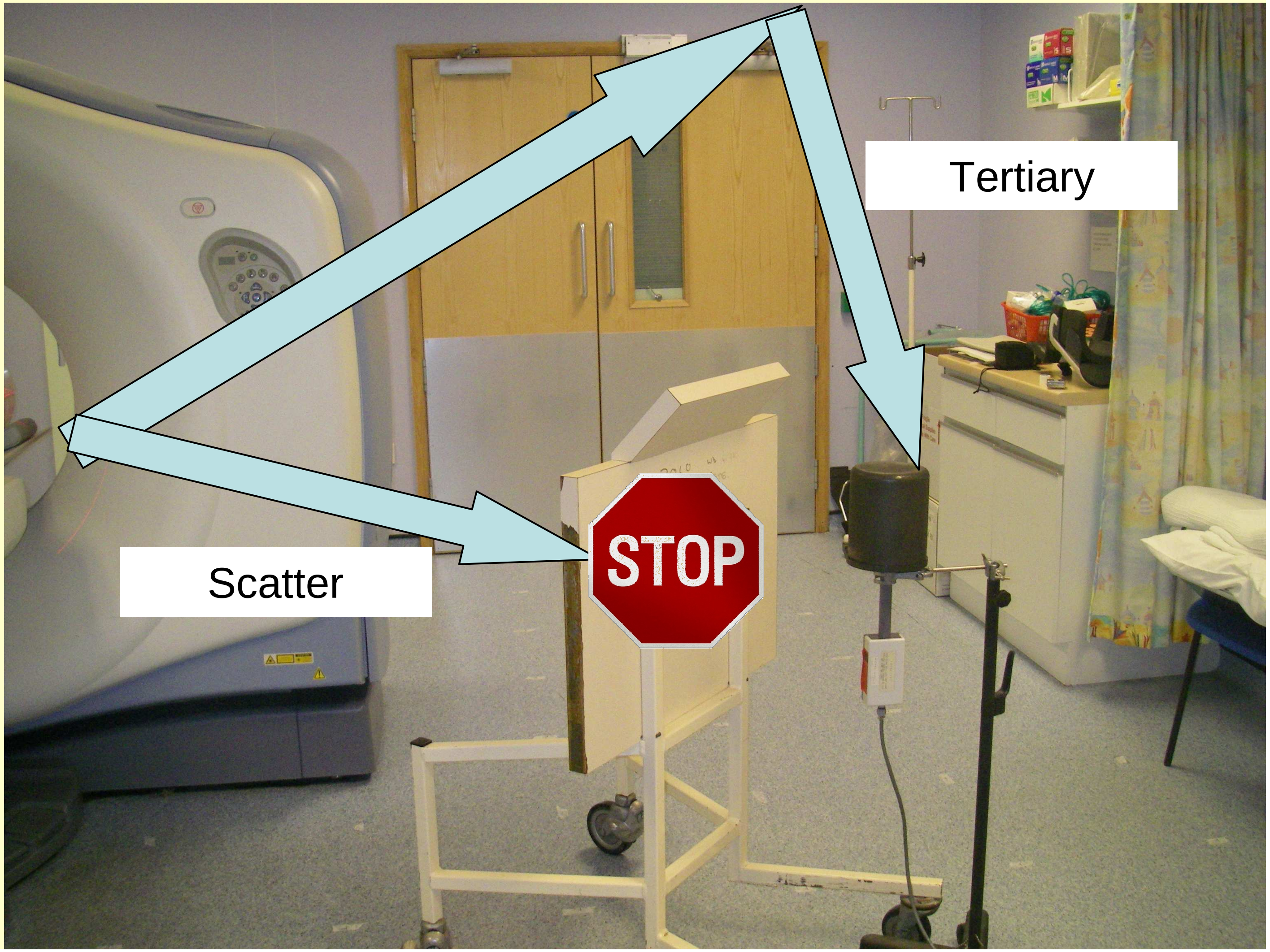
Discussion:

- In CT leakage radiation represents a smaller fraction of the incident dose than in plane film x-ray, but is particularly significant in the shadow of the gantry and at narrow collimations.

Measurement methodology:

Scatter and Tertiary:

- Use a 25.4mm thick lead screen to block scatter and record tertiary.
- Remove the screen and measure again. Identify scatter by subtraction.



Results:

140kVp (GE Medical Systems Lightspeed VCT)

Modelled

	-1	-0.5	0	0.5	1	1.5	2	2.5	3
-1	5	2	1	2	8	61	166	210	219
-0.5	50	1		2	52	80	92	108	124
0						33	53	75	96
0.5	3	1		1	3	11	22	32	43
1	3	2	2	2	3	6	12	21	33
1.5	5	5	4	5	6	7	10	14	22
2	9	8	8	8	9	10	12	14	18
2.5	13	12	12	12	13	13	14	16	18
3	16	16	16	16	17	17	18	18	19
3.5	20	19	20	20	20	20	20	21	21

Ratio of tertiary dose rate to scatter dose rate (expressed as a percentage)

Measured

	-1	-0.5	0	0.5	1	1.5	2	2.5	3
-1						83	100	68	
-0.5							122	75	
0							76	71	
0.5						51	69	69	61
1					2	3	13	33	47
1.5					3	4	4	11	18
2					4	5	5	6	9
2.5					5	6	7	7	7
3	9	10	19	12	8	8	8	9	
3.5	11	8	18			10	10		

Discussion:

- Quantitative agreement is limited as the model used has significant limitations:

-Angular dependence of the tertiary scatter intensity was neglected.
-Blocking of incident tertiary radiation by the gantry was neglected.
-Contributions from the floor and walls were neglected.

-The BS4094 data used to define *k* was produced using a 200 kVp x-ray machine which may be substantially spectrally different than CT scattered radiation, the quality of CT scattered radiation varies with scattering angle.

-The method is predicated upon inverse square extrapolation from an isodose line of the manufacturer’s scatter map. The survey isodose data does not fall off as rapidly – suggesting the survey isodose data contains a tertiary component.

Conclusion:

- The measured tertiary scatter data reflects the qualitative trends of the model →concern regarding tertiary scatter is justified.
- **Staff will be required to wear lead coats behind the mobile screen.**

Results –
Prediction of dose behind a 0.5mm portable screen

$$\mathbf{Dtotal = aD_{leakage} + bD_{scatter} + cD_{tertiary}}$$

	-1	**-0.5**	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**
-1						122	95	142	
-0.5						94	136	145	
0	▨	▨	▨	▨	▨		146	126	
0.5			░			102	111	151	
1			░		58	84	100	121	
1.5			░		66	66	69	82	
2			░		71	48	70	69	
2.5					54	70	74	71	
3					76	75	76	73	
3.5	76	88	62			71	75		

Ratio of measured dose to predicted dose (expressed as a percentage)

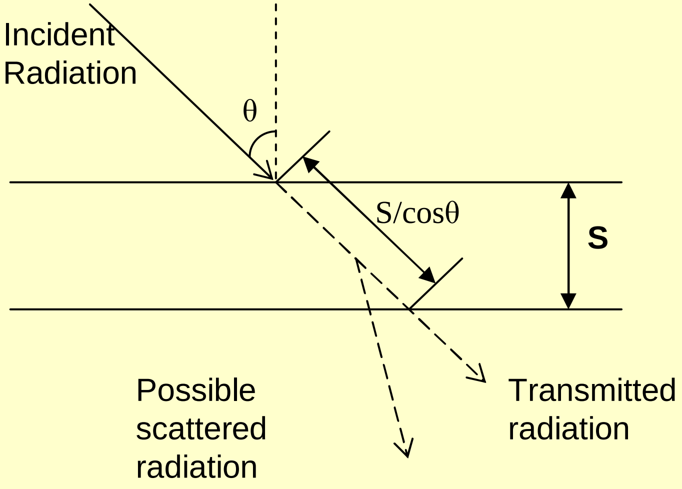
Discussion:

- Uncertainty in coefficients a, b, c as a result of assumptions
- Different measurement geometry as a result of different shield dimensions
- Beam hardening by the gantry?

Additional work that I don’t have time to talk about:

- Demonstration of beam hardening by the gantry
- Theoretical methods to calculate the lead equivalence of the gantry (Harpen 1998) and the impact of tertiary scatter

- Obliquity corrections and tertiary scatter as an extended source



- Attenuation and beam hardening by the patient, modelled using a Rando phantom

Height above floor(m)	**%**					
1.9	39					
1.8	36					
1.7	36					
1.5	28					
1.4	25					
1.3	22					
1.2	22					
1.1	22					
0.93	22	30	33	34	39	44
horizontal distance from table central line (m)	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**

The following ratio is presented as a percentage:

$$\frac{\mathbf{Dose}_{\textbf{CTDI head and Rando}}}{\mathbf{Dose}_{\textbf{CTDI head}}}$$

Outcomes:

- The additional shielding affords a dramatic improvement
- Calculations based around 1 scan per bed, per day on a six bed ward with a 30 day occupancy project ward patient doses are acceptable.
- Derriford has partition walls – we are keen on a thicker rearward shield.

The radiographer is the critical group:

- The radiographer requires a mobile screen
- The radiographer is also required to wear a lead coat
- Workload is likely to be restricted to ~10 scans per day

- Detailed measurements will be required in each proposed location
- A carefully constructed staff training programme will be required
- Novel QA tests will be required

Food for thought:

- Protocols:

-Will not be possible to transfer directly from existing scans
-What is the target image quality/noise for each use?

- Staffing:

-take existing staff from CT
-use existing ‘mobile’ radiographers
-regrading?!

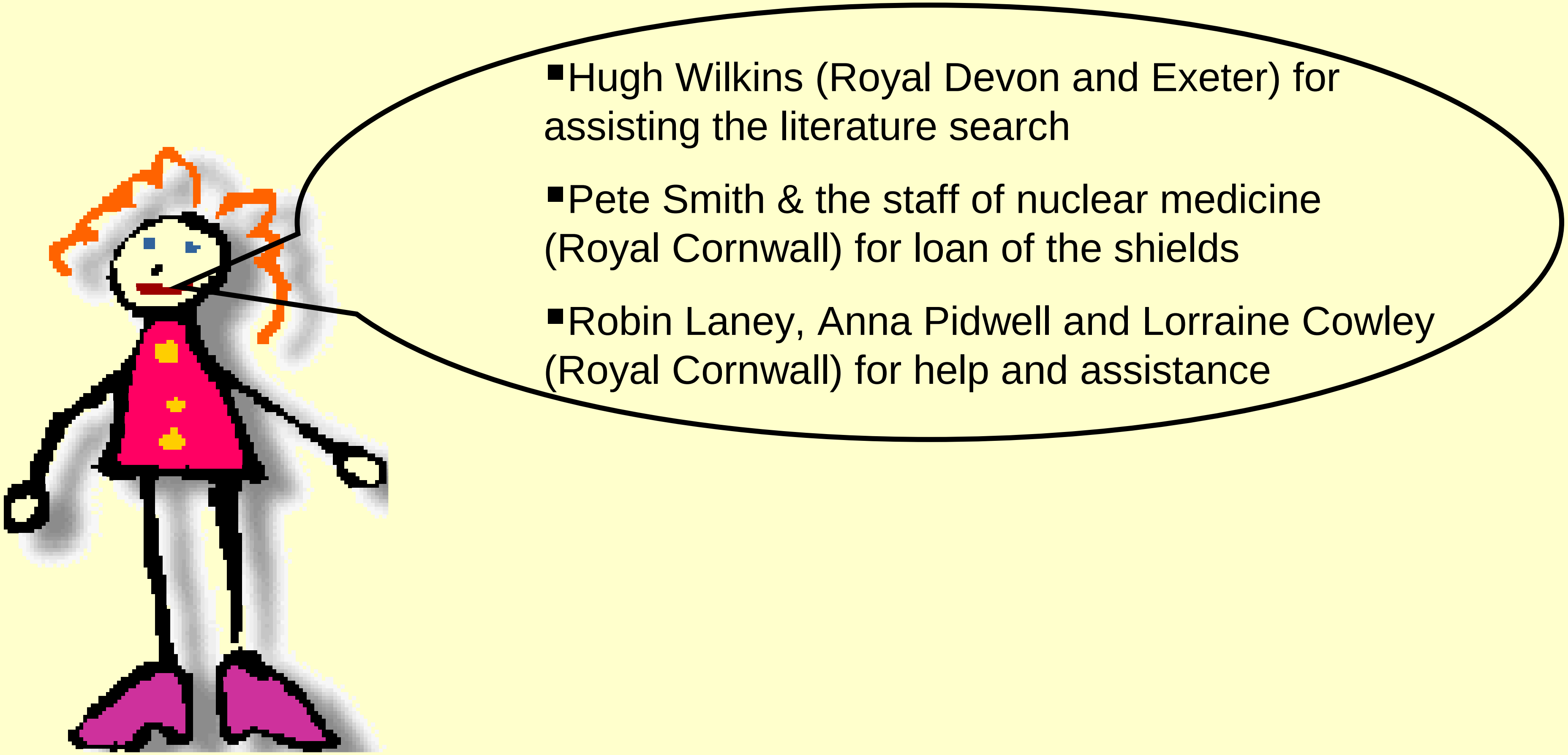
- Infection control:

-??

- Floors:

-soft floor coverings = harder to push

Acknowledgements:



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