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Medical radiation physics

6. Fluoroscopy

Learning objectives

- Describe the main differences between the radiography units and the fluoroscopy units
- Explain the challenges of radiation protection when dealing with fluoroscopy units
- Describe the principle of the dose indicators used in fluoroscopy and their use

Radiography and fluoroscopy

- Similarities?

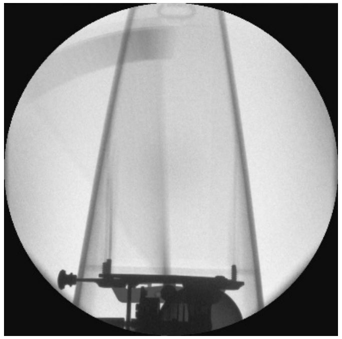
- Differences?

Radiography and fluoroscopy

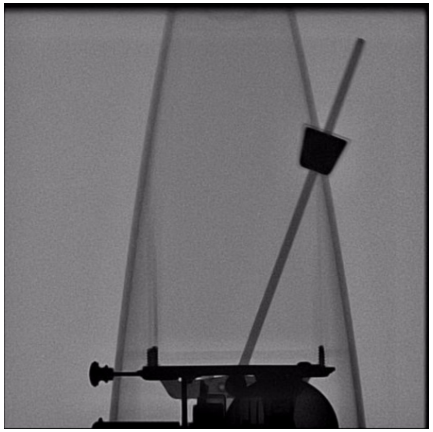
- Similarities
  - – Projection of the anatomy
  - – Similar X-ray beam energy
  - – Image detector: different for analog/similar for digital
- Differences
  - – Recording of moving structures
  - – Order of magnitude of patient/staff exposure
  - – In general invasive procedures
    - Diagnostic/therapeutic

Dynamic imaging

- Spatial resolution: parameter of influence?



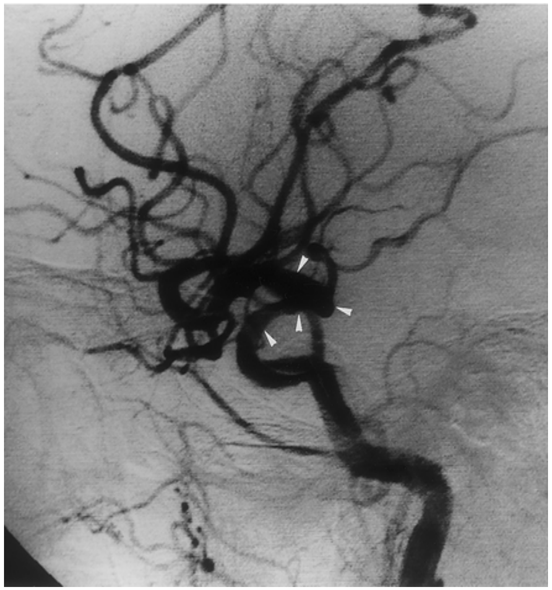
- Temporal resolution: parameter of influence?



Use of fluoroscopy

- Diagnostic (dynamic imaging) → less and less applications
  - Digestive functions
  - Excretion function
  - Vascular functions (High spatial and temporal resolutions)
  - Cardiac functions (High temporal resolution)

- Interventional
  - Biopsies
  - Opening of vessels
  - Closing of vessels
  - Communication between vessels



artery aneurysm

Imaging chain (analog)

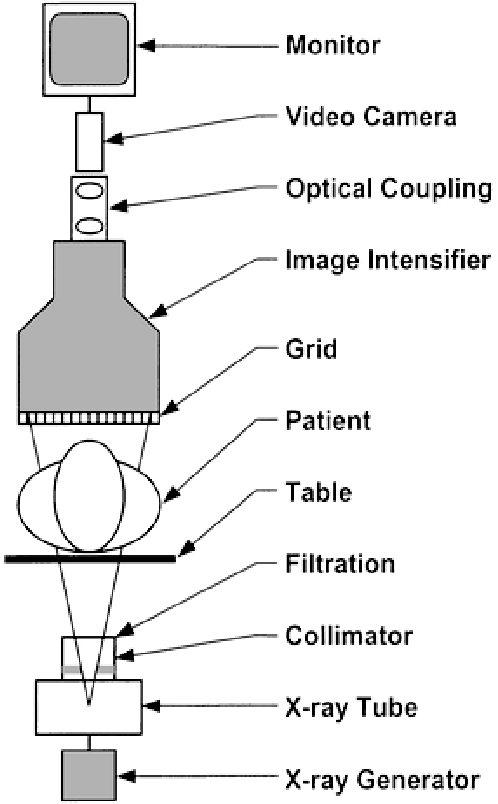
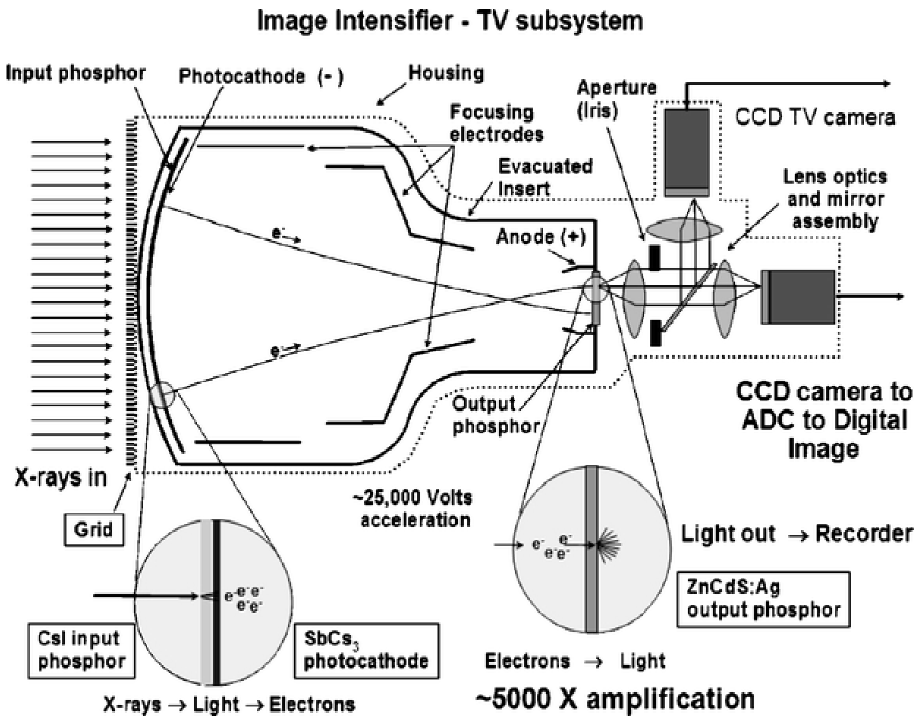
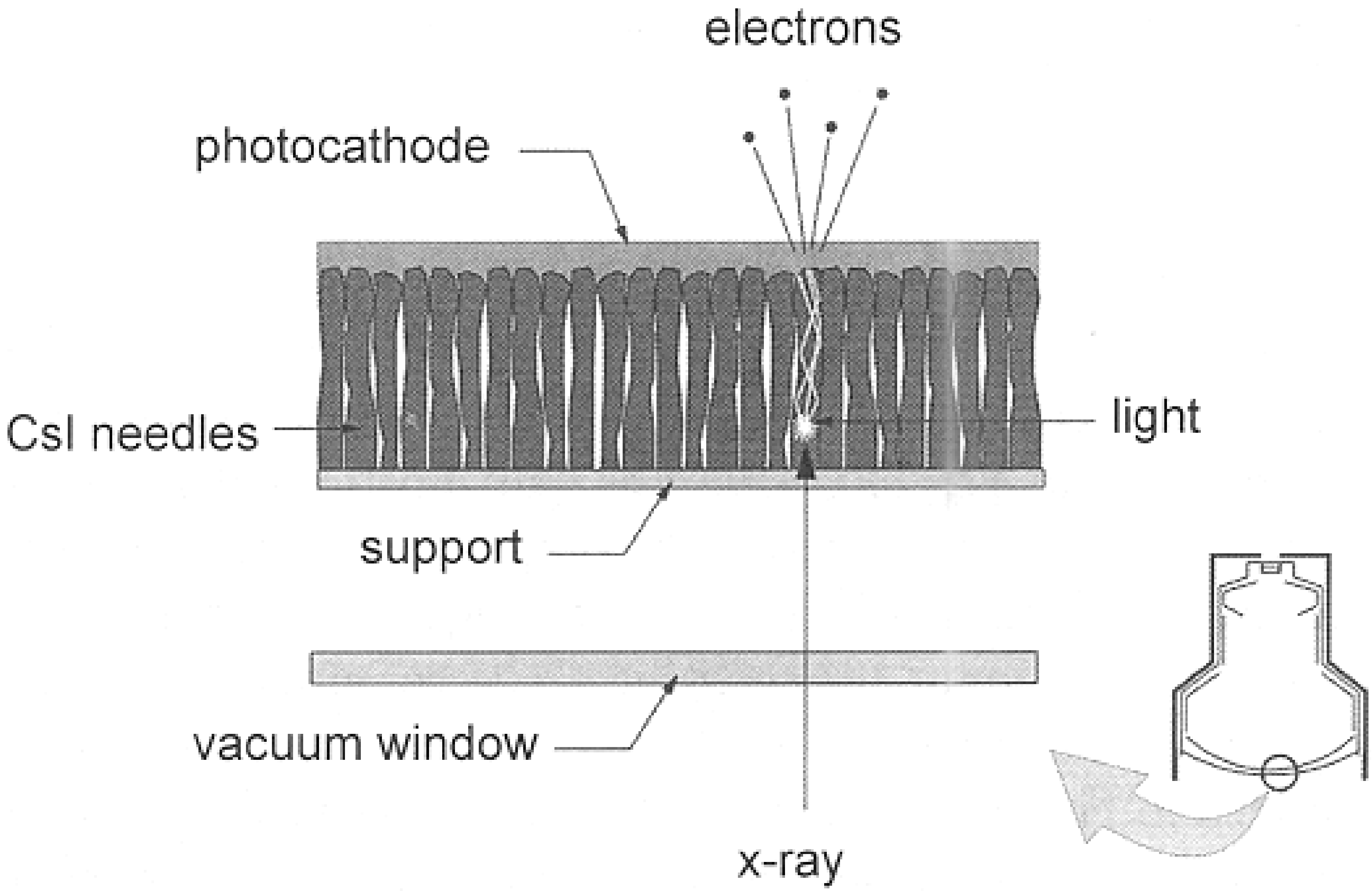


Image intensifier (analog detector)



- Conversion of X-ray into visible light
- Conversion of light photons into electron
- Electron acceleration and focalisation
- Conversion of the accelerated electrons into visible light

Entrance of the image intensifier



In more details

Entry CsI

- Good efficiency at kV used (Kedge 35 - 40 keV)
- Emission of 420 nm photons
    - Spatial resolution - Efficiency compromise
    - CsI under the form of crystal needles (5 µm : light guide)
    - Thickness of 300 to 450 µm

- Photocathode (CsSb alloy)
    - 10 - 20 % of visible light into electrons

- Acceleration through 25 to 35 kV

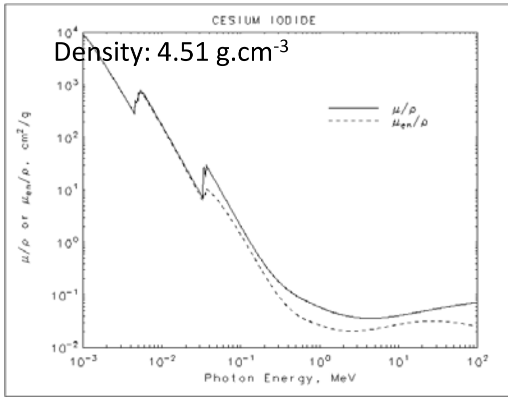
- Silver-activated Zinc-Cadmium sulphide (Zn Cd S: Ag) : P20
    - about 400 photo-electrons for 1 photon of 60 keV
    - Emission of 520-540 nm photons
        - Thickness 4 to 8 µm; size of the crystals 1 to 2 µm
        - 1 electron of 30 keV produces 1000 light photons

- Optical coupling to a camera

Exercise

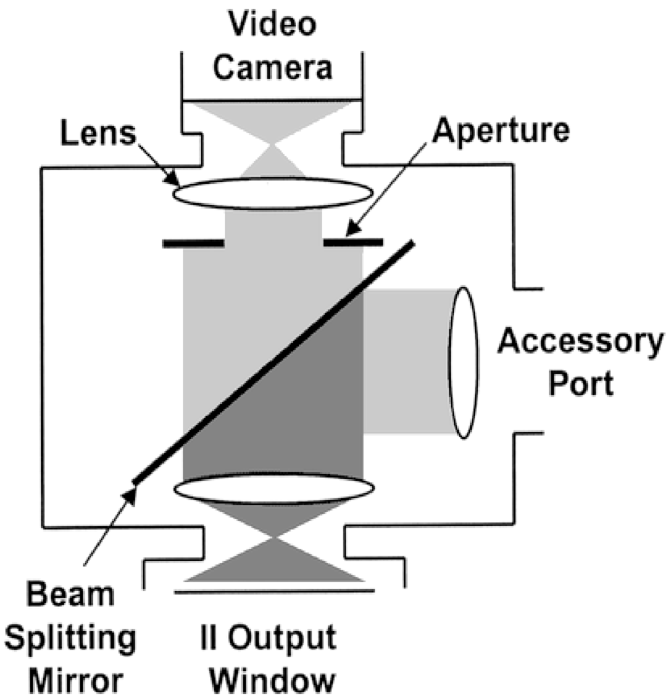
1 X-ray photons of 30 keV impinge the image detector (CsI thickness: 0.4 mm).
What is the expected number of visible photons produced (420 nm) with an efficiency of 100%

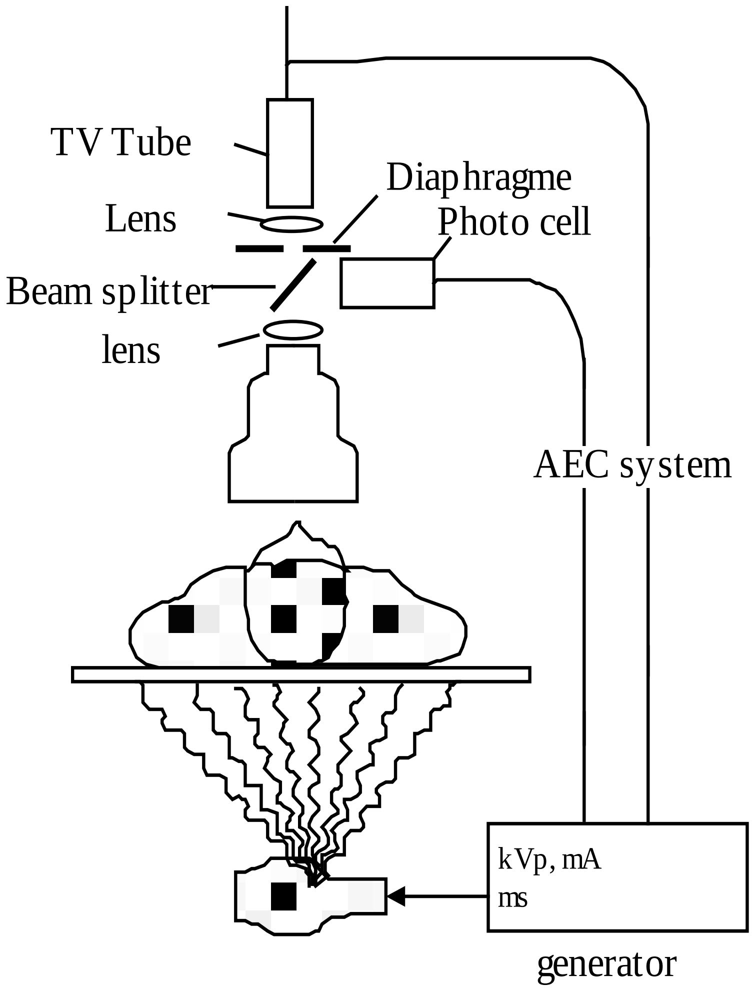
Energy (MeV)	μ/ρ (cm^2/g)
1.00000E-03	9.234E+03
2.00000E-03	2.114E+03
3.00000E-03	7.880E+02
4.00000E-03	3.836E+02
5.00000E-03	5.296E+02
6.00000E-03	6.448E+02
8.00000E-03	3.071E+02
1.00000E-02	1.711E+02
1.50000E-02	5.815E+01
2.00000E-02	2.686E+01
3.00000E-02	9.045E+00
4.00000E-02	2.297E+01
5.00000E-02	1.287E+01
6.00000E-02	7.921E+00
8.00000E-02	3.677E+00
1.00000E-01	2.035E+00
1.50000E-01	7.290E-01
2.00000E-01	3.805E-01
3.00000E-01	1.818E-01
4.00000E-01	1.237E-01
5.00000E-01	9.809E-02
6.00000E-01	8.373E-02
8.00000E-01	6.769E-02



Planck constant : h=6.626 10^{-34}

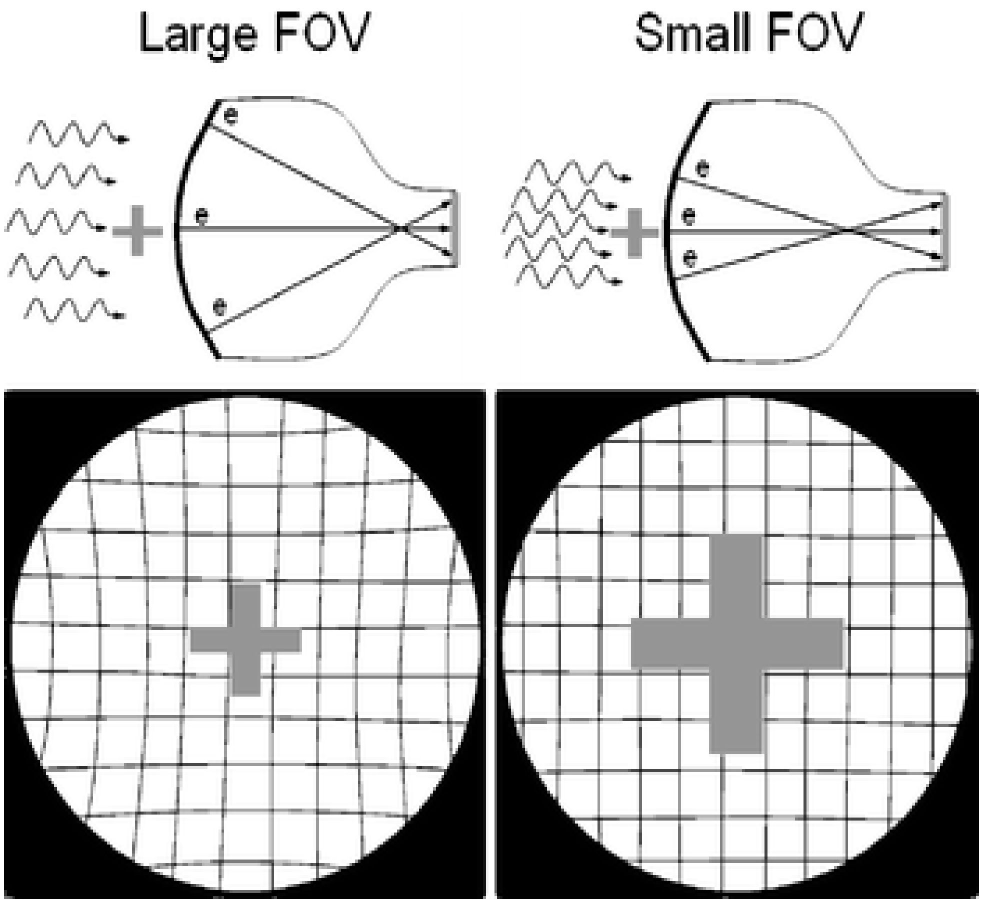
Control of the output





Continuous monitoring of light output → continuous adjustment of kV mA/ms per image

Magnification principle



Exercise

- When going from FOV_1 to FOV_2 how should evolve the dose rate at the entrance of the detector?
  - Example Ø30 cm to Ø15 cm

- What solutions could exist to reduce this trend?

Fluoroscopy systems : the basics

- Two operating modes:
  - Fluoroscopy mode
    - “low dose” → noisy images
      - Can now be recorded for 20 – 30 s
  - “Radiography” mode
    - Dose per image very close to a standard radiography
      - Cine (7.5 – 30 i/s; 512x512)
      - Graphy (1 – 10 i/s; 1024x1024)
        - » Standard
        - » DSA: Digital Subtraction Angiography

Control on patient and detector exposure

- Automatic dose rate and image quality control (ADRIQ) or Automatic brightness control (ABC)
  - Use of a set of rules (algorithms) to control the system's response to dynamic changes
  - Maintain the absorbed energy fluence per pixel at the imaging detector's x-ray capture layer
  - Patient skin entrance air kerma rate (SEER)
    - To be characterized by medical physicists
  - Air kerma rate to the detector (EERD)
    - Controlled by manufacturers

Question?

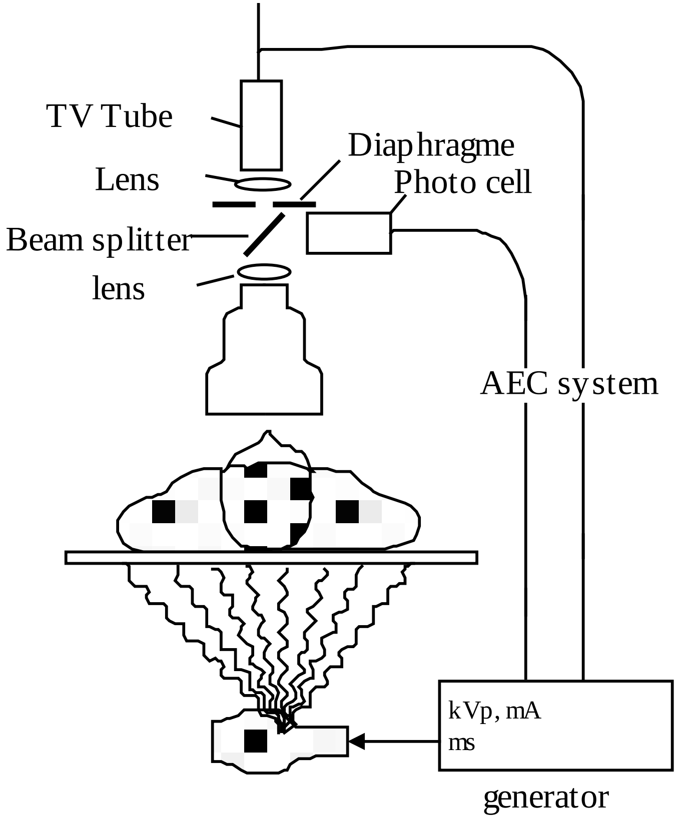
- Patient skin entrance air kerma rate (SEER)

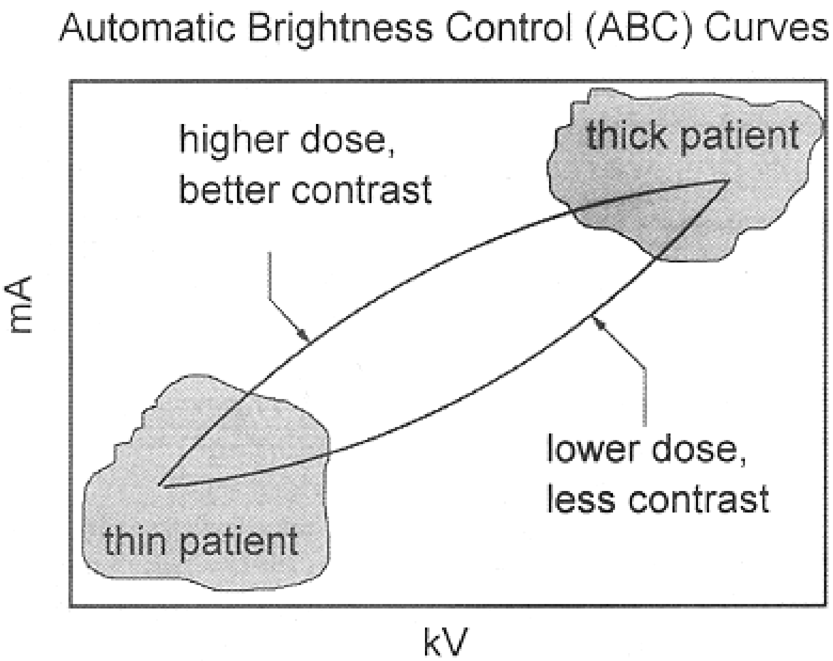
Which parameter modifies this relationship?
What impact?

- Air kerma rate to the detector (EERD)

Automatic dose rate and image quality control (ADRIQ)

- Parameters: kV, mA, ms
- ABC: Automatic Brightness Control
  (AEC: Automatic Exposure Control)





Parameters of the ADRIQ system

- kV and mA can be increased
  - Fast increase of kV : low dose mode
  - kV constant and mA increase : high dose mode
- Pulsed systems
  - Action on kV, mA and pulse duration
- Fluoroscopy modes
  - Lowest dose modes
  - Wide aperture (optics part)
- Recording of image modes
  - Small aperture → to increase exposure at detector level
    - "Cine" modes
    - radiography modes
    - DSA modes

Order of magnitude

- Examination in the abdominal area at 15 i/s
  - 80 kV – 200 mA – 1 ms per image (scopy)
  - Distance focal spot-skin: 70 cm
  - Dose rate at skin level?

Patient skin entrance air kerma rate (SEER)

- Fluoroscopy (with copper filter - XRII)
  - Several image quality levels available
    - For a standard abdomen in adult: 5 – 50 mGy/min at 15 i/s
    - XRII: X-ray image intensifier

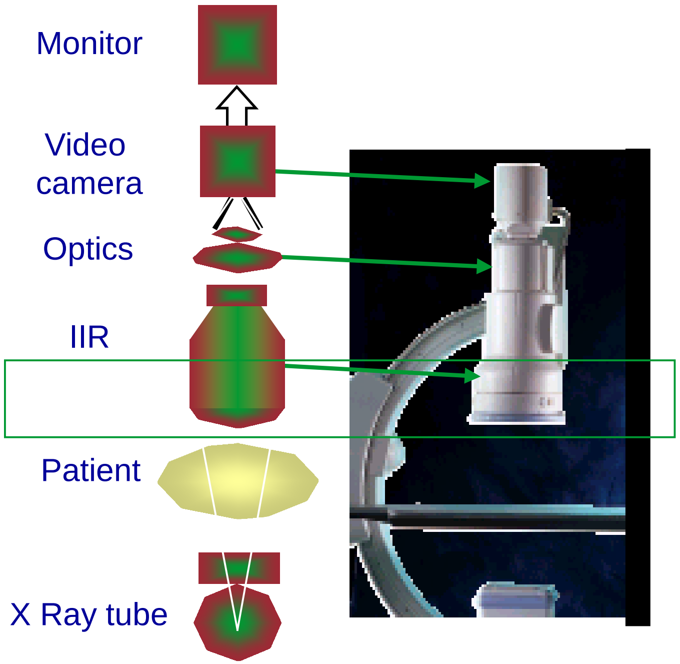
- Image acquisitions
  - Cine: 15 i/s
    - **50 à 150 mGy/min**

digital subtraction angiogram demonstrates a bilobed aneurysm fed by the ulnar artery

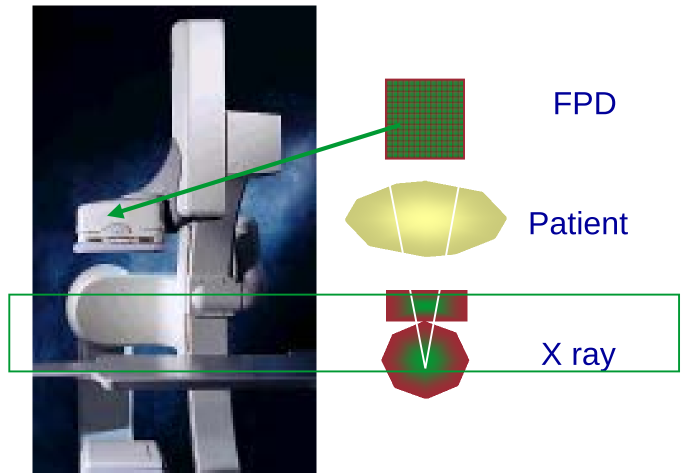
  - DSA
    - **0.5 à 5 mGy/image**
    - Run de 30 images → 15 à 150 mGy par séquence (de ~5 à 20 s)

Hypothenar Hammer Syndrome in a Postal Worker: Hypothenar hammer syndrome is caused by chronic repetitive trauma to the ulnar artery and superficial palmar arch. This syndrome was originally described in males working in occupations that involved repetitive blunt trauma including working with jackhammers. It is believed that the ulnar artery is repetitively damaged by blunt compression against the hamate. Our patient was a postal worker who frequently used a rubber stamper – Radiology 2007- DOI: 10.2484/rcr.v3i2.207

Detector evolution → Digital



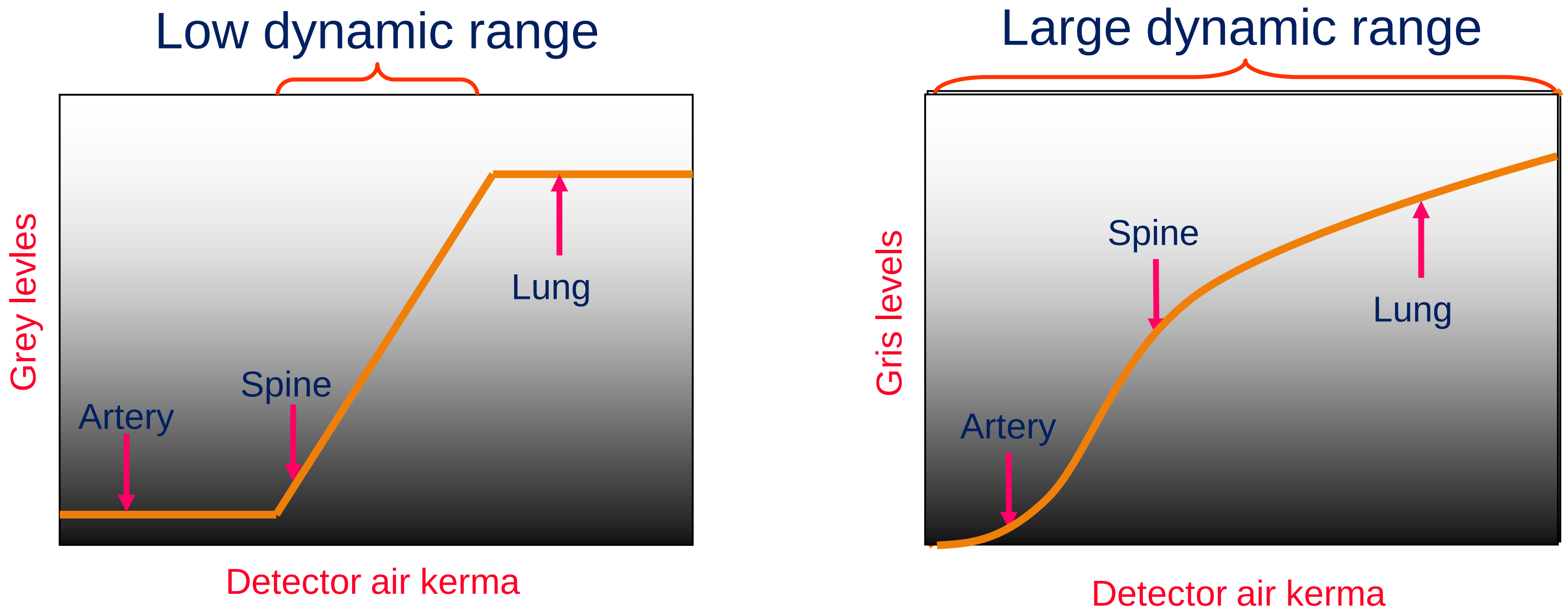
IIR imaging chain



FPD imaging chain

- No spatial distortion
- Better dynamic range
- Compact

XRII – FPD (Flat Panel Detector)



From XRII → FPD X-ray collimation can be a lot poorer

From Analog to digital: dose saving?

- To summarize
  - Radiography
    - From film → CR: Not much dose saving expected
    - Film → Flat panel: Potential for dose reduction
  - Fluoroscopy
    - Similar Efficiency → no major dose saving expected but:

      (+) → Better beam filtering

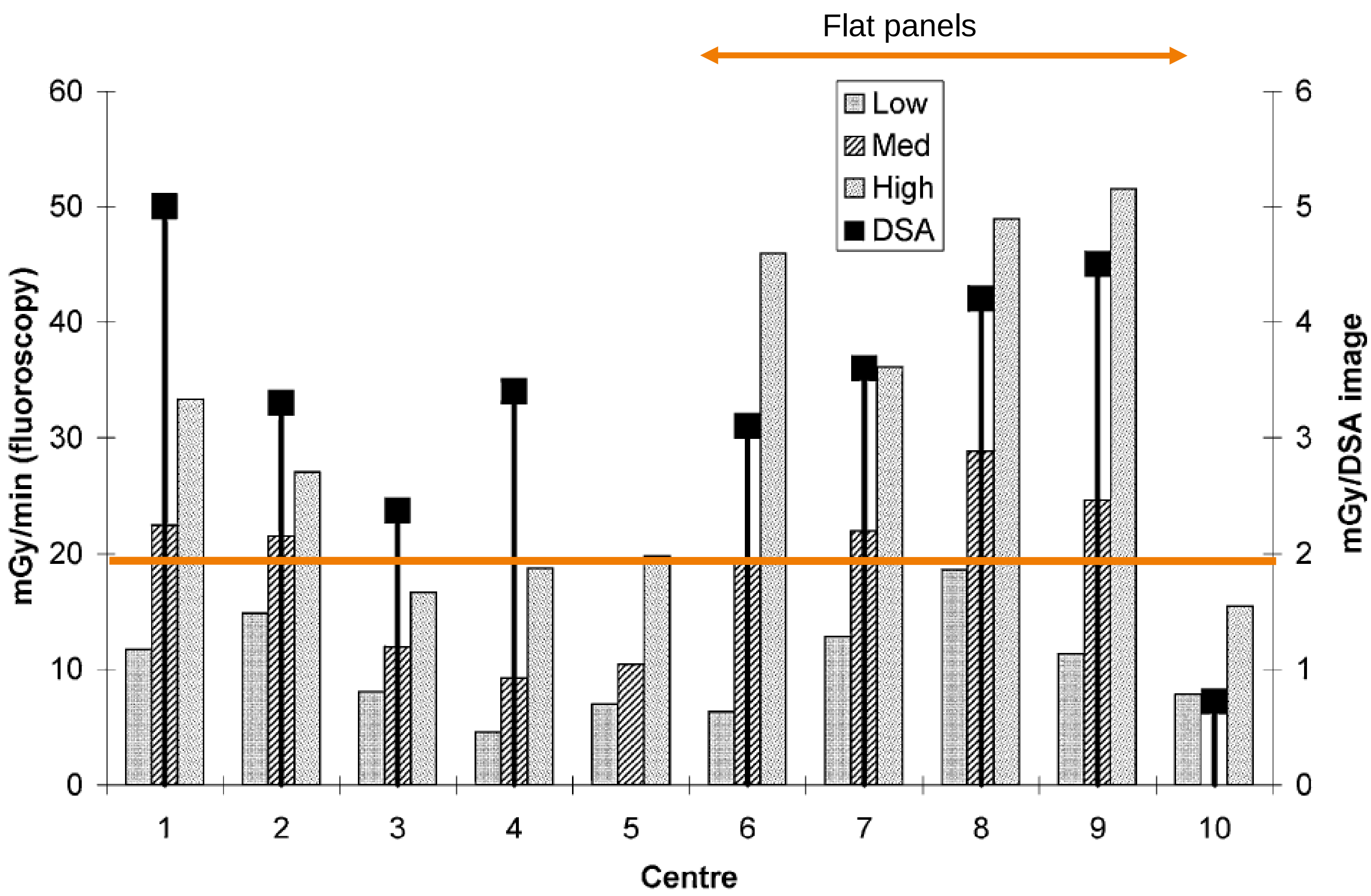
      Similar CNR (contrast-to-noise ratio) for less skin dose

      (+) → Pixel binning (lower the spatial resolution)

      (-) → Large latitude → X-ray collimation often neglected

CHUV

Wide variations of settings



20 cm PMMA in the beam

Cardiovasc Intervent Radiol (2009) 32:121–126

Radiation risk monitoring

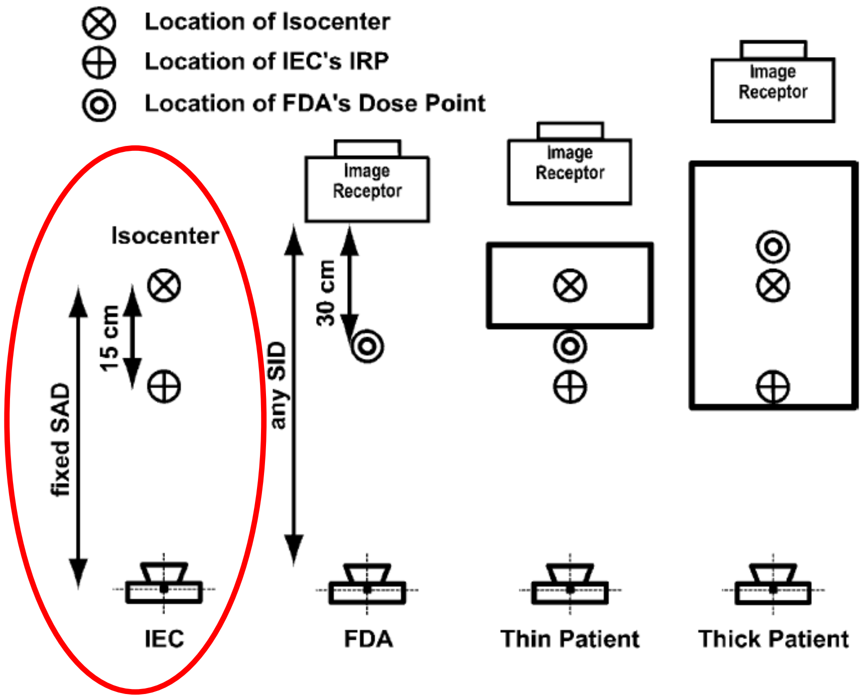
- Short term
  - Deterministic
  - To be no surprise

- Dose indicator
  - IRP (interventional ref. point)
    - Representative of:
      - Peak skin dose

- Long term
  - Stochastic
  - To be optimized

- Dose indicator
  - KAP
    - Representative of:
      - Effective dose

Cumulative dose at IRP: skin dose



FDA tends to underestimate dose in large patient → not good!

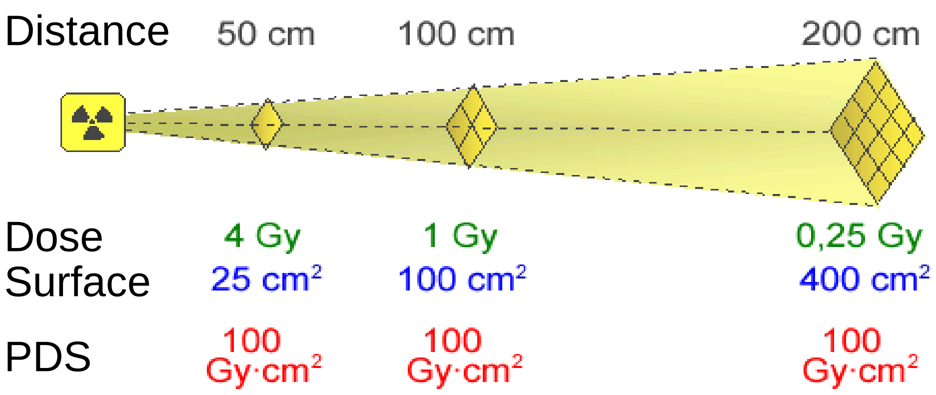
IEC tends to overestimate dose in thin patient → might be better

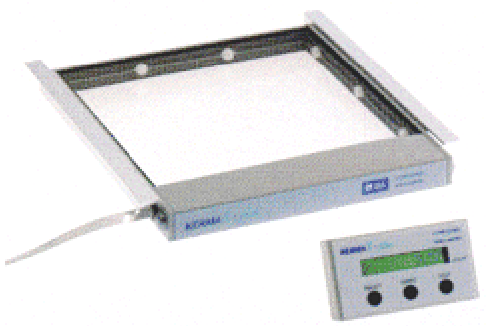
IEC 60601-2-43 : Interventional reference point IRP
IEC : fixed distance from isocenter
FDA : fixed distance from image detector

Stephen Balter
Methods for measuring fluoroscopic skin dose
Pediatr Radiol (2006) 36 (Suppl 2): 136–140
DOI 10.1007/s00247-006-0193-3

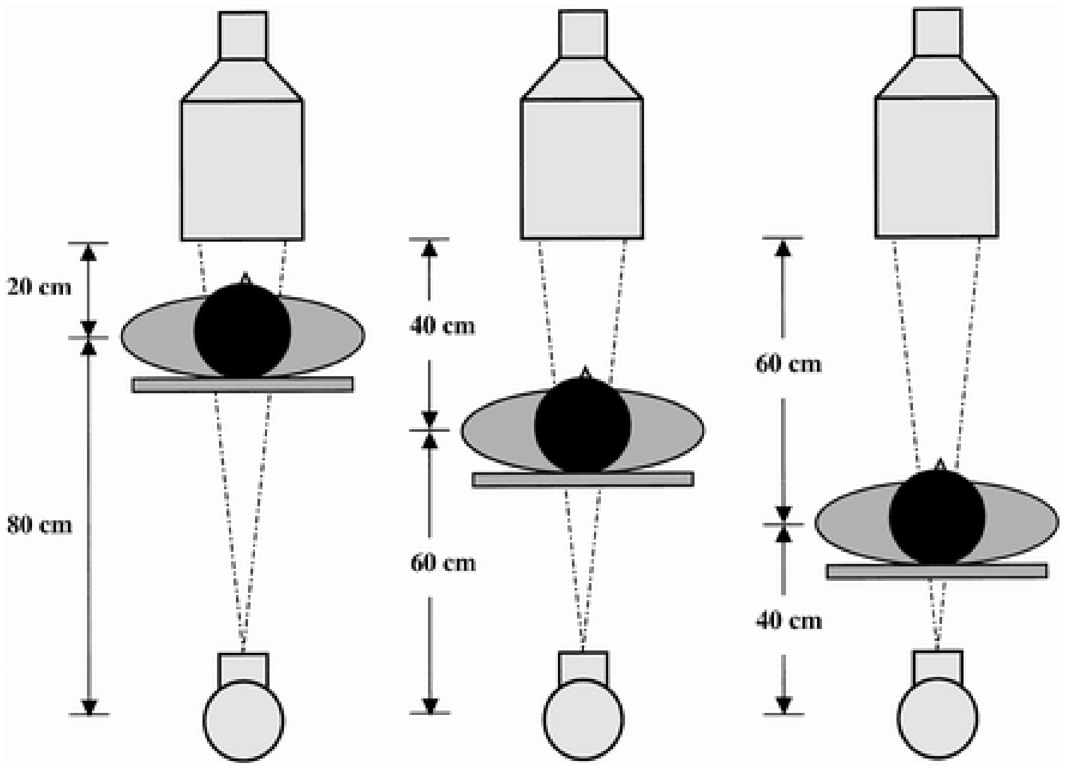
KAP: stochastic effects

- Kerma area product (KAP)
  - PDS or DAP
  - Be careful on the units used
    - Can be measured or calculated on the unit
    - Can take into account the table attenuation





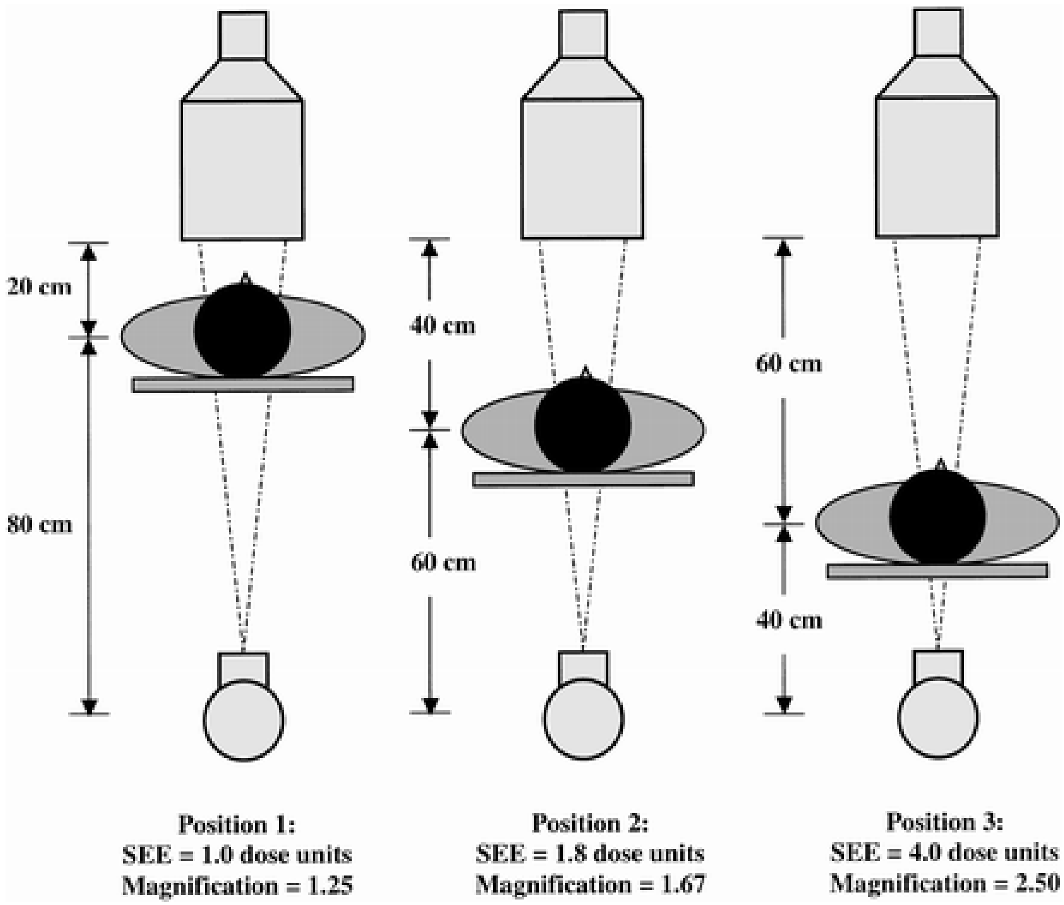
Major rule: Patient positioning



Position 1:
SEE = 1.0 dose units
Magnification = 1.25

SEE = ?
Magnification ?

Major rule: Patient positioning

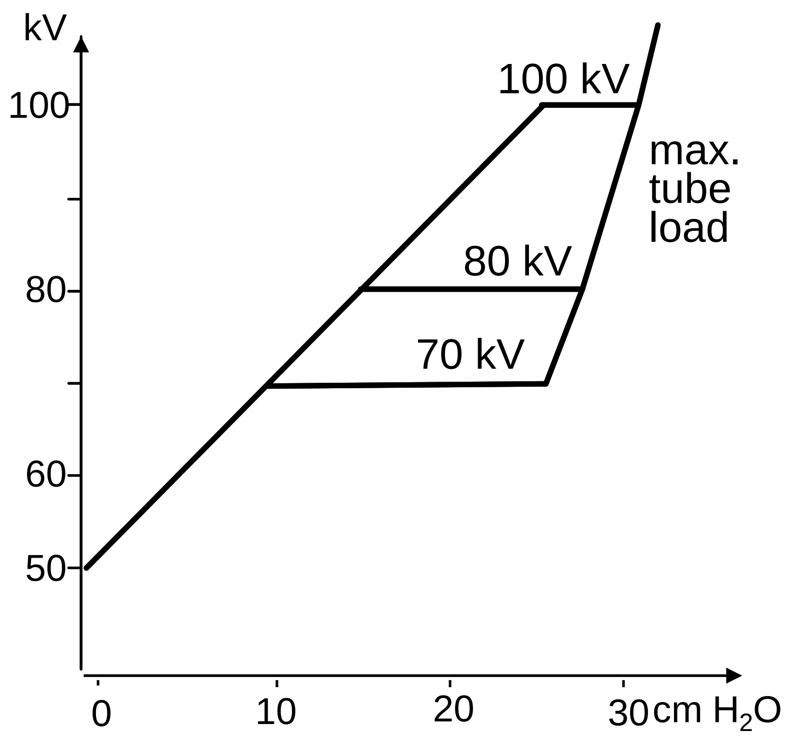


Available to lower SEER

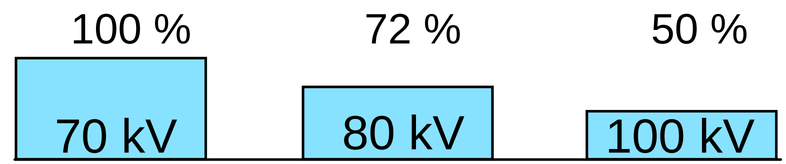
- ADRIQ setting
- X-ray beam filters
  - Efficient to lower skin dose (but not so for effective dose)
  - Contrast reduction compensate by dose increase at detector
    - CNR remains acceptable
  - Often not used in image recording mode
- Pixel binning
  - Larger pixel → less noise for a given SEER
    - Loss a spatial resolution
- Image processing
  - Recursive filtering → loss of temporal resolution

ADRIQ

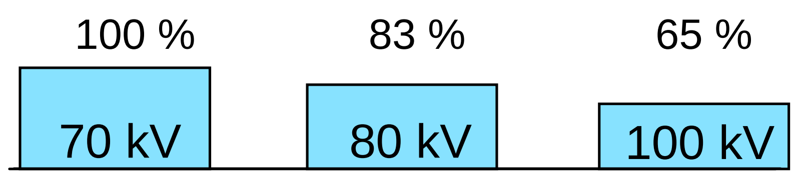
kV variation vs thickness



For 25 cm water

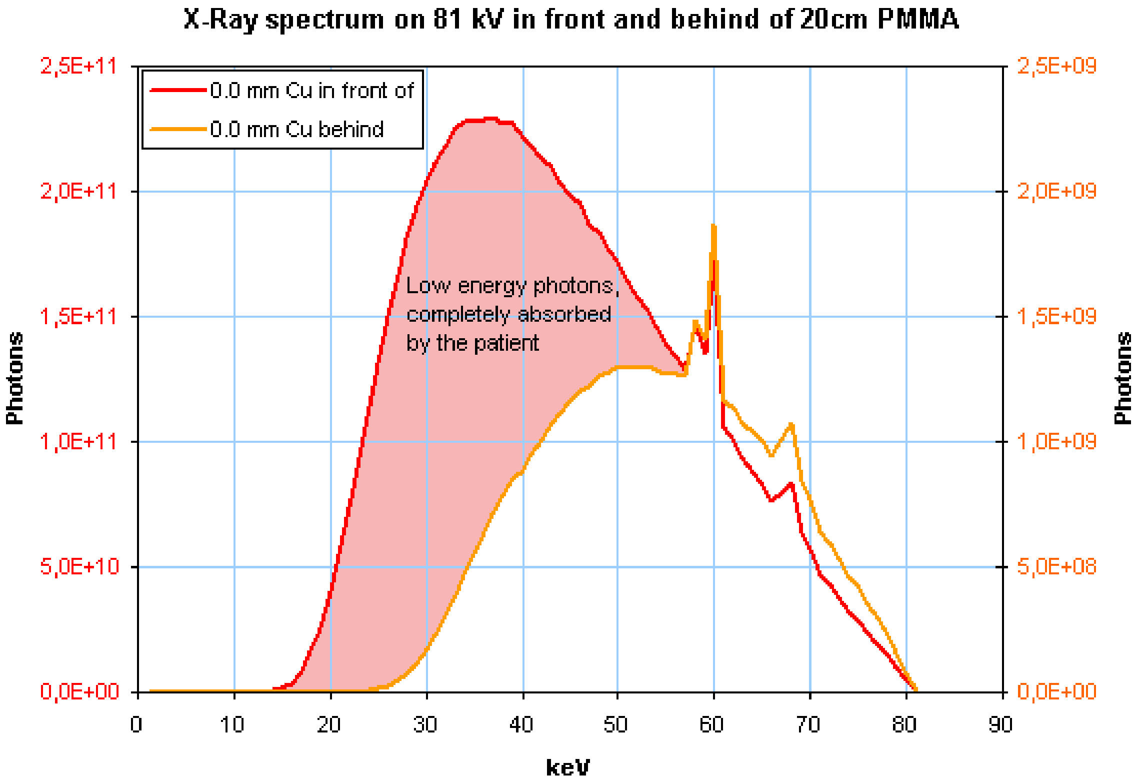


SEER (relative)



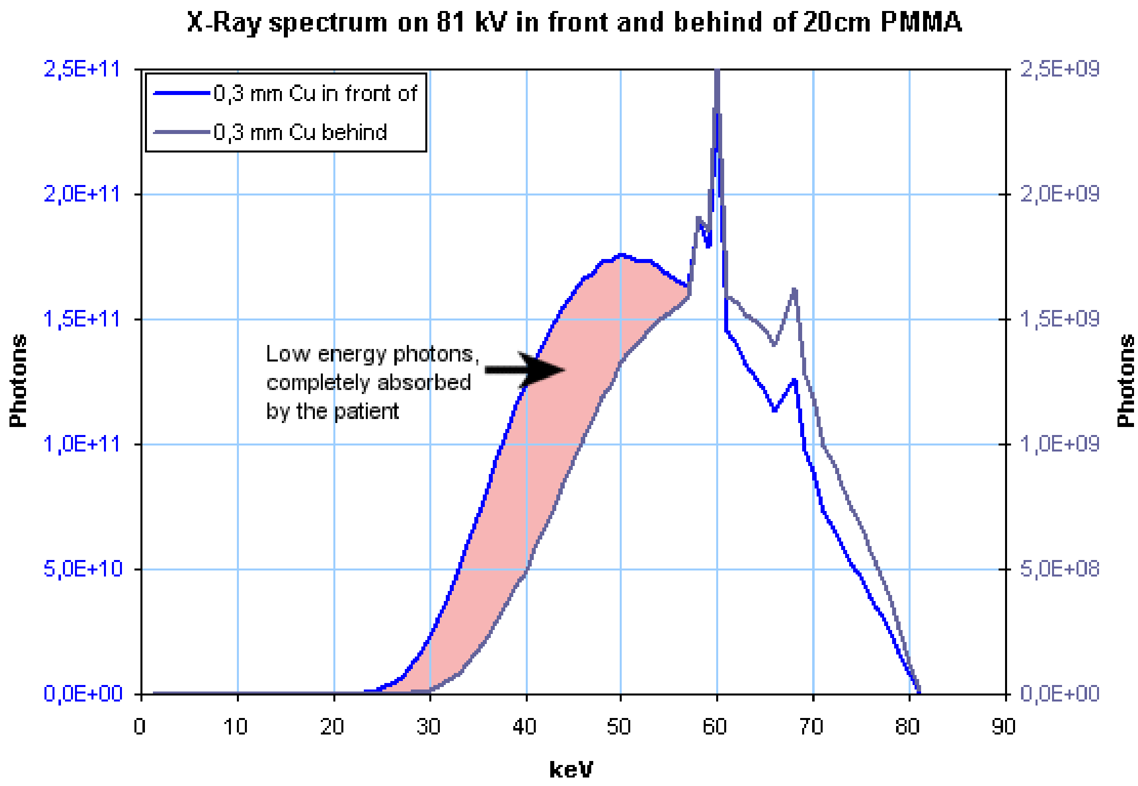
Iodine contrast (relative)

Effect of Cu filter



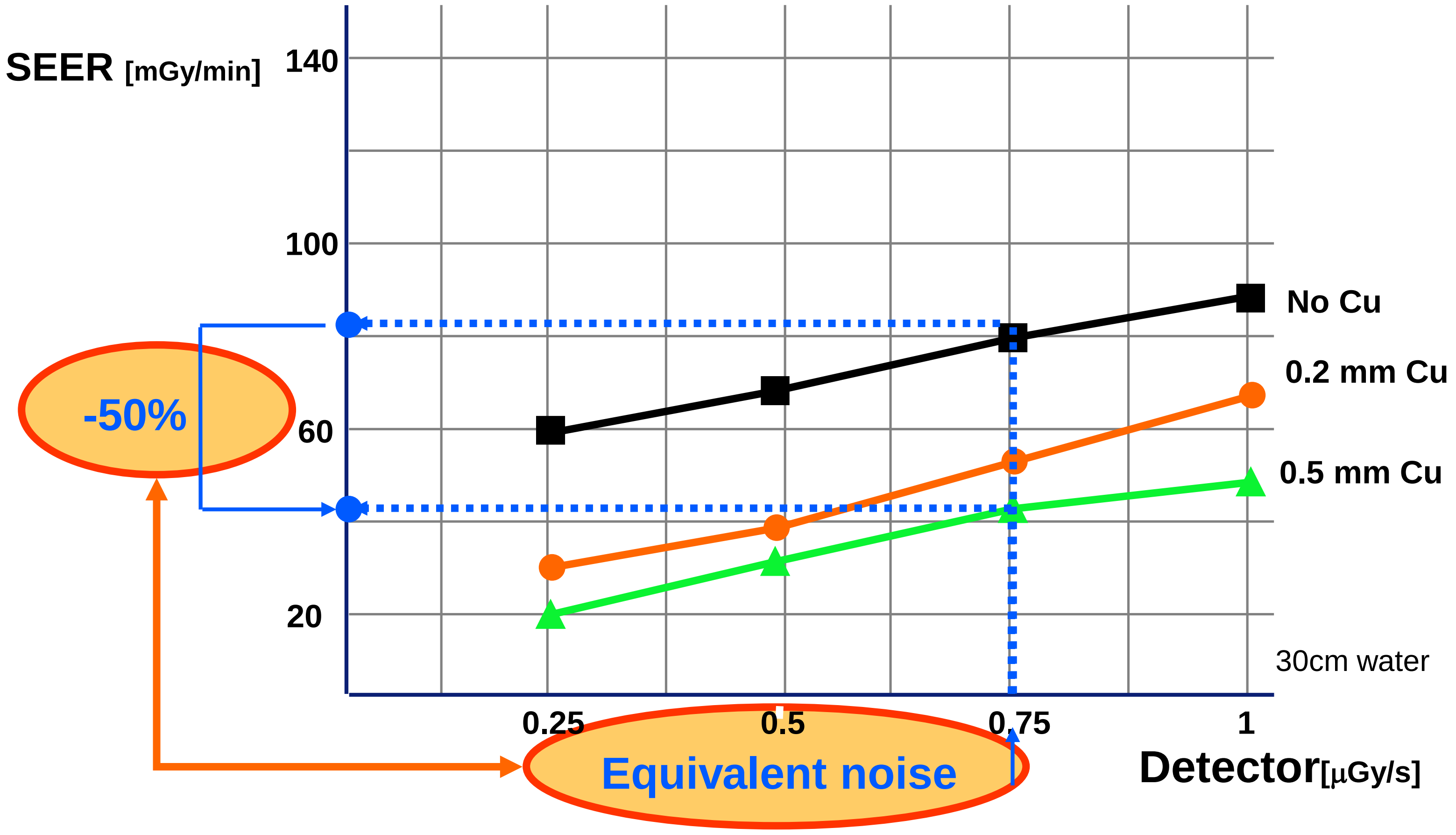
X-ray spectrum at the entrance and exit of the patient – (without Cu filter)

Effect of Cu filter

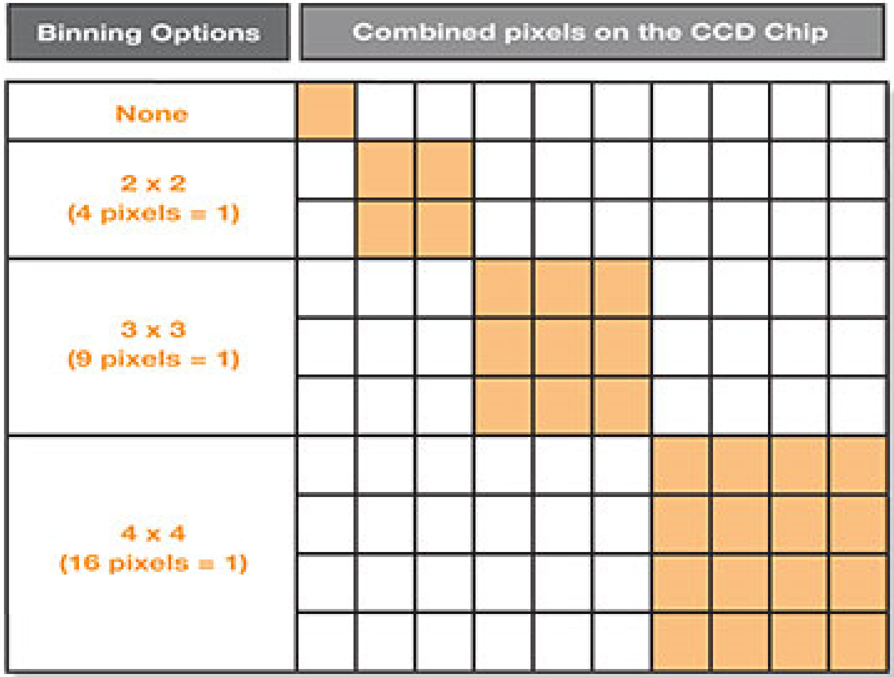


X-ray spectrum at the entrance and exit of the patient - (with Cu filter)

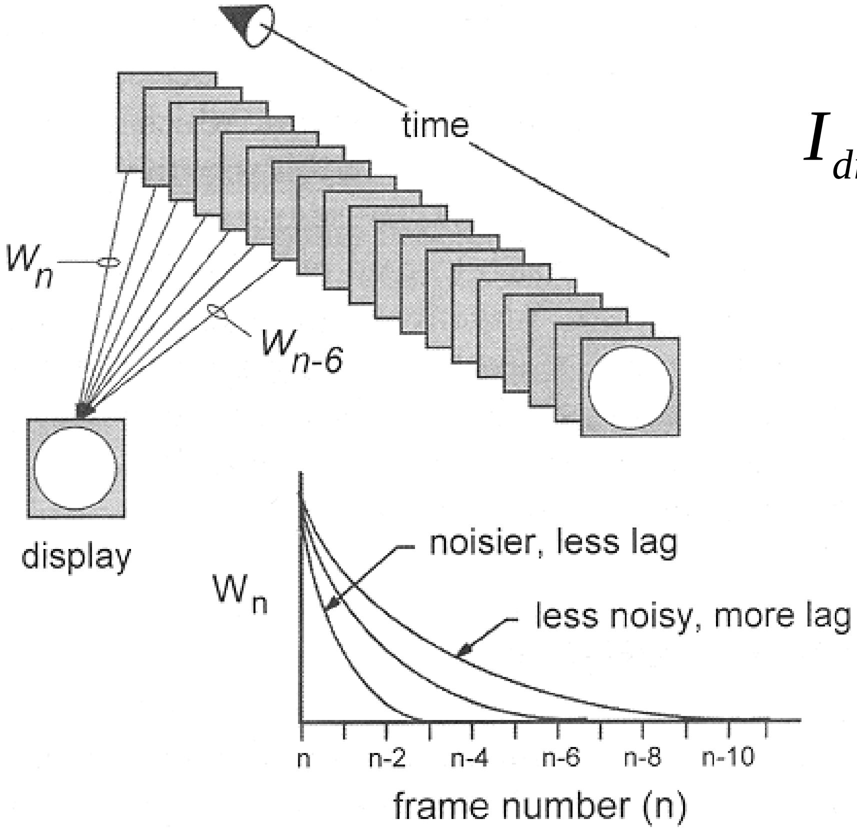
Copper filter



Pixel binning

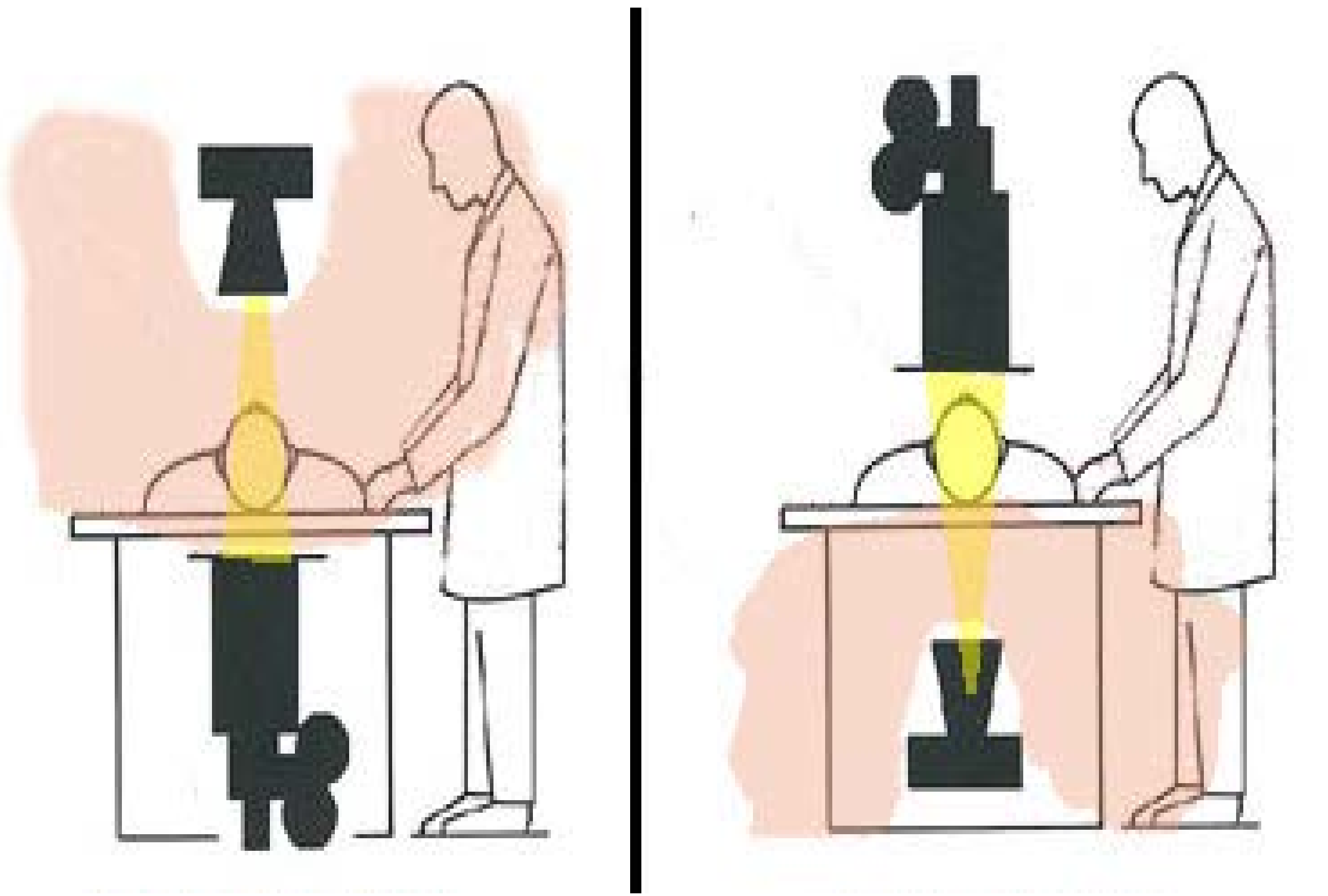


Recursive filtering



$$I_{displayed} = \alpha I_n + (1-\alpha) I_{n-1}$$

The patient is the main source



Exercice

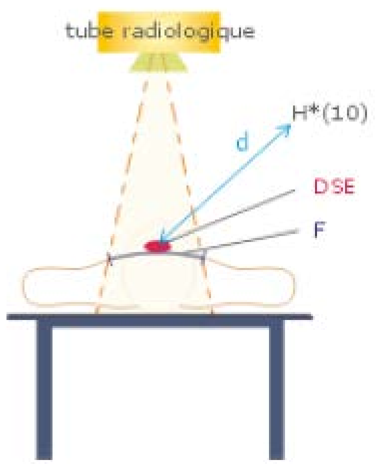
- Considering that the operator receives one thousandth of patient skin dose what is the range of dose rate to be expected?

What is the dose rate here in this room?

1. 0.12 μSv/h
2. 1.2 μSv/h
3. 12 μSv/h
4. 120 μSv/h
5. 1.2 mSv/h

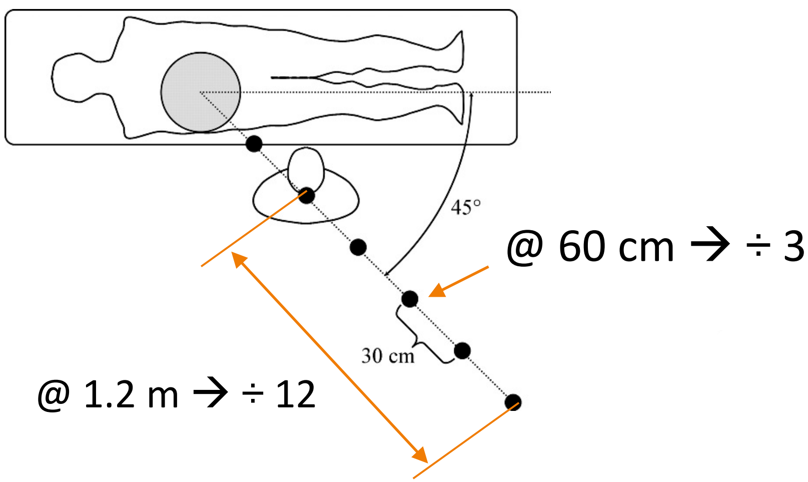
dose rate / dose around a unit

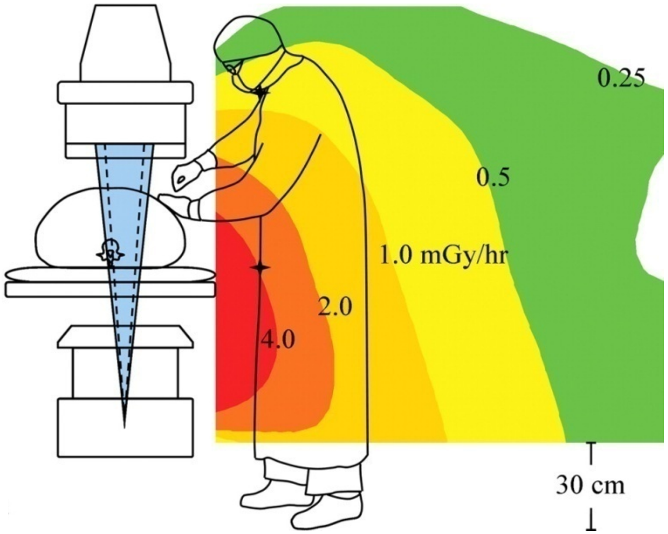
distance au patient (m)	surface du champ (cm^2)		
	10 x 10	20 x 20	30 x 30
0.5	0.12	0.48	1.08
1.0	0.03	0.12	0.27
2.0	0.0075	0.03	0.0675



- For 300 cm^2 @ 1 m
- → H*(10) ~ 1‰ DES
  - 20 mGy/min → 1.2 Gy/h
    - **dH*(10)/dt ~ 1.2 mSv/h**
    - **300 Gy.cm^2 → 1 mSv**

Dose rate and distance





The tube is shielded→ Limit: < 100 $mR.h^{-1}$ (0.87 $mGy.h^{-1}$) @ 1 m

The higher the skin dose the higher the staff exposure

The larger the X-ray field the higher the staff exposure

Schueler B A et al. Radiographics 2006;26:1533-1541

Summary

- Background exposure
  - Here and now: 0.1 to 0.2 µSv/h
    - Increase by a factor of 2 every 1500 m
  - At 10'000 m → 3 à 5 µSv/h
  - MIR satellite (400 km) : 30 µSv/h

- At interventionist level:
  - Body: 0.5 - 2 mSv/h → Lead apron mandatory
    - Unprotected thyroid or eye lens: 0.5 - 5 µSv/min
    - hand: 2 – 25 µSv/min
  - Body: under the apron (4% transmission) → 40 µSv/h
    - 500 hours of fluoroscopy → 20 mSv!

- Dose to the nurse (with lead apron!)
  - @ 60 cm from interventionist → about 13 µSv/h
  - @ 1.2 m from interventionist → about 3 µSv/h

Staff survey in cardiology at CHUV

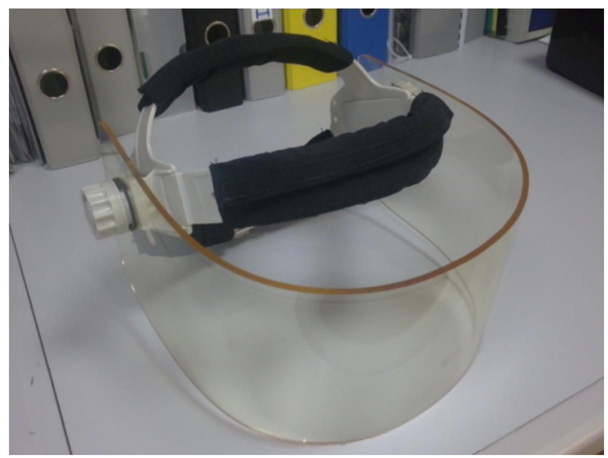
- Follow-up of 30 cardiologists over 5 years

- Monthly doses were measured using:
  - Whole body dosimeters under and above the apron

  - Extremity dosimeters (TLD-100)

Data from N. Ruiz-López and M. Sans-Merce - IRA

Strategy to low staff exposure



Conclusions

- Fluoroscopy is a challenge for radiation protection
  - Highest doses delivered (patient and staff)
- Interventional radiology/cardiology should be carefully monitored
  - Dose reduction can be obtain most of the time (efficient protection devices)
- Dose indicators allow a good control on patient exposure
- All other sectors where fluoroscopy is used should be closely monitored (operating rooms, gastroenterology, urology, orthopedics…)