National Training Course on Radiation Protection for Radiological Practice performed outside Radiology using Fluoroscopy
(Tel Aviv, 3rd of June, 2018)

How to protect the patient in fluoroscopy guided procedures, including interventional cardiology

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Atoms for Peace: The First Half Century
1957–2007

Key topics

- Why is it necessary to consider radiation protection of patients?
- How do X ray technique and physical factors affect patient dose?
- What is the role of the operator in patient dose management?
- How to manage patient dose using physical and equipment factors?
- To add: specific examples orthopaedics, gastro, etc. cardio

Why is it necessary to consider patients protection?

- Patient is irradiated by the direct beam
- Medical personnel is irradiated by the scatter radiation
- Patients may undergo repeated radiation procedures
- A patient may receive in one procedure a dose equivalent to dose the staff may receive in more years

Why is it necessary to consider patients protection?

- There are no fluoroscopy time constraints
- Poor fluoroscopy technique can multiply patient dose rates many times above normal (>10 times)

Implies →There is a potential for high and unnecessary patient doses

→ and, skin injury in high dose procedures (e.g. > 30 min fluoroscopy time and hundred of images)

Why is it necessary to consider patients protection?

- 15 minutes of fluoroscopy at 40 mGy/min skin dose rate → cumulative skin dose: 0.6 Gy
- With thick patients, the radiation dose can be quite high with the possibility of radiation injury
- X ray system not optimized and operators not trained in radiation protection could increase patient dose by a factor of 10:

Skin necrosis from Coronary Angioplasty
Skin Doses > 20 Gy

>100 minutes fluoro time

The objectives of patient radiation protection are:

1. To protect the patient from **deterministic effects**, e.g., skin burns

2. To optimize X ray exposure to minimize risk of **stochastic effects**, e.g., development of cancer

Basic principles

- Justification
  - avoid unnecessary exams and unnecessary images
- Optimization
  - choose factors and perform the exam to yield the required diagnostic information while minimizing the dose to the patient.

→ ALARA: keep dose to patient As Low as Reasonably Achievable

Factors affecting patient dose in fluoroscopy

- Patient entrance surface dose rate
- X ray beam area
- Beam ON time

(Note: these same factors influence staff doses)

Factors affecting patient dose in fluoroscopy

- **Patient dependent factors:**
  - body mass or body thickness in the beam
  - complexity of the lesion and anatomic target structure
  - previous radiation exposure
  - radiosensitivity of some patients

- **Equipment dependent factors:**
  - Setting of dose rates in pulsed fluoro- and continuous fluoro mode
  - Selected image quality (higher → higher dose)
  - last image hold, acquisition
  - collimation
  - appropriate quality control

Factors affecting patient entrance surface dose rate

- Thickness & composition of patient.
- X ray beam quality (kVp, filtration)
- II Mag mode (Normal, Mag 1, Mag 2, etc.)
- II Dose mode (low, medium, high)
- Pulse rate and pulse width for pulsed fluoro
- Anti-scatter grid
- Angulation

Image formation

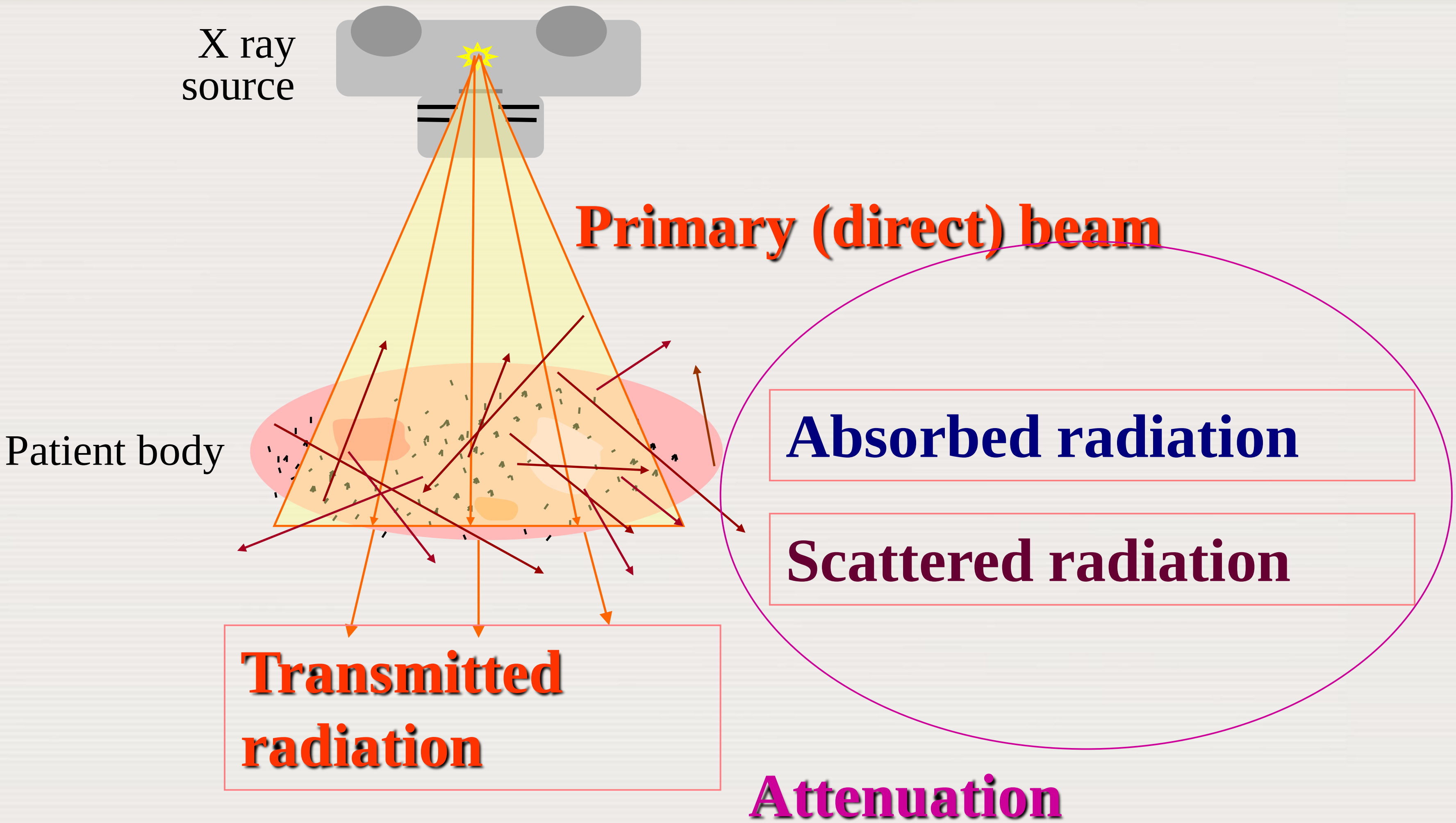
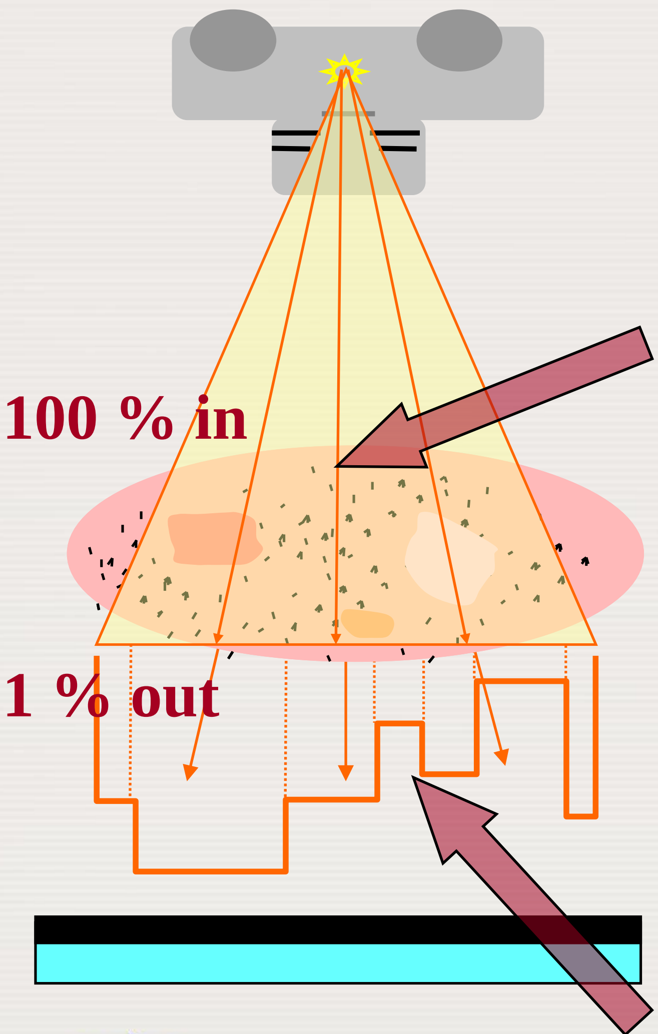


Image formation



Beam entering patient typically 100 - 500x more intense than exit beam

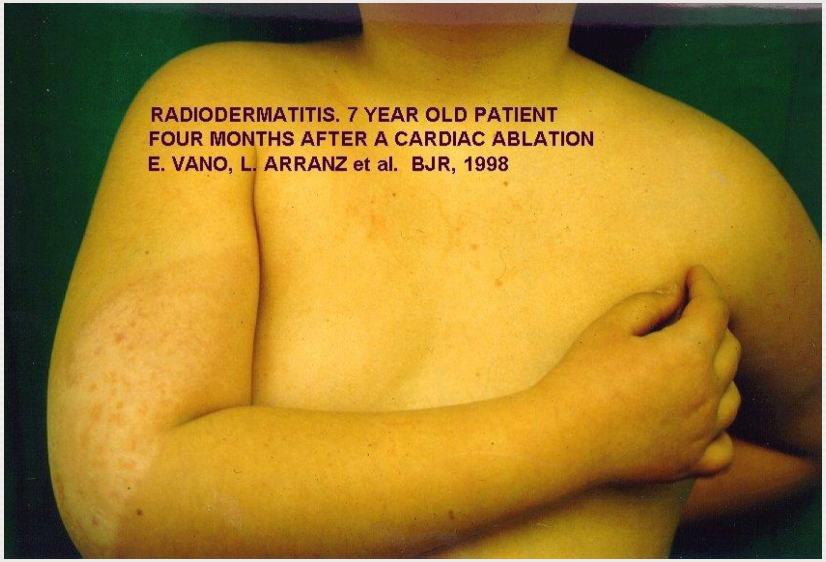
As beam penetrates patient, x rays ionize tissue

Only a small percentage (typically ~1%) penetrate through to create the image.

Risk of injury

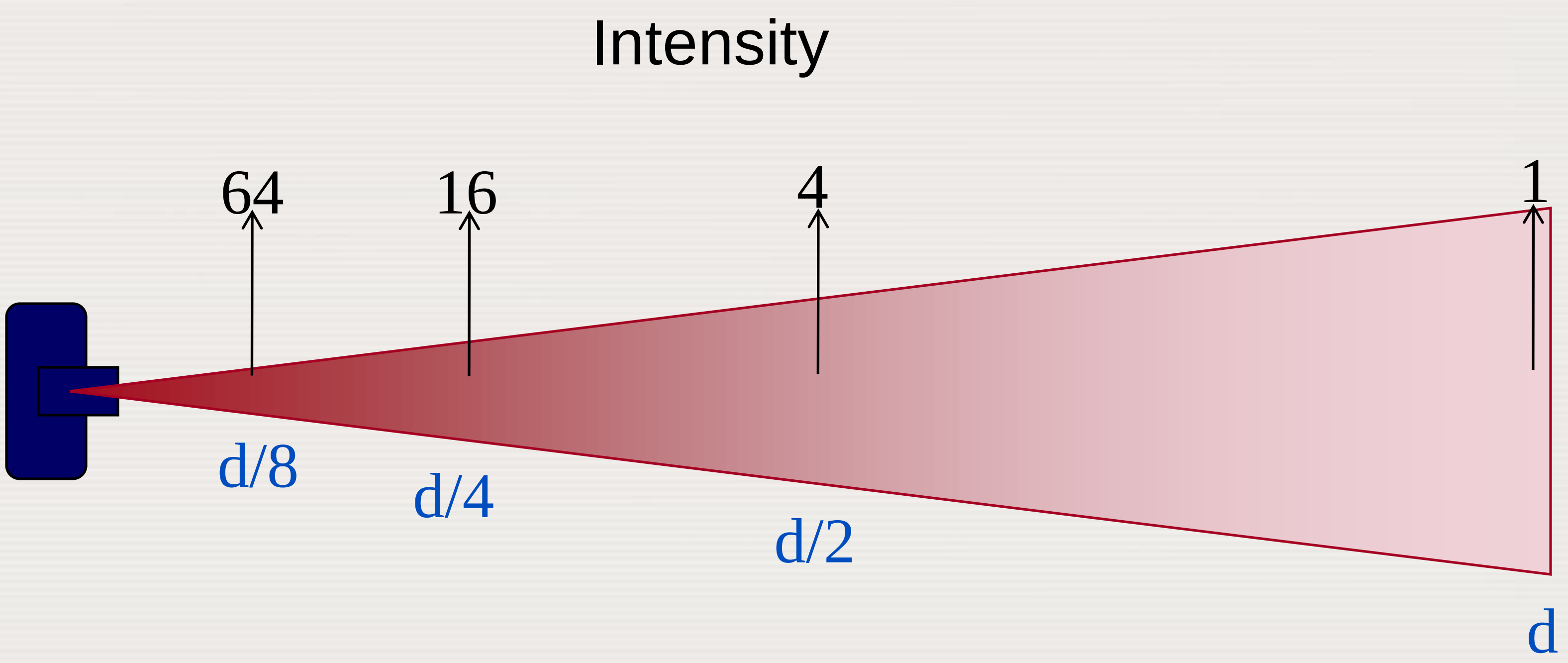
<u>Lesson:</u>

Entrance skin tissues receives highest dose of X rays and are at greatest risk of injury.



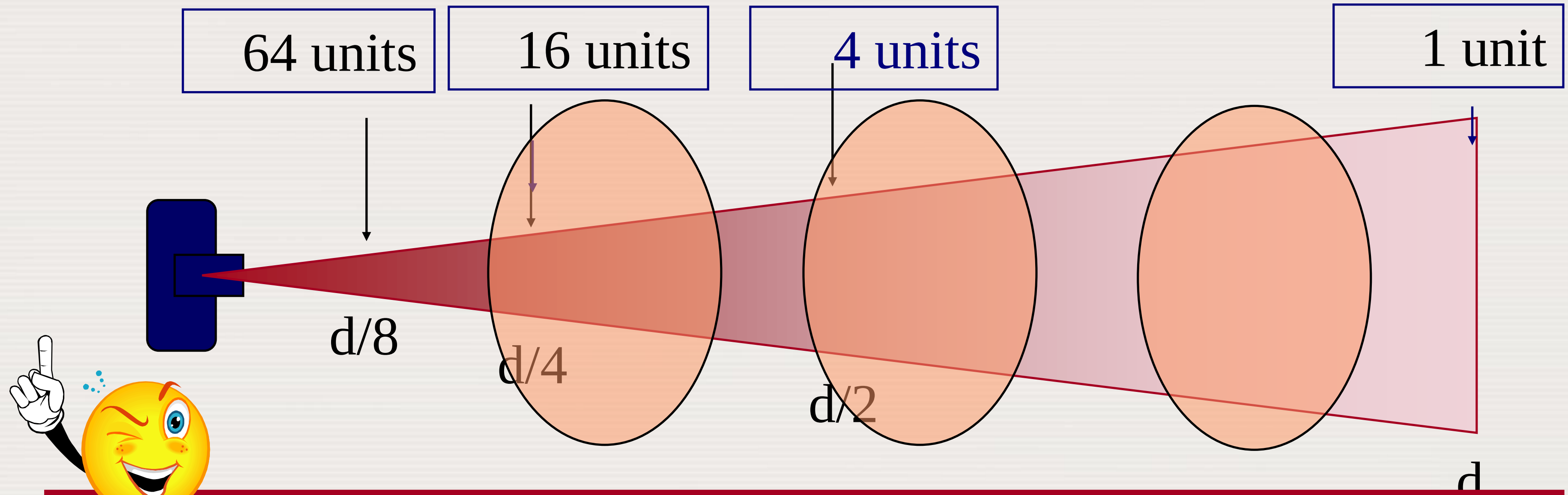
Inverse Square Law

X ray intensity decreases **rapidly** with distance from source; conversely, intensity increases **rapidly** with closer distances to source.



Inverse Square Law & the Patient

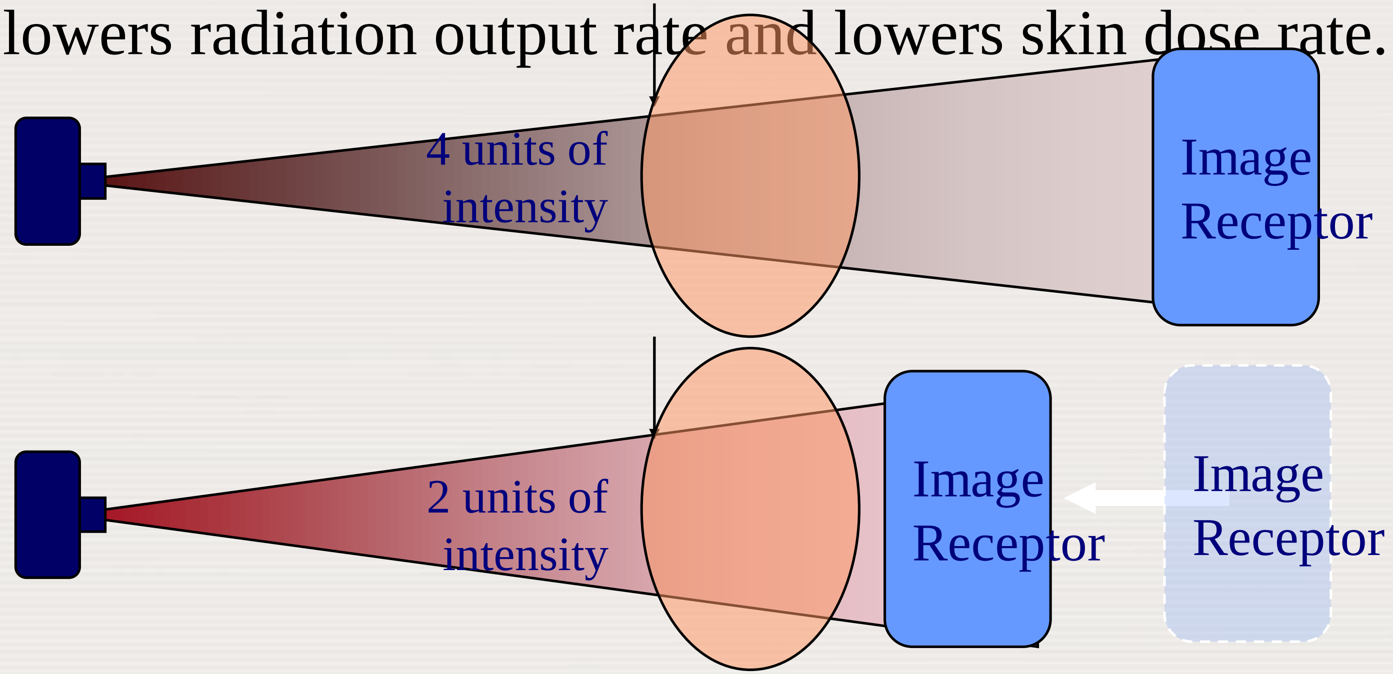
- All other conditions unchanged, moving patient toward or away from the X ray tube can significantly affect dose rate to the skin



<u>Lesson:</u> Keep the X ray tube at the practicable maximum distance from the patient.

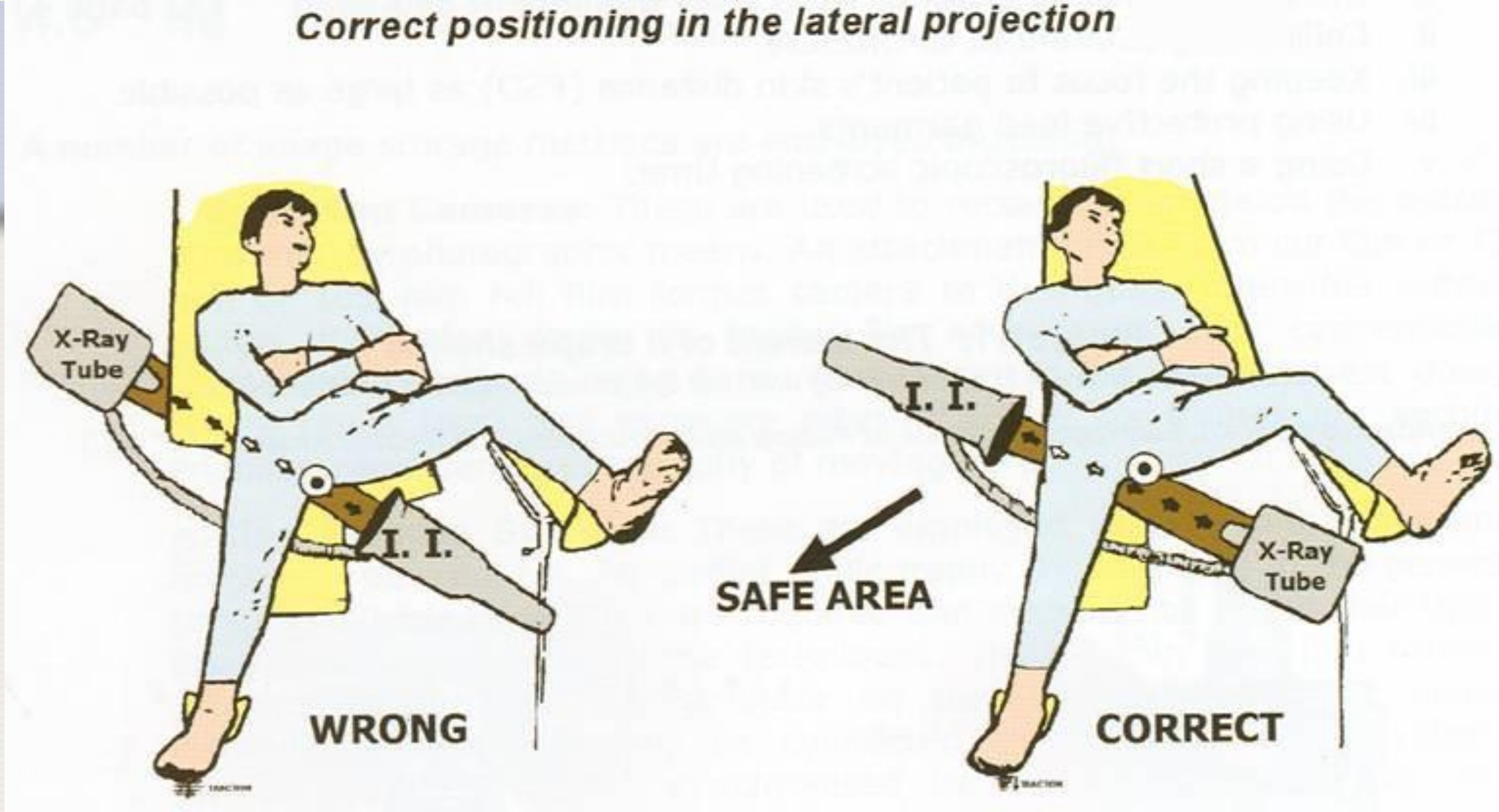
Inverse Square Law & The Image Receptor (Image Intensifier)

All other conditions unchanged, moving image receptor toward patient lowers radiation output rate and lowers skin dose rate.



Remember, ABC adjusts dose to maintain same image brightness

Lesson: Keep the image receptor as close to the patient as is practicable for the procedure.



- Backscatter from thigh- high dose to operator
- Position prevents close positioning of II

- Forward scatter towards the operator is attenuated by mass of thigh
- Patient at edge, allows close positioning of II

Scatter Levels Hip Lat Cross Table Projection* (µSv per 1000 cGy cm2)

Distance (m)	-1	-0.5	0	0.5	1
1.5	1	1	1	1	1
1	1	2	2	2	1
0.5	2	5	5	3	2
0	3	15	29	6	2
	Feet				Head
0	73	252	1080	114	11
0.5	73	160	301	104	8
1	48	70	105	85	24
1.5	24	37	48	43	30

Image intensifier side

X ray tube side

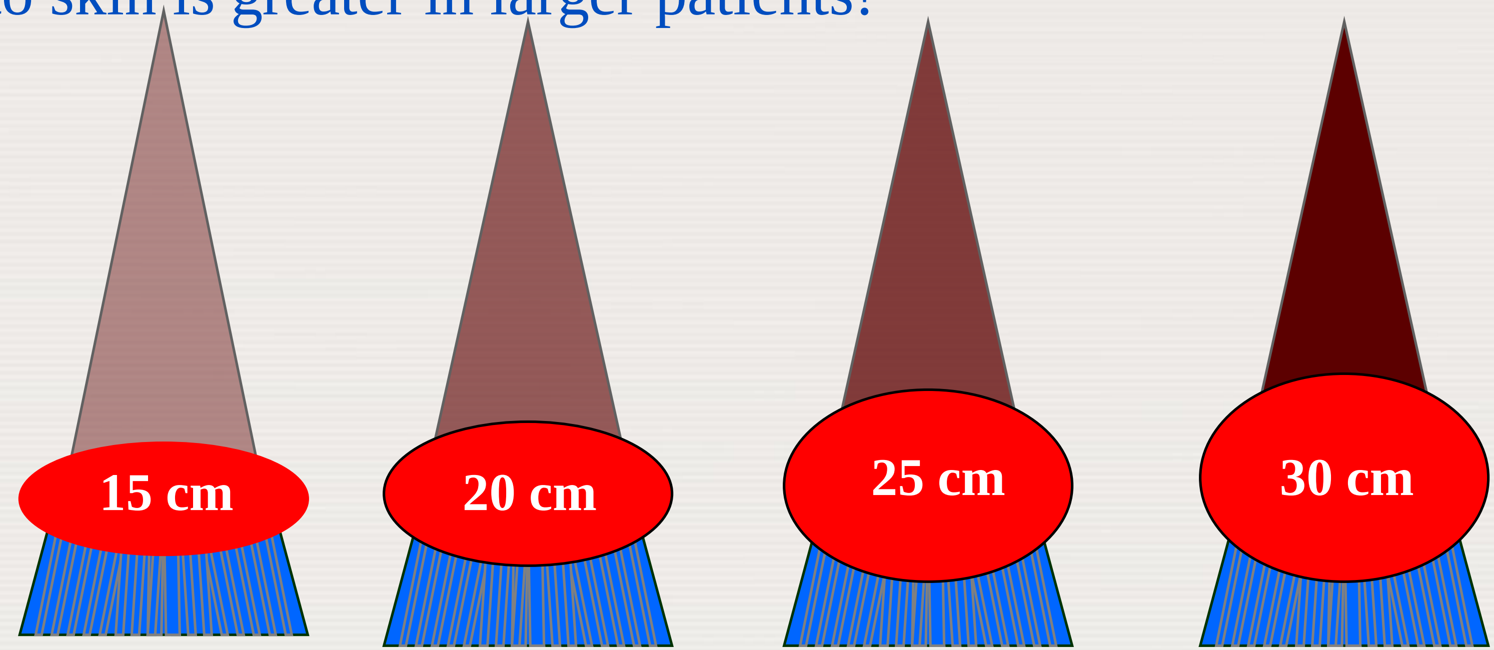
- Dose rate substantially higher on X ray focus side of patient compared to Image intensifier side because of scatter from the patient

***Occupational exposure from common fluoroscopic projections used in orthopedic Surgery** Nicholas Theocharopoulos et al *Journal of Bone and Joint Surgery;* Sep 2003; 85, 9;

Effect of Patient Size on Dose

Thicker tissue masses absorb more radiation, thus much more radiation must be used to penetrate the large patient.

Risk to skin is greater in larger patients!



ESD = 1 unit   ESD = 2-3 units   ESD = 4-6 units   ESD = 8-12 units

Need ~2x more exposure for every 5 cm increase in thickness.

Entrance Dose to Patient vs. Imaging Geometry

Lowest (GOOD) ----------------------------→ Highest (BAD)

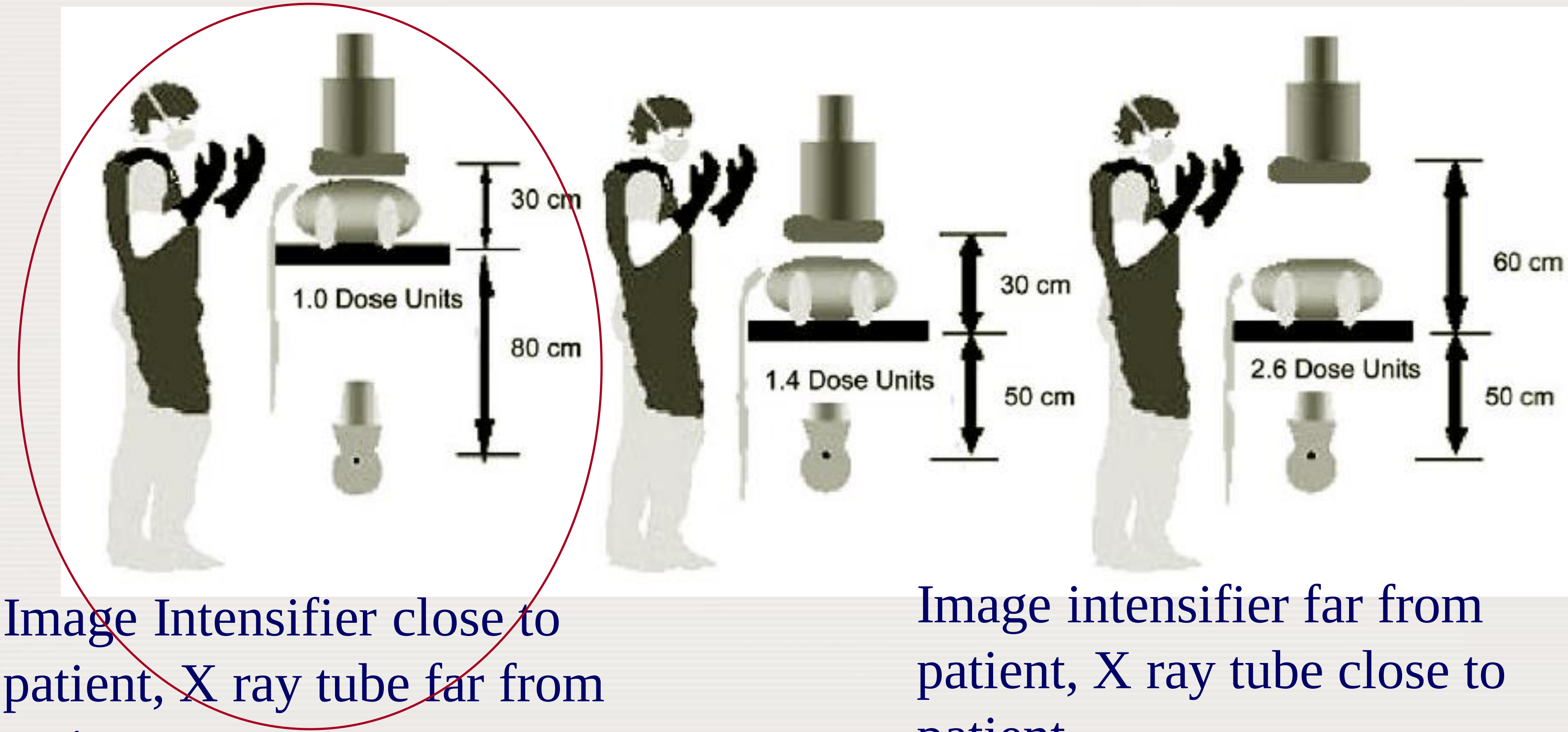


Image Intensifier close to patient, X ray tube far from patient

Image intensifier far from patient, X ray tube close to patient

From: J American College of Cardiology 2004; 44(11): 2259-82

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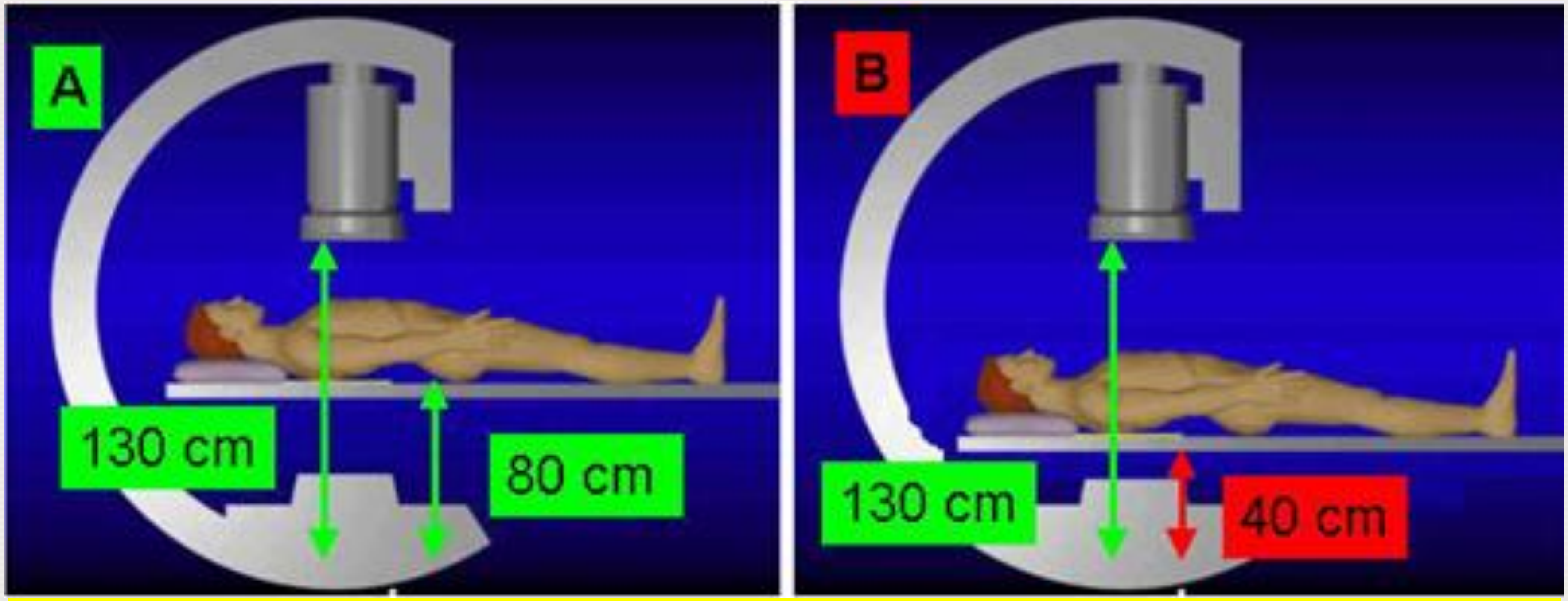
Entrance Dose to Patient vs. Imaging Geometry

- Keep the X ray tube as far away from the patient as possible



For the same dose rate at II,
Entrance skin dose for B is (80/40)2 = 4 times higher

Variation in dose rate to patient's skin with projection

anthropomorphic phantom (average-sized) measurements

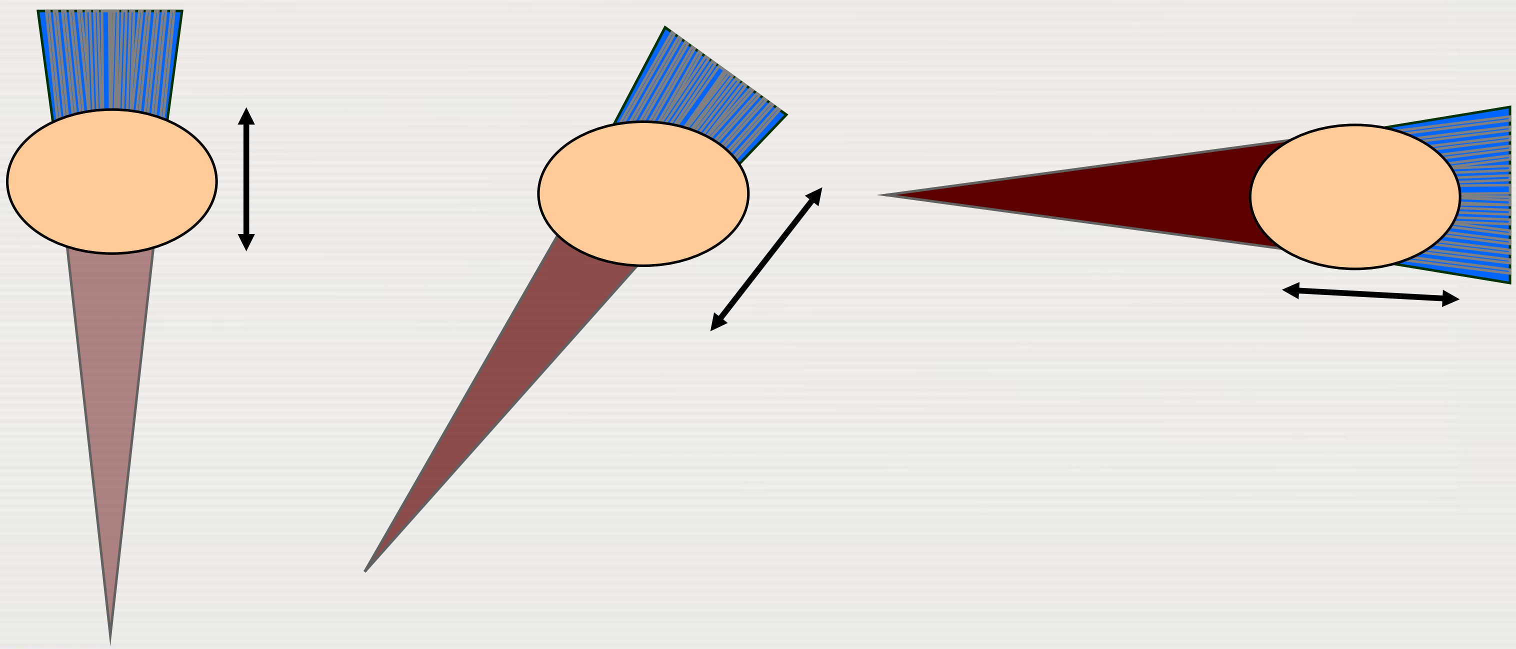
Angiographic projection	Fluoro kerma rate (mGy/min)	Cine kerma rate (mGy/min)
AP	30	390
RAO 30º	19	205
LAO 40º	20	215
LAO 40º, Cran 30º	80	990
LAO 40º, Cran 40º	99	1240
LAO 40º, Caud 20º	29	340

Oblique view, more scatter

Tissue Thickness & Dose Rate

Thicker tissue masses absorb more radiation, thus much more radiation must be used.

- Higher dose to patient when imaging through steep projections
- Risk to skin is greater with steeper beam angles!

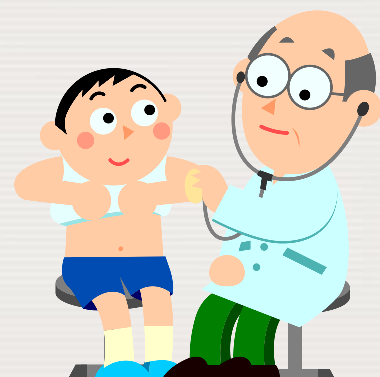


Factors Affecting Patient Entrance Surface Dose Rates - Grids

- Grids
  - Grid is placed in front of the image detector
  - A grid reduces the effect of scatter (degrading of image contrast), BUT it also attenuates the primary X ray beam (both scatter & primary hit grid strips).
  - typically require a 2 times increase in patient dose rate to compensate for attenuation & maintain same X ray intensity at image intensifier as without grid.

Grids in Paediatric Imaging

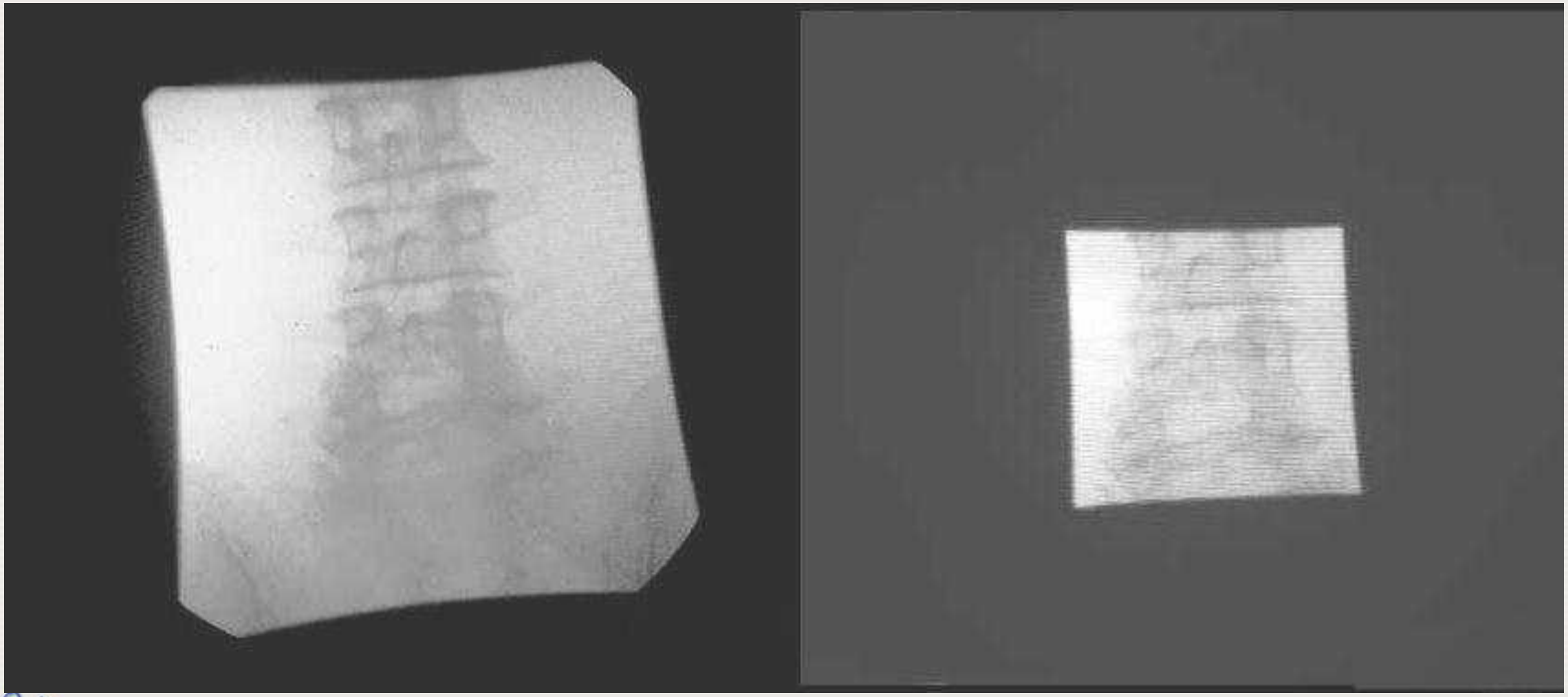
- Small patients produce less scatter
- For smaller patients & small body parts (e.g. a hand) adequate imaging may be obtained without grid
- Consider removing grid for patients < 20 kg



A word about collimation

What does collimation do?

Collimation confines the X ray beam to an area of the user's choice.



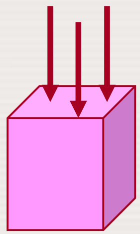
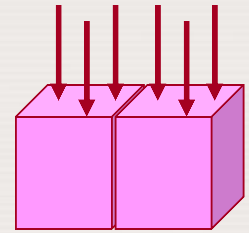
Collimation

Why is narrowing the field-of-view beneficial?

1. Reduces cancer risk to patient by reducing volume of tissue irradiated
2. Reduces scatter radiation at image receptor to improve image contrast
3. Reduces ambient radiation exposure to in-room personnel
4. Reduces potential overlap of fields when beam is reoriented

Dose & Dose Area Product (DAP) & radiation risk

Note: Dose is independent of size of area exposed:

a)  **vs.** **b)** 

Dose = Energy absorbed (E) / Mass

Dose = 2 E / 2 Mass = E / Mass = same dose!

Like rainfall. For example, 10 ℓ/m^2 rain in each case. Doesn't tell you how much water fell - need to know area.

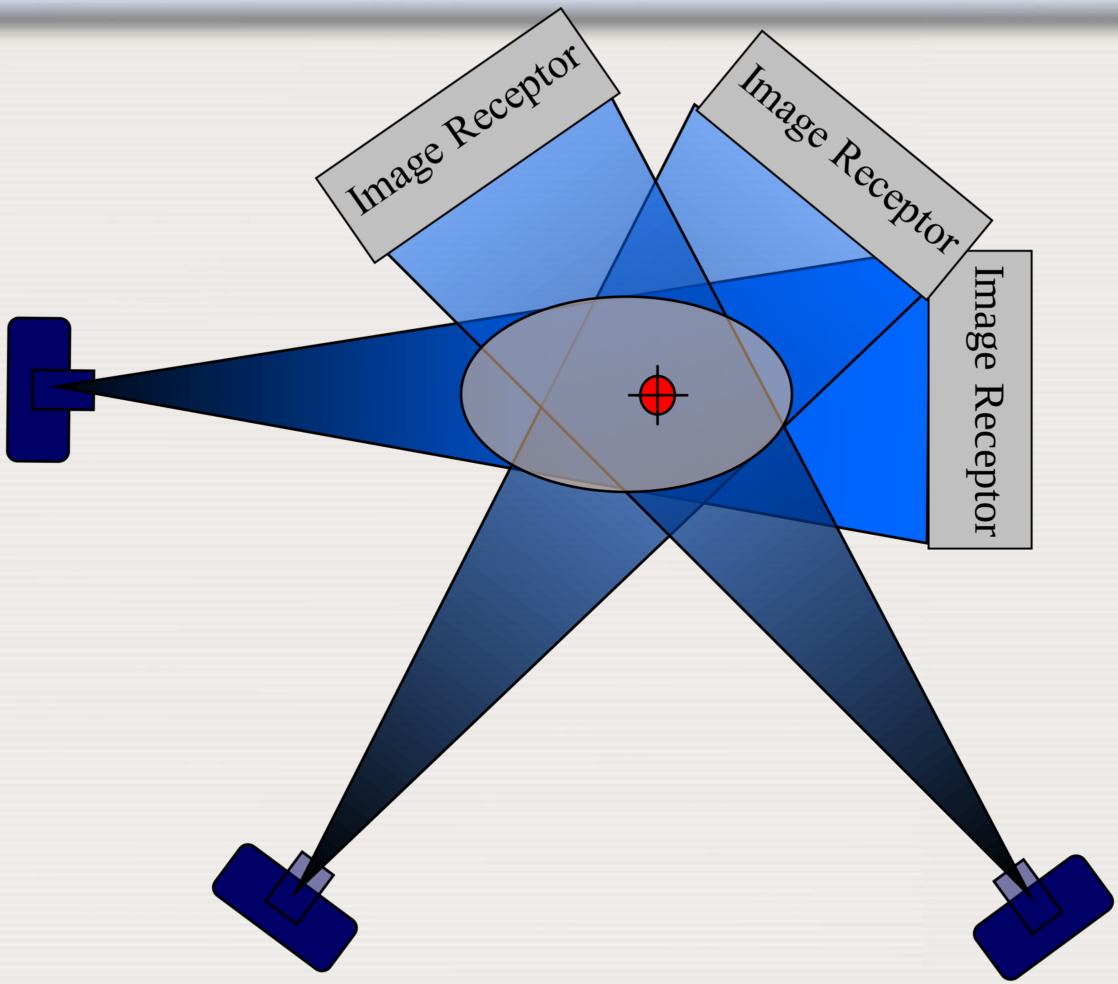
Dose Area Product (DAP) = dose x area exposed

$DAP_b = 2 \times DAP_a$

- **A better estimate of <u>overall</u> cancer risk.**

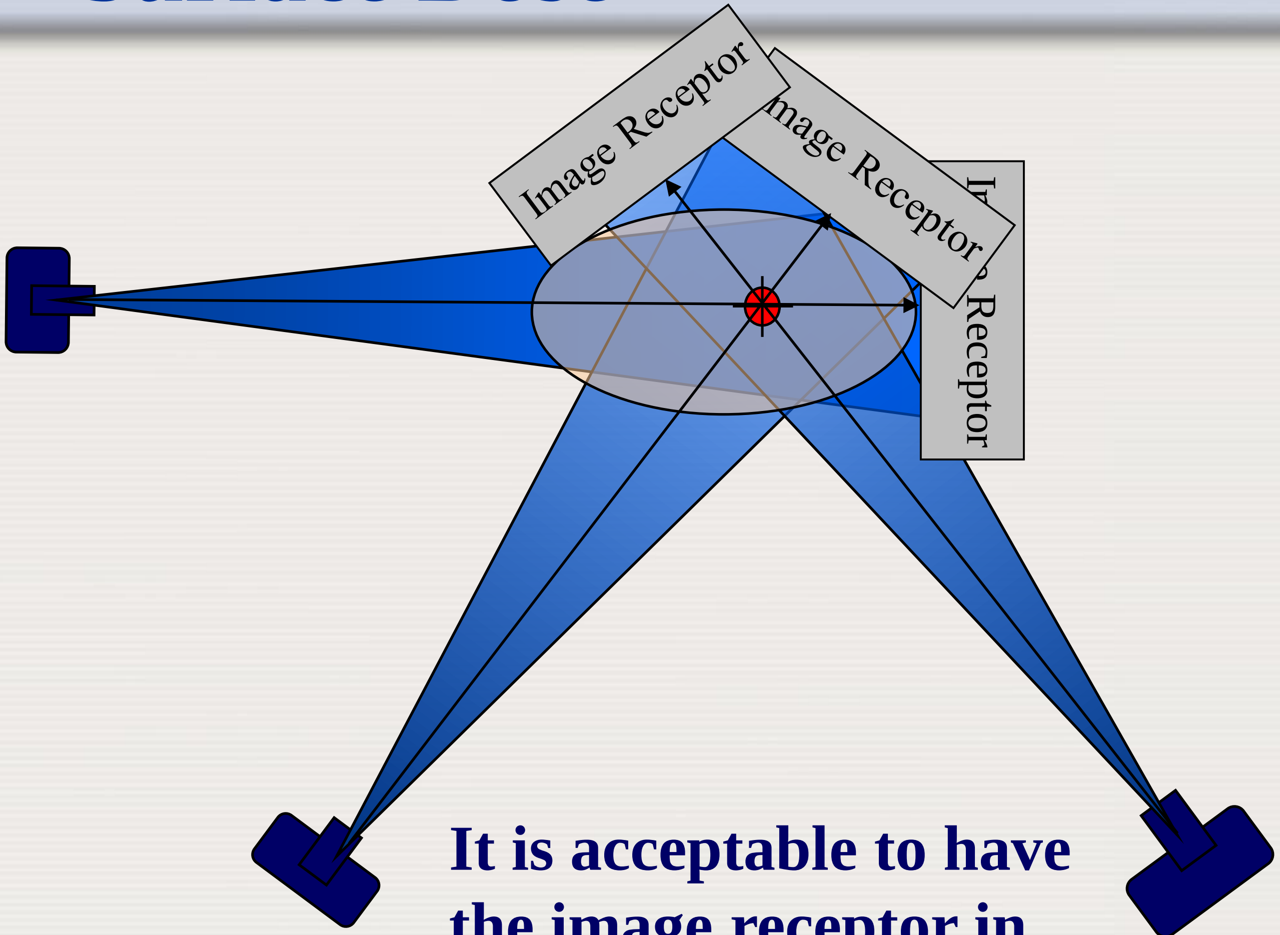
Projection Angle & Peak Entrance Surface Dose

Positioning anatomy of concern at the isocenter permits easy reorientation of the C-arm but in this case the image receptor is too far away from the patient's exit surface. This causes a high skin entrance dose.



Projection Angle & Peak Entrance Surface Dose

When isocenter technique is employed, move the image intensifier as close to the patient as practicable to limit dose rate at the entrance skin surface.



It is acceptable to have the image receptor in contact with the patient

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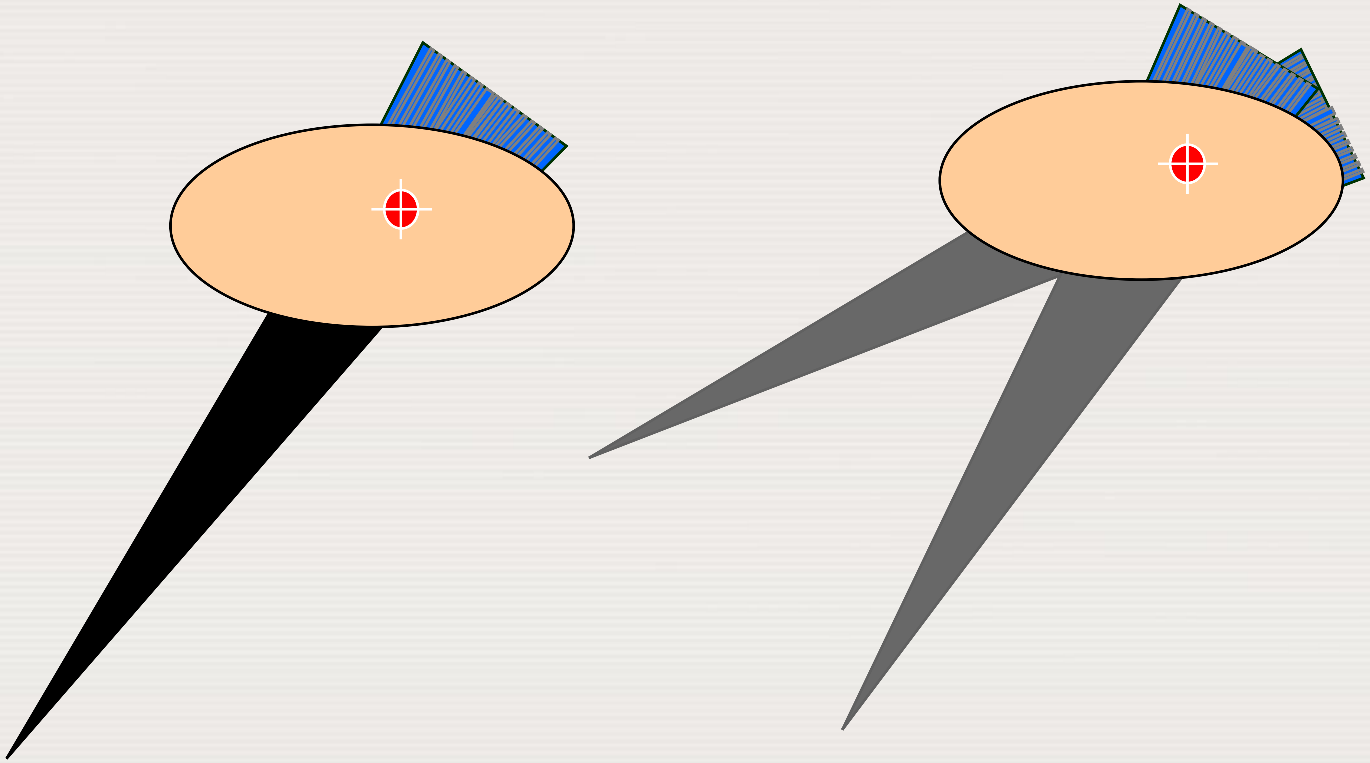
Projection Angle & Peak Entrance Surface Dose

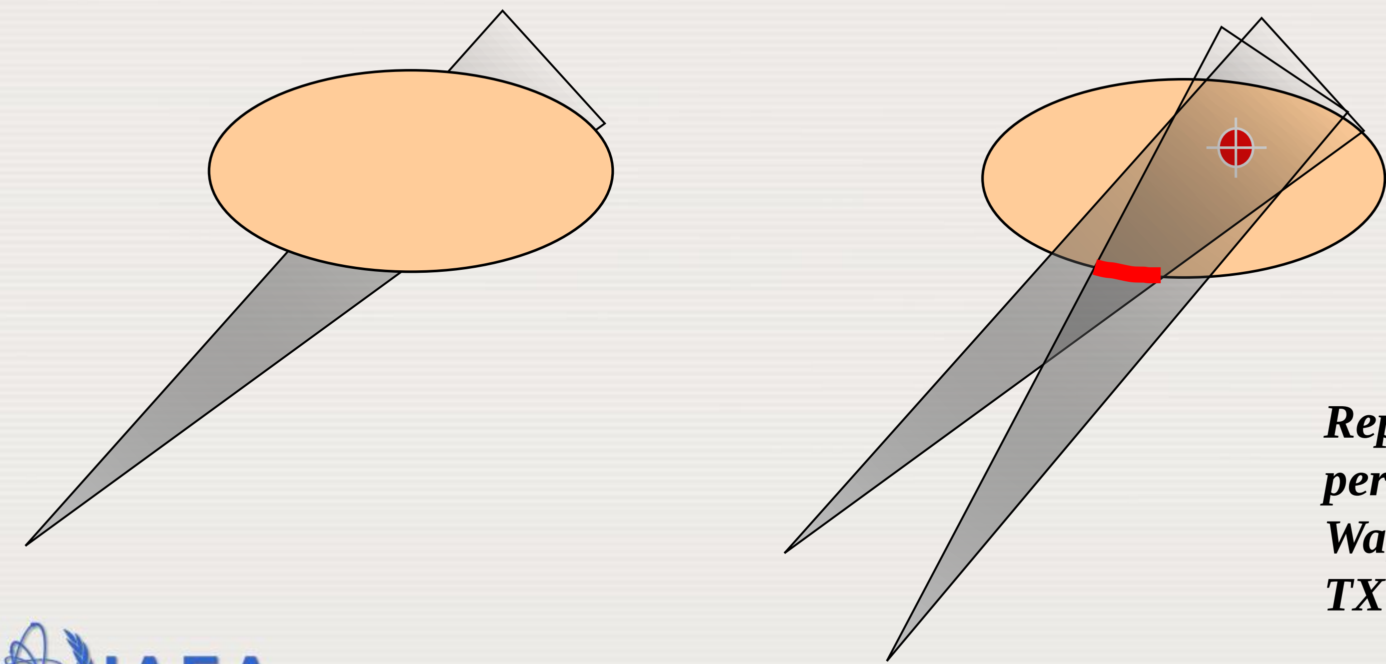
Lesson: Reorienting the beam distributes dose to other skin sites and reduces risk to single skin site.



Reproduced with permission from Wagner LK, Houston, TX 2004.

Projection Angle & Peak Entrance Surface Dose

<u>Lesson</u>: Reorienting the beam in small increments may leave area of overlap in beam projections, resulting in large accumulations for overlap area (red area).



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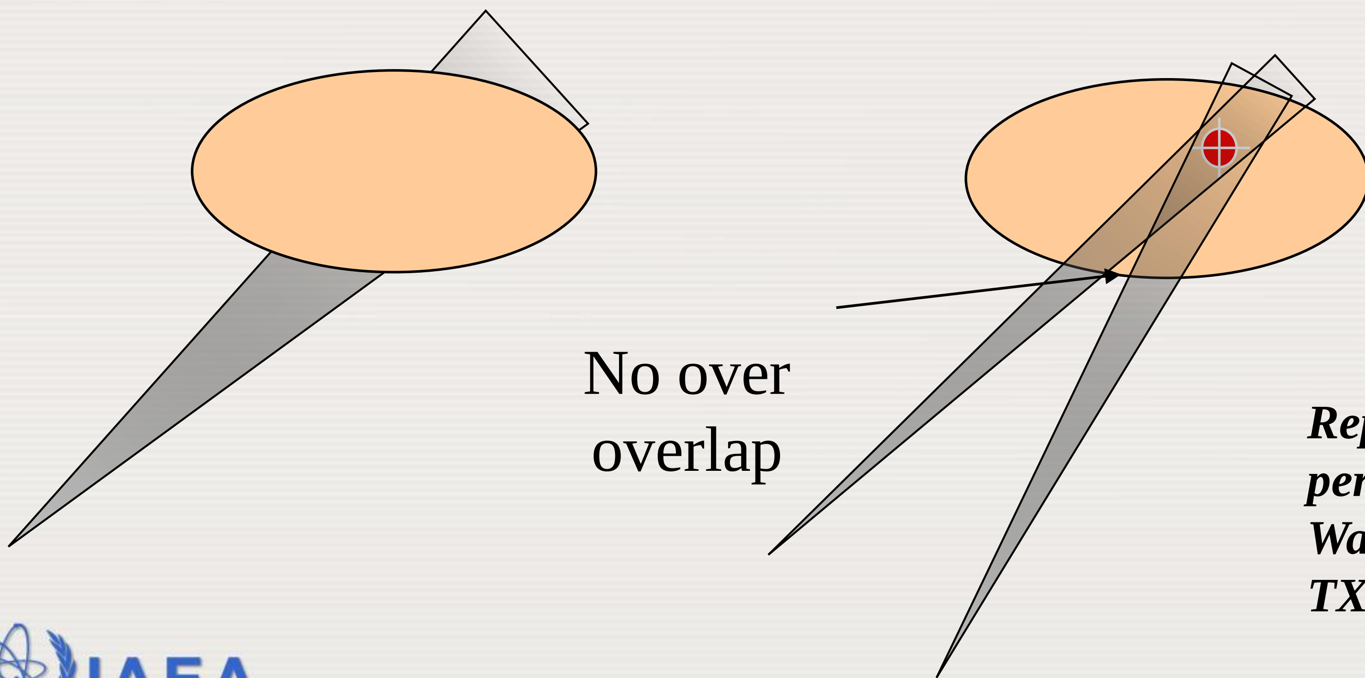
Projection Angle & Peak Entrance Surface Dose

<u>Lesson</u>: Reorienting the beam in small increments may leave area of overlap in beam projections, resulting in large accumulations for overlap area (red area).

Good collimation plus adequate rotation can emilinate this effect.



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Projection Angle & Peak Entrance Surface Dose

Conclusion:

- Orientation of beam is usually determined and fixed by clinical need.
- When practical, reorientation of the beam to a new skin site can lessen risk to skin.
- Overlapping areas remaining after reorientation are still at high risk. Good collimation reduces the overlap area.

Dose rate dependence field-of-view or magnification mode

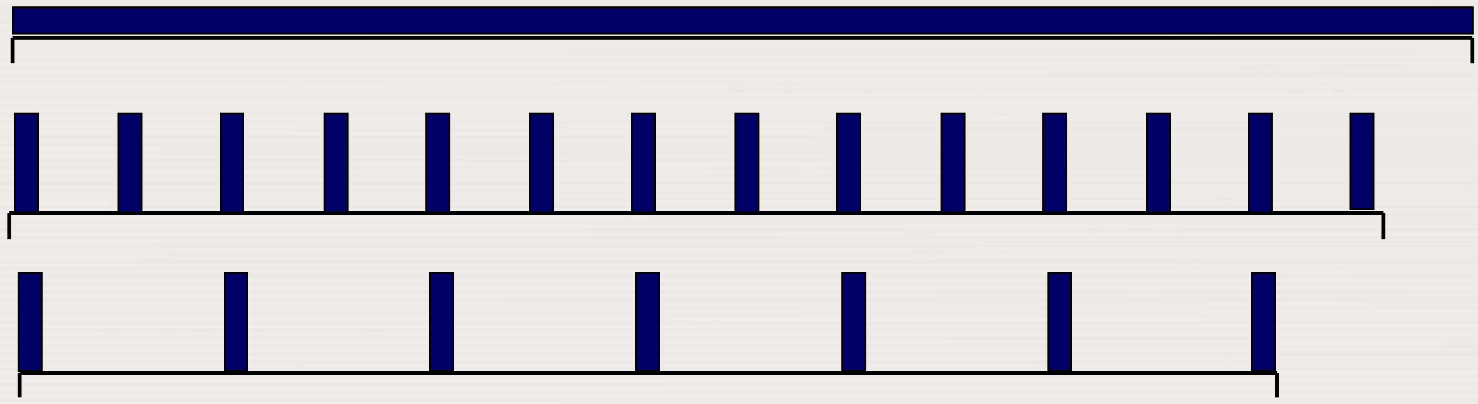
INTENSIFIER Field-of-view (FOV)	RELATIVE PATIENT ENTRANCE DOSE RATE FOR SOME UNITS
12" (32 cm)	**100**
9" (22 cm)	**177**
6" (16 cm)	**400**
4.5" (11 cm)	**700**

Dose rate dependence field-of-view or magnification mode

- How input dose rate changes with different FOVs depends on machine design and must be verified to properly incorporate use into procedures.
- A typical rule is to use the least magnification necessary for the procedure, but this does not apply to all machines.

How to protect the patient

Pulsed Fluoroscopy



- Usually, the lower the pulse rate, the lower the dose.
- Amount of decrease varies by machine & settings.

Pulsed Fluoroscopy

<u>Example:</u> R&F system

Phantom = Adult Abdomen; 33cm FOV, 0.2 mm Cu filtration

Measured Input Exposure Rate (mR/minute)

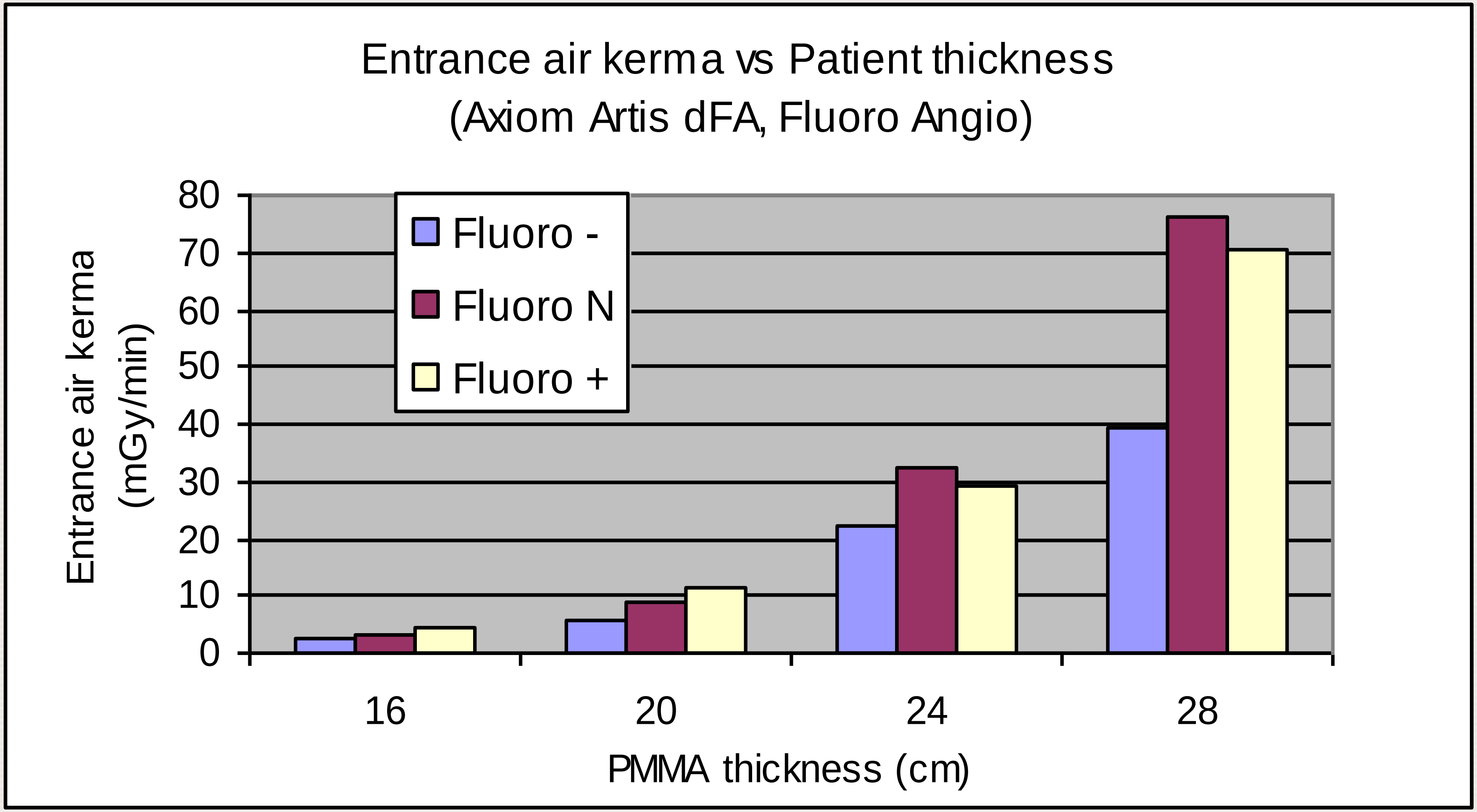
pulses/sec	Fluoro low	Fluoro normal	Fluoro high
12.5	320	492	1041
8	199 (-38%)	396 (-20%)	1007 (-3%)
3	76 (-76%)	232 (-53%)	710 (-32%)

<u>Note:</u> ( ) = % decrease relative to 12.5 pps

8 pps / 12.5 pps = (-21%); 3 pps / 12.5 pps = (-76%)

Dose @ 3 pps in Fluoro 3 is almost 50% > Dose @ 12.5 pps in Fluoro 2

Patient skin dose rate vs patient thickness and fluoro image quality

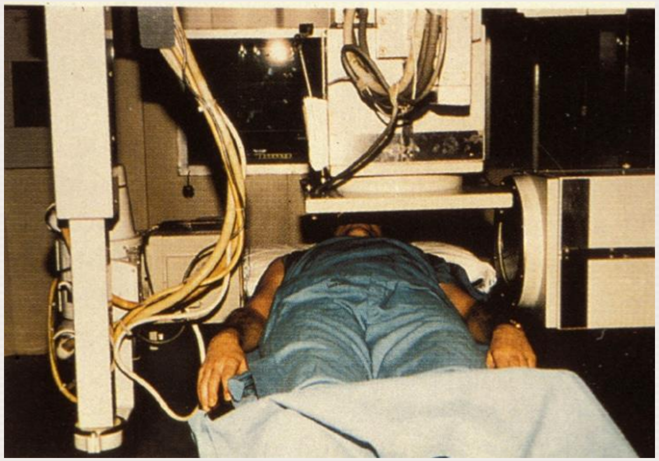


Design of fluoroscopic equipment for proper radiation control

Fluoroscopic X ray Output

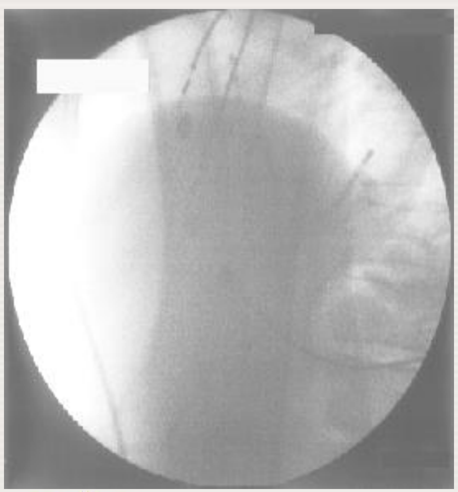
- Fluoroscopic dose output in modern systems is controlled by the equipment.
- The operator can influence the way the system works by selecting various
  - imaging modes (fluoroscopy, cine)
  - Image quality (low, normal, high)
- High quality Modes (boost) increase the imaging detector input dose rates (typically x2 each step), and hence the patient entrance dose rate increases.

Unnecessary body parts in direct radiation field



Vañó et al, Br. J Radiol 1998, 71, 510-516

Injury to arm of 7-year-old girl after cardiological ablation occurred due to added attenuation of beam by presence of arm and due to close proximity of arm to the source.



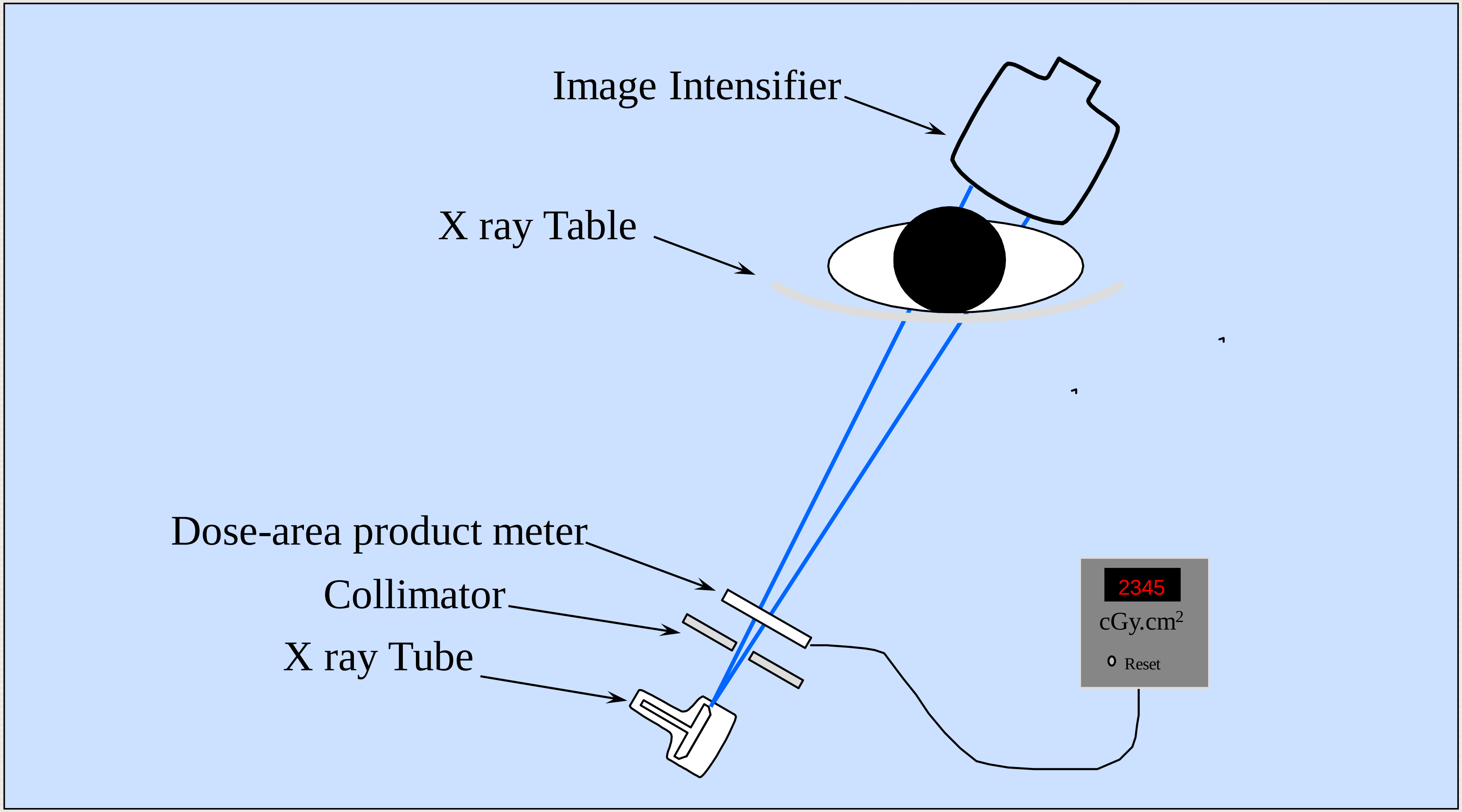
Wagner – Archer, Minimizing Risks from Fluoroscopic X Rays, 3rd ed, Houston, TX, R. M. Partnership, 2000

Patient was draped for procedure and physicians did not realize that she had moved her arm so that it was resting on the port of the X ray tube during the procedur

Monitoring doses in complex exams

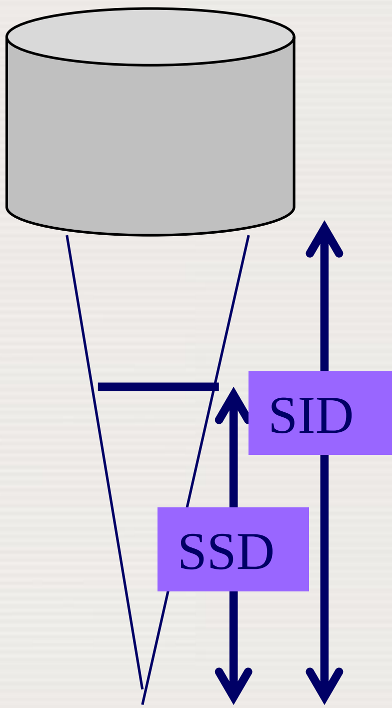
- Exam may involve one or more of:
  - Fluoroscopy
  - Radiography
  - Digital acquisition
  - DSA, conebeamCT
- During the exam the following varies
  - Dose rate
  - Beam size
  - Beam orientation (PA, Lat., etc)
  - Body Part being X rayed

Monitoring doses in Complex exams – Dose-Area Product Meters



Monitoring patient dose

- KAP (DAP) can be used to compare dose performance with published data
- Units $Gycm^2$, $cGycm^2$…
- Can be used to estimate skin dose
  - Via conversion tables
  - Via software within X ray machine (need estimate of field size @ skin)
  - Via calculation. Must estimate field size @ skin from imaging geometry (SSD & SID) & collimator size at image intensifier.
- **Can be used to set action levels to prevent skin injury, but dose rather than DAP is best for this.**



Diagnostic Reference Levels (DRL) for X ray procedures

- DRL is NOT a dose limit
- DRL is the amount of radiation that in average and under normal circumstances, one should not need to exceed in performing an X ray procedure on an average size patient
- Median values from a group of procedures of our practice can be compared with national DRL to identify practice requiring patient dose reduction (optimisation)

Examples of DRLs

- UK and Ireland
- DRLs are setup from national patient dose surveys

Examination	DRL
Femoral Angiogram	33 Gy.cm^2
ERCP	19.0 Gy.cm^2
Venography – Leg	5.0 Gy.cm^2
MCU	17 Gy.cm^2
Hysterosalpinogram	4 Gy.cm^2
Nephrostogram	13 Gy.cm^2
Small Bowel Enema	50 Gy.cm^2
T-Tube Cholangiogram	10 Gy.cm^2
Water soluble enema	31 Gy.cm^2
Water soluble swallow	11 Gy.cm^2
TIPPS	237 Gy.cm^2
TIPS follow up	93 Gy.cm^2
Central Line Insertion	10 Gy.cm^2
Abdominal Angiogram	132 Gy.cm^2
Renal Angiogram	93 Gy.cm^2
Mesenteric Angiogram	145 Gy.cm^2

Procedure	DRL Gy.cm^2
Biliary Drainage	54
Biliary Intervention	50
Hickman Line	4
Oesophageal dilation	16
Pacemaker insertion	27
Coronary Angiogram	36

DRL and complexity PCI procedures

Med. Phys. 35 (2), February 2008

A pilot study exploring the possibility of establishing guidance levels in x-ray directed interventional procedures

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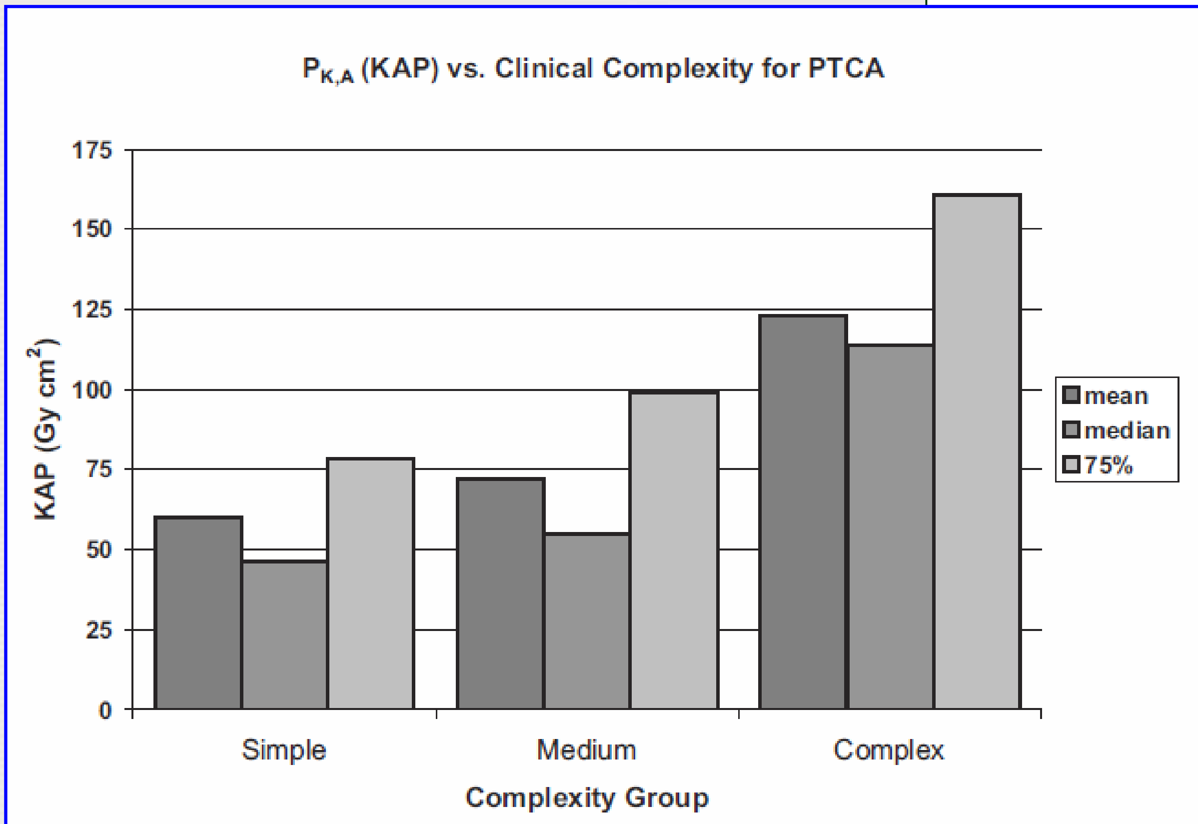

Approx.

Medium = 1.5 x simple

Complex = 2.0 x simple

Example. DRL to apply to an installation or/and to each IR professional?

- Example:
  - 4 operators performing CA in the same hospital, sharing the same mix of patients (similar complexity)

Interventionalist	No. CA procedures	KAP (Gycm2)	Fluoro time (min)	No. images
B	72	23.4	4.6	323
S	60	36.8	3.7	603
Z	89	58.8	3.7	818
BT	57	56.1	5.0	765

Summary

- Keep screening times and acquisitions to a minimum
- Use low dose settings as defaults
- Keep the X ray tube as far away from the patient as possible
- Keep the Image Intensifier close to the patient

Summary

- Use magnification mode as little as possible
- Collimate when possible
- Use last image hold and fluoro storage if available
- Remove grid for procedures on small patients

Summary

- Use low pulse rate
- Use higher kVp unless it compromises image contrast
- Compare procedure fluoroscopy time and dose with published values (or national Diagnostic Reference Levels - DRL)

https://rpop.iaea.org/RPOP/RPoP/Content/InformationFor/HealthProfessionals/4_InterventionalRadiology/DiagnosticFluoroscopy.htm

A final general recommendation

Be aware of the radiological protection of your patient and you will also be improving your own occupational protection

IAEA http://www.rpop.org

Radiation protection of patients

Thank you