National Training Course on Radiation Protection in Interventional Radiology
(Tel Aviv, 4th and 5th of June, 2018)

How to protect staff and patients: procedure optimisation

Renato Padovani, ICTP, Italy

IAEA

Atoms for Peace: The First Half Century
1957–2007

Key topics

- Basic methods for radiation protection
- Factors affecting staff doses in fluoroscopy
- Practical rules
- Protection devices
- Individual dose monitoring
- Health surveillance

BSS - Dose limits

"The occupational exposure of any worker shall be so controlled that the following limits be not exceeded:

For effective dose:

20 mSv per year averaged over five consecutive years and **50 mSv** in any single year;

For equivalent dose:

to the lens of the eye of **20 mSv* in a year**; averaged over 5 years; not exceeding 50 mSv in any single year.

Dose limit for the extremities (hands and feet) or the skin of **500 mSv** in a year.

*IAEA BSS 2014

IAEA BSS - Responsibility of workers

Workers shall:

- Follow any applicable rules and procedures for protection and safety specified by the employer
- Use properly the monitoring devices and the protective equipment and clothing
- Co-operate with the employer with respect to the operation of radiological health surveillance and dose assessment programmes
- Abstain from any wilful action that could put themselves or others in situations of risk

Basic Radiation Protection

"Golden rules" :

- Time – minimize exposure time
- Distance – increasing distance
- Shielding –Lead or non-lead equivale
  inside the room with X ray machine
    - fixed, portable and pull- down shi
    - Personal protective devices
- Technique factors e.g. ... e fluoroscopy, magnification, filters

Each of these can reduce staff doses by factors from 2 to 20 or more

IAEA
Atoms for Peace: The First Half Century
1957–2007

Parameters affecting staff and patient exposure

- Patient dependent factors:
  - body mass or body thickness in the beam
  - complexity of the lesion and anatomic target structure
- Procedure factors
  - Beam projections
  - Number of series and total number of images
  - Fluoroscopy time
  - Operator training and experience
- Technical factors
  - Image quality level
  - Pulsed fluoro and acquisition rate, DSA
  - Electronic vs. Geometric magnification
  - Performance of the X ray equipment
  - Available dose reduction tools

Parameters affecting staff and patient doses in detail

PROTOCOL

NUMBER OF IMAGES

TIME

BEAM GEOMETRY

COLLIMATION & FILTERS

PROTOCOL USED

- low dose rate modes for fluoroscopy,
- low pulse-rate fluoroscopy options, low dose per frame
- settings for image acquisition,
- low frame rate options for image acquisition.

PROTOCOL USED

- A useful indication is provided by the dose rates (dose per unit of time or dosage per image).
- For the different modes of operation the measurement is made in a position corresponding to the input beam to the patient.
- TIPICAL RATES
  - FLUOROSCOPIC MODE : 10 – 60 mGy/min
  - FLUOROGRAPHIC MODE : 0.2 – 3 mGy/frame

TIME

- Under control of the operator
- Radiation is produced only when the x-ray beam is on
- Fluoroscopy only to observe motion
- Use last-image-hold
- Pay attention to your foot!

TIME OPTIMIZATION

- Fluoroscopy should be used only to observe objects or structures in motion.
- Use short taps of fluoroscopy instead of continuous operation.
- Review the last-image-hold for study, consultation, or education instead of additional fluoroscopic exposure.
- If available, use fluoroscopy run recording to review dynamic processes.
- Fluoroscopy to determine or adjust collimator blade positioning can be eliminated by using the virtual collimation feature, when present.

NUMBER OF ACQUIRED IMAGES

- The number of images acquired has a great effect on patient and operator dose.

→ Play attention to the total number of acquired images

→ The number of runs and the images per run should be the minimum required to achieve the clinical purpose.

COLLIMATION & FILTERS

COLLIMATION

- Reduces patient dose,
- Improves image quality by reducing scatter
- Reduces occupational exposure

SEMI-TRANSPARENT OR WEDGE FILTERS

- improve image quality
- reduces patient and scatter doses.

→ Adjust collimator blades tightly to the area of interest.

→ Utilize the virtual collimation, if it is available.

Geometry: dose rates to patient's skin with projection

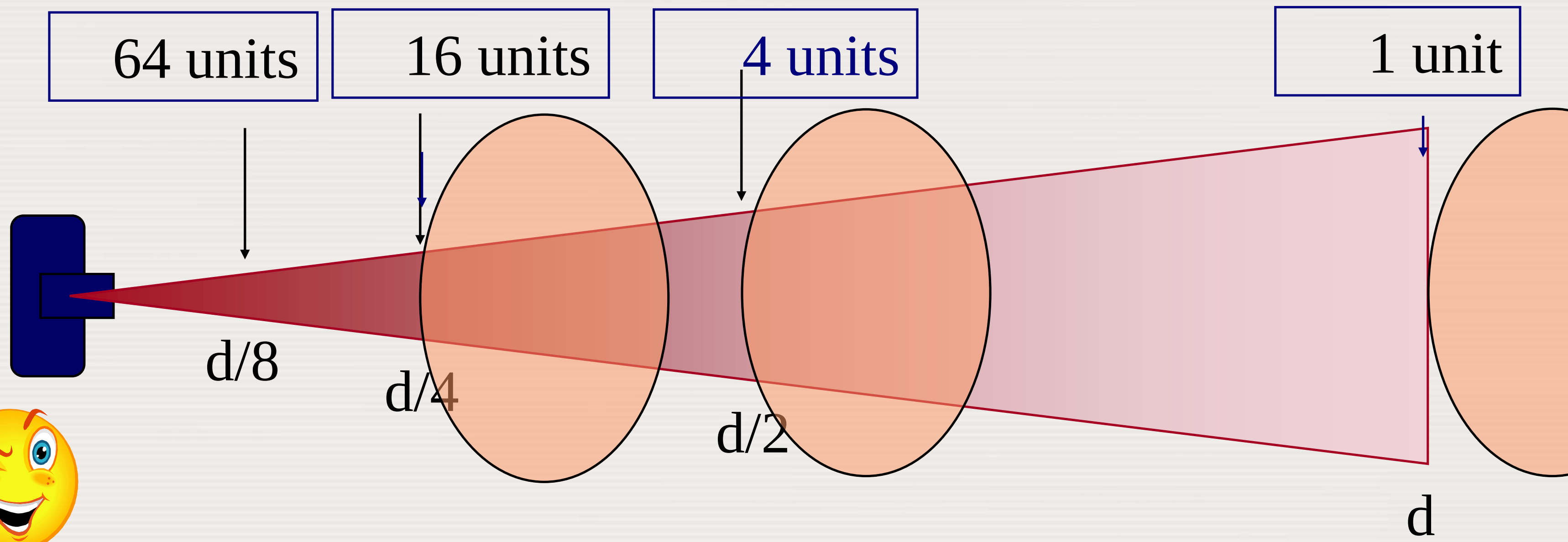
anthropomorphic phantom (average-sized) measurements

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

Geometry: X-ray tube – Patient – Imaging detector

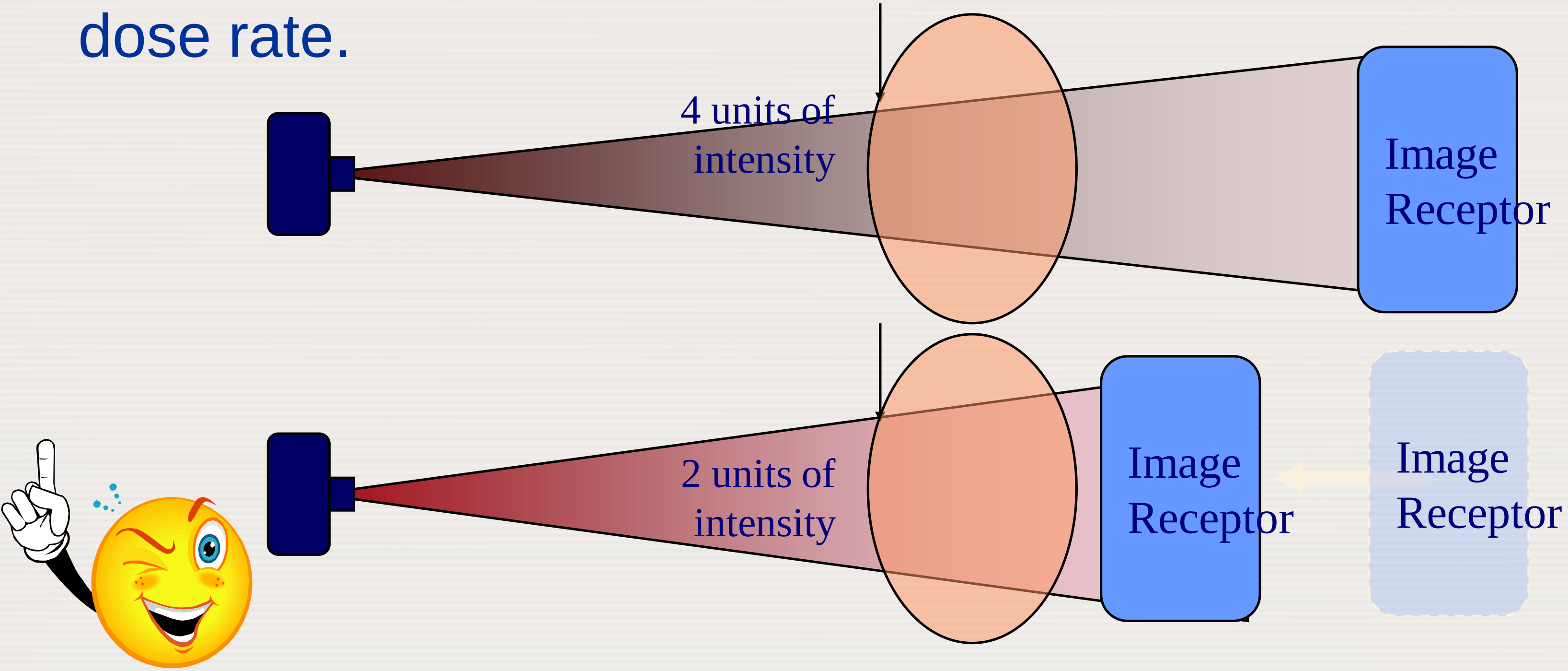
- All other conditions unchanged, moving patient toward or away from the X ray tube can significantly affect dose rate to the skin



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

Inverse Square Law & the Image Receptor

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

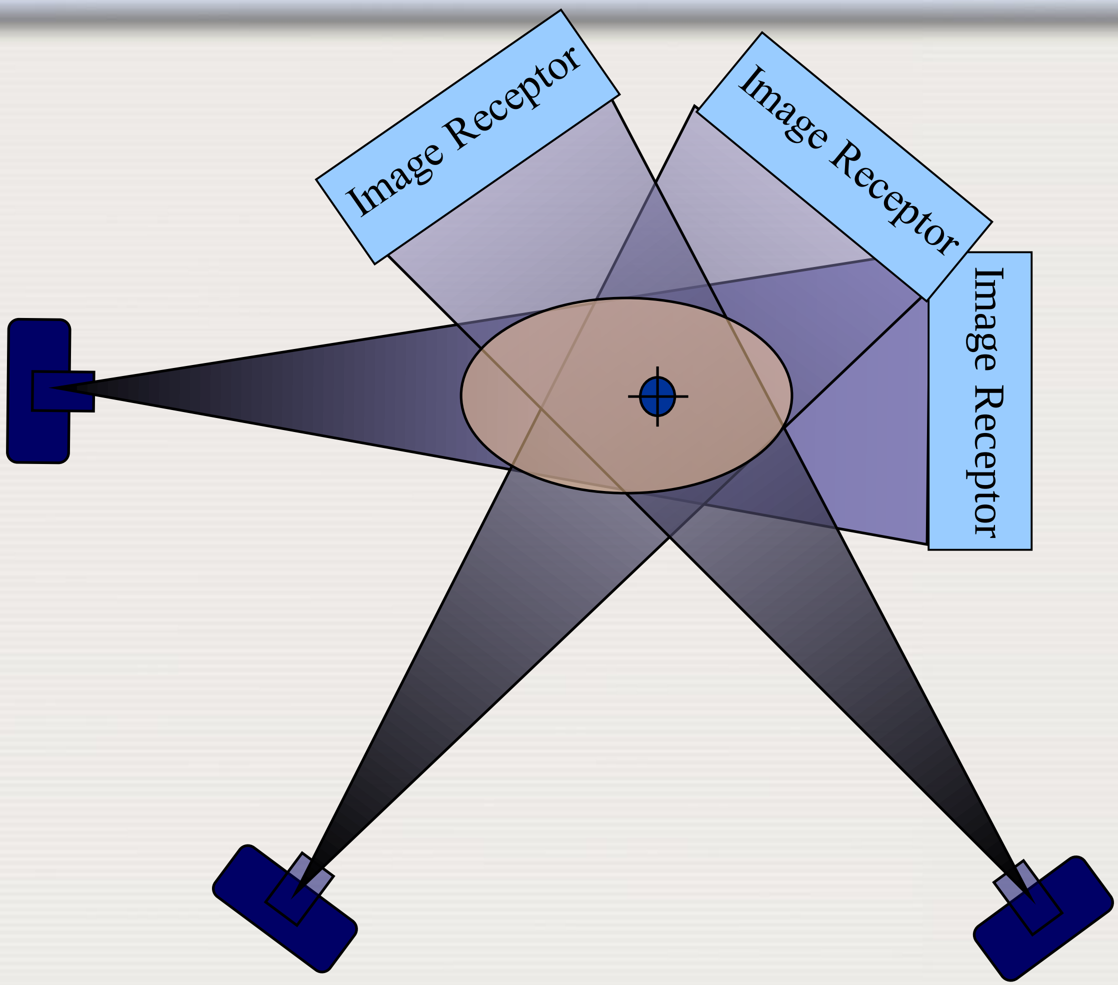


Remember, ABC adjusts dose to maintain same image brightness

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

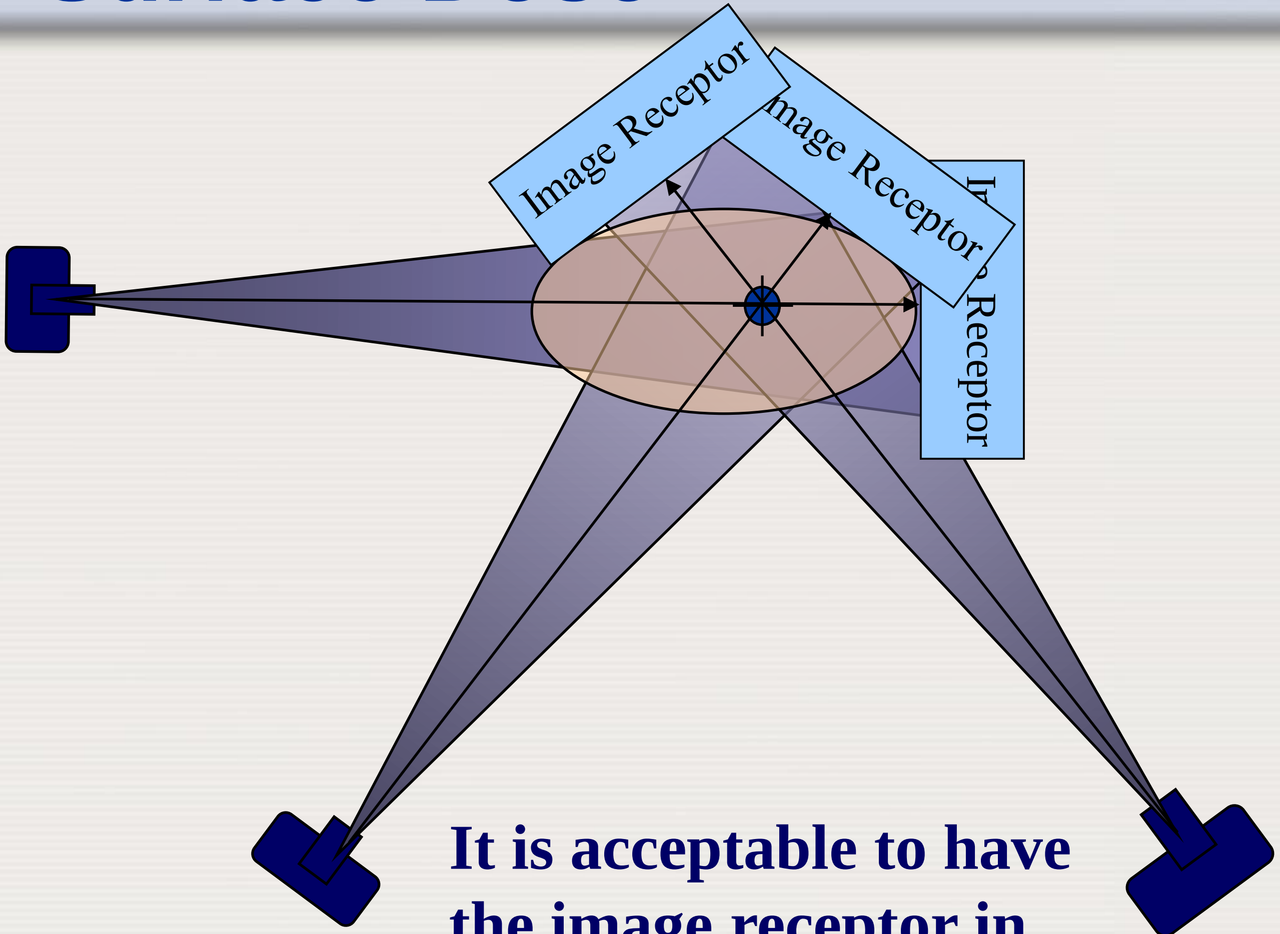
Projection Angle & Peak Entrance Surface Dose

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

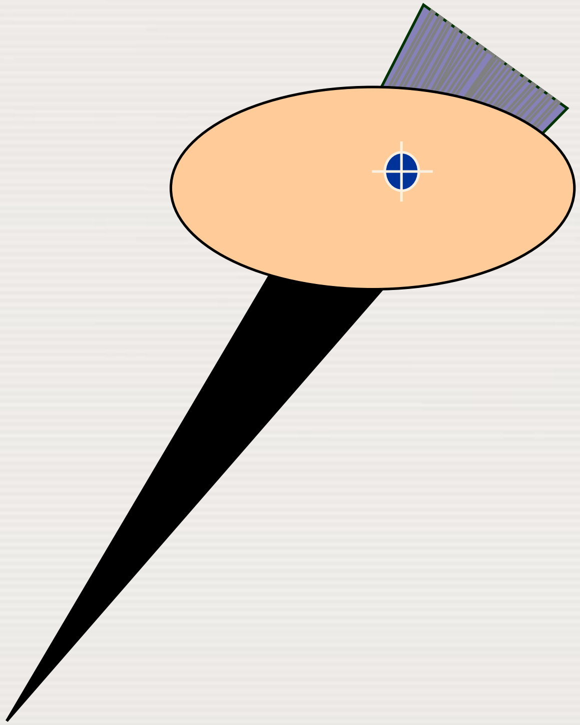
When isocenter technique is employed, move the image intensifier as close to the patient as practicable to limit dose rate at the entrance skin surface.

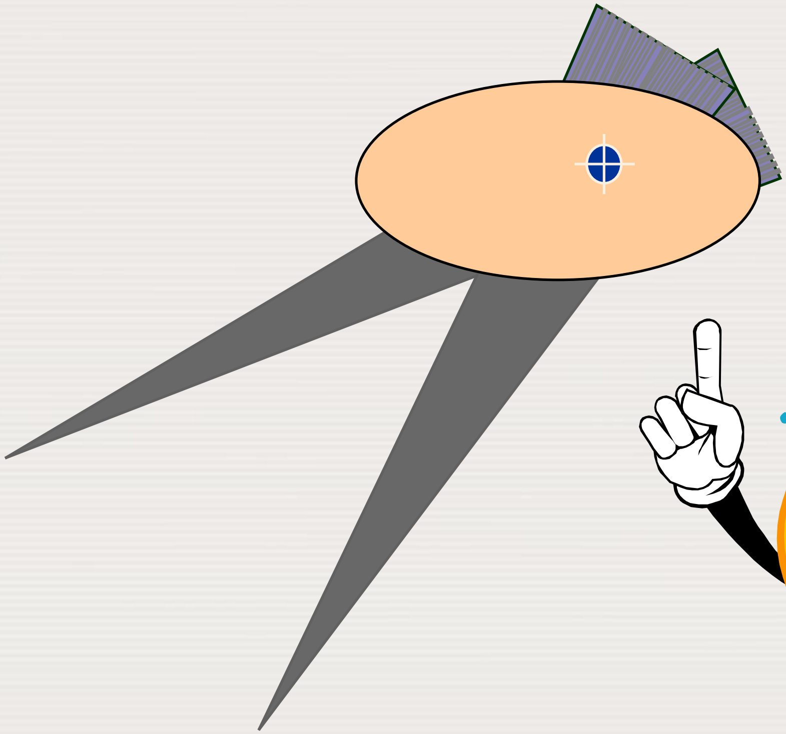


It is acceptable to have the image receptor in contact with the patient

Projection Angle & Peak Entrance Surface Dose

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



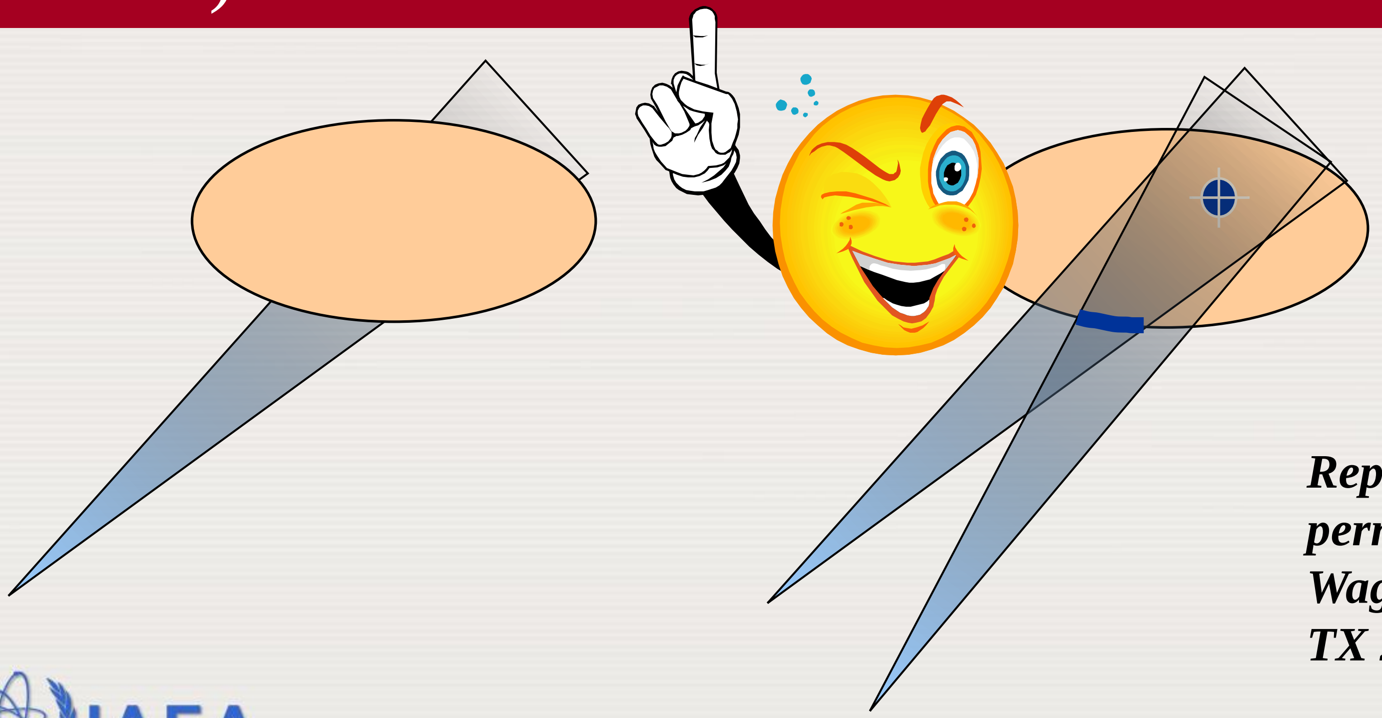


Reproduced with permission from Wagner LK, Houston, TX 2004.

How to prote

Projection Angle & Peak Entrance Surface Dose

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

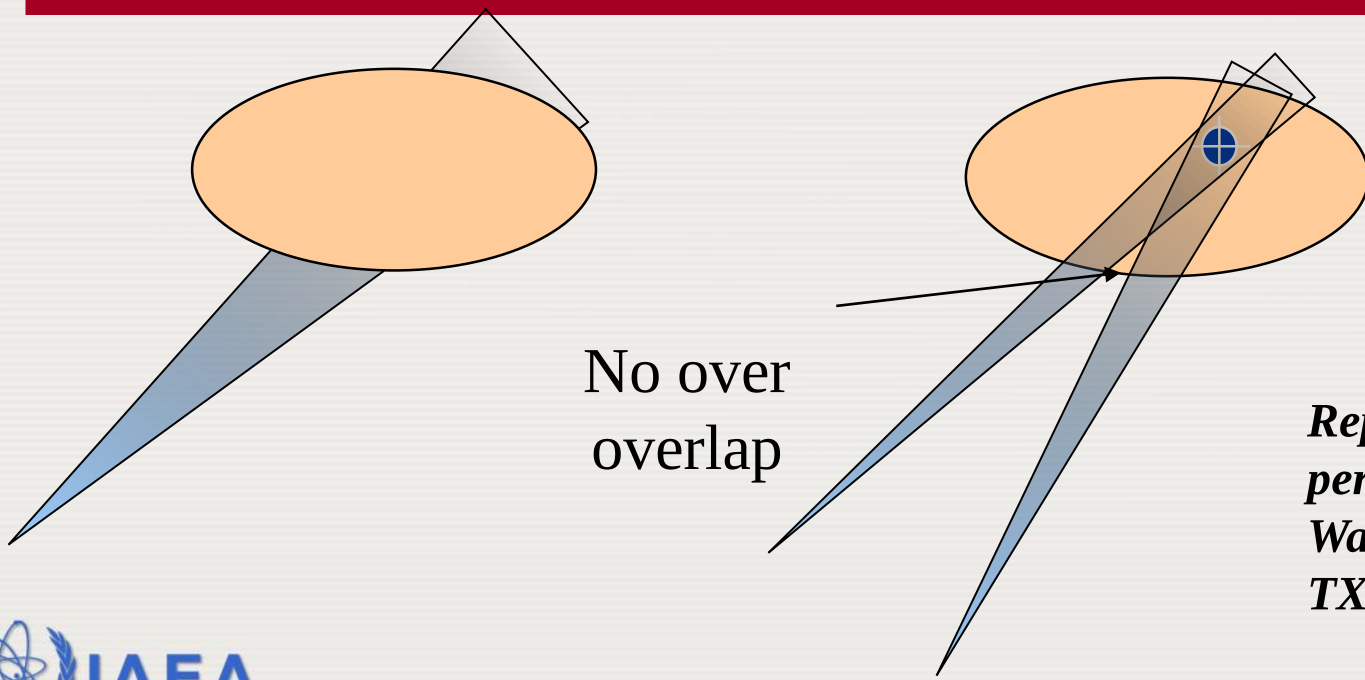


Reproduced with permission from Wagner LK, Houston, TX 2004.

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).

Good collimation plus adequate rotation can emilinate this effect.

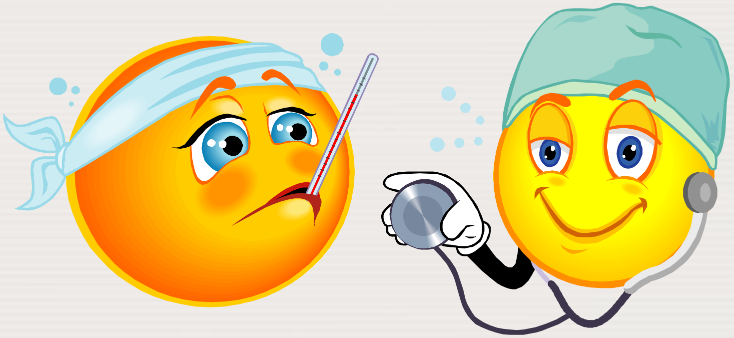


Reproduced with permission from Wagner LK, Houston, TX 2004.

Image magnification (Zoom)

IMAGE DETECTOR Active 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)	711

Image quality

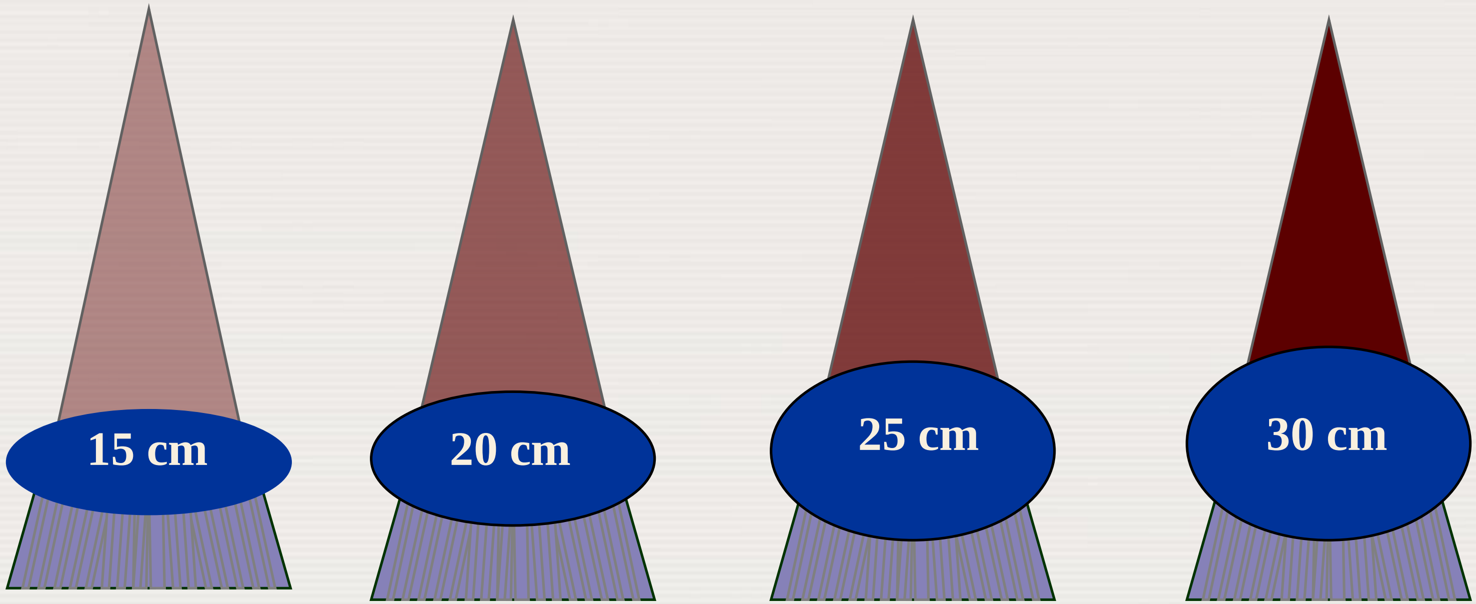


CHANGING FROM LOW TO NORMAL FLUOROSCOPY MODE (OR HIGH MODE)

INCREASES DOSE RATE BY A FACTOR OF
2 OR MORE
(OR x 4)

Effect of Patient Size on Dose

- Thicker tissue masses absorb more radiation → 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.

FACTORS AFFECTING STAFF DOSE

DISTANCE

POSITION

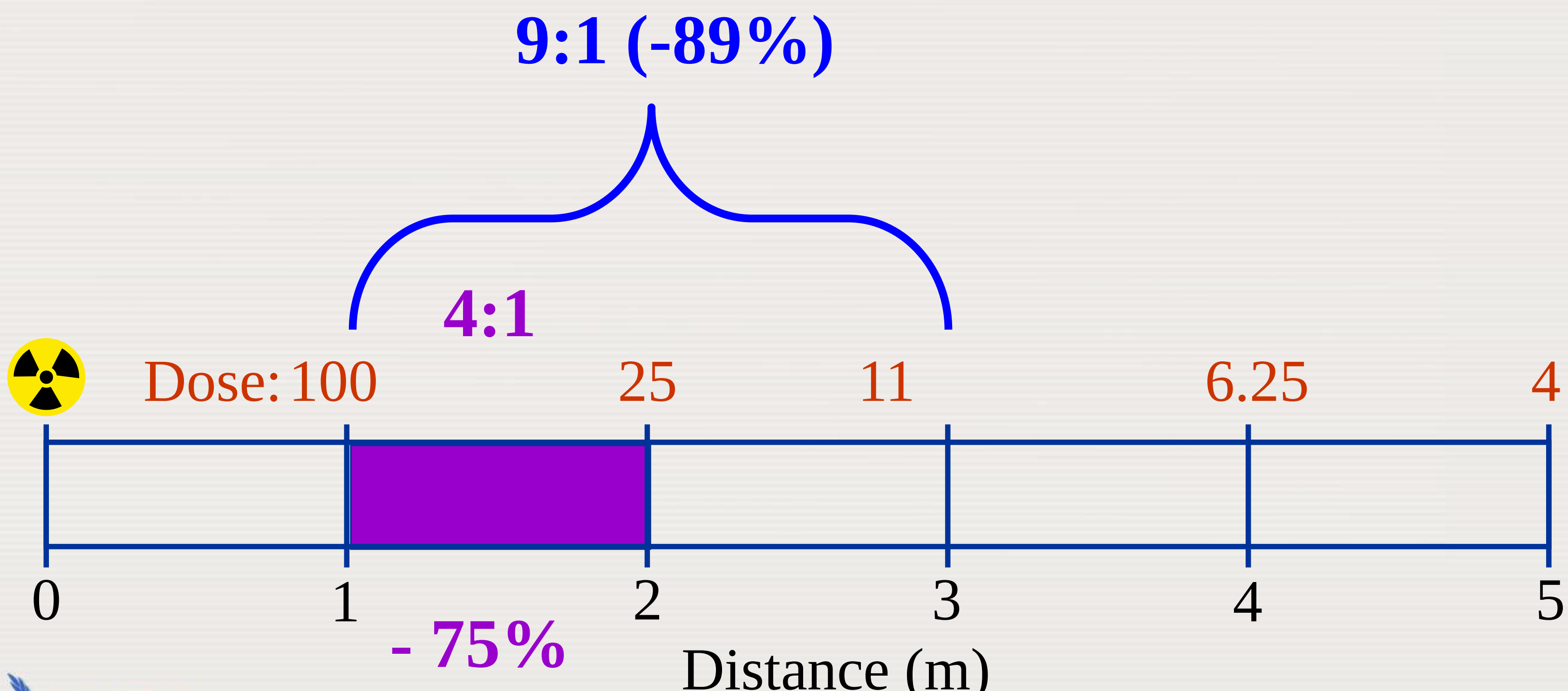
PROJECTION

SHIELDING

PATIENT SIZE

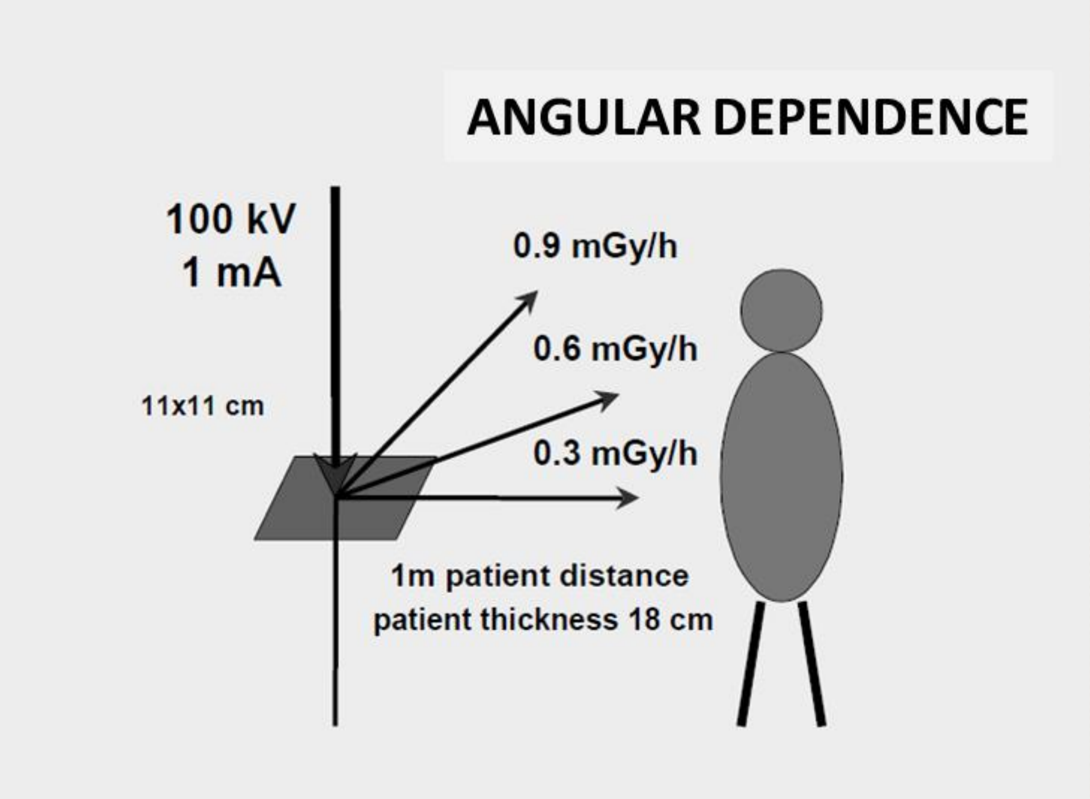
DISTANCE

- Inverse square law
  - Dose decreases as the square of the distance from the source



distance

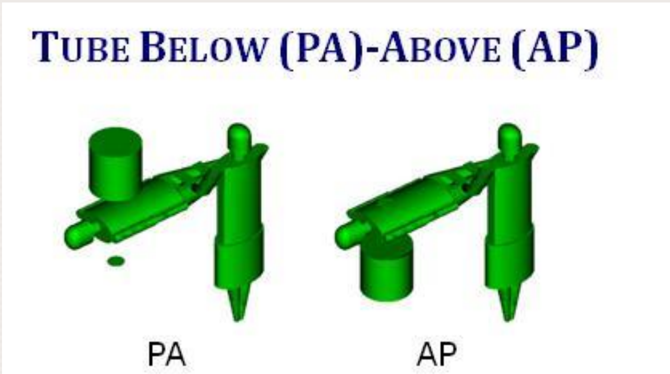
- Scatter radiation is higher near the area where the beam enters the patient

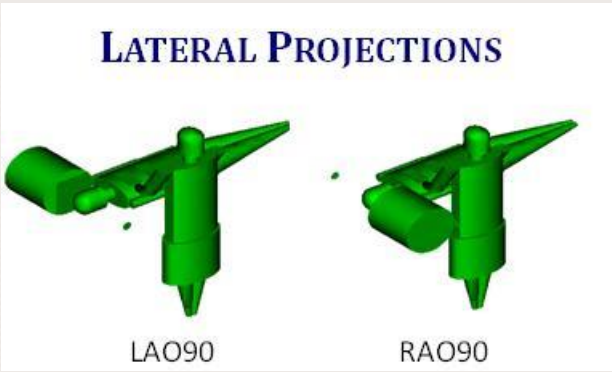


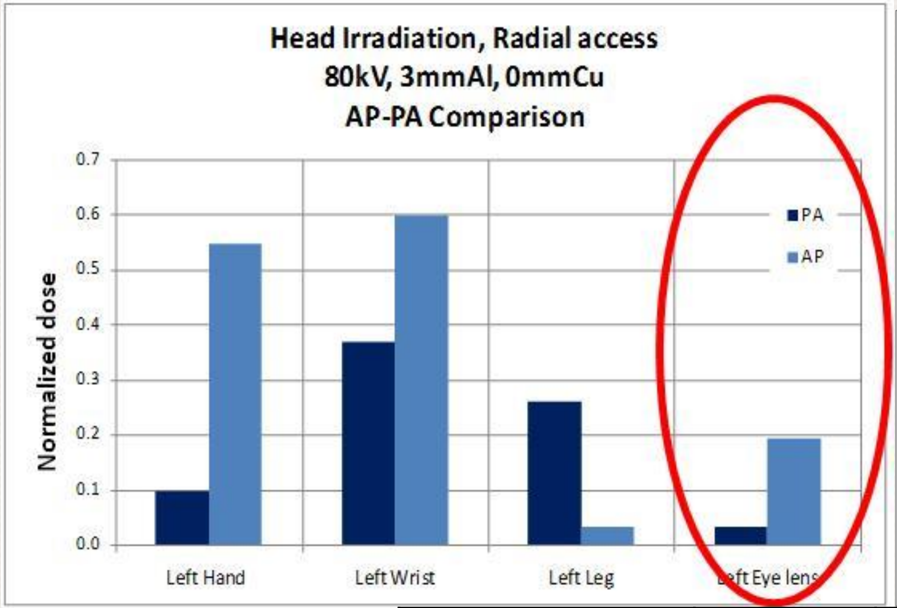
DISTANCE

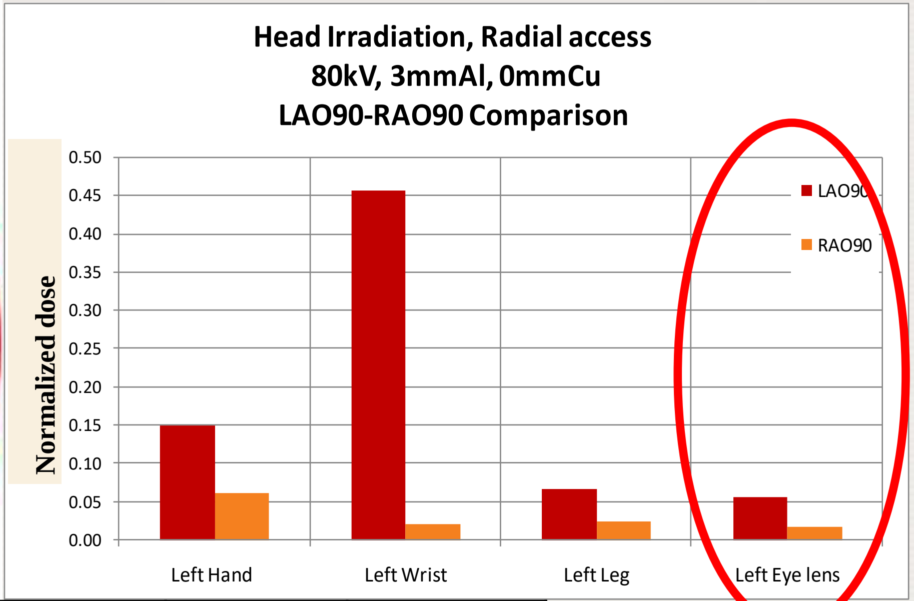
- Know when the beam is on
- Try not to be standing next to the patient
- Keep your hands out of the radiation field
- Not to be in the room if not necessary

Scatter radiation vs Beam projection



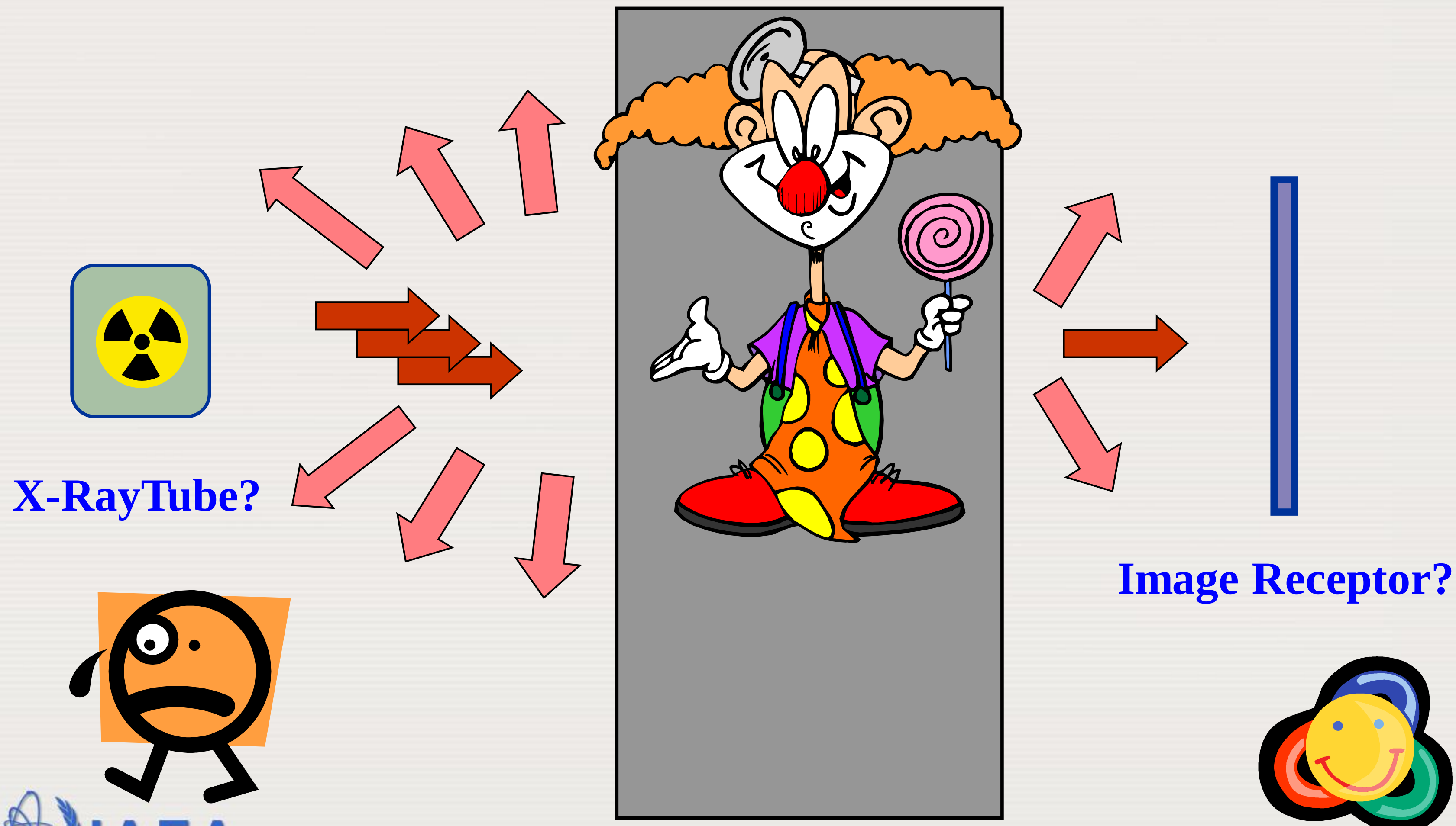




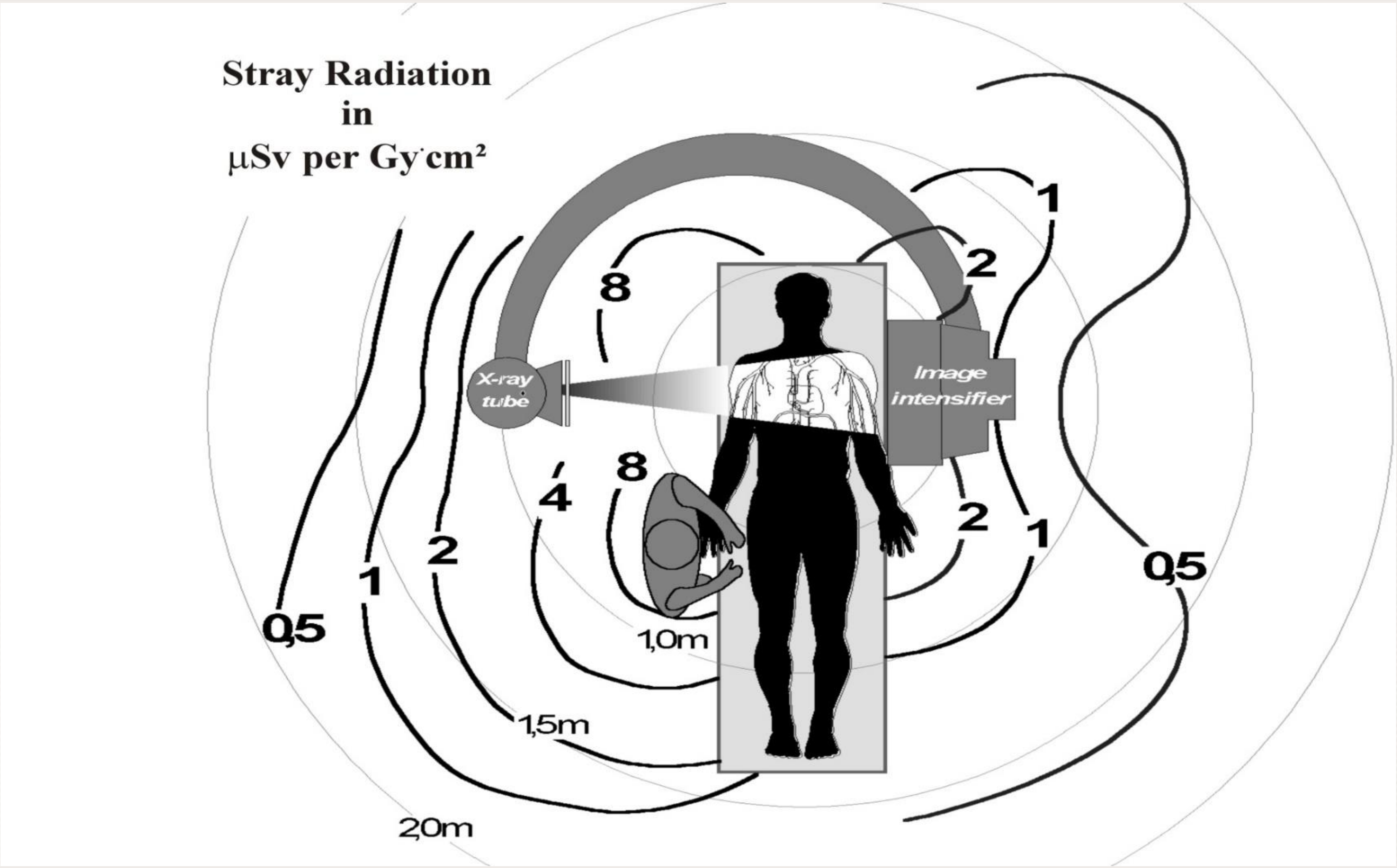


Head Irradiation	L hand	L wrist	L leg	L eye lens
Ratio (AP/PA)	5.6	1.6	0.1	5.8
Ratio (LAO90/RAO90)	2.4	22.1	2.7	3.1

WHICH SIDE IS SAFER?



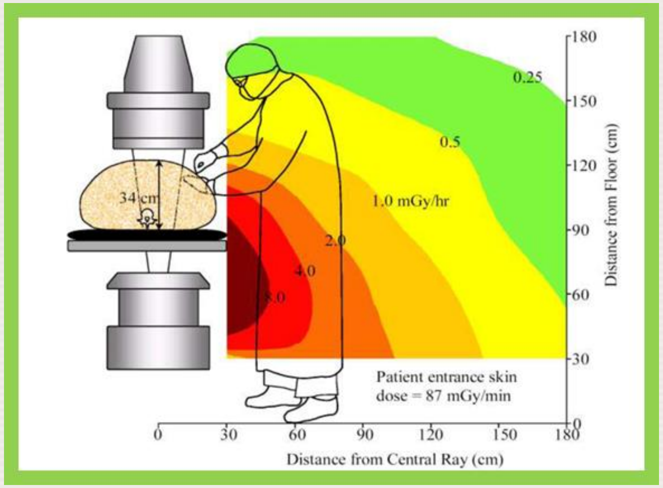
Which side is safer?

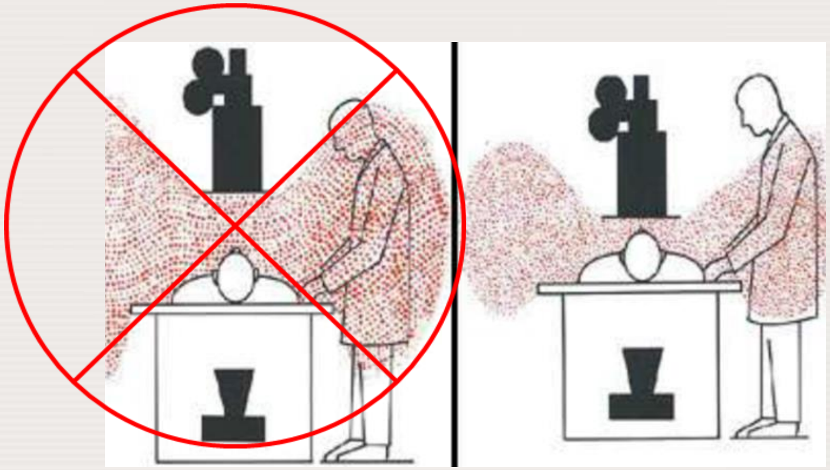


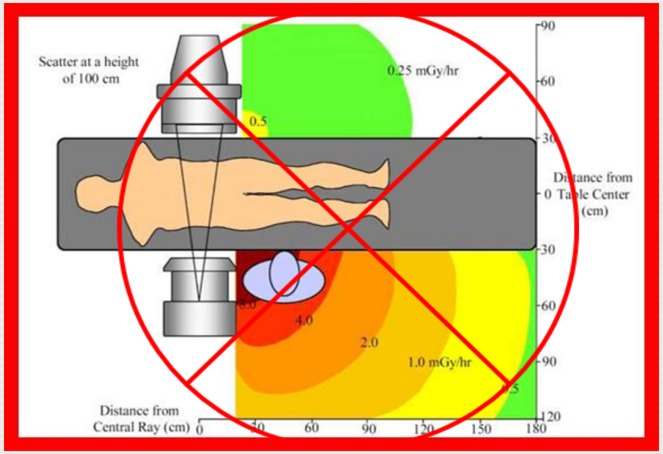
→ Dose maps provided in IR equipment manuals (IEC standards)

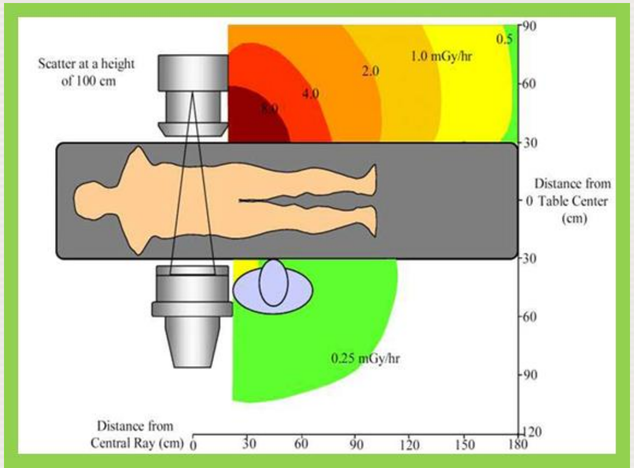
DISTANCE and POSITION OPTIMIZATION

→ Minimize distance between imaging detector and patient









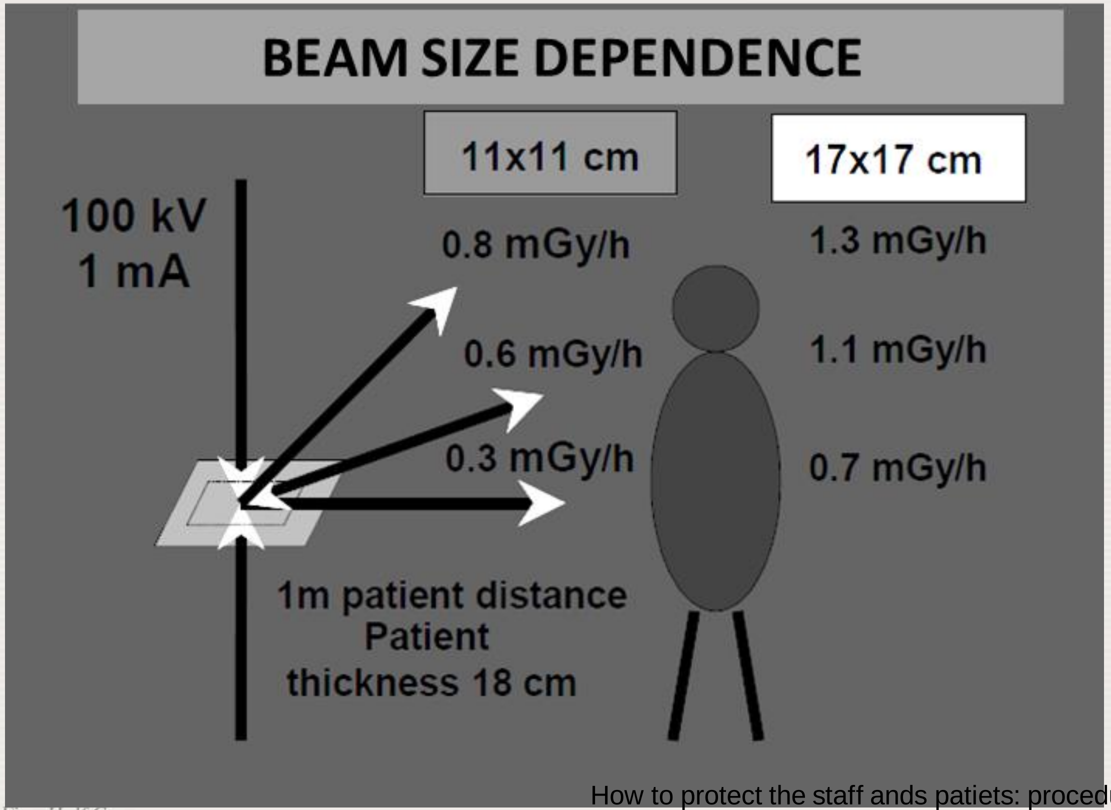
→ Pay attention to staff placement during procedure

DISTANCE and POSITION OPTIMIZATION

- Stay as far away from the X-ray beam as possible.
- Never place your hands in the X-ray beam.
- Use power injectors for contrast material injections when feasible, during image acquisitions, step back, preferably behind shielding or outside the room.
- When using angulated or lateral projections, keep in mind that the highest intensity of scattered radiation is located on the X-ray beam entrance side of the patient.
- Cranial left anterior oblique projections result in high levels of scatter to the operator.

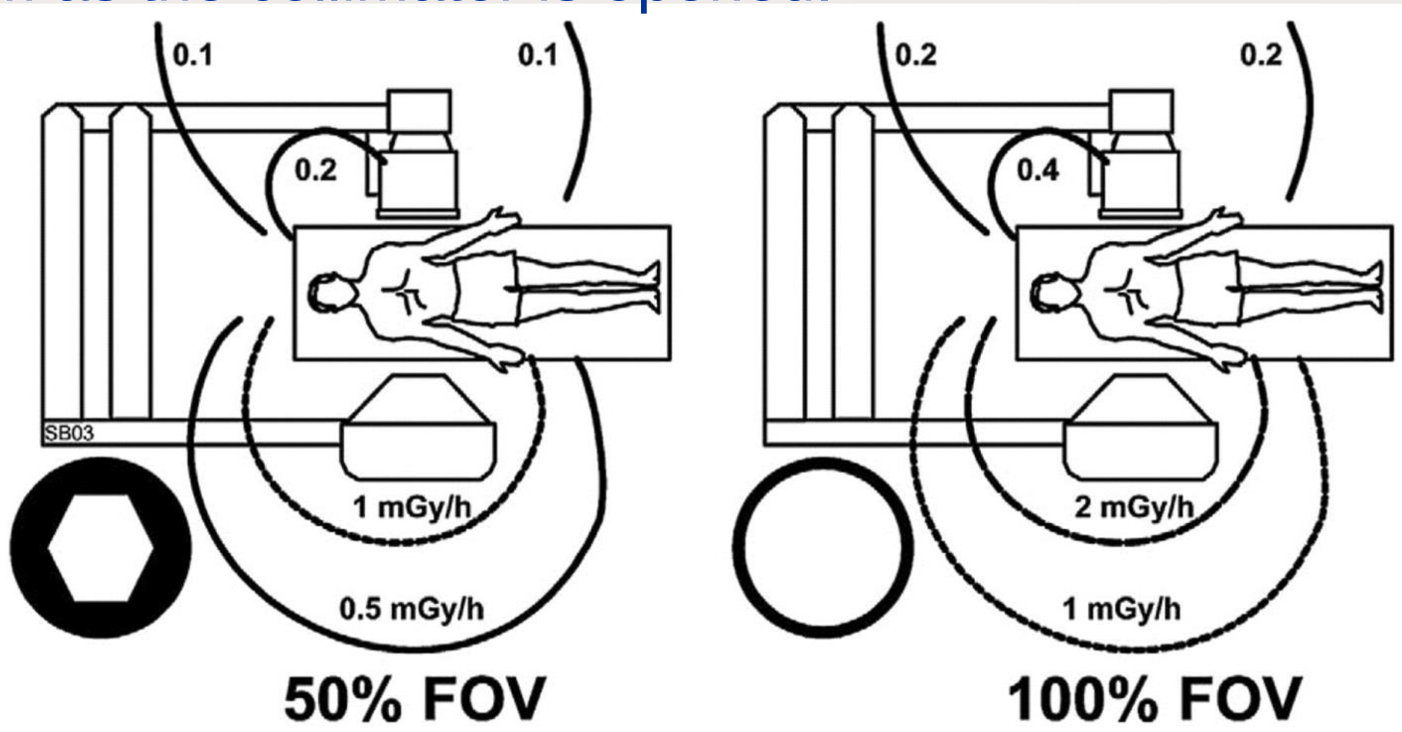
FIELD SIZE

- Scatter radiation is increased when you increase **beam size**.



FIELD SIZE

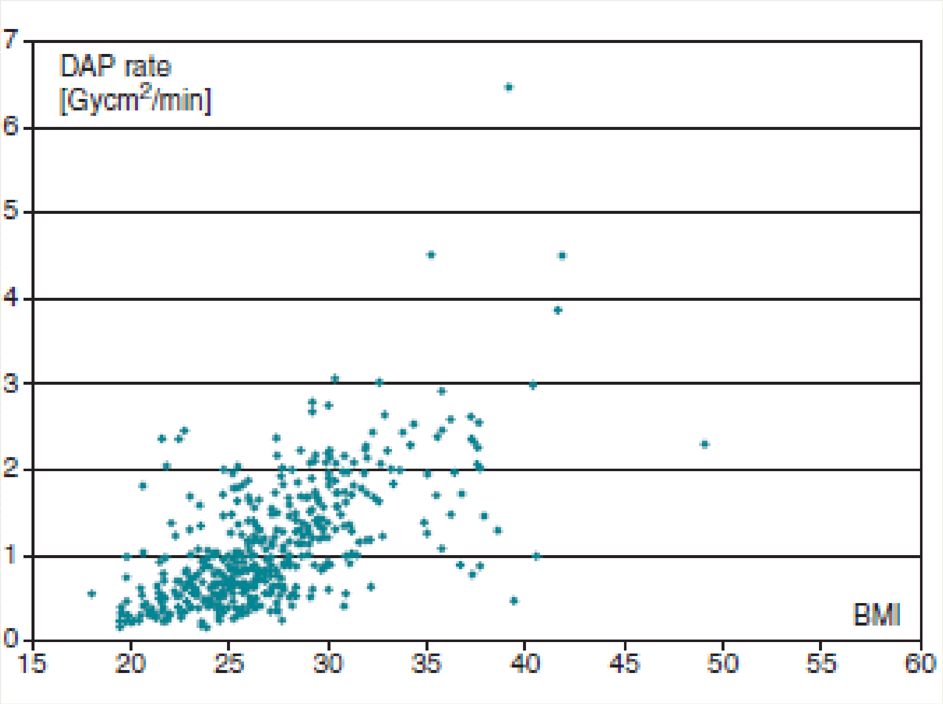
- The intensity of scattered radiation as a function of exposed field size. For the same magnification mode of the image intensifier, scatter intensity increases everywhere in the room as the collimator is opened.



Patient size

- Scatter radiation is correlated with **patient size**.

Figure 5 The impact of BMI on the radiation dose. The DAP values for 450 patients who underwent PV antrum isolation with sequential radiofrequency applications in the University Medical Center Utrecht, The Netherlands, are plotted against their BMI. Their difference in the radiation dose rate between patients with a BMI of 20 and 40 approximately is a factor of 6. The same factor also applies for the level of scattered radiation to the personnel in the cath lab.



Personal protective equipment

- Employer shall ensure that workers are provided with suitable and adequate personal protective equipment which meets any relevant regulations or standards (BSS).

☛ But it is the responsibility of workers to use this devices!

☛ However, protective clothing must not be used as a substitute for proper protective measures.

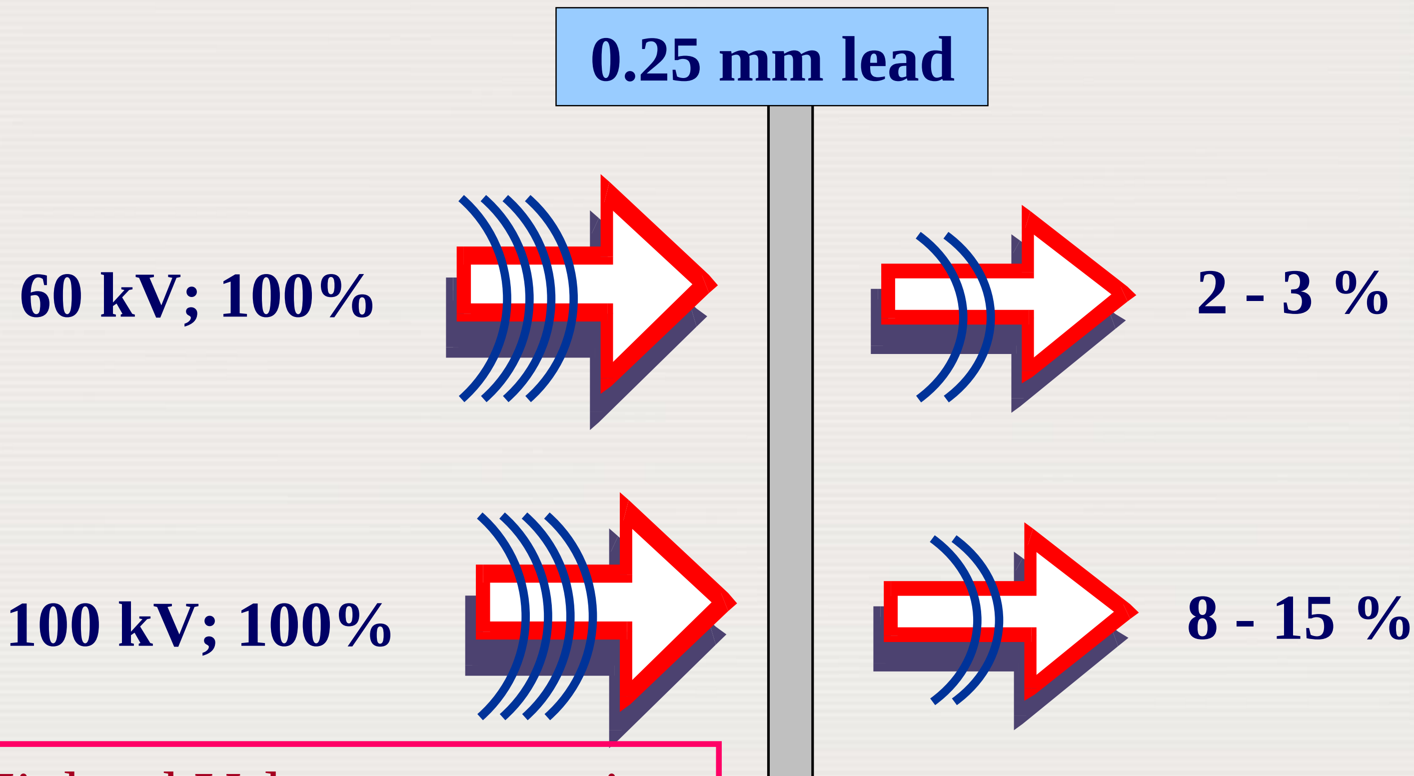
Protective clothing:

- Protective equipment includes lead aprons, thyroid protectors, protective
eye-wear and gloves.
- Aprons should be equivalent to :
- **at least 0.25 mm Pb** (non-cardiologists)
- **at least 0.35 mm Pb or two pieces overlapping in the fornt** (cardiologists)

- Aprons may be of the style which is open, or contains less lead, at the back, due to the extra weight of lead required - this assumes, however, that the wearer is always facing the radiation source

Personal protective equipment

Attenuation of lead



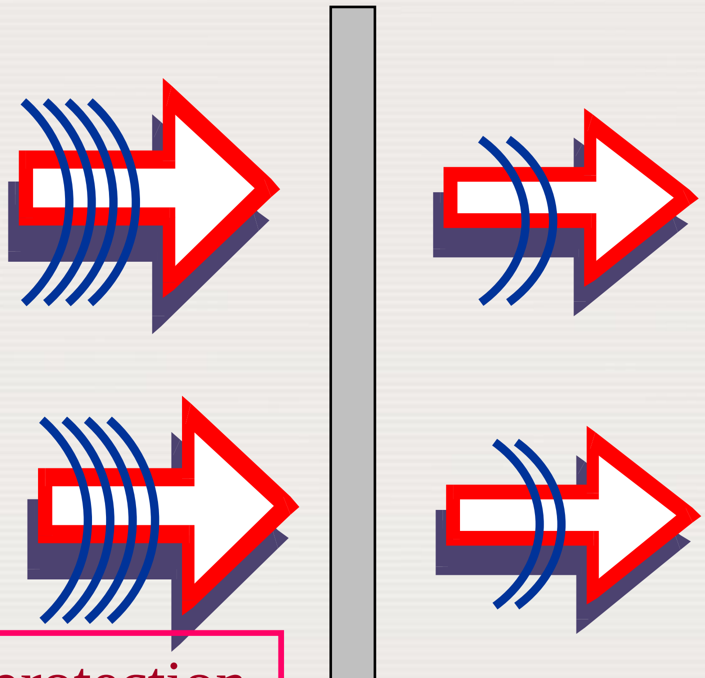
Higher kV, lower protection

Courtesy of Prof. E. Vano

Personal protective equipment

Attenuation of lead

0.50 mm lead



60 kV; 100% → **< 1 %**

100 kV; 100% → **3 - 7 %**

Higher kV, lower protection

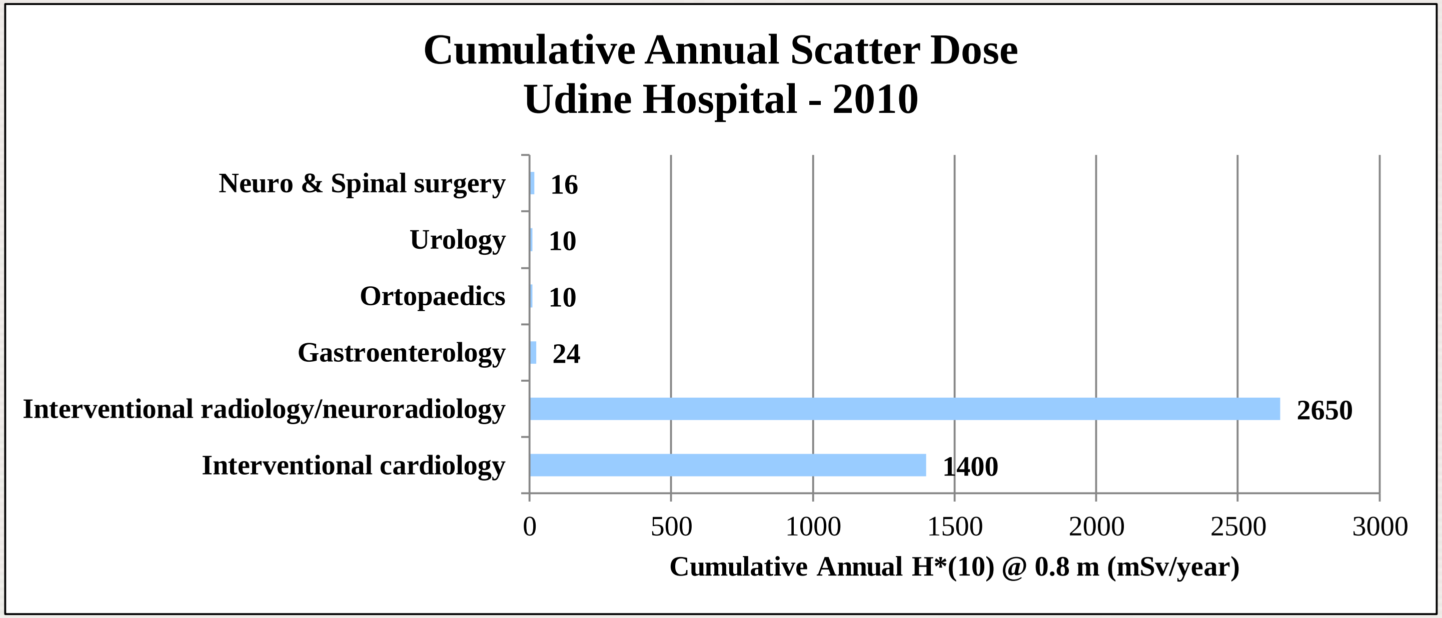
Courtesy of Prof. E. Vano

Personal protective equipment

- Leaded shielding may reduce doses to 5% or less(1-15%)
- Shielding must be between the patient and the person to be protected.
  If back is facing patient (radiation scatter source), protection on back is essential
- Everyone in the procedure/surgical room ***must*** wear a protective apron
  - In surgical rooms with low radiological workload, staff staying at ab. 2 m from the patient cannot be required to use lead aprons

Typical radiological workload (cumulative scatter radiation dose)

- Fluoroscopy image guided interventions

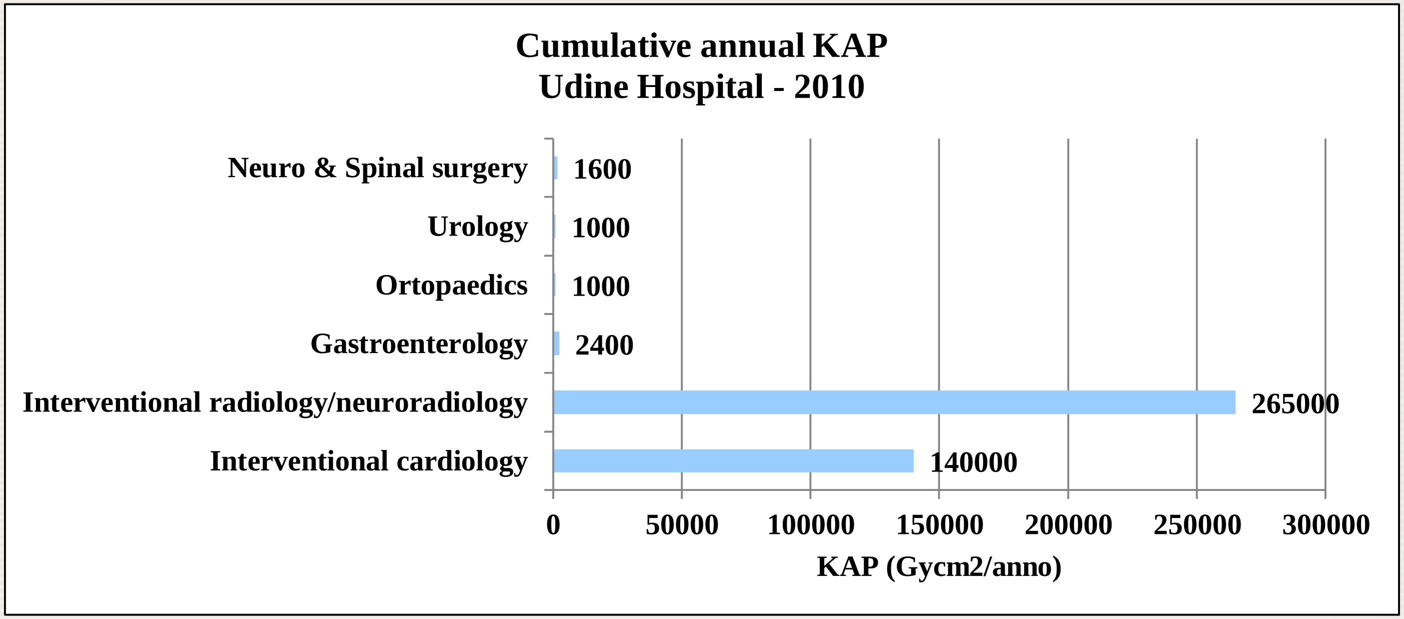


(courtesy Udine Univ. Hospital, Italy, 2010)

→ The no. of procedures is not a good indicator of the radiation risk

Typical radiological workload (cumulative KAP)

- Fluoroscopy image guided interventions



(courtesy Udine Univ. Hospital, Italy, 2010)

→ The total KAP is a good indicator of the radiological workload

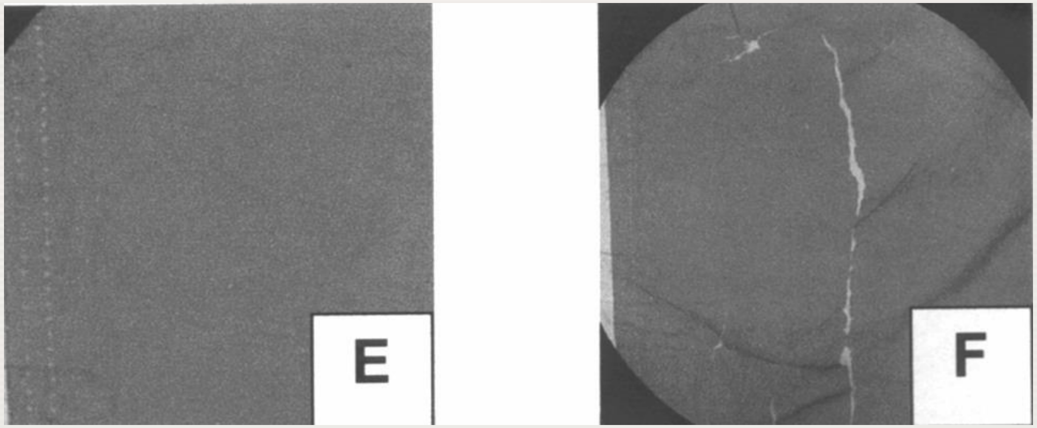
Personal protective equipment

Vest-Skirt Combination distributing 70% of the total weight onto the hips leaving only 30% of the total weight on the shoulders.

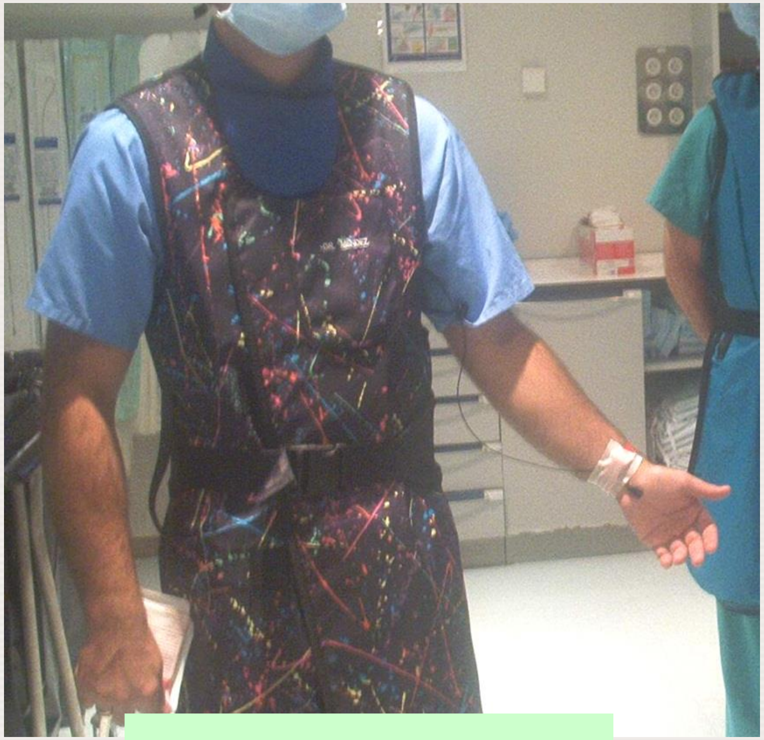
Option with light material reducing the weight by over 23% while still providing 0.5 mm Pb protection at 120 kVp

Personal protective equipment

Hang aprons! Do not fold them!



Personal protective equipment



Before

After cleaning …$1000 loss!

Expensive light protective apron sent to Laundry

Personal protective equipment

Thyroid protectors (for high workload)

Personal protective equipment

Protective goggles (for high workload)

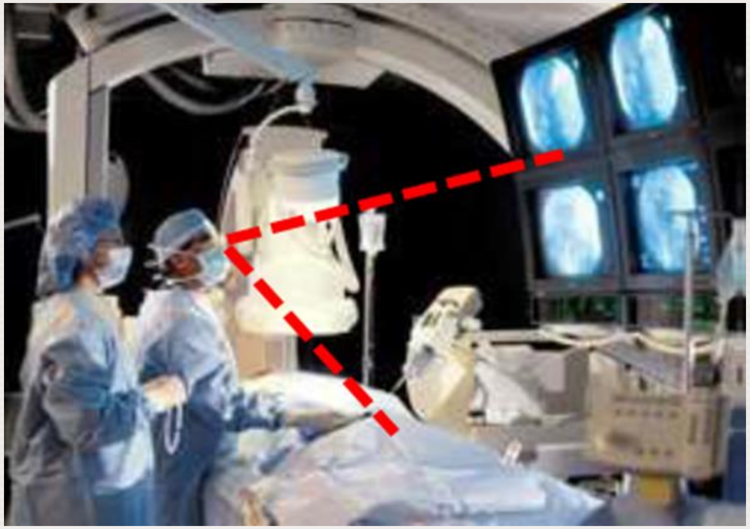
Lead Equiv: 0.5-0.75mm front and side shields leaded glass;

Weight: 80 grams

Eye lens dose assessment

Dose quantity:

- Hp(3)
- Hp(0.07) can be properly used



- Several factors are influencing eye dose:
  - use of eye shields (suspended lead screen, lead glasses)
  - position of the operator, X-ray projection
  - Dosimeter position:
    - Above the eye on the side of the x-ray tube
    - Alternative: dosimeter at the neck over the apron
    - Different studies are providing corrective factors from 0.4 to 0.9

IAEA
Atoms for Peace: The First Half Century
1957–2007

Effect of protective eyewear

Radiation direction	Dose transmission factor (%)							
	1	2	3	4	5	6	7	8
Frontal, left lens	18	14	27	26	23	14	16	20
Frontal, right lens	17	13	25	26	24	17	19	17
Below, left lens	72	43	78	85	86	22	35	70
Below, right lens	98	89	97	94	97	89	88	92

→ When radiation is coming from below, great difference between models due to the gap created between the eyewear and the cheek and the nose

T. Geber, Eye Lens Dosimetry for Interventional Radiology, Rad. Meas. 46 (2011)

→ Design and individual fit is decisive.

→ Design should minimise gaps

IAEA
Atoms for Peace: The First Half Century
1957–2007

- Gauntlets are **heavy** gloves. They have limited value because they are difficult to use and should therefore only be used where appropriate

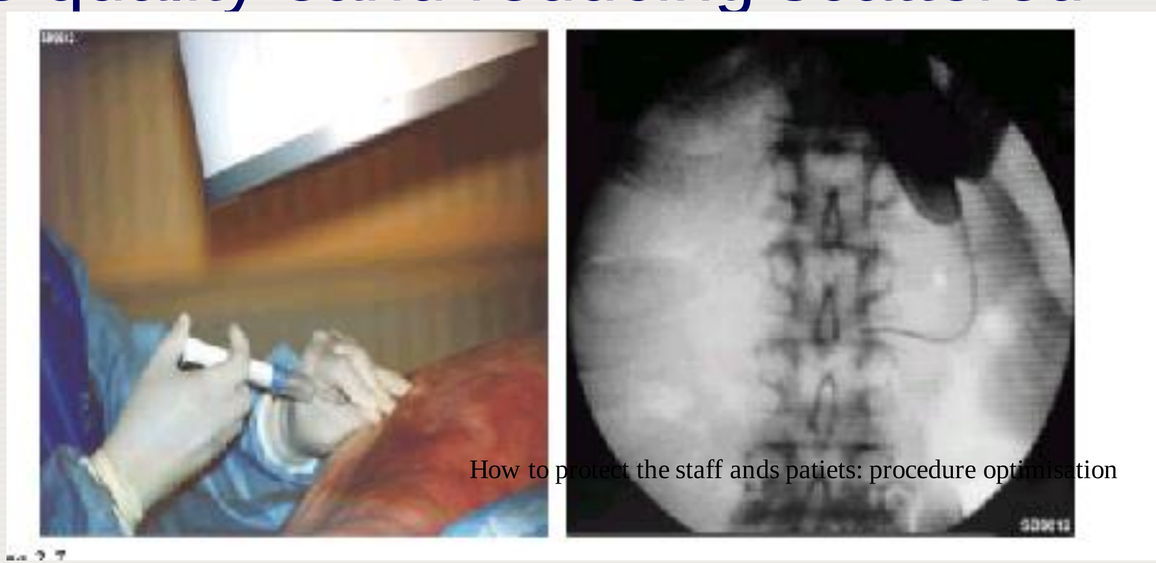
- Thin gloves are not providing useful attenuation
- When the hand is in the x-ray beam, the AEC increases dose rate

ATTENUATION - RADIATION REDUCTION %
(as shown on glove manufacturers labels)

Direct Beam Energy Level	PRO*Guard* RR - 2	PRO*Guard* RR - 1	Intl. Biomedical	F & L Medical Products
60 KVP	55%	45%	34%	32%
80 KVP	43%	35%	30%	25%
100 KVP	35%	26%	16%	18%
120 KVP	31%	23%	12%	14%

Radiation Protection of Hands

- Best way to minimize dose to fingers and hand:
- **Keep your fingers out of the beam!!!**
- Dose rate outside of the beam and on side of patient opposite x-ray tube: Very low compared to in the beam!
- Collimation can efficiently reduce hand dose, improving image quality eand reducing scattered radiation



Protective devices

- Additional protective devices MUST be available in interventional rooms as appropriate:
  - Ceiling suspended protective screens.
  - Protective lead curtains mounted on the patient table.

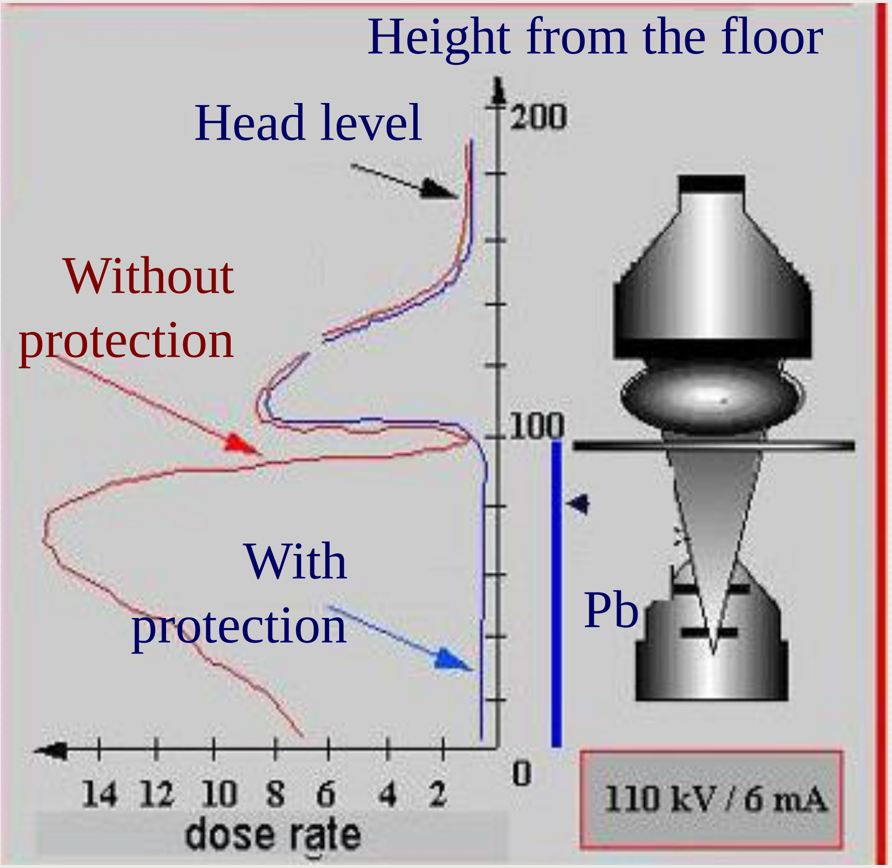
Ceiling suspended screen

- Typically equivalent to 0.5 - 1mm lead
- Very effective if well positioned
- Not used by all the interventionalists
- Not always used in the correct position
- Not always used during the whole procedure

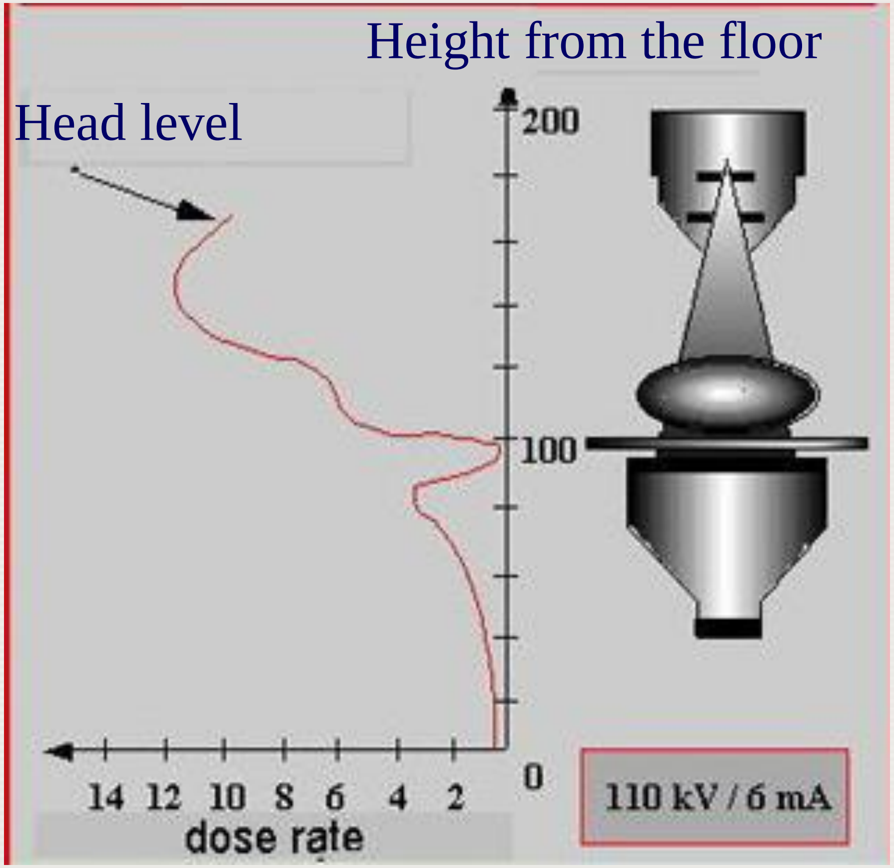
Protective lead curtains and ceiling suspended screens

Protective lead curtains

Under-couch tube



Over-couch tube



RADIOLOGY SAFETY PROGRAM: SUMPT

Cardiovasc Intervent Radiol (2010) 33:230–239
DOI 10.1007/s00270-009-9756-7

CIRSE GUIDELINES

Occupational Radiation Protection in Interventional Radiology: A Joint Guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology

Table 1 Key points for safe practice

- Minimize fluoroscopy time.
- Minimize the number of fluorographic images.
- Use available patient dose reduction technologies.
- Use good imaging-chain geometry.
- Use collimation.
- Use all available information to plan the interventional procedure.
- Position yourself in a low-scatter area.
- Use protective shielding.
- Use appropriate fluoroscopic imaging equipment.
- Obtain appropriate training.
- Wear your dosimeters and know your own dose!

IAEA
Atoms for Peace: T
1957–2007

SAFETY PROGRAM

1. Remember that reducing patient dose reduces scatter and dose to personnel also: they are tied together
2. Personal protective equipment:
   - Leaded eyewear
   - Well fitted lead apron
   - Thyroid shield
3. Use hanging lead shields to protect lower extremities and movable overhead shields for face and neck protection. Set up the room at the start of the case with lead table skirts and all shielding. Don’t be hesitant to remind the operator of their use.
4. When using lateral fluoroscopy, position personnel on same side as the image receptor/detector to decrease operator scatter dose from X-ray source
5. Step away during fluoroscopy or image acquisition if possible
6. Operator hands out of beam
7. Use power injector when possible. If hand injection, use extension tubing.
8. Distance: Advise the personnel in the room of the inverse square law (nurses, anesthesia, physicians)

Health surveillance

- Primary purpose is to assess the initial and continuing fitness of employees for their intended tasks
- Medical surveillance (medical examinations) to workers as specified by the Regulatory Authority.
- Counselling should be provided for women who are or may be pregnant

This is especially relevant in interventional radiology.

Protection of the embryo or foetus

- The female worker should, on becoming aware that she is pregnant, notify the employer in order that her working conditions may be modified if necessary.
- The pregnancy shall not be considered as a reason to exclude a female worker from work,
- But it is the responsibility of the employer to adapt the working conditions, to ensure embryo/foetus receives <1 mSv equivalent dose to the end of the pregnancy period

IAEA
Atoms for Peace: The First Half Century
1957–2007

TRAINING PROGRAME

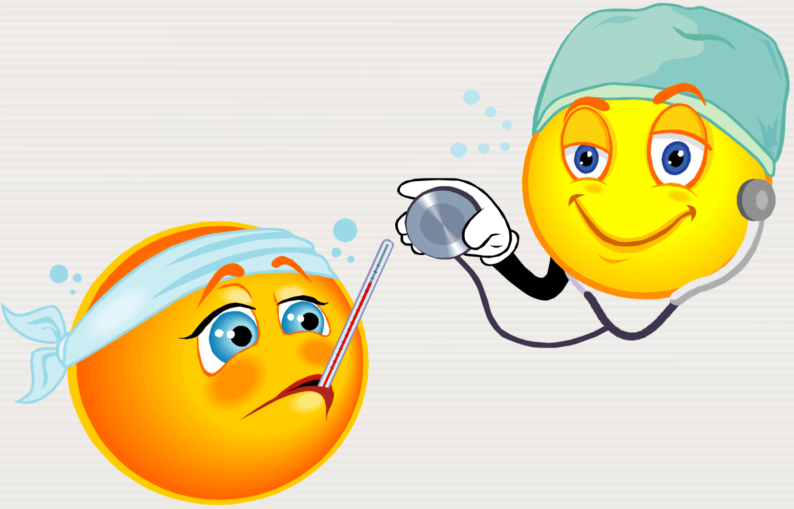
- Appropriate training in radiation protection is essential to ensure safe practice in the interventional cardiology laboratory.
- Training programs should include both initial training for all incoming staff and regular updating and retraining.

International Atomic EnergyAgency has produced a free training program, which can be downloaded at

http://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Training/1_TrainingMaterial/Radiology.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
Atoms for Peace: The First Half Century
1957–2007