Cath conference

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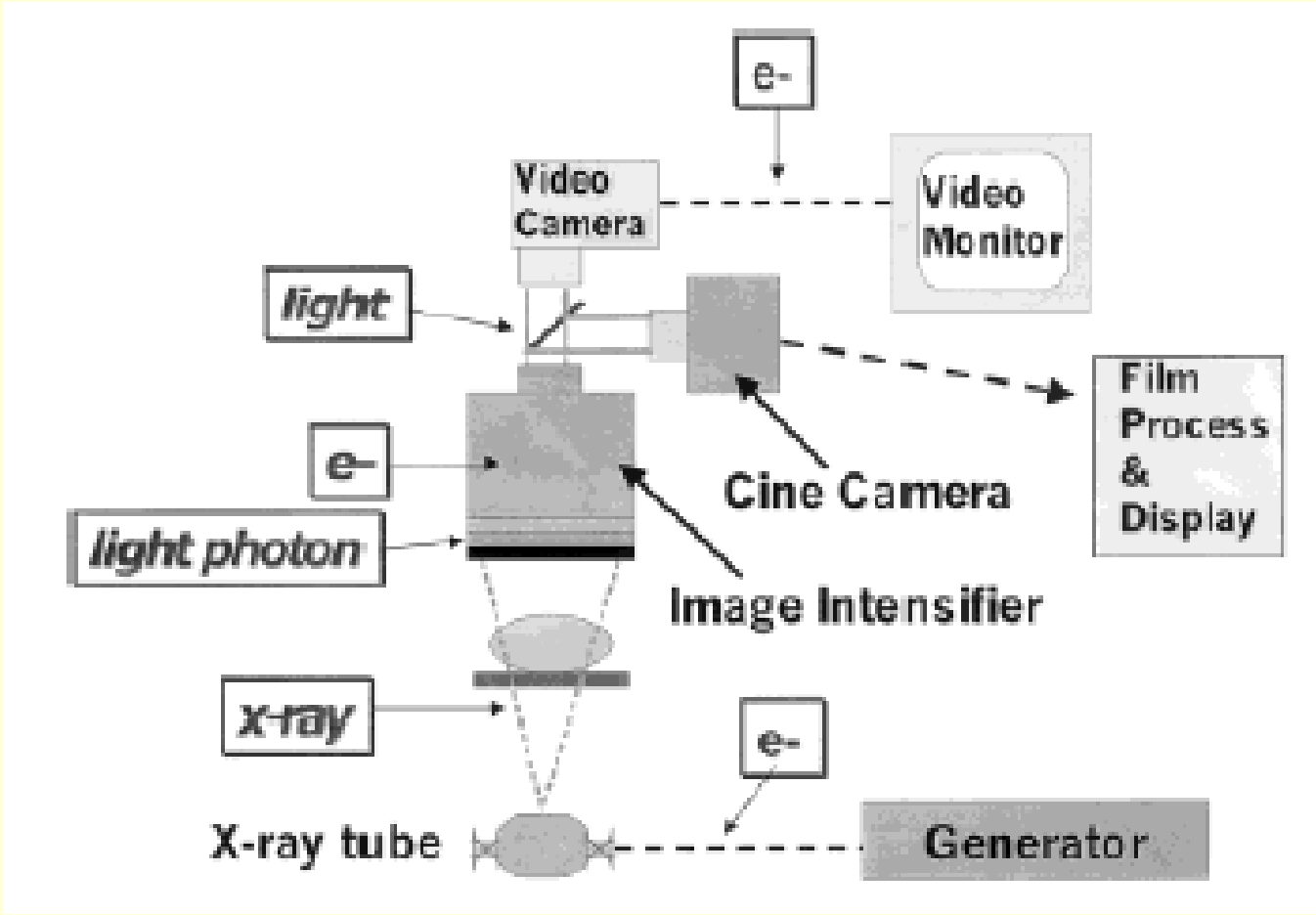
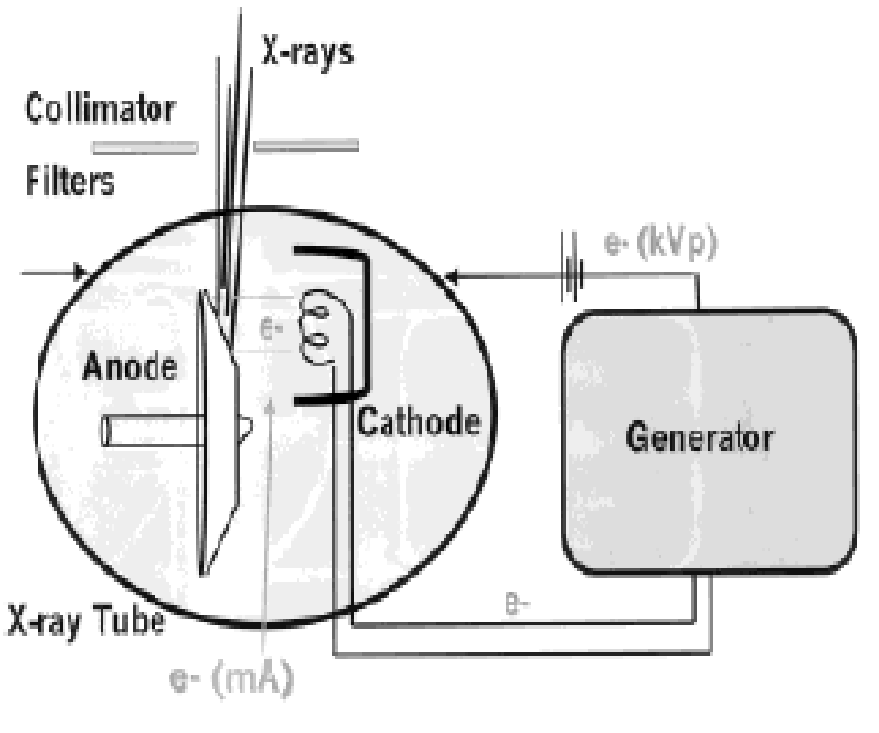
Fundamentals of X-ray imaging

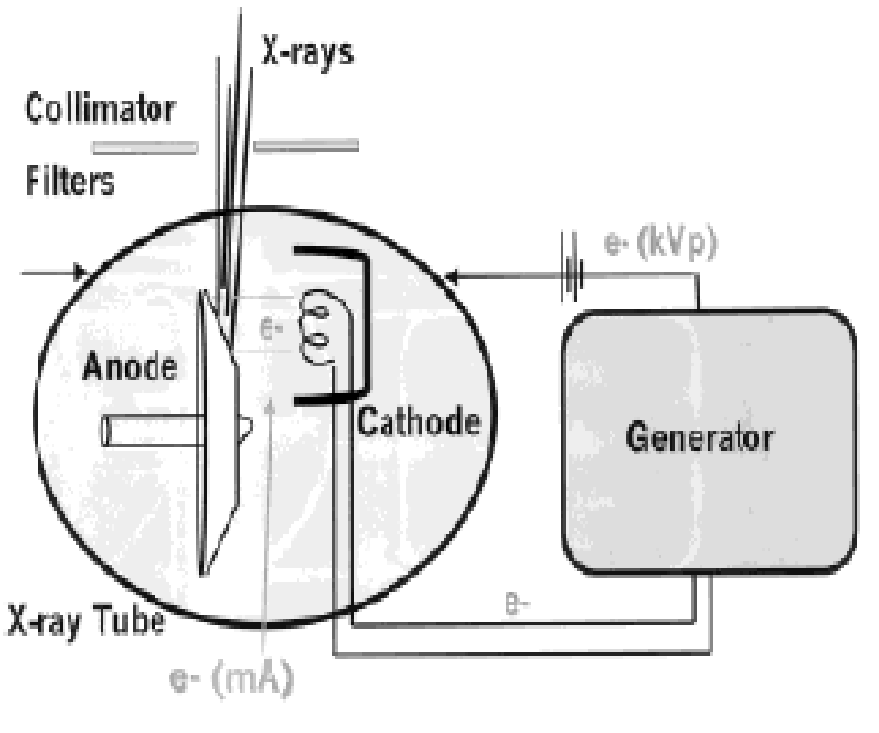


Generator and X-ray tube



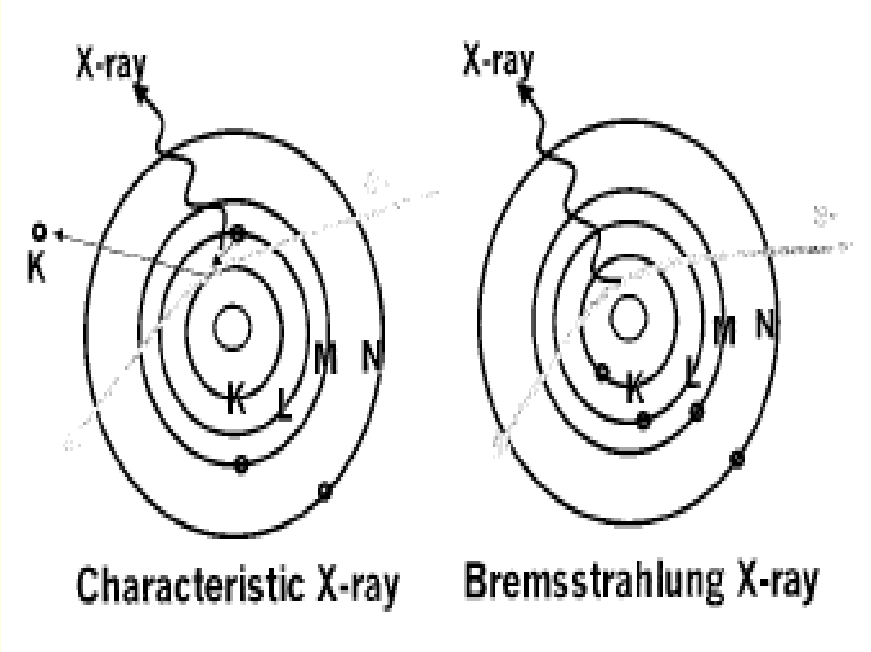
- X-ray tube is a vacuum tube
- Electrons:generator to the cathode, white-hot (about 3,000°F). Electrons virtually boil off the cathode at this temperature (thermionic emission)
- jump from the cathode to the anode by the large voltage potential across the X-ray tube.
- The maximal (peak) voltage potential across the X-ray tube is referred to as the kVp of the system.
- cup sets up a local voltage potential - focus and control the number of e
- The number of electrons sent from the cathode to the anode is referred to as the mA of the system and directly correlates with the eventual number of X-rays produced.

Generator and X-ray tube



- The anode rotates rapidly (3,500 – 10,000 rpm) to help dissipate the tremendous heat generated.
- X-ray tube surrounded by circulating oil
- The whole system is remarkably inefficient
- Anode is tungsten - converts the electrons into X-rays.- steeply angulated (8 –15°) - X-rays come from as much a point source
- Since low-frequency X-rays contribute to radiation exposure but not image quality- aluminum or copper filters
- The beam is also shaped by the use of collimators at this point to help focus the eventual direction the X-rays travel.

X-ray generation



- Electrons -close to the nucleus and slow down - the loss of energy when the electron slows results in Bremsstrahlung (braking) X-rays being released.
- Electrons - knock out an electron from one of the shells of the tungsten atom – outer shell electron moves to fill the vacant lower shell, energy is lost in the form of an X-ray- Characteristic X-ray

Effect of KVp on X-ray generation

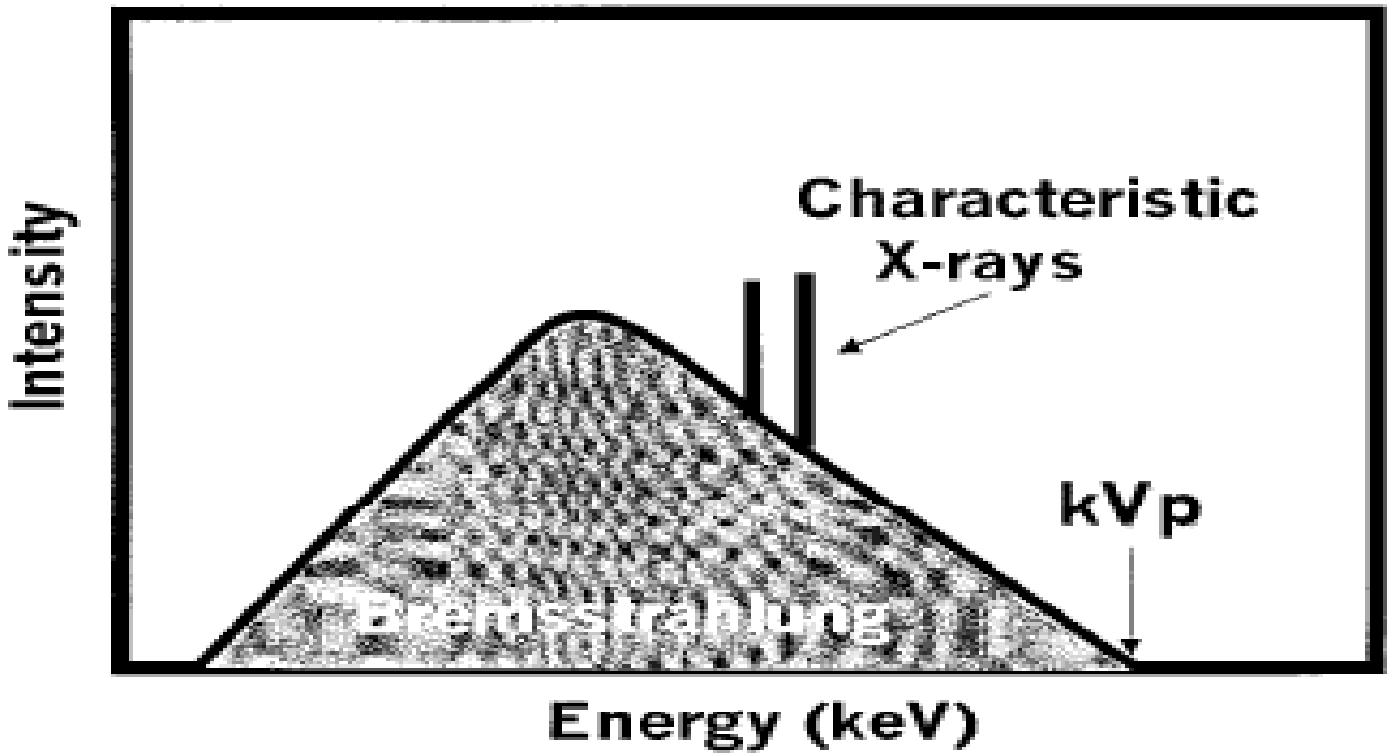


Fig. 4. The energy spectrum emitted from the X-ray tube. This schematic represents the types of X-rays emitted and their energy spectrum. The maximal energy corresponds to the kVp.

Effect of KVp on Iodine's contrast effect

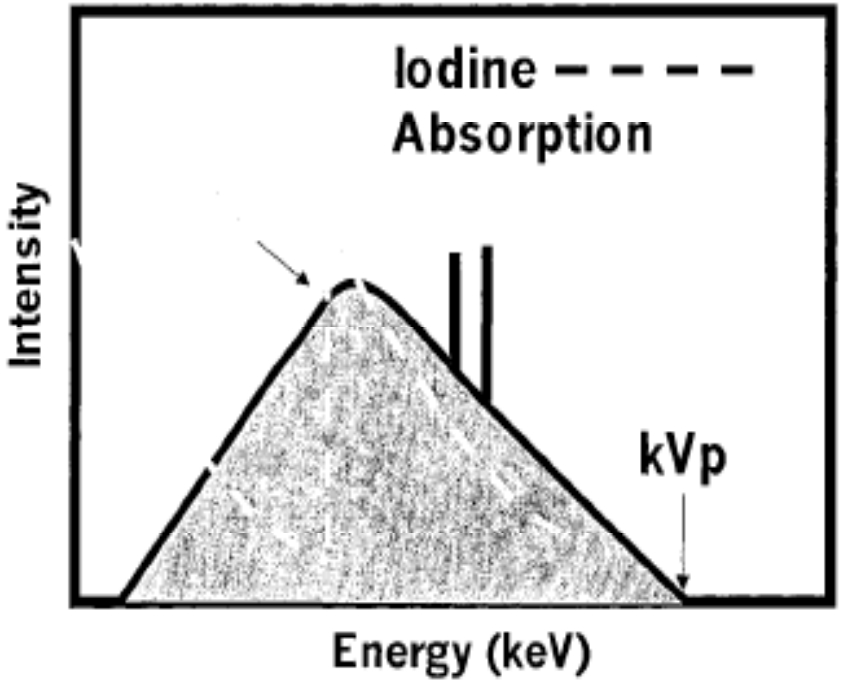


Fig. 5. Iodine absorption. Iodine is used as a contrast agent because of its absorption spectrum shown here. Note that as the energy of the X-rays increase, the iodine absorption goes down until there is a sudden marked absorption region, known as the K-edge, corresponding to the K-shell electron energy of the iodine.

- The energy of the X-rays increase, there is less absorption by iodine until suddenly this is a sudden increase in the absorption.
- This sudden increase in the absorption occurs at the energy of the K-shell electrons of iodine;
- Energies below this edge do not contribute to the iodine image

Effect of KVp on Iodine's contrast effect

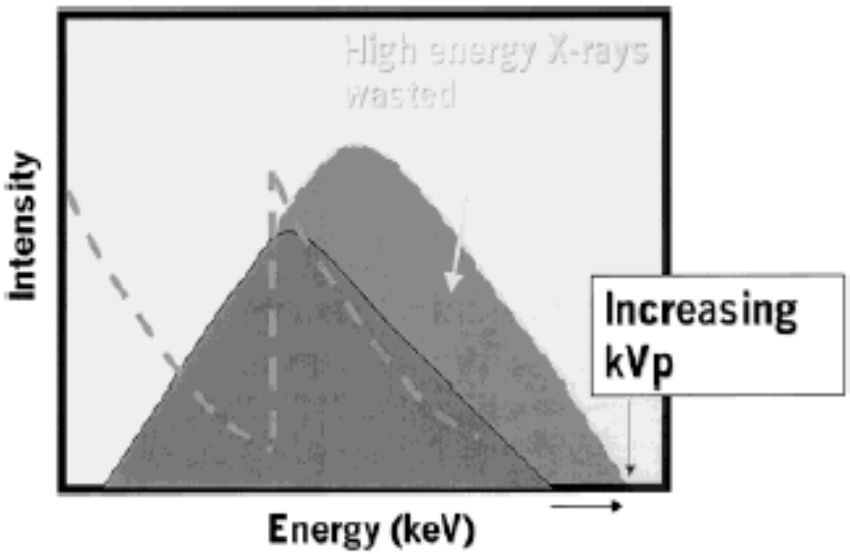
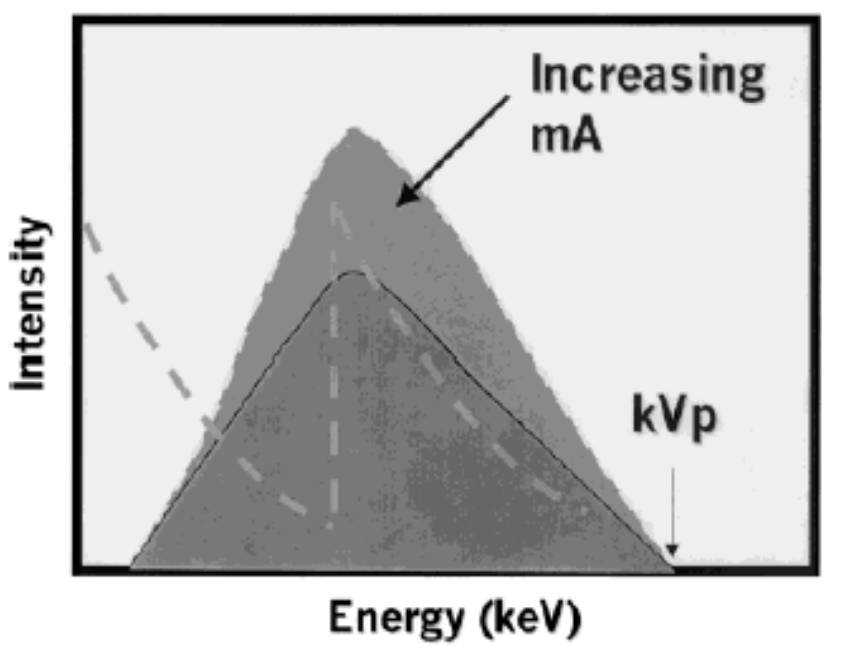


Fig. 6. Effect of increasing the kVp. Increasing the kVp results in many high-energy X-rays being produced. These will not be absorbed by the iodine and the image will have poor contrast.

- When the kVp is too high, there are many high-energy photons wasted that are not absorbed by the iodine.
- These high-energy photons overpenetrate the iodine column, creating a gray or washedout image.
- Better image contrast occurs if the kVp is kept at a reasonable low level (usually around 70–80 kVp).

Effect of mA on Iodine's contrast effect



- The result of increasing the mA (and subsequently the number of X-rays) is demonstrated.
- When the mA is increased, but the kVp kept optimal for image contrast, these extra X-rays contribute to overall image quality by providing for improved exposure.
- Also adds to scatter radiation

- Once the X-rays leave the X-ray tube, they diverge and travel through the table and the patient toward the image intensifier. Most never make it to the image intensifier as they are absorbed, attenuated, or scattered in the table or in the patient.
- Much of the occupational X-ray scatter important to the invasive cardiologist occurs on the entrance side of the patient.
- When the X-ray tube is near the operator(cranial LAO) six times a (caudal RAO view)

Image Intensifier

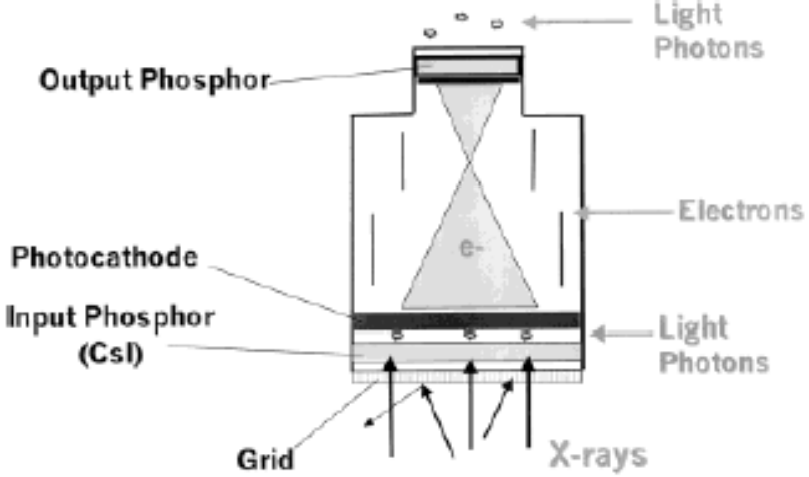


Fig. 8. The workings of the image intensifier. X-rays are filtered at the grid before striking the input phosphor. Light photons created at the input phosphor strike a photocathode and are converted to electrons. These electrons are accelerated through the II and the image minified to enhance brightness by a factor of 1,000. The image at the output phosphor can be viewed by the naked eye.

- Grid that helps screen out scattered X-rays
- The input face- covered with a phosphor of cesium iodide- converts x-ray to photon (scintillation)
- light photons strike a photocathode that converts the light energy back to electrons
- These electrons are then accelerated through the image intensifier and strike a smaller output phosphor on the other end of the II.
- The output image is both minified (made smaller) and about 1,000 times brighter than the input image.

Image Distributor

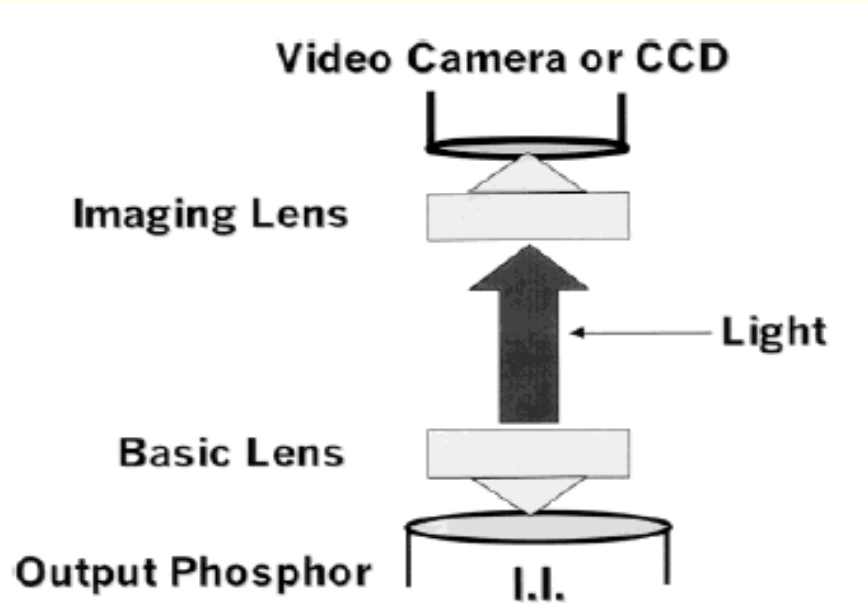


Fig. 9. The image distributor. A series of lenses beam the output of the II toward the video camera.

- This visual output image is then sent through a series of lenses in the image distributor to a video camera or a charged-coupled device (CCD).

Control of the X-ray output

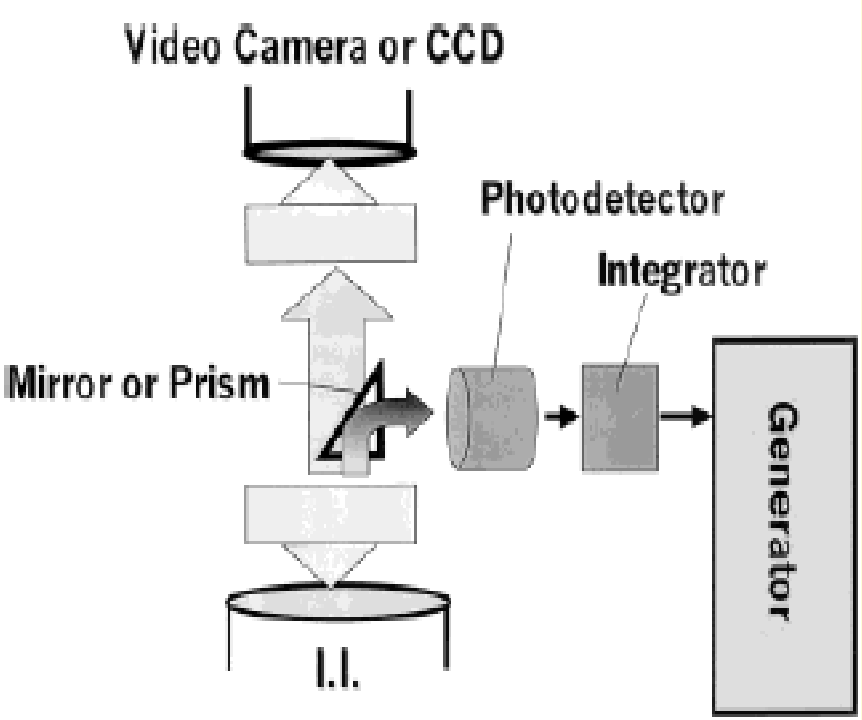
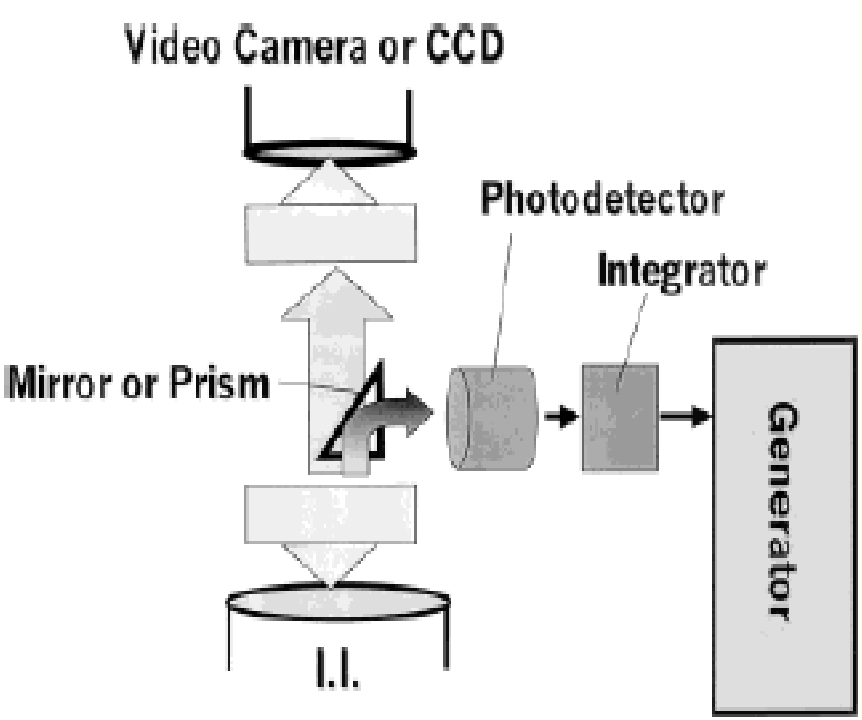


Fig. 10. Exposure control. A mirror or prism is in place in the beam of output from the II and sends information to the generator regarding exposure. Exposure is a product of the mA × the kVp × the pulse width.

- Within the image distributor, a partially silvered mirror or prism - to a photodetector.
- Information from photodetector-to the generator to control the output
- Exposure is a function of the number of electrons made into X-rays (the mA) times the maximum voltage across the X-ray tube (kVp) times the pulse width (the length of time the X-rays are sent per frame).
- Too high kVp - washed-out image
- Too high mA-excessive scatter radiation
- Too high pulse width-blurring of image.

Control of the X-ray output



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- X-rays emitted - pulsed by electronics- allows framing rates of 7.5–60
- During cine - frame to frame
- Pulsing during fluoroscopy reduce total exposure
- Most studies are now acquired at 15–30 frames/sec in adults.
- Higher frame rates young children(HR)
- Dense structure – needs more exposure (bones) – angulated views in obese people – more scatter radiation

Effect of magnification on X-ray output

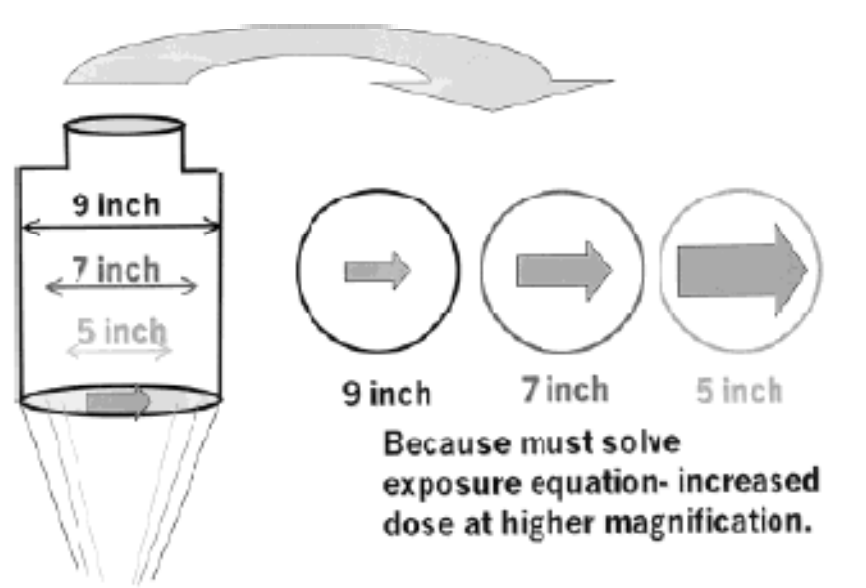


Fig. 11. Magnification in the image intensifier. By using progressively less of the input face of the II to capture the image, the result is magnification at the output phosphor of the II. A greater amount of X-ray dose is required at the more magnified images in order to meet the exposure equation.

- Magnification increases X-ray exposure
- Electronic magnification at the image intensifier – by using less and less of the face of the II - results in the image appearing larger on the output phosphor
- To use less of the input phosphor means a greater dose of X-rays
- An image acquired at 5” mode,- may require over three times the X-ray in compare to 9” mode

Effect of II distance on X-ray output

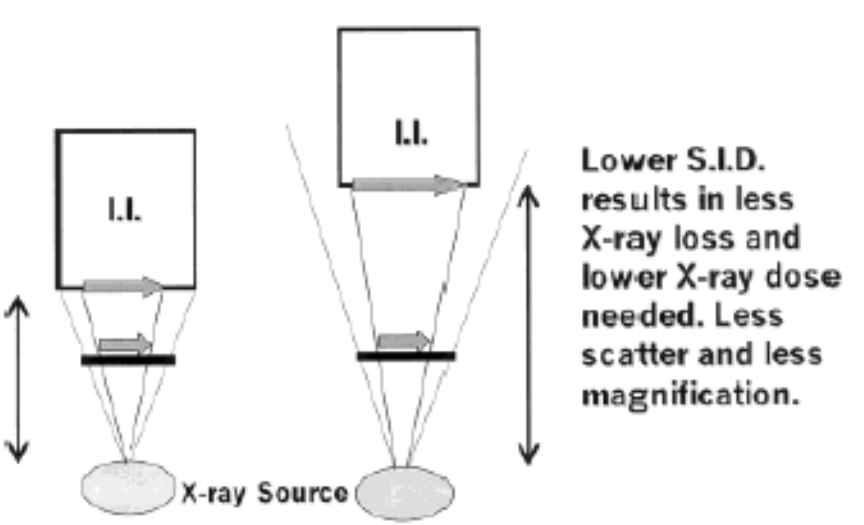


Fig. 12. Magnification using the SID. Due to X-ray divergence, the greater the SID, the larger the image appears on the face of the II. X-rays are lost in the process, however, and a greater dose with more radiation scatter results.

- Source-to-image distance (SID)
- Changing the SID affects both X-ray exposure and image magnification
- As the SID is increased, there is greater loss of X-rays, and the image appears more magnified (means more X-rays needed - exposure equation)

Older camera

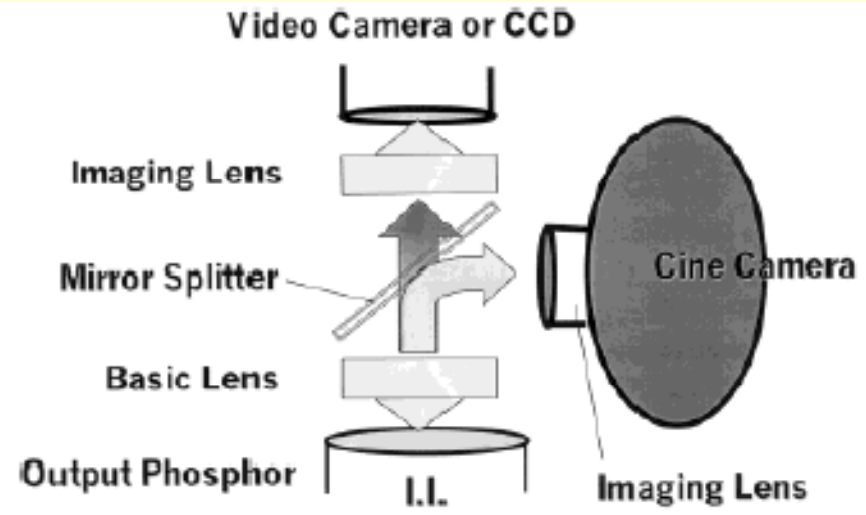


Fig. 13. Mirror splitter. A partially silvered mirror can split the beam from the II so that much of the image is reflected to the cine camera, allowing a lesser amount to reach the video camera or CCD.

- To cine and yet still see an image - a partially silvered mirror (up to 85% of the beam is diverted to the cine camera)
- The human brain is unable to distinguish flicker at framing rates of greater than 50 frames/sec
- So even after acquiring at 30 frames/sec- by the projector each image is shown twice thus fooling the brain by displaying the images at a rate of 60 images/sec.

Digital Imaging

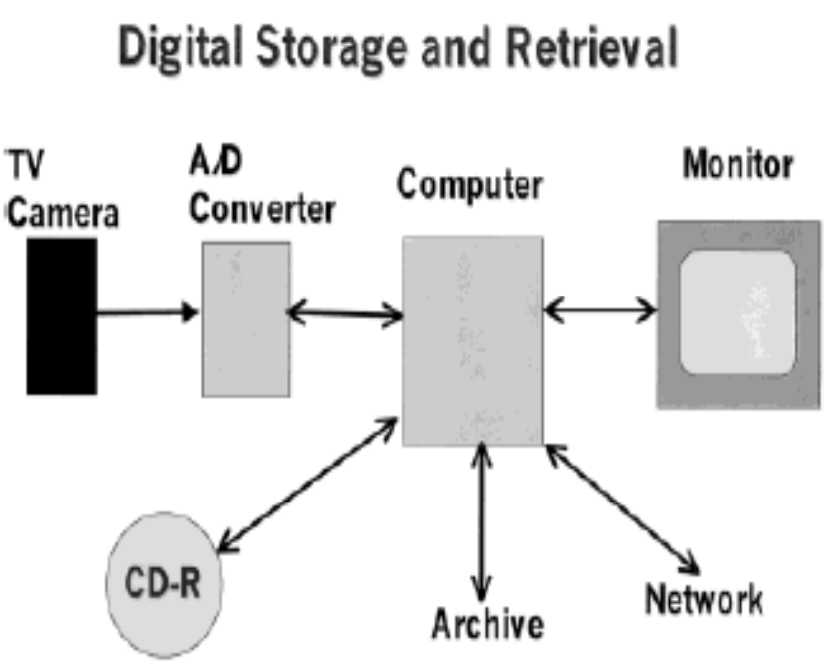


Fig. 20. Digital storage and retrieval. Once the image data are in digital form, the information can be displayed, archived, and transferred among laboratories using either a fixed media or via networking.

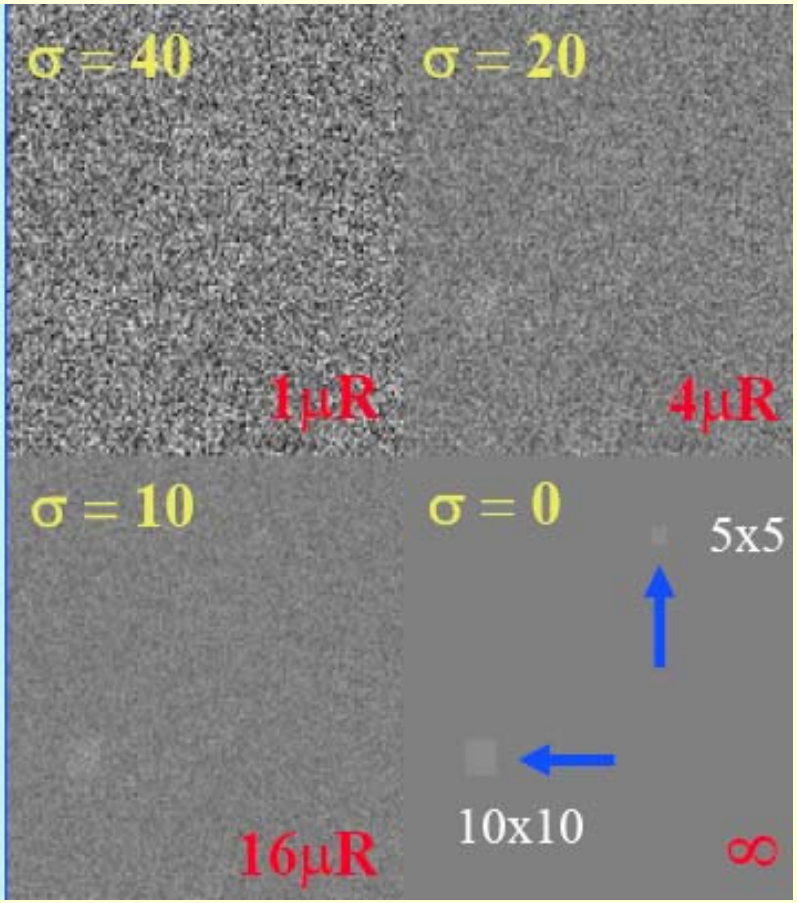
- Conversion of the video signal to digital information
- flicker-free viewing
- freeze-frame displays
- high-resolution image data immediately
- digital format
- network
- short- or long-term archival
- Digital Communication in Medicine (DICOM)

Factors effecting Angiographic Image contrast

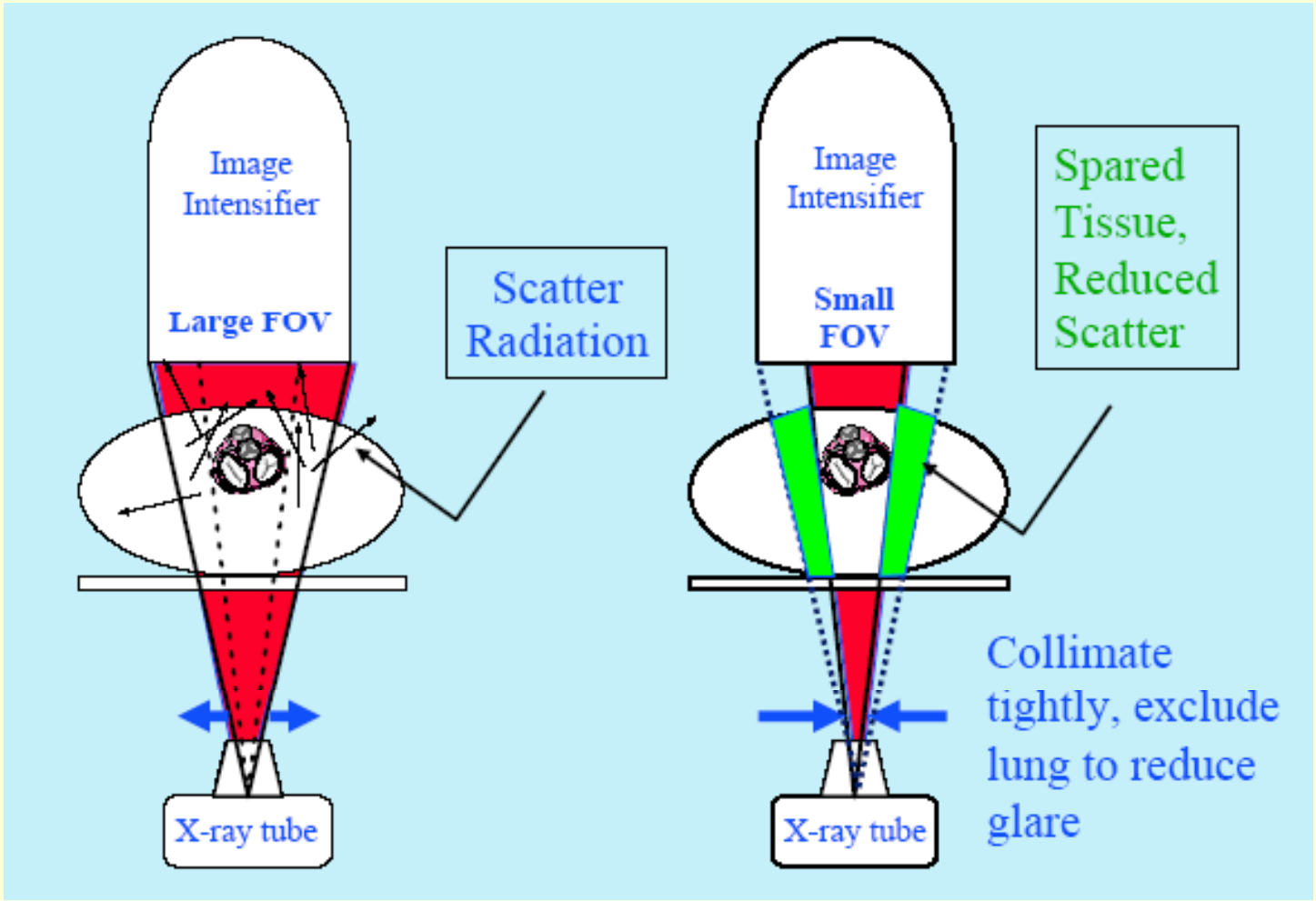
- **Subject Contrast**
  - Vessel size
  - X-ray KV (lower contrast at > 75 KV
- **Scatter:**
  - Patient thickness along beam
  - X-ray beam area (FOV & Collimation)
- **Image intensifier veiling glare**
- **Digital image processing**

Relationship between image quality and dose

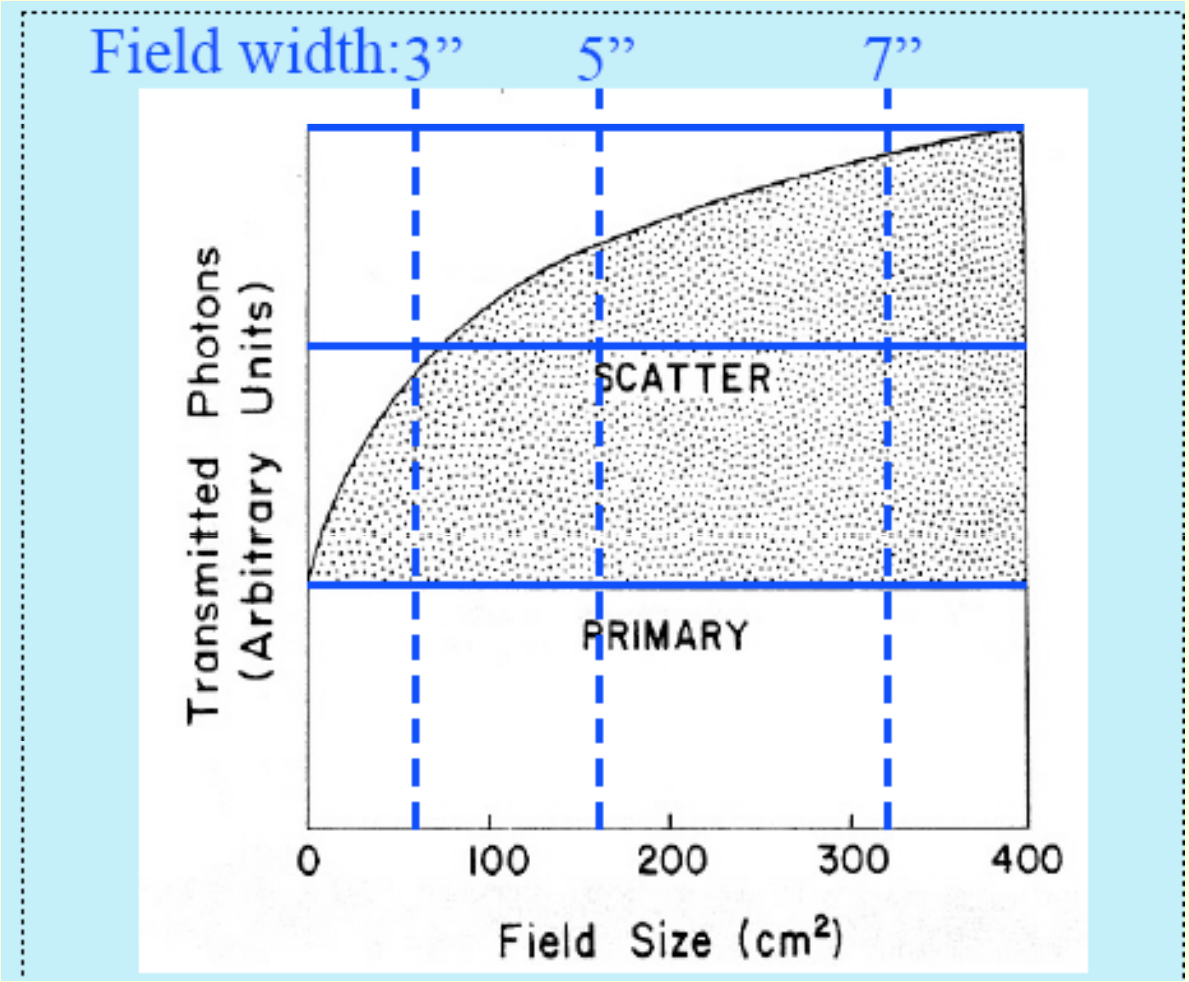
- Detection is limited by noise
- Acceptable noise level depends on task
- Noise $\propto 1/\sqrt{Dose}$
- Acceptable dose depends on task



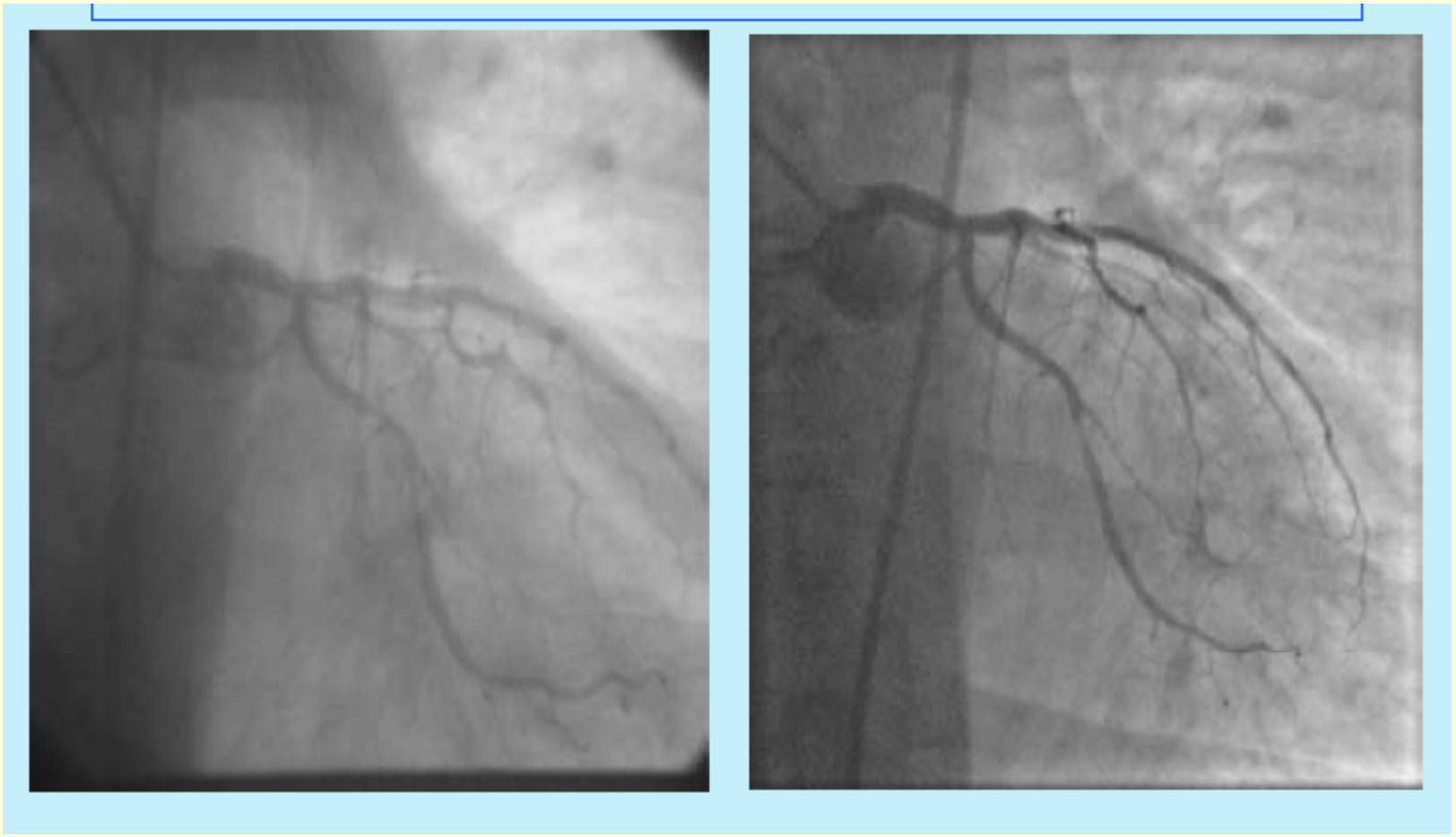
Scatter and Veiling glare depend on FOV



Effect of X-ray beam area on scatter



Raw image intensifier versus process flat panel Detector



Effect of Digital image on the X-ray dose

Reduced Dose

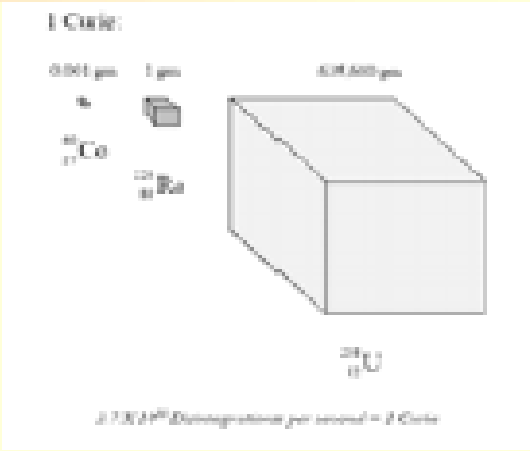
- **Last image hold** (reduces fluoro time)
- **Edge enhancement** (improves feature detectability)
- **Pulsed fluoroscopy** (reduces noise by increasing dose efficiency)
- **Reduced frame rate** pulsed fluoroscopy can further reduce dose for equivalent perception.

Increased Dose

- **Lossy compression** adds noise at a given dose, reducing dose efficiency.

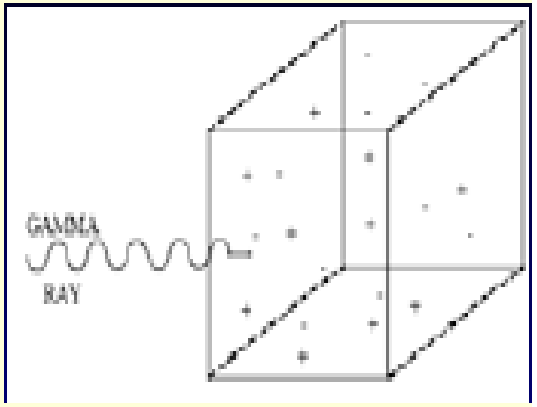
Activity of Radioactive Material

Curie: equivalent to the activity of 1 gram of radium
1 becquerel = amount of material which will produce 1 nuclear decay per second
1 curie = 3.7 x 1010 becquerels
1 curie = amount of material that will produce 3.7 x 1010 nuclear decays per second

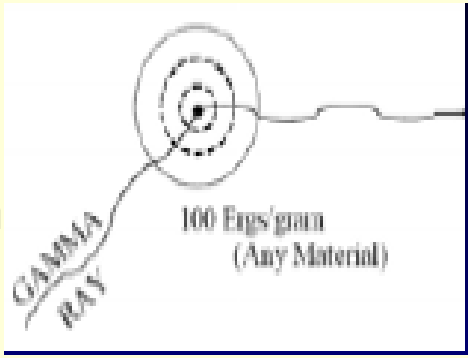


Measurement of Exposure

- The emitted x- or gamma ray interacts with tissue or air that it passes through, causing ionization events
- Ionization in air is measured in units of Coulombs/kg or (frequently in the US) in milliroentgens, or mr/hr
- Roentgen: Ionization liberating a charge equal to 2.58 X 10 -4 coulombs/kg of air
- Coulombs: 1 coulomb/kg = 3876 R



Measurement of Dose (Absorbed)



RAD

- Measure of energy deposition in tissue from radiation
- Units: rads, ergs, or Grays
- **RAD –** is the deposition of one hundred ergs of energy in one gram of any material (NRC Regulations use per gram of body tissue) due to the ionization from any type of radiation
- 100 rads = 1 Gray (gy)

Measurement of Dose (Equivalent)

Measurement of Dose (Equivalent)

REM

- REM estimates biological damage caused by ionization in human body tissue (term for dose equivalence)
- 1 REM = biological damage that would be caused by one RAD of dose
- REM = RAD X Quality Factor

QUALITY FACTOR: amount of biological damage caused by the different types of radiation

– **Q = 1 for gamma rays, Xrays, and beta particles**

– **Q = 20 for alpha particles**

DOSE

Energy Deposition		"Damage"
1 RAD Gamma	=	1 REM
1 RAD Beta	=	1 REM
1 RAD Neutron	=	10 REM
1 RAD Alpha	=	20 REM

REM = RAD X Quality Factor

Effective dose

TABLE I. Weighting Factors Used to Calculate Effective Dose

0.01	0.05	0.12	0.20
Bone surface, skin	Bladder, breast, liver, esophagus, thyroid, remainder	Bone marrow, colon, lung, stomach	Gonads

$$E = \sum_T W_T H_T$$

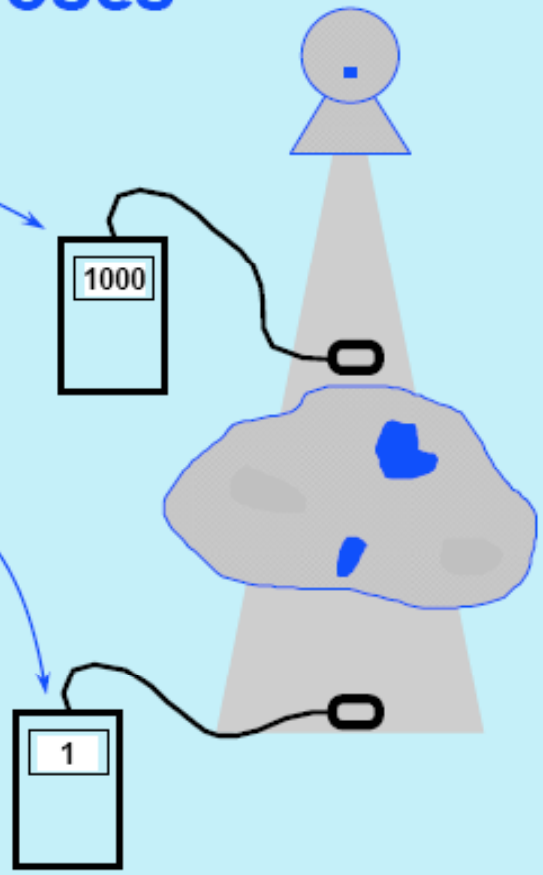
- **Same probability of inducing a cancer or genetic disease whether the irradiation is uniformly delivered to the whole body or nonuniformly to part of the body or to specific organs**
- **The weighting factors: different radiosensitivity of different tissues**
- **Operator risk not easily related single collar film badge: the radiation field in the laboratory is highly variable; superficial tissues attenuate X-rays; lead aprons and thyroid collars significantly reduce the dose delivered to shielded organs.**

Quantity	US units	SI units	Conversion factor
Radioactivity	Curie, Ci	Becquerel, Bq	1 Ci = 3.7 x 10^{10} Bq 1 Bq = 27 picocurie (pCi)
Exposure	Roentgen	Coulomb/kg	3876 R ≈ 1 coulomb/kg 1R = 2.58 X 10^{-4} coulombs/kg
Absorbed dose	Rad	Gray, Gy	100 rad = 1 Gray (Gy) 1 Gy = 0.01 rad
Dose (Equivalent dose)	Rem	Sievert, Sv	100 rem = 1 Sievert (Sv) 1 Sv = 0.01 rem

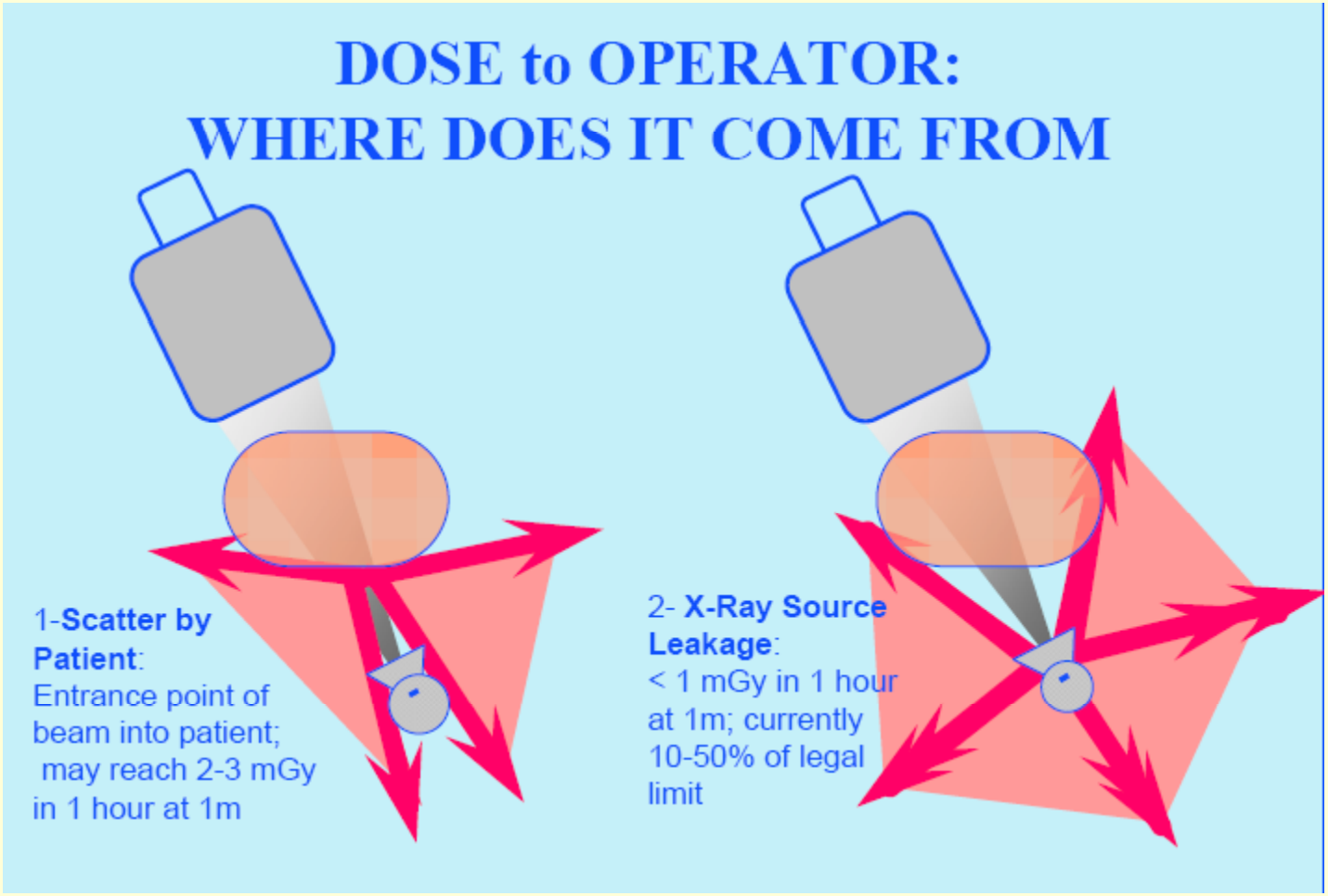
Basics of Radiation in Cathlab
Radiation to Patient

Typical Skin Doses

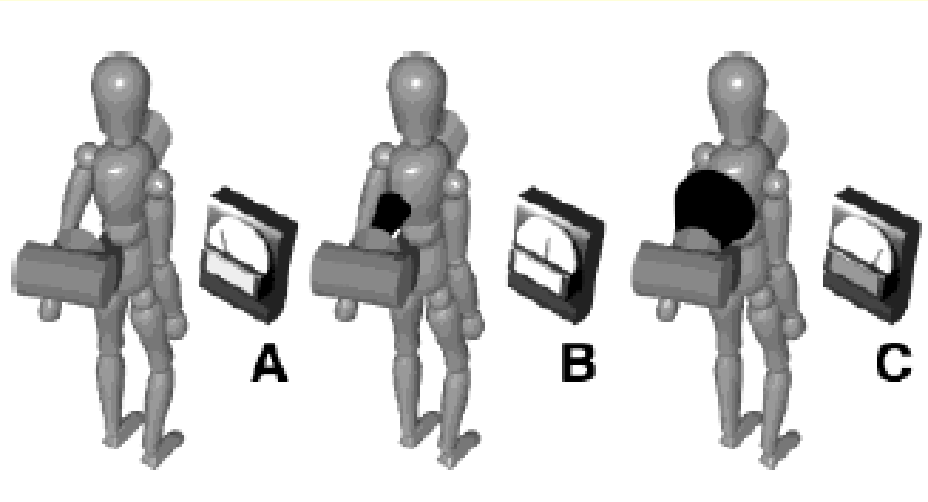
- **SKIN DOSE:**
  - Chest X-Ray: 300 -500 µGy (30-50 mR)
  - Fluoroscopy: 10-100 mGy/min (1-10 R/min)
    - Diagnostic exams: 1-5 min fluoro, i.e. 10 - 500 mGy
    - Interventional procedures: 15 -120 min, i.e. up to 12 Gy !
- **IMAGE RECEPTOR ENTRANCE EXPOSURE**
  - Used to assess the quantity of X-Ray used to form the image (⇒quantum noise)
  - Typically: 1/1000 of skin dose
    - 10 to 100 µGy/min (fluoro);
    - 0.05 to 0.25 µGy/image (cardiac record)



Basics of Radiation in the cath lab



Basics of Radiation in the cath lab

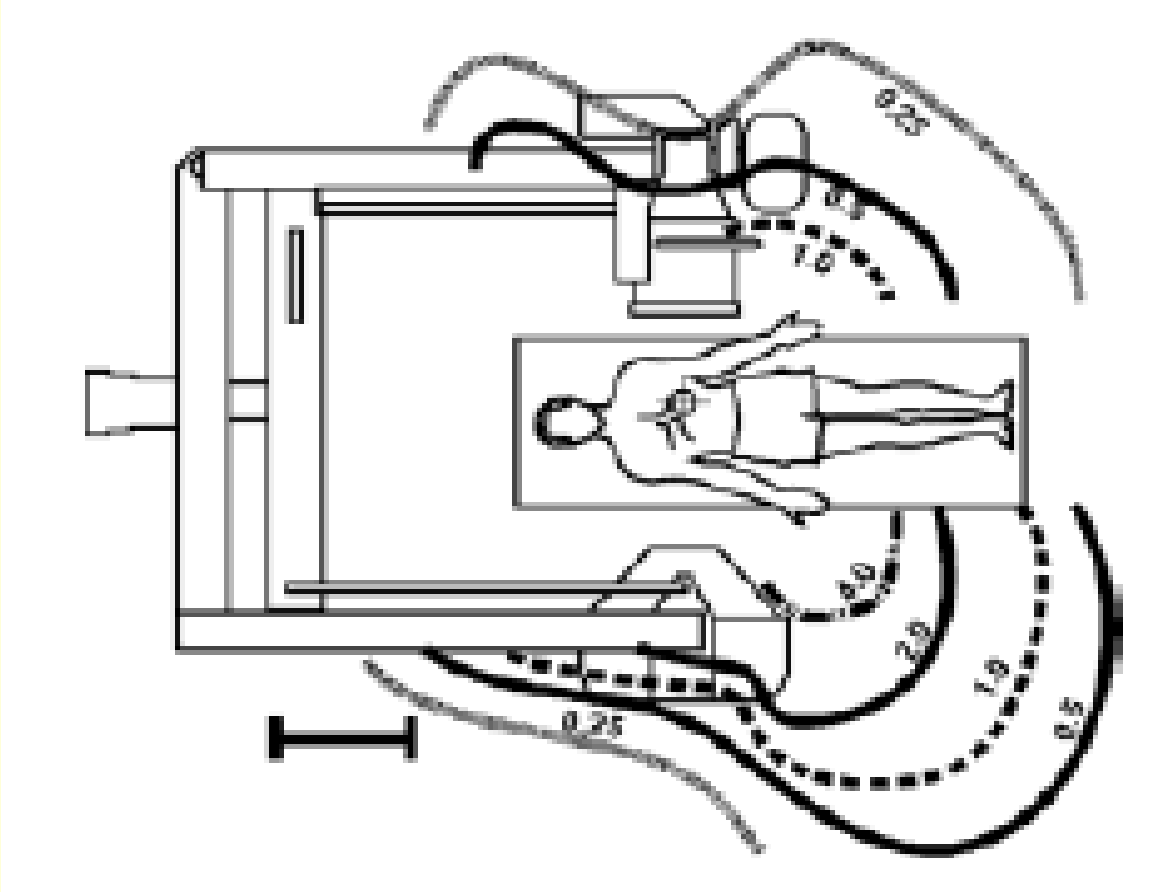


- **The total amount of scatter is proportional to the intensity of the primary beam and the area of the entrance port**
- **the effect of beam size on the amount of stray radiation**
- **collimator is closed - meter only detects leakage from the tube**
- **A partially opened collimator - Leakage plus scatter from the small field**
- **A fully open collimator yields the maximum beam size Leakage plus the greater degree of scatter**

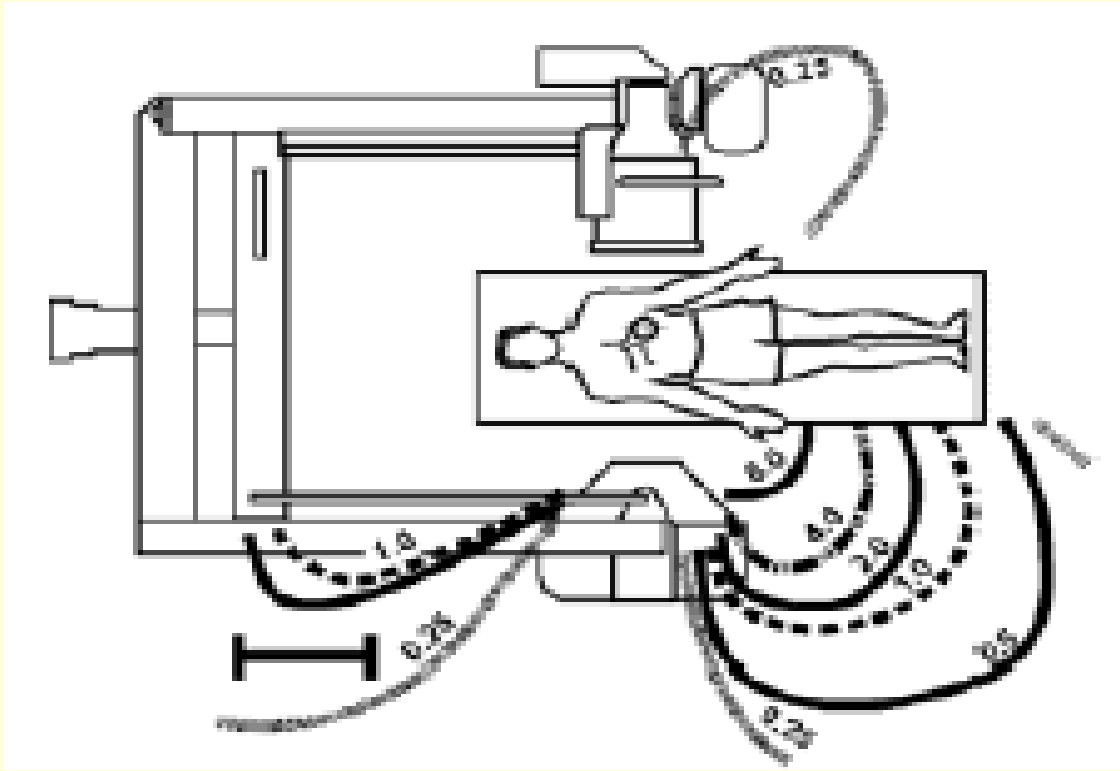
Basics of Radiation in the cath lab

- The distribution of scatter- highly dependent on the angiographic projection
- The distribution of radiation described in the form of isokerma curves (Air kerma is the unit of dose delivered to air. Higher values- more intense radiation)
- Outside a particular isokerma curve -less than the the curve
- More stray radiation on the X-ray tube side of the patient than II
- Entrance surface of the patient is the main source of scatter - patient's tissues provide shielding on the image intensifier side
- less stray radiation at waist and eye level - X-ray tube is close to the floor - Distance- advantage of large size labs

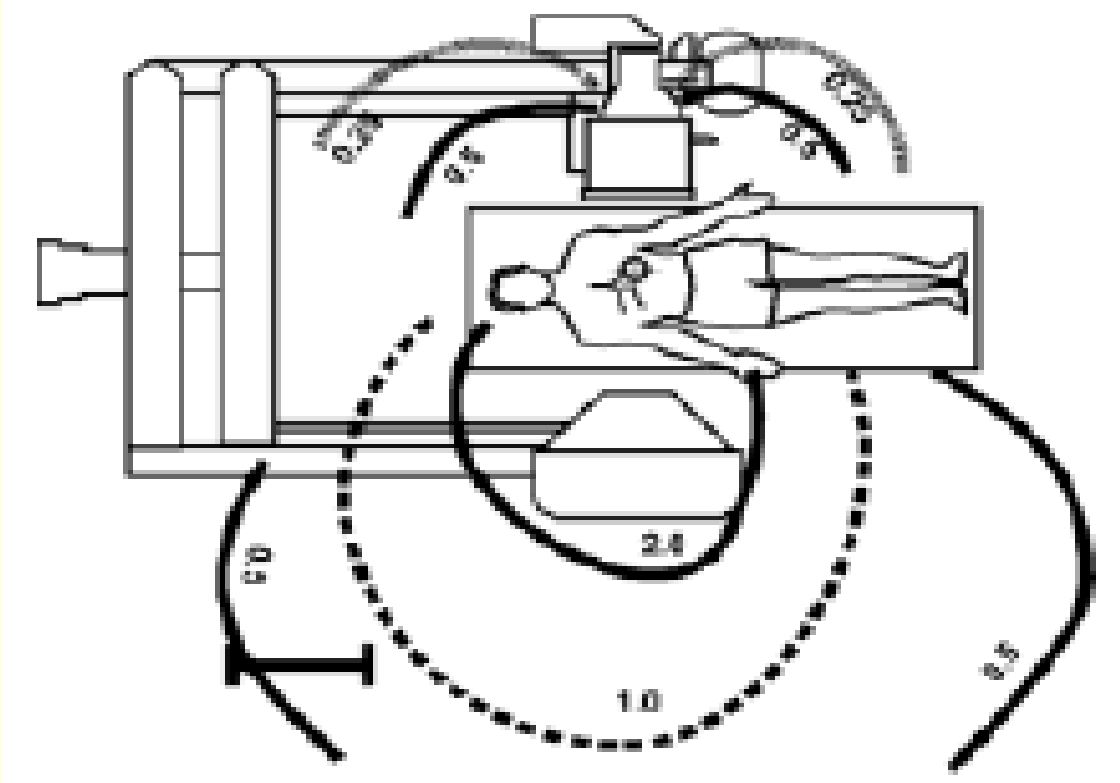
90 LAO 150 cm above floor (at eye level)



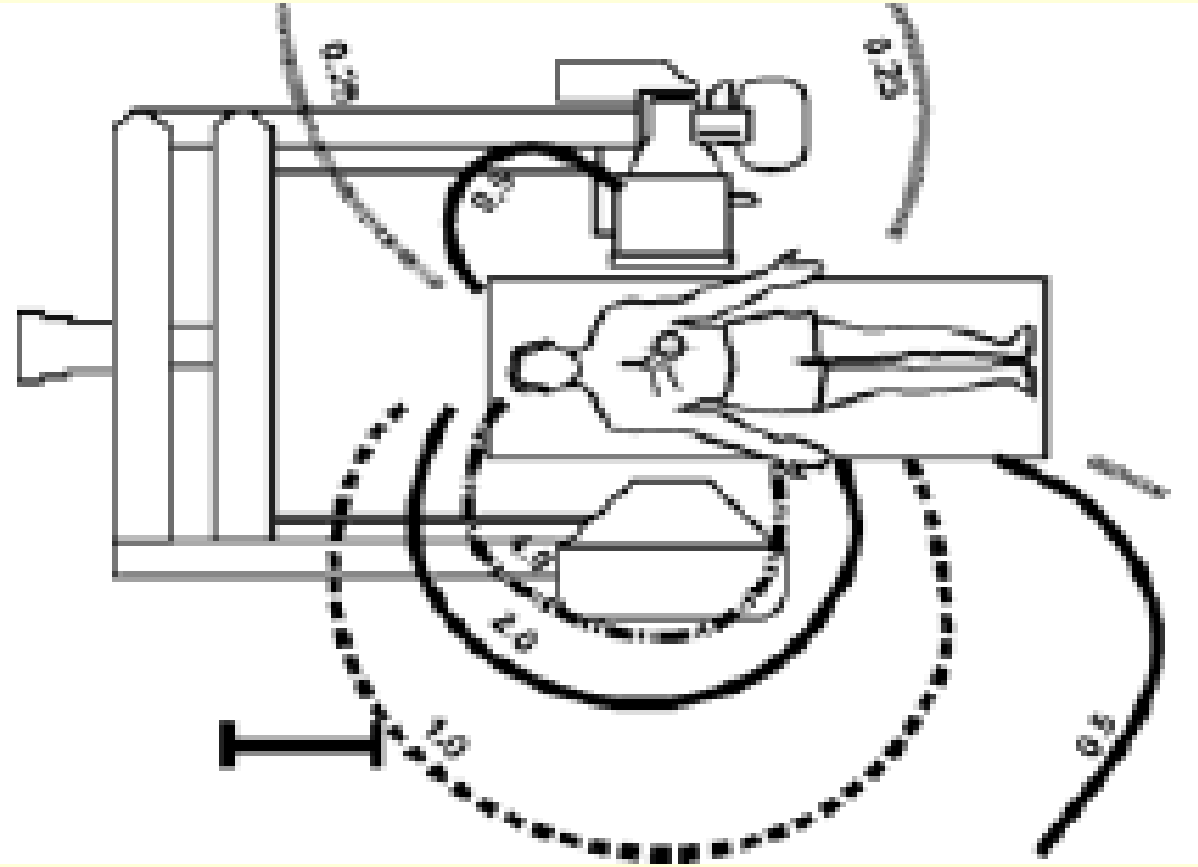
90 LAO 100 cm above floor (at west level)



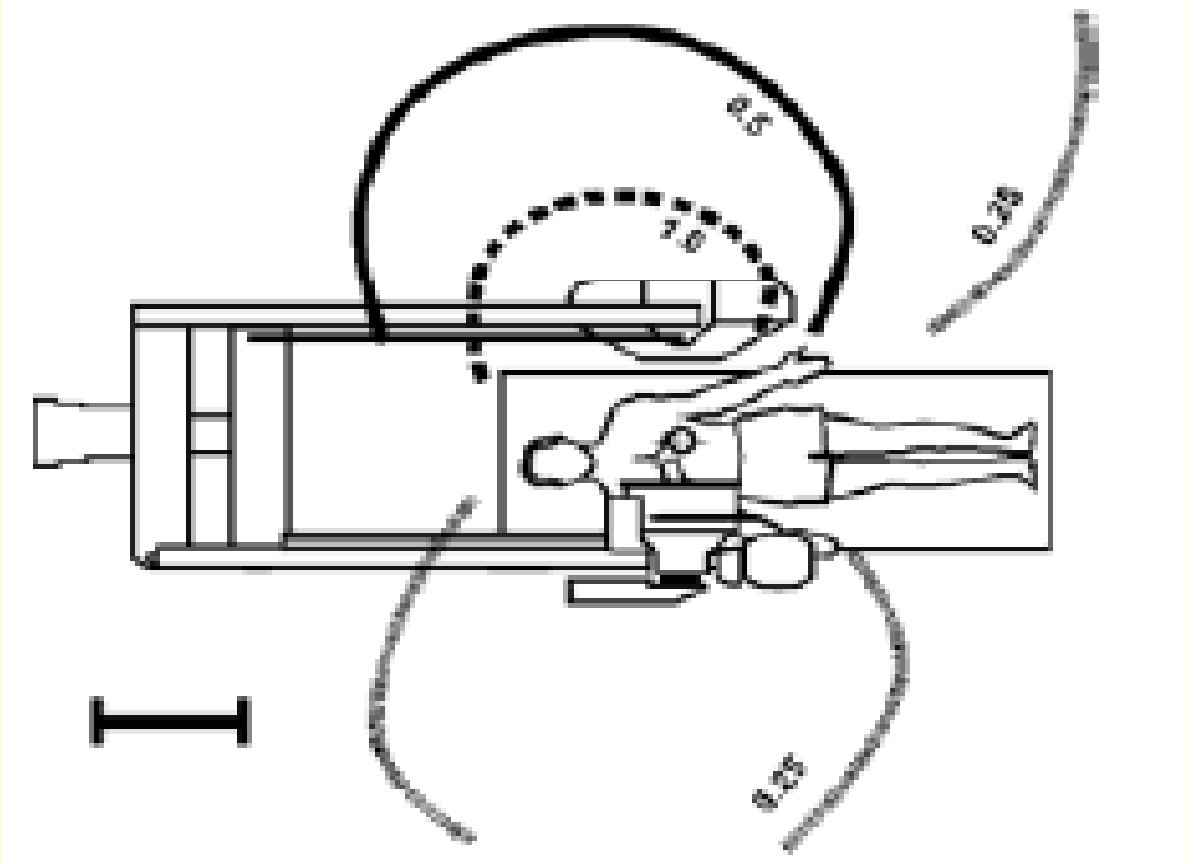
60 LAO 150 cm above floor (at eye level)



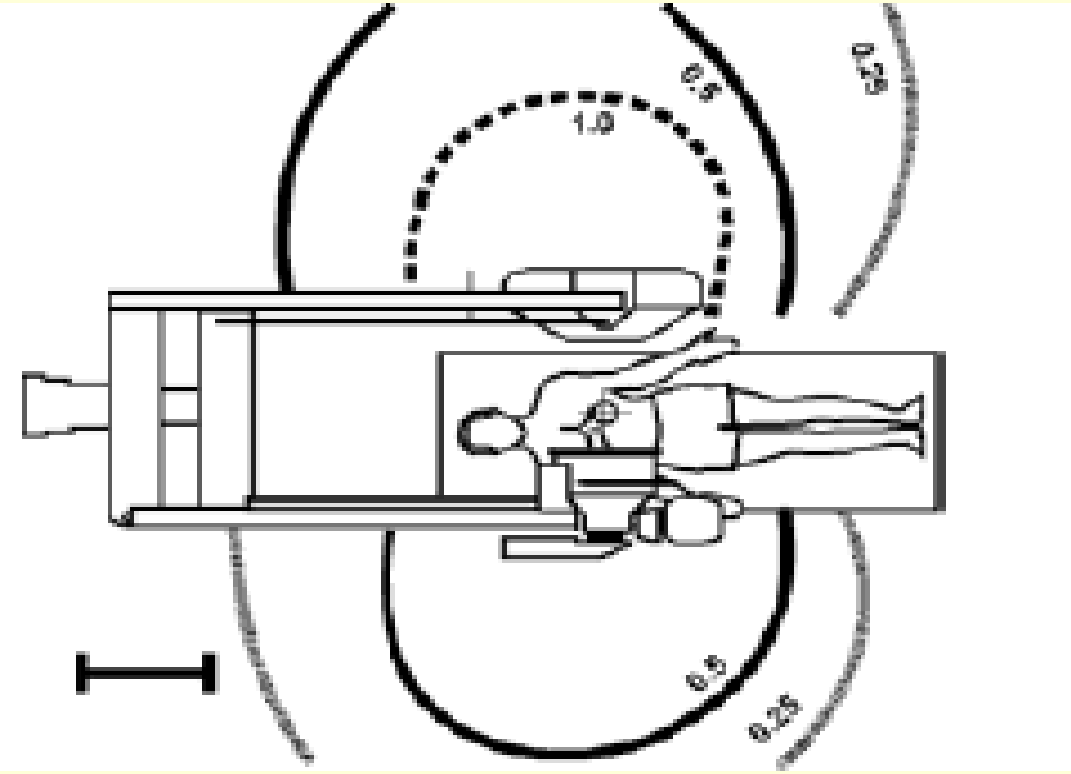
60 LAO 100 cm above floor (at west level)



90 RAO 150 cm above floor (at eye level)



90 RAO 100 cm above floor (at west level)



Typical exposure in Cardiac Angiography

Location	Fluoro	Cine
Image intensifier input	3 mR/min	17 μR/frame*
Entrance skin exposure rate	3 R/min	30 R/min*
Scatter rate at 1 meter†	3 mR/min	30 mR/min
Scatter rate at 2 meters†	0.75 mR/min	7.5 mR/min

* 30 frames/second, 9-inch mode

† Full-field collimation

Biological Effect

Dose Modifying Factors

- **Amount of exposure**
- **Duration of exposure**

– Given rads over minutes > months or years

- **Type of radiation**

– Alpha particles and fission fragments > ionising radiation beta particles or gamma rays

- **Biological variability**

– Age (Children > adults)

– Health status (Sick > healthy)

- **The part of body exposed**

– Total body > partial body exposure

– Major organs > limbs

• Gonads, lens, blood forming organs more radiosensitive

Shielding

- Inversely proportaional to half value layer- atomic number of shielding material, density, size

Biologic Effect

- **Stochastic effect**
- **Deterministic effect**

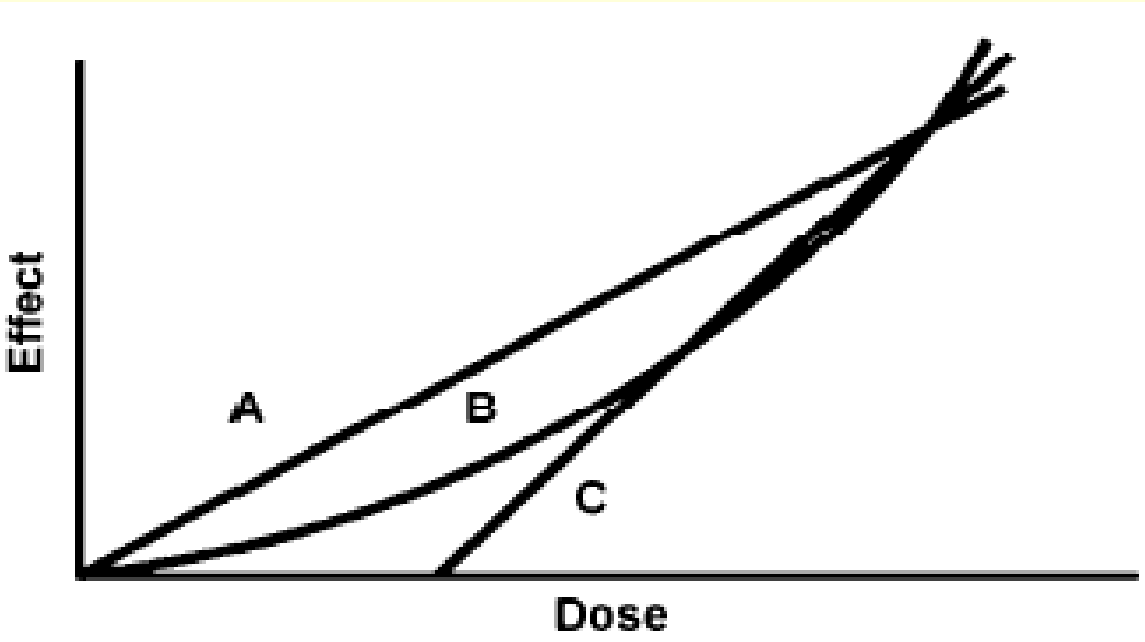


Fig. 1. Dose-response curves. Linear, no threshold (line A); nonlinear, no threshold (line B); linear with a threshold (line C). The linear, no-threshold model (line A) is assumed to be true for radiation protection purposes.

Biologic effects of radiation

- **Stochastic effects of radiation (Cancer/Mutations)**
  - Likelihood of occurrence is dose dependent
  - Severity of effect is dose independent
  - Safe threshold may not exist
  - Risk depends on sex and age at exposure
- **Deterministic (non-stochastic) effects of radiation**
  - Threshold dose: zero occurrence below threshold
  - Severity is dose dependent
  - Relatively high doses, > 0.5 Gy (50 rad)
- **Most susceptible:** Bone marrow, GI mucosa, breast, gonads and lymphatics.
- **Latency:** Few years for leukemia, Considerably longer for solid tumors.
- **Cancer fatalities:** 4% per Sv (whole body)
- **Genetic risk to workers:** 0.4% per Sv (100 rem).

Radiation Dose limit

Maximum permissible dose, annual limits:

- Occupational workers:

Whole body = 5,000 mrem/yr

Eyes = 15,000 mrem/yr

Skin = 50,000 mrem/yr

- If pregnant = 500 mrem/gestational period, not to exceed

50 mrem/month

- General public = 500 mrem, whole body, infrequentexposure
- Patient: No described limit by NRC. Risk vs benefit evaluation by physician

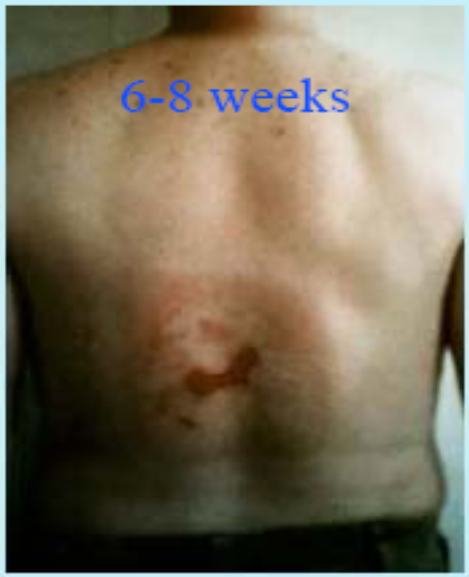
Minimizing the risk of Radiation

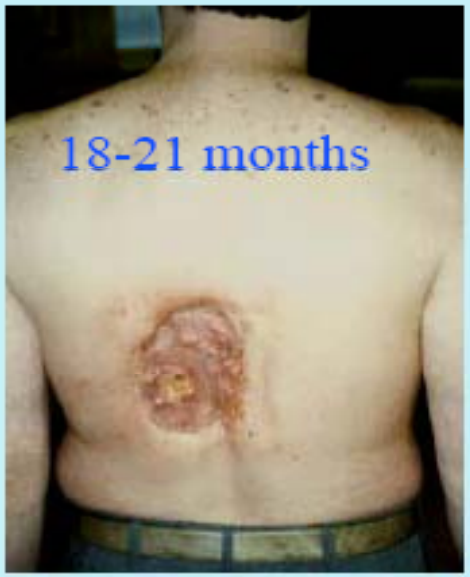
- **Time:** Exposure is proportional to time
  - Keep it brief. Experts can reduce by 1/2!
- **Distance:** Inverse square from source
  - Stand back. Just 12” can reduce by 1/2!
- **Shielding:** Lead barriers are very effective...

Shield Thickness	Transmission
0.25 mm lead-equivalent	4.0 %
0.50 mm lead-equivalent	2.0 %
1.6 mm lead-equivalent	< 0.1 %

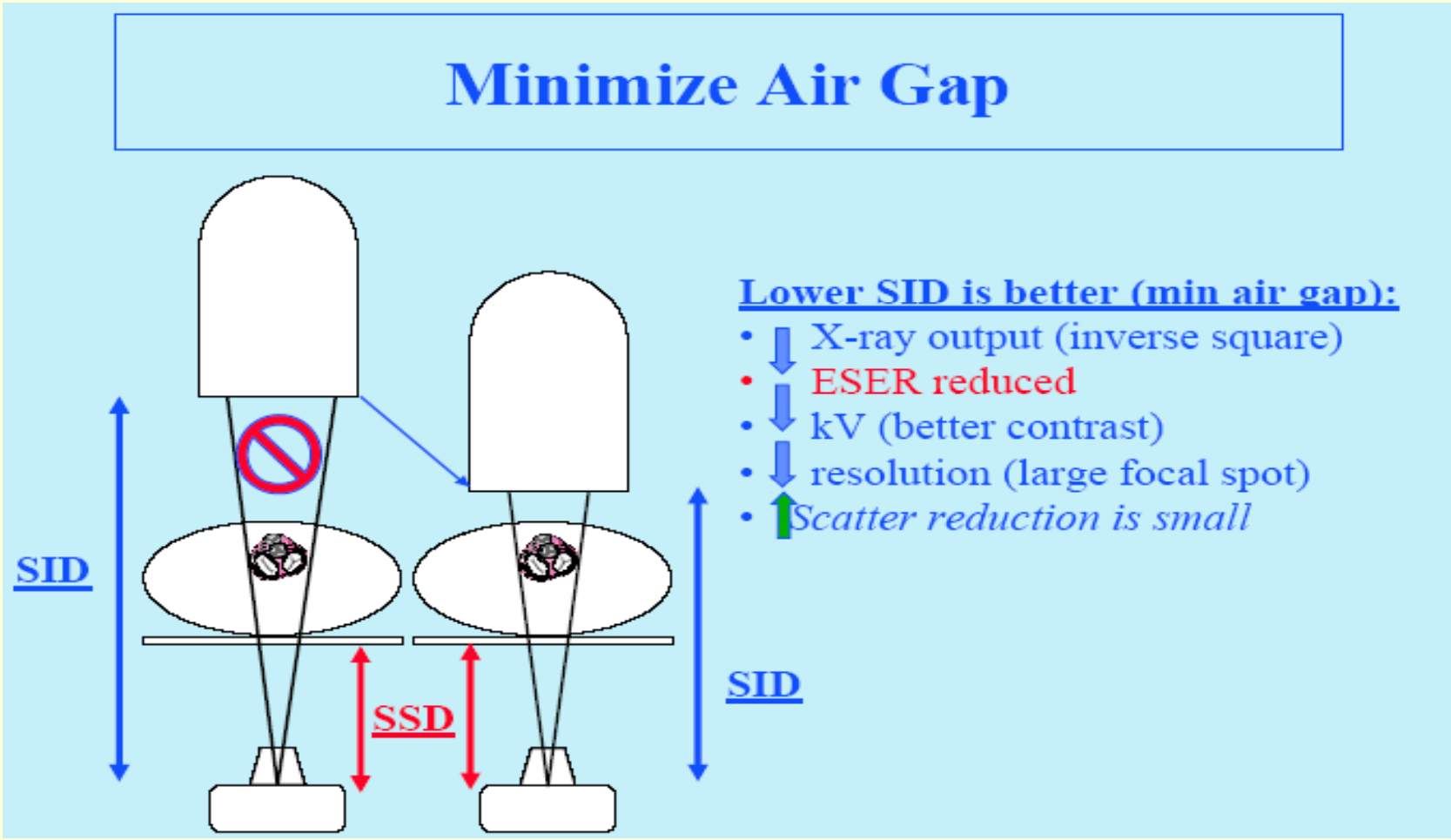
Deterministic Radiation effect in Cardiac Angiography

3 Gy (300 rad)	Temporary Epilation	Hours to days
6 Gy (600 rad)	Main Erythema	Days to one week
15 to 20 Gy (1,500 to 2,000 rad)	Moist Desquamation, Dermal Necrosis, Secondary Ulceration	Weeks to months



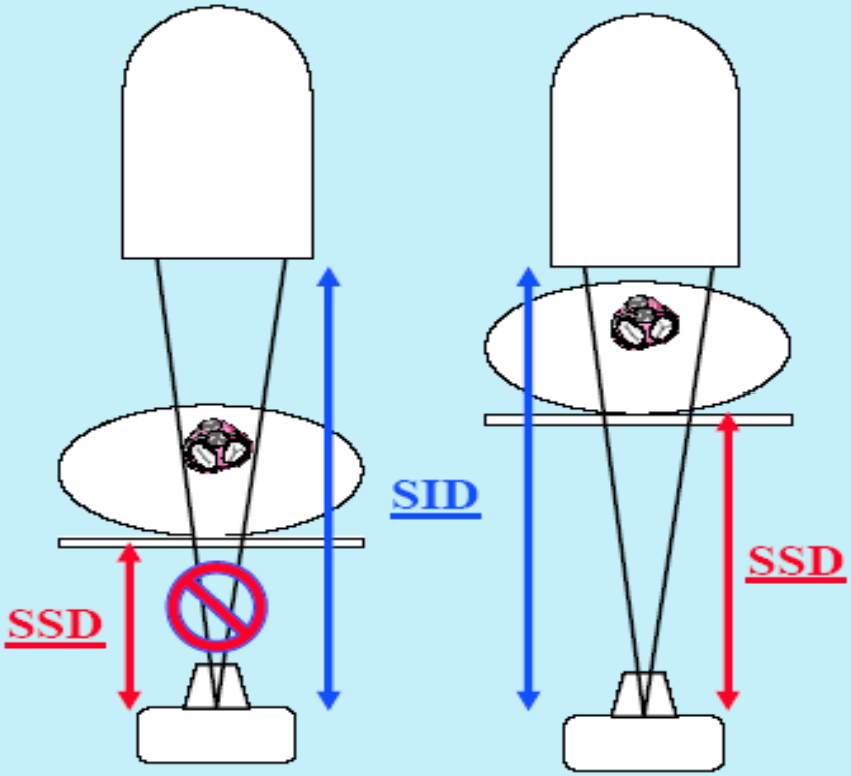


Practical Tips



Practical Tips

Keep X-ray Tube Far From Patient

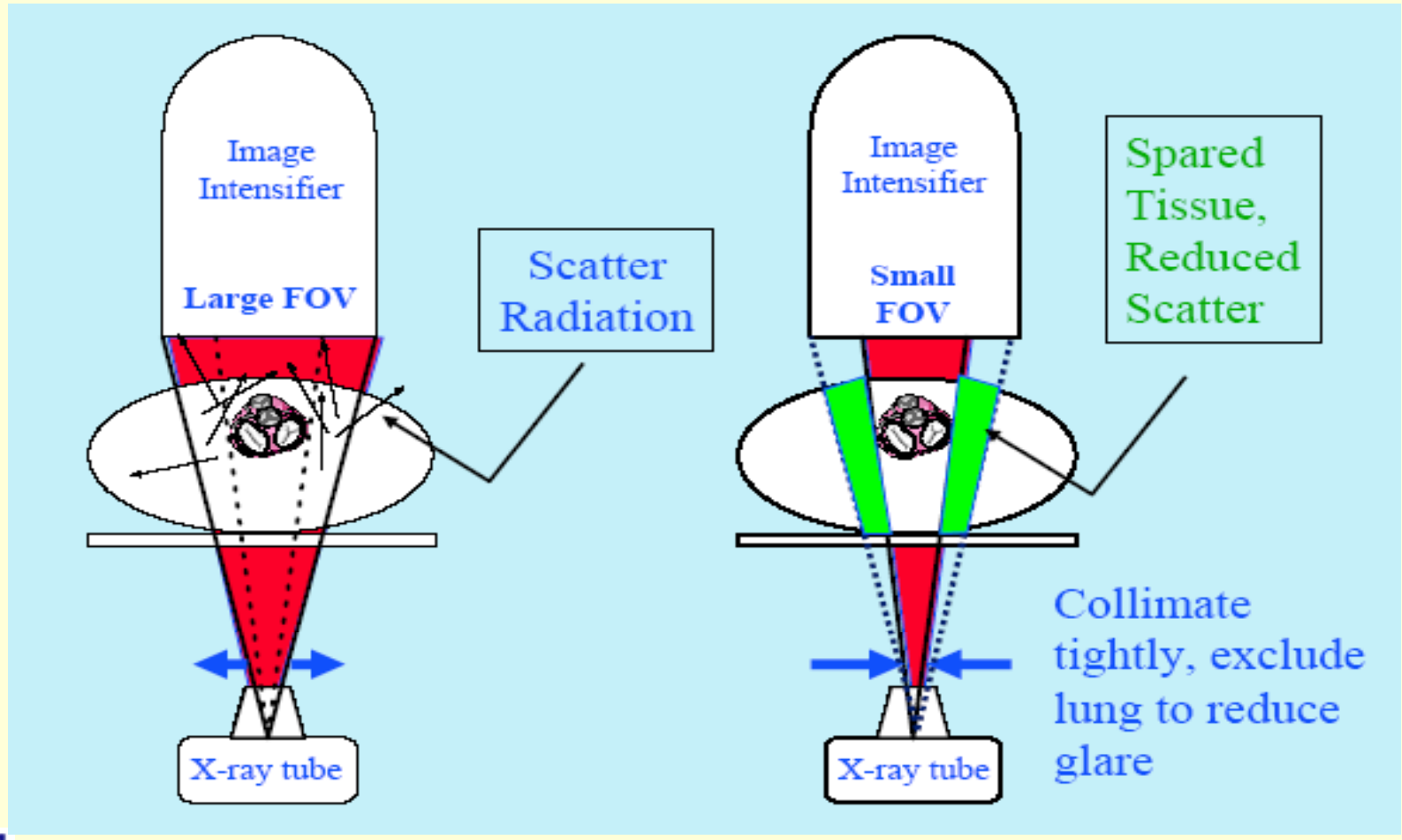


High Source-to-Skin Distance (SSD):

- X-ray tube output unchanged, BUT
- ESER reduced by inverse square
- Improves resolution (large focal spot)

- SSD >> 40 cm
- SID ≥ 100 cm

Collimate to reduce Scatter, Glare, Exposure



Practical Tips

- **Time:** Exposure is proportional to time
  - Keep it brief. Experts can reduce by 1/2! Use last-image-hold versus prolonged fluoroscopy.
- **Distance:** Inverse square from source
  - Keep X-ray tube as far from skin as possible (SSD)
- **Distribution:** Vary views when possible during long procedures to keep skin dose below threshold
- **Dose Rate:** Minimize use of boost mode and cineangiography versus lower-dose fluoroscopy

Practical Tips

How to minimize radiation exposure

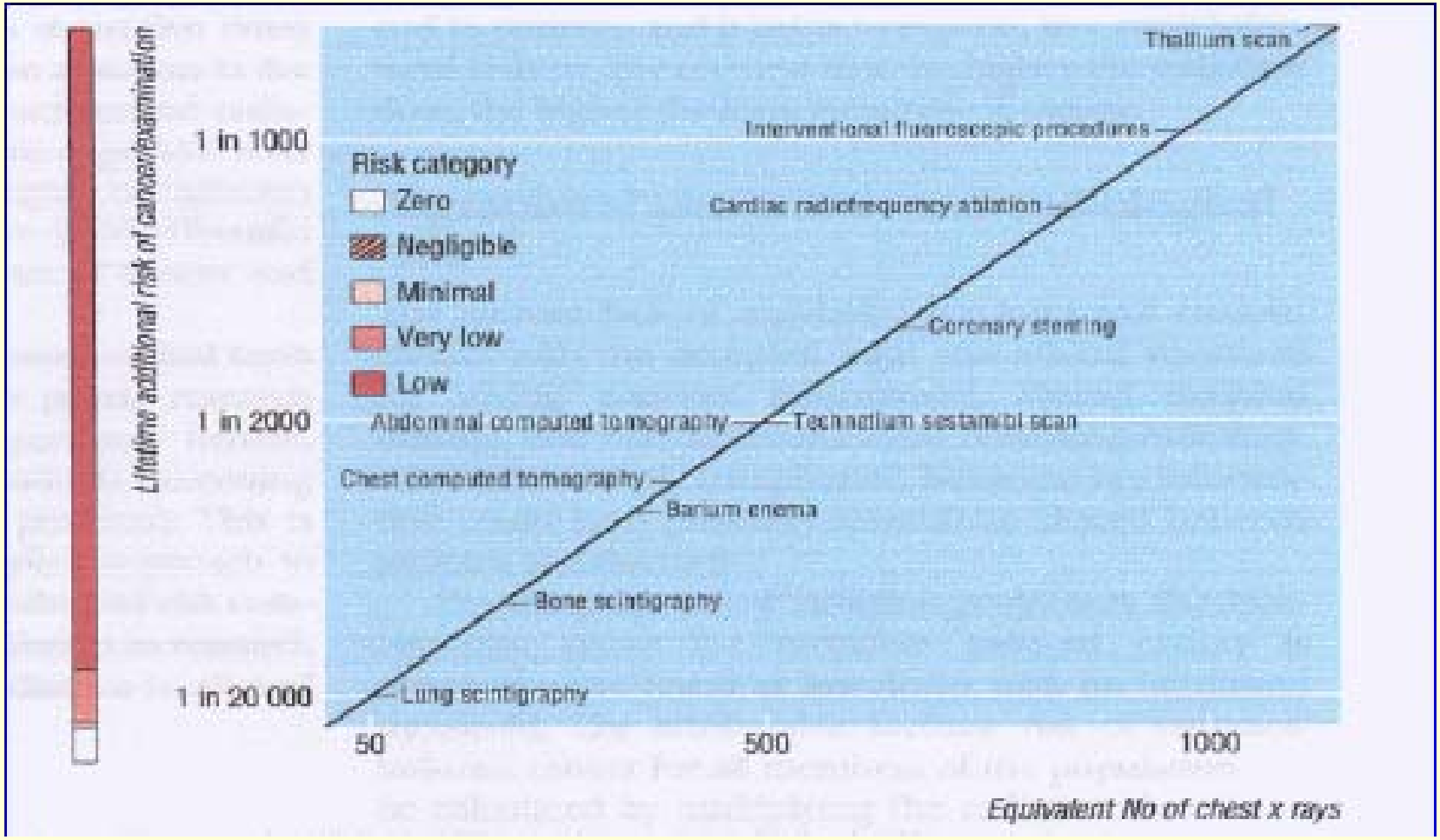
Technical Method

- **X-ray system**
  - Lower dose per frame
  - Increase filtration
  - Use pulsed flouroscopy
  - High image intensifier reception
- **Digital system**
  - Instant replay
  - Edge enhansement
  - Lower flouro frame rate

Imaging Technique

- **Time**
  - Shorter “picks”
  - Fewer “picks”
  - Don’t record flouro
- **Distance**
  - Stand back
  - Increase SSD
  - Minimize air gap
- **Shielding**
  - Collimate
  - Minimize air gap
  - Use portable shields
  - Wear 2- piece aprons

Graphical Presentation of Cancer Risk and Radiation Dose



Picano, E. BMJ 2004;328:578-580

Radiation Dose From Selected Nuclear Cardiology Procedures

Study	Total-body effective dose (mSv)
Tc-99m tetrofosmin rest-stress (10 mCi + 30 mCi)	10.6
Tc-99m sestamibi 1-day rest-stress (10 mCi + 30 mCi)	12
Tc-99m sestamibi 2-day stress-rest (30 mCi + 30 mCi)	17.5
Tl-201 stress and reinjection (3.0 mCi + 1.0 mCi)	25.1*
Dual-isotope (3.0 mCi Tl-201 + 30 mCi Tc-99m)	27.3
Rb-82 PET myocardial perfusion (45 mCi + 45 mCi)	16†
Ge-68 transmission for PET	0.08
Gd-153 transmission for SPECT	0.05
Cs-137 transmission for PET	0.01
CT transmission source for PET (low-dose CT protocol)	0.8
Fluorine 18 fluorodeoxyglucose PET viability (10 mCi)	7
Radionuclide angiogram, Tc-99m–labeled red blood cells (20 mCi Tc-99m)	5.2
Iodine 123 MIBG myocardial imaging (10 mCi)	4.8
Iodine 123 BMIPP myocardial imaging (5 mCi)	4.7
Ventilation/perfusion lung (200 MBq Tc-99m MAA + 70 MBq Tc-99m aerosol)	2.8

MIBG, metaiodobenzylguanidine; *BMIPP*, beta-methyl-iodophenyl-pentadecanoic acid; *MAA*, macroaggregated albumin.
*Thallium dose based on package insert is 39 mSv/3 mCi.
†Rubidium dose based on calculations from the package insert is 5.5 mSv for 60 mCi (rest) + 60 mCi (stress).[17]

RC Thomas and J Cullom. J Nucl Cardiol 2006;13:19-23

Cardiology department, SVCMC

Radiation Dose From Selected Cardiac CT Procedures

Study	Total-body effective dose (mSv)
EBCT coronary calcium scoring (male), retrospective ECG triggering	1.0
EBCT coronary calcium scoring (female), retrospective ECG triggering	1.3
MDCT coronary calcium scoring (male), no ECG pulsing	2.3–2.9
MDCT coronary calcium scoring (female), no ECG pulsing	3.2–3.6
MDCT coronary calcium scoring (male), with ECG pulsing	1.3–1.4
MDCT coronary calcium scoring (female), with ECG pulsing	1.9–2.0
16-Slice MDCT coronary CTA (male), no ECG pulsing	7.9–11.8
16-Slice MDCT coronary CTA (female), No ECG pulsing	11.1–16.3
16-Slice MDCT coronary CTA (male), with ECG pulsing	4.0–6.2
16-Slice MDCT coronary CTA (female), with ECG pulsing	5.6–8.7
64-Slice MDCT coronary CTA (male), no ECG pulsing	9.6–15.2
64-Slice MDCT coronary CTA (female), no ECG pulsing	13.5–21.4
64-Slice MDCT coronary CTA (male), with ECG pulsing	4.8–10
64-Slice MDCT coronary CTA (female), with ECG pulsing	6.8–14

Data are from references 2, 6, 7, and 18-21 and courtesy of Dr Thomas Flohr.
EBCT, Electron-beam computed tomography; *ECG*, electrocardiographic; *MDCT*, multidetector computed tomography; CTA, computed tomography angiography.

RC Thomas and J Cullom. J Nucl Cardiol 2006;13:19-23

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