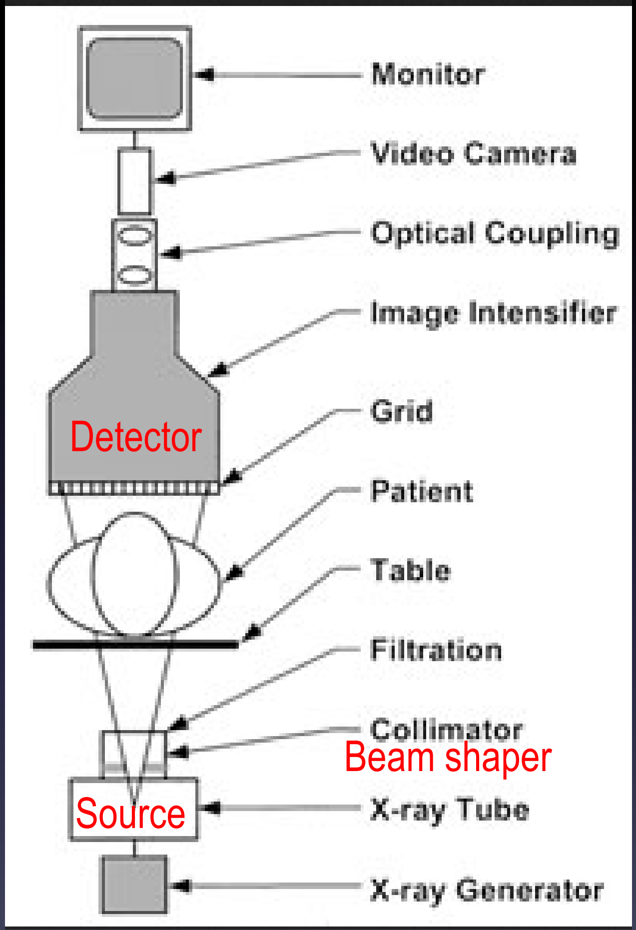
Practical Photon Physics & Radiation Safety

Isabel Newton, MD, PhD
Vascular and Interventional Radiology
University California, San Diego
VA San Diego Healthcare System


Everything You Need
To Know About Radiation
And How to
Protect Yourself!

1: BASICS

How fluoroscopic images are generated


Monitor
Video Camera
Optical Coupling
Image Intensifier
Detector
Grid
Patient
Table
Filtration
Collimator
Beam shaper
Source
X-ray Tube
X-ray Generator

Scatter radiation is the highest near the point where the beam enters the patient's skin

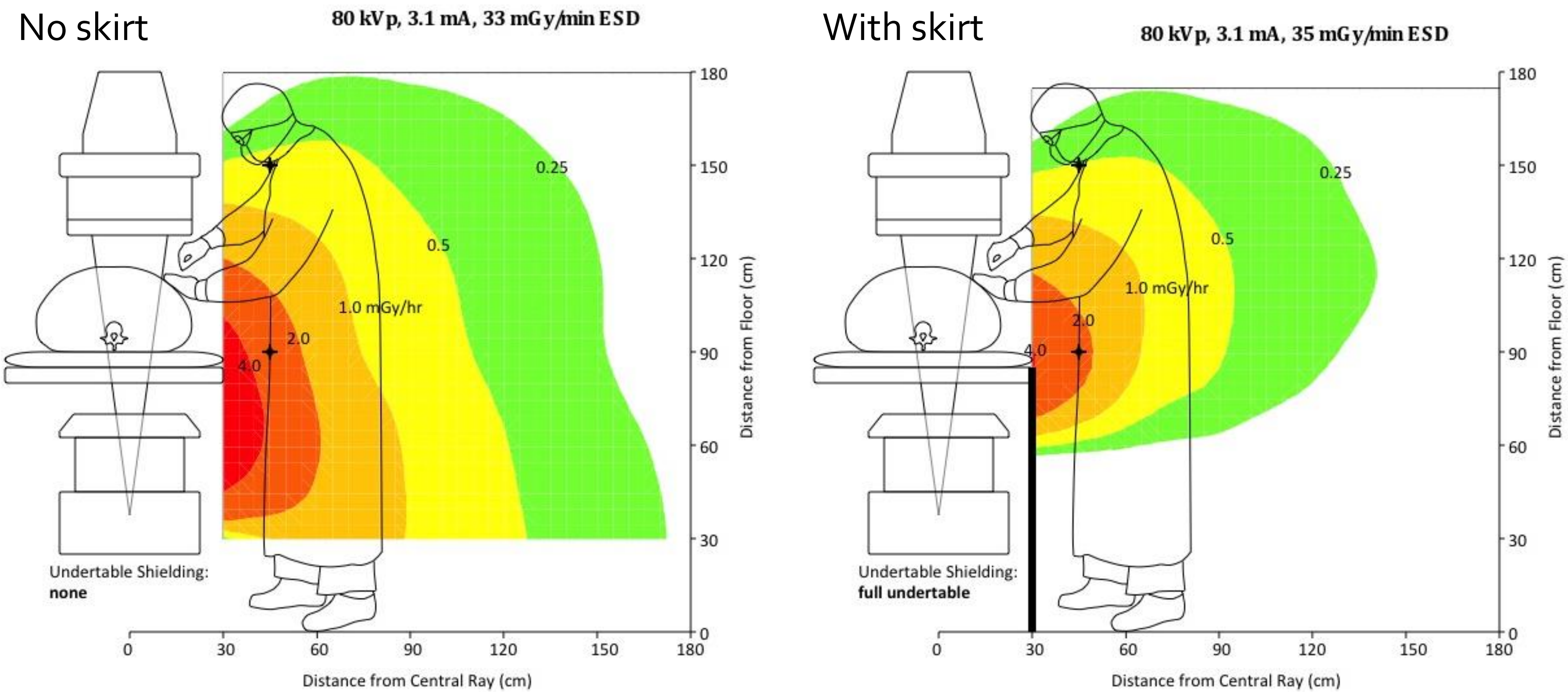


Figure: Scatter radiation distribution. A) Without table skirt. B) With table skirt. Reproduced with permission from Schueler et al. "An Investigation of Operator Exposure in Interventional Radiology". *RadioGraphics* 2006; 26:1533-1541

Physics: it's not just for physicists

- Understanding how fluoroscopic images are created is *essential*
  - To generating *diagnostic* quality images
  - To understanding *artifacts*
  - To protecting patients and operators from harmful effects of radiation

So, let's get PHYSICAL!

Radiation interactions: *beam meets tissue*

1) Properties of the beam:

- Energy of photons (kV)
  - Higher voltage = less attenuation/ greater penetration = lower contrast
- Number of photons (mA)
  - More photons = more to interact with the tissue but higher chance some will reach the detector

2) Properties of the tissue:

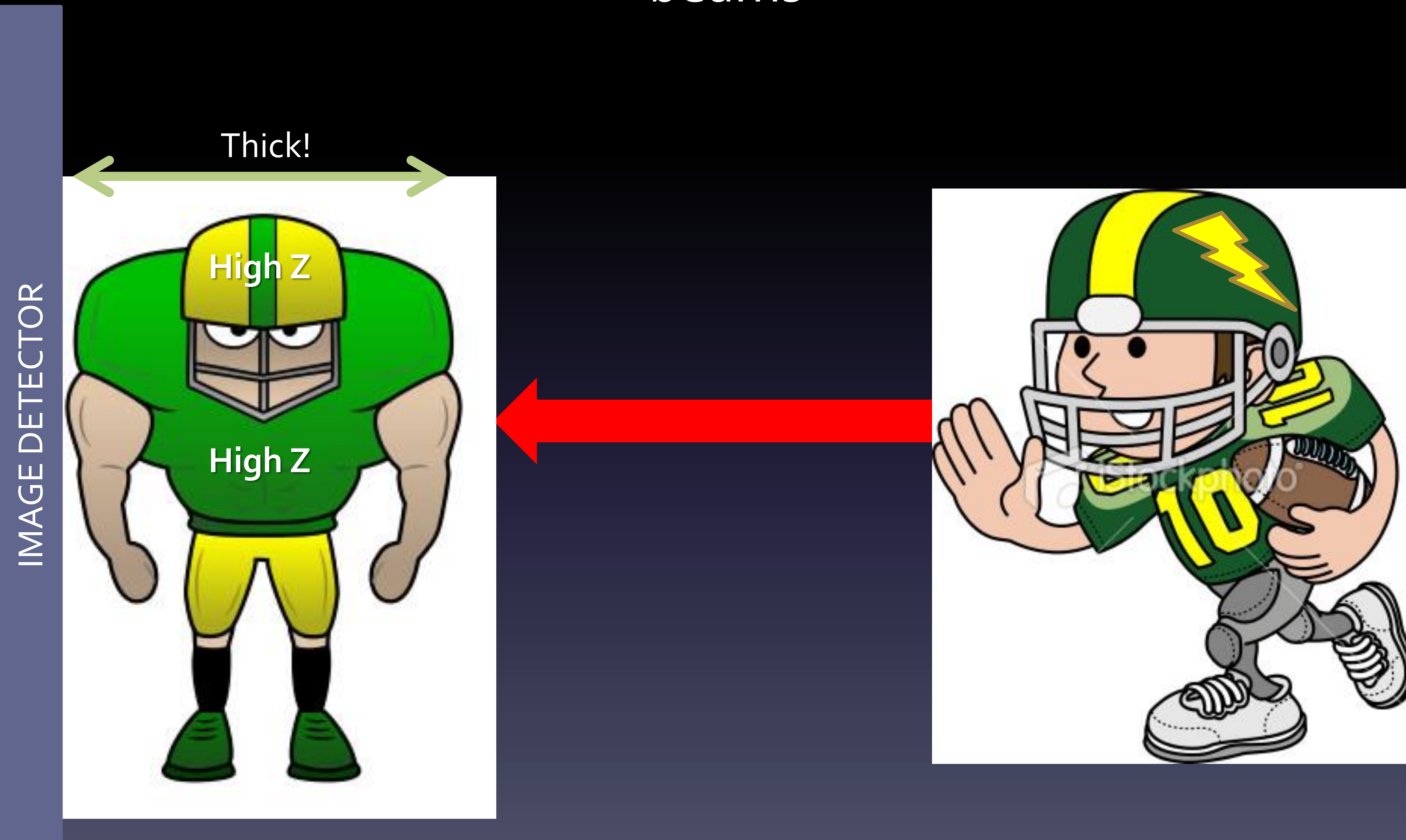
- Photons are least able to penetrate dense, high Z, thick tissue
  - Density from least (photons pass through) to most (photons absorbed):
    - Air, fat, soft tissue, bone, contrast, metal
  - Tissue thickness:
    - Thicker body parts remove more x-rays from the beam than thinner parts
    - Thicker body parts also produce more scatter

Radiation interactions are like football

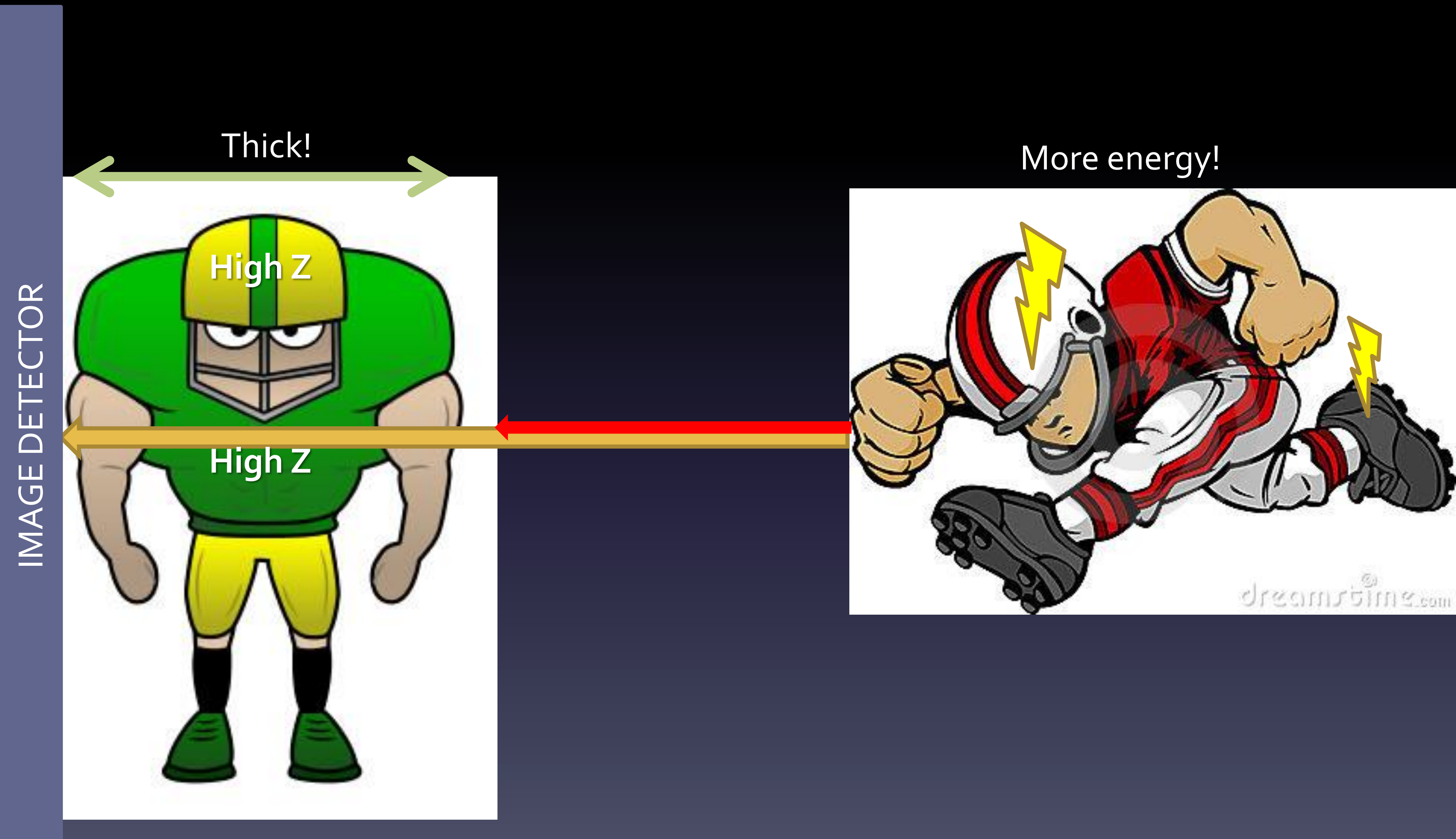
Radiation interactions are like football

IMAGE DETECTOR

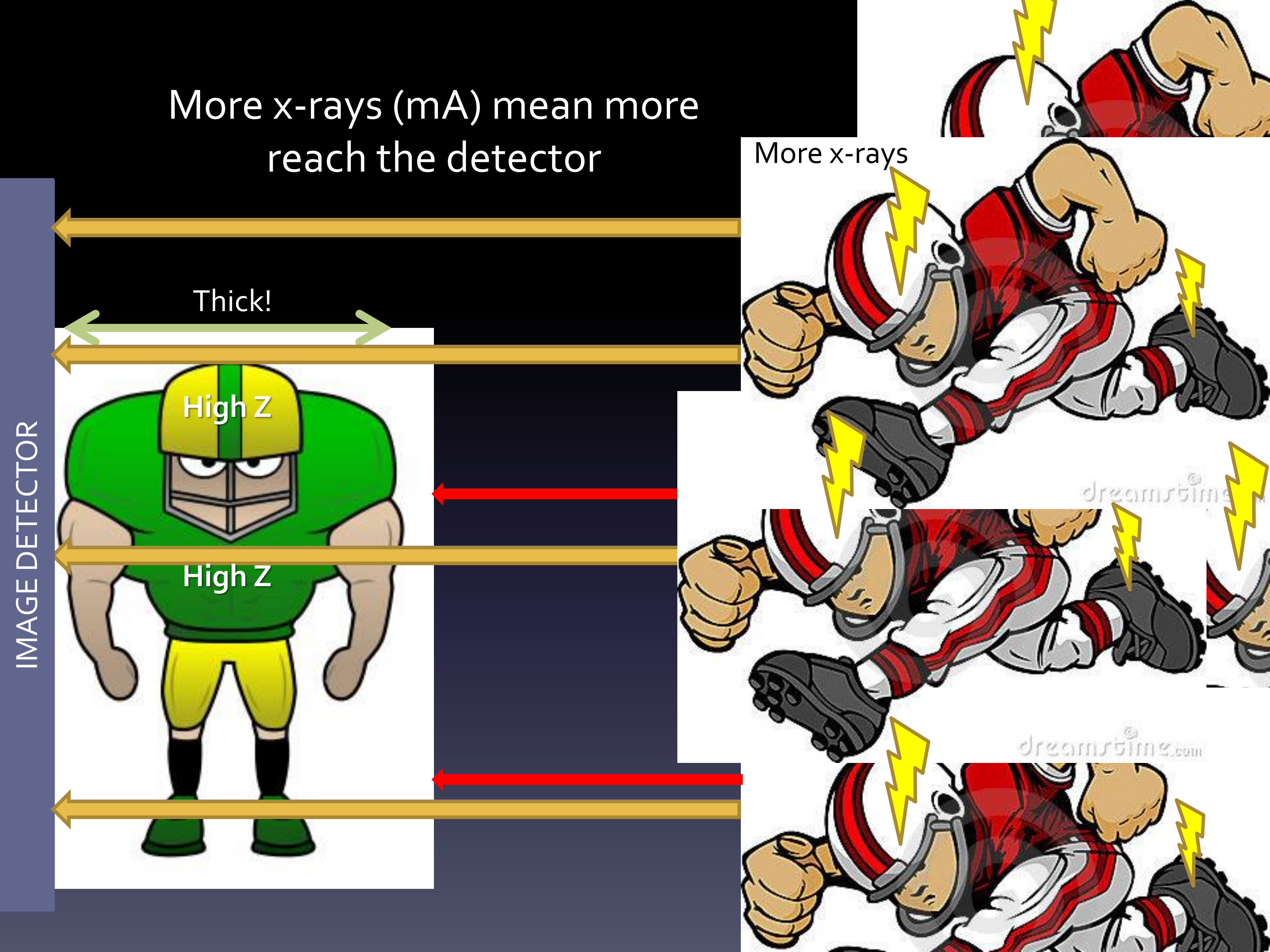
Thick tissues, with high atomic number attenuate beams



Higher energy beams (kV) penetrate better



More x-rays (mA) mean more reach the detector



Dense tissues attenuate beams

IMAGE DETECTOR

Noise

#1 source of noise = <u>**Quantum mottle**</u>

QM = random variation in the # of x-ray photons detected by individual areas on the detector

Noise

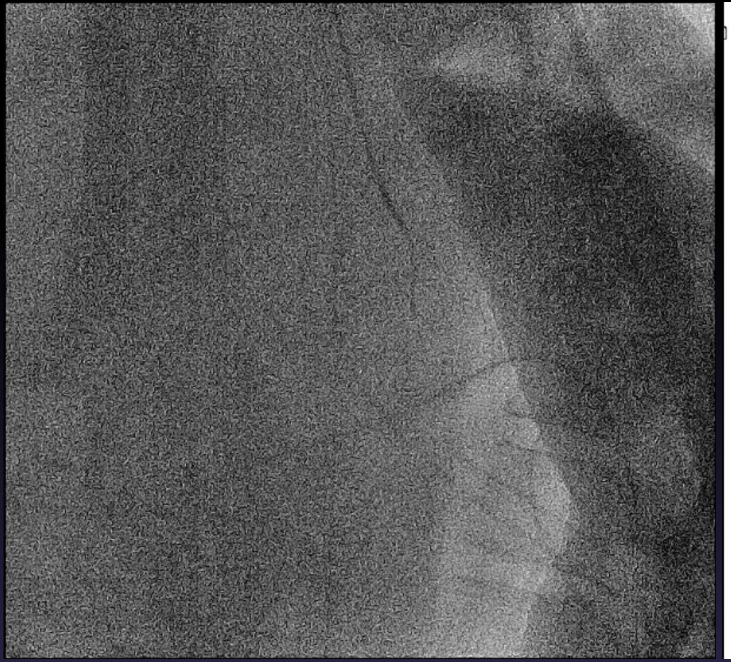
Factors that can influence image noise include:

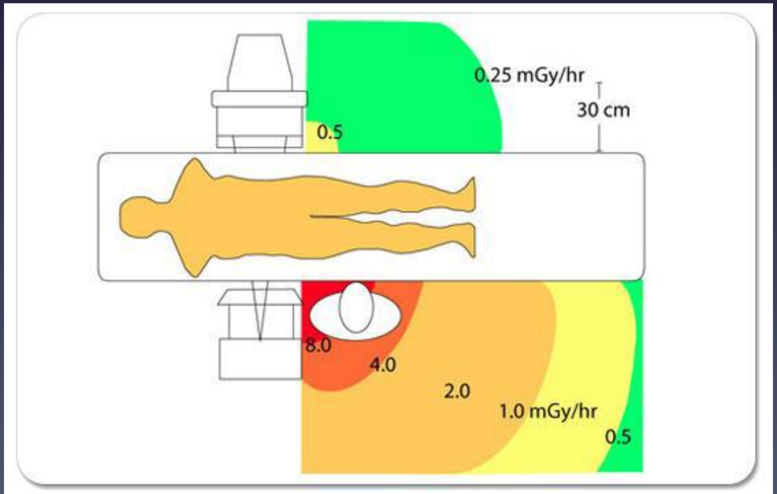
- mA and kV:
  - To maintain image quality while penetrating thicker tissues (obese, lateral views), you must increase dose or use more energetic beams
- Resolution:
  - With electronic magnification, the smaller detector area requires more photons per area to maintain the same level of noise
    - Must increase the mA and sometimes kV to keep apparent noise constant
- Duration of the acquisition:
  - Longer fluoro pulses increases signal at the expense of motion blurring
- Scattered radiation reaching the detector:
  - Higher scatter with thicker body parts
  - Larger x-ray field of view

Set-up for NOISE in fluoroscopy

- Thick tissues
  - Obese habitus
  - Arms in the way
  - Lateral view
- Lack of collimation
- Long acquisition with motion blurring

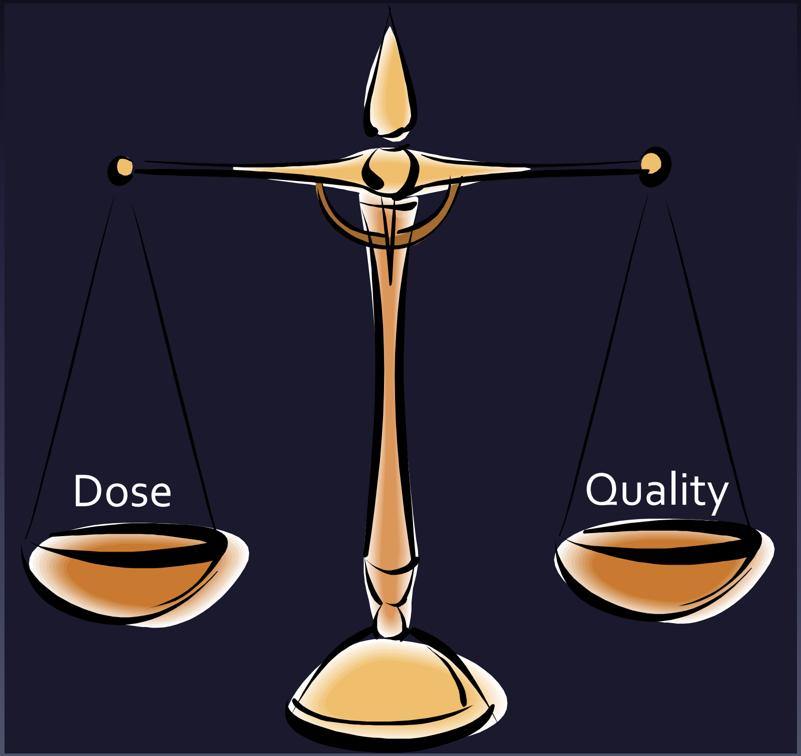
Lateral view: *Which is the best image?*





How can we use dose *wisely* to make diagnostic images?

- Imperative word: "*Diagnostic*"
  - not "*Gorgeous*"



Factors affecting dose

- Photon number and energy
  - Tube filtration, generator voltage, current
  - Pulse rate/ number of images taken
  - Fluoroscopy time
- Beam geometry
  - Distances between the patient – source – II
    - Field of view
    - Magnification
  - Collimation
- Photon attenuation
  - Patient body habitus
  - Thickness of tissue being imaged
- Scattered radiation is directly proportional to patient dose

2: SAFETY

The biological effects of radiation

RADIATION BIOLOGY

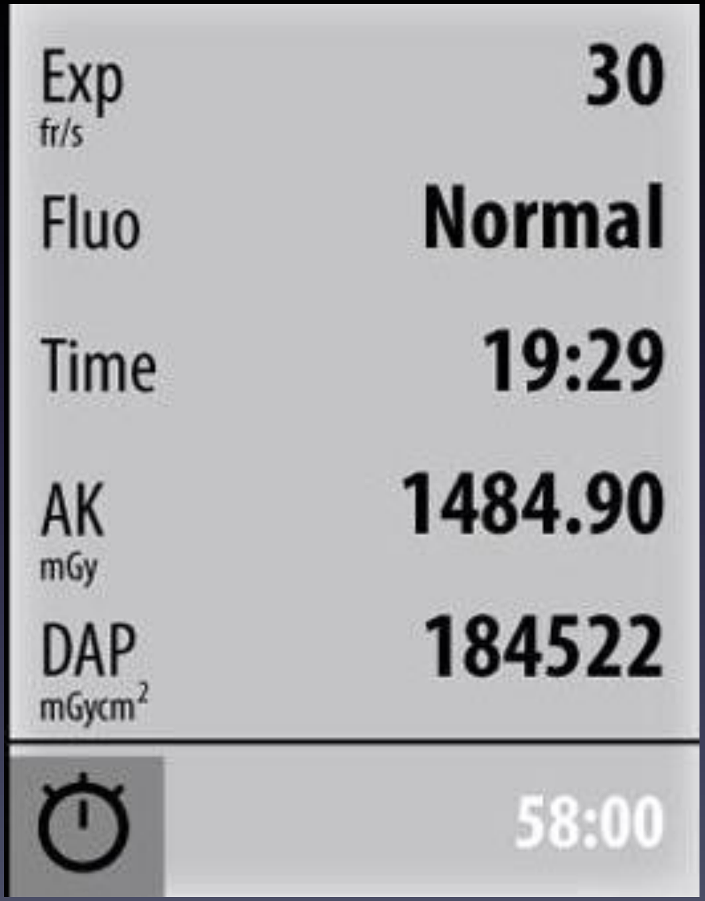
- Effects of radiation
  - Stochastic
  - Deterministic

Stochastic effects

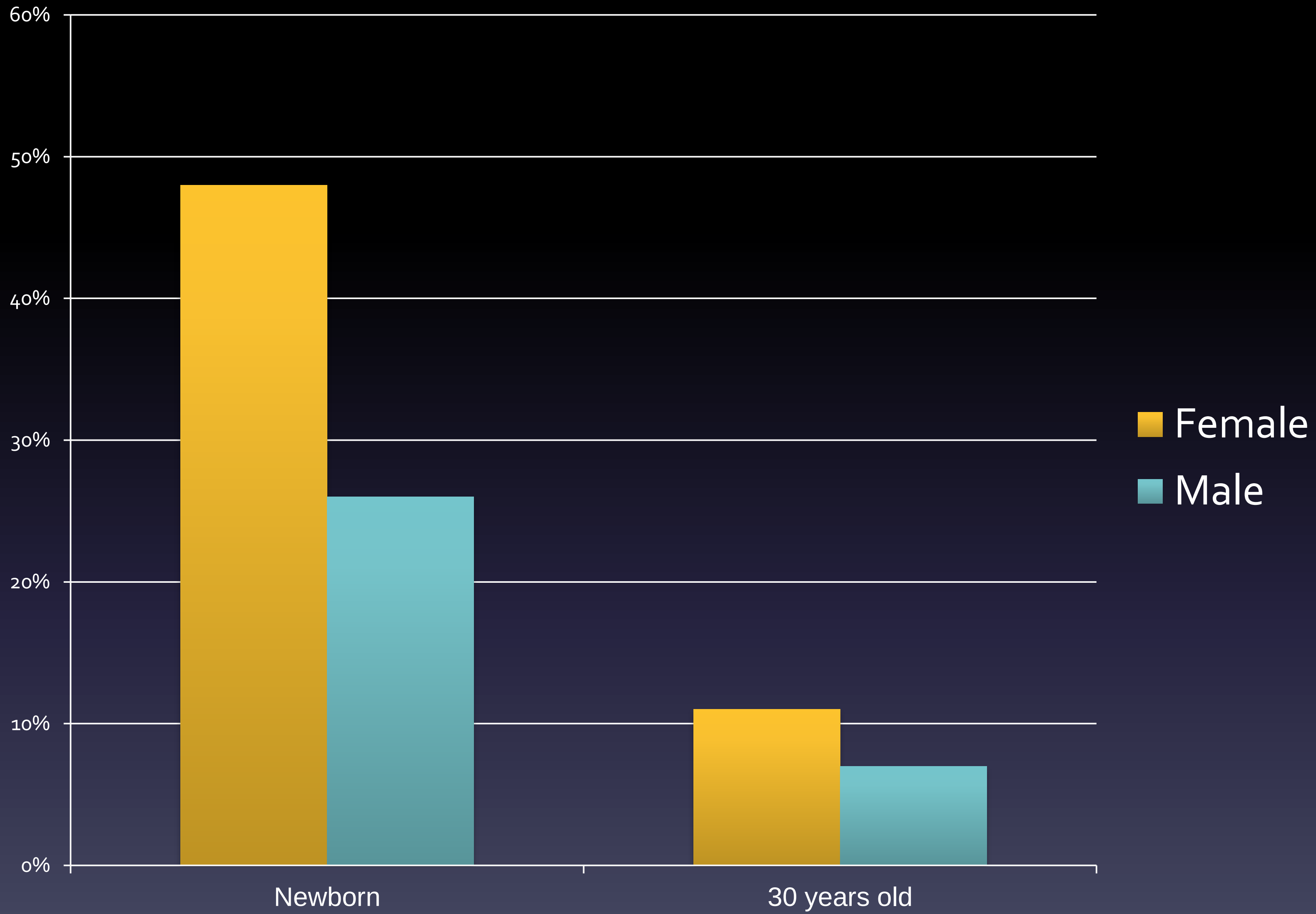
- SER depend on CHANCE
  - May or may not occur
  - More absorbed dose means higher probability of developing SER
- No threshold
  - Any amount of radiation can cause SER
  - Severity of SER is independent of absorbed dose
    - A small dose of radiation can induce an aggressive cancer
    - A large dose of radiation can induce a curable cancer
- Examples:
  - Radiation-induced cancer
  - Genetic modifications

DAP (total energy deposition across entire exposed skin) is the best predictor of SER (cancer)

- Pulse rate
- Normal vs boost
- Fluoro time
- Air Kerma
- Dose Area Product
- Exam time

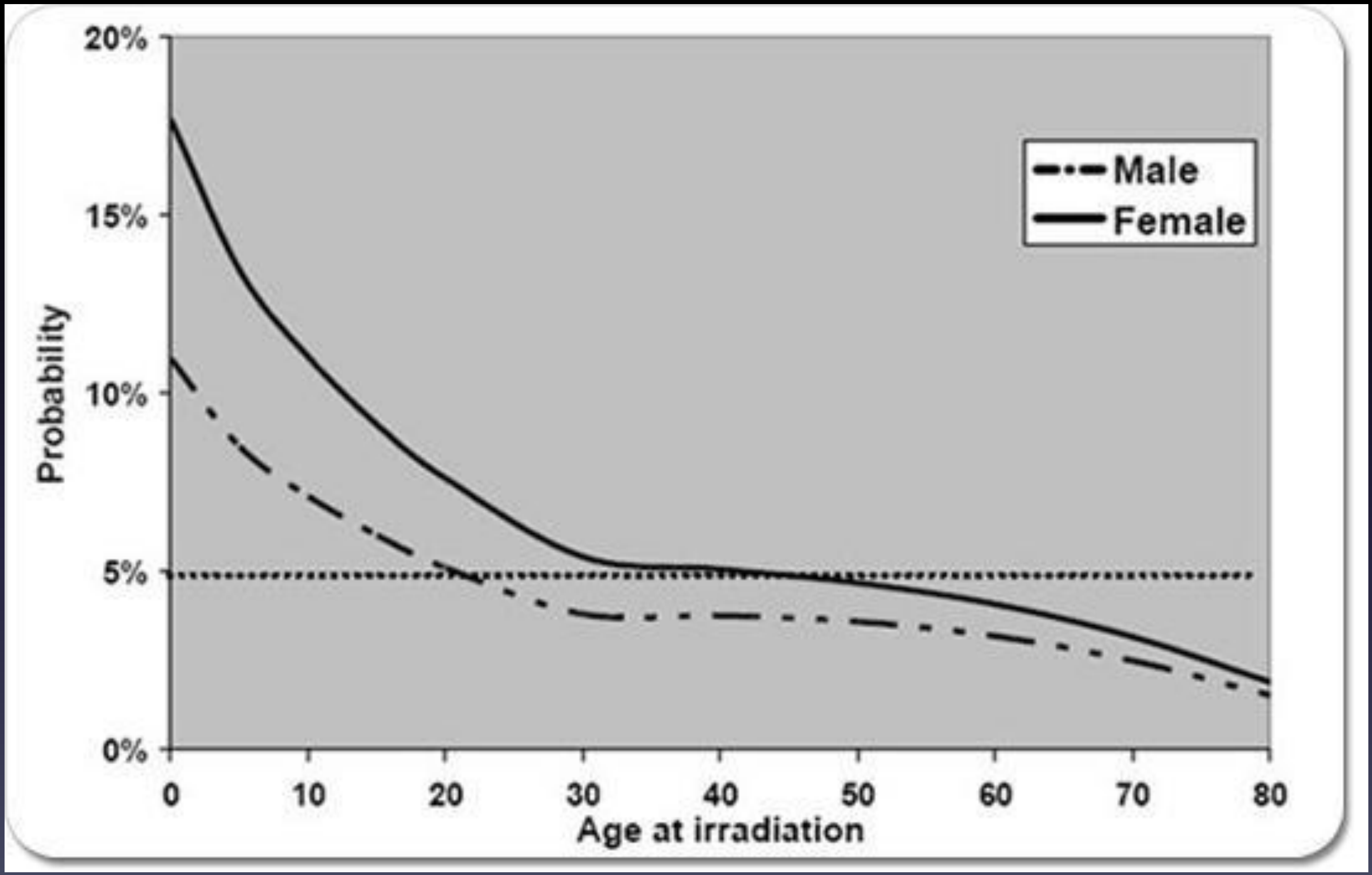


RISK OF CANCER INCIDENCE PER GY WHOLE BODY IRRADIATION



Adapted from: Huda W. *Review of Radiologic Physics*. 3rd ed. Lippincott Williams & Wilkins; 2010.

Risk of cancer after radiation goes down with age



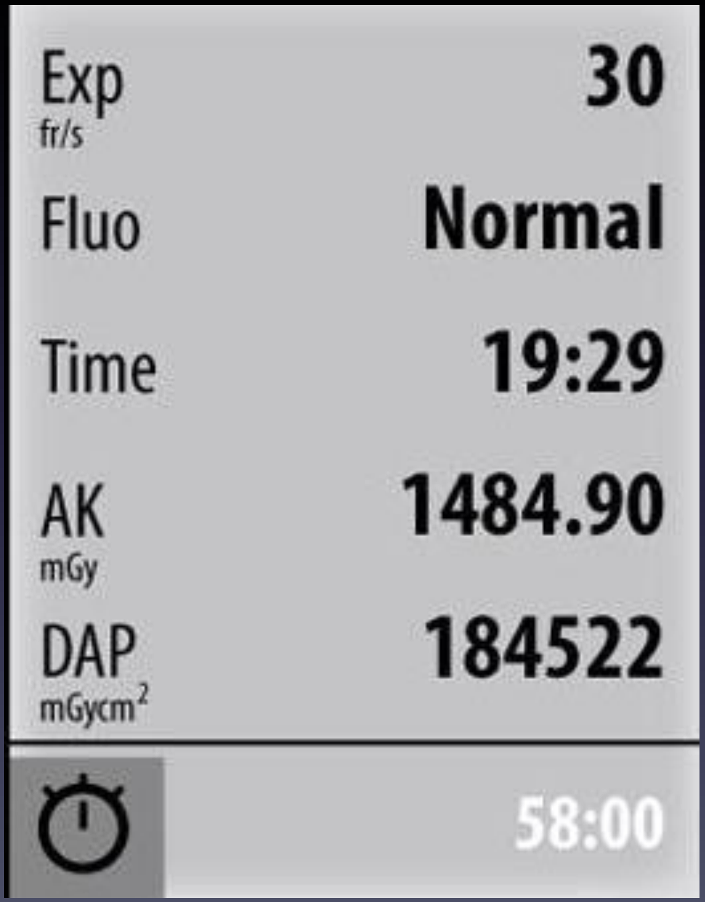
Source: National Academy of Sciences (2006)

Deterministic effects

- Effects of radiation that occur after a threshold of absorbed dose is reached (usually 2 Gy)
  - above that dose, the severity of symptoms is dose-dependent
- Examples of DER:
  - Erythema, skin burns
  - Hair loss
  - Cataracts
  - Infertility
  - Impaired hematopoiesis
- How did we figure this out? Direct knowledge & extrapolation based on…
  - Atomic bombs (Hiroshima, Nagasaki, Churnobyl)
  - Observation after radiation exposure
  - Experiments on animals

AK (radiation at a point) is the best predictor of DER (skin injury)

- Pulse rate
- Normal vs boost
- Fluoro time
- Air Kerma
- Dose Area Product
- Exam time



Potential clinical effects of radiation exposures to the skin and lens of the eye

Effects	Threshold dose (Gy)	Time of onset
SKIN		
Early transient erythema	2	2-24 hours
Main erythema reaction	6	~1.5 weeks
Temporary epilation	3	~3 weeks
Permanent epilation	7	~3 weeks
Dermal necrosis	>12	>52 weeks
EYE		
Lens opacity (detectable)	>1-2	>5 years
Lens/cataract (debilitating)	>5	>5 years

http://members.sirweb.org/members/misc/Interventional_Fluoroscopy.pdf

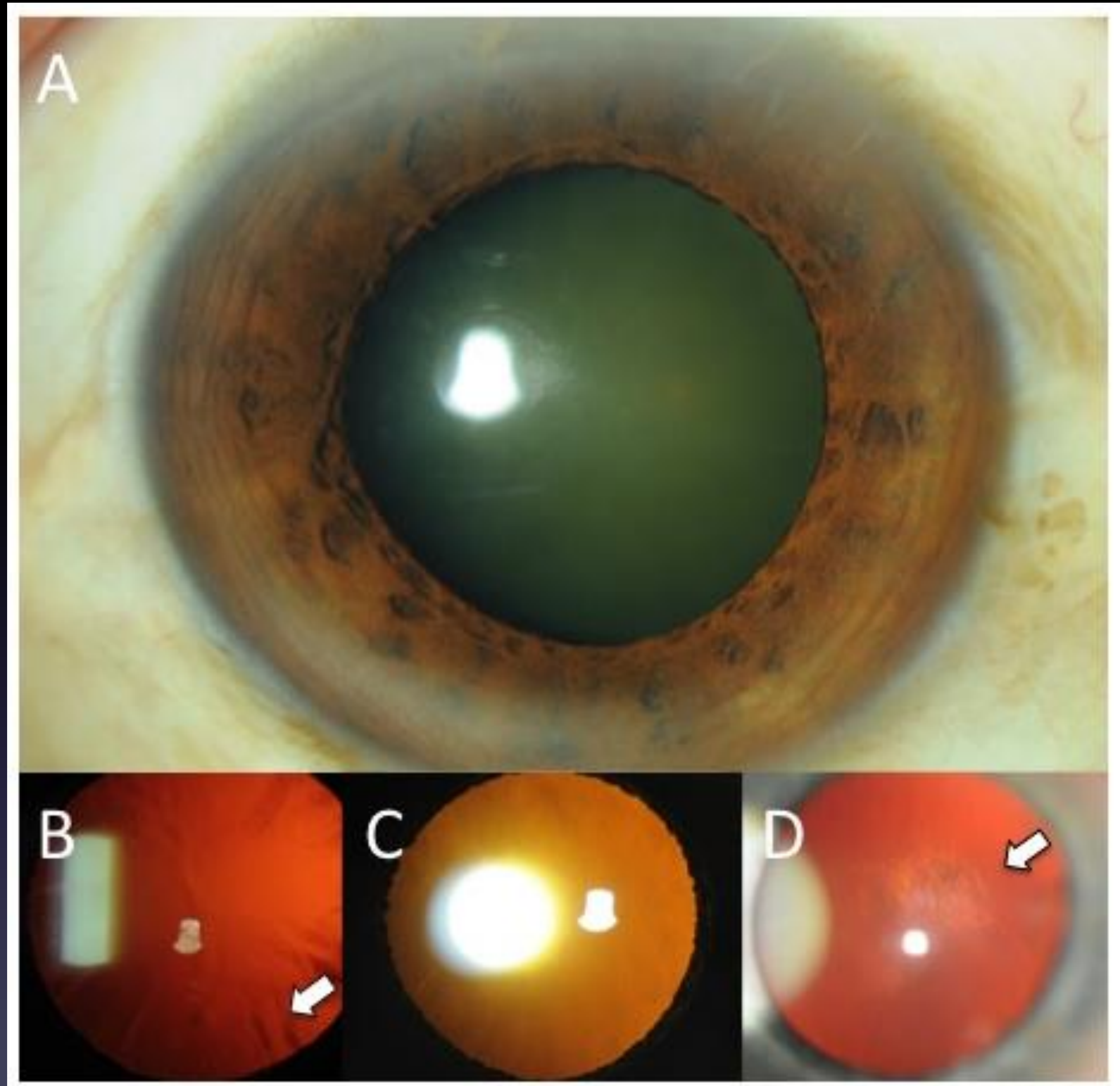


Figure: A) Photograph of visible cataract, characterized by opacification of the crystalline lens. B-D) Retroillumination demonstrating the different types of cataracts (arrows): cortical (B), nuclear (C), and posterior sub capsular (D). *Photographs courtesy of Dr. Natalie Afshari, Shiley Eye Institute, La Jolla CA.*

AK 6.3 Gy: What do you do next?

- Counsel patient to perform self exam for erythema for the next 2-3 weeks
- See patient in clinic in 2-3 weeks
- Schedule follow-up in 4-8 wks post procedure (Derm)
- Report AK > 5000 mGy to Radiation Safety Office

Effects		Threshold dose (Gy)	Time of onset
SKIN			
	Early transient erythema	2	2-24 hours
	Main erythema reaction	6	~1.5 weeks
	Temporary epilation	3	~3 weeks
	Permanent epilation	7	~3 weeks
	Dermal necrosis	>12	>52 weeks

http://members.sirweb.org/members/misc/Interventional_Fluoroscopy.pdf

Effects of Radiation Summary

- Deterministic effects are like *drinking*
  - You must consume a threshold dose of alcohol to get drunk
  - After that dose, the more you drink, the drunker you get
  - Some of the effects of too much alcohol are reversible, some are not, and sometimes it can result in death

- Stochastic effects are like *gambling*
  - Or at least like playing the lottery
  - Even if you enter the lottery once, you could be a "winner"
  - But, if you buy more tickets (more dose), you increase your chances of "winning"
  - The value of your "prize" (i.e. severity) does NOT depend on how often you enter

3: RADIATION PROTECTION

Practical guide to protecting yourself, your team, and your patients

4 primary methods of personal radiation protection:

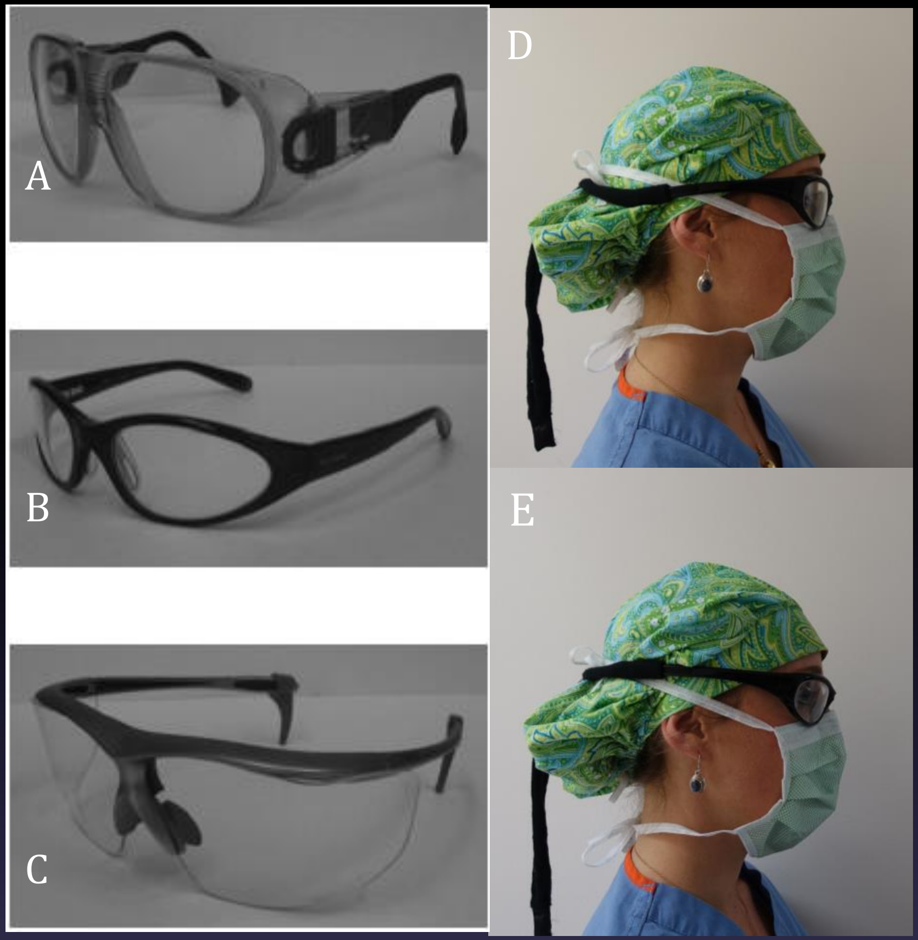
Time: Minimize the time the beam is on

Distance: Stand away from the source and *where the beam enters the patient.*

Shielding:
- Wear protective gear
- Use x-ray barriers and movable shields

Reduce dose to the patient:
- Collimate
- Avoid placing unnecessary objects in the field of view
- Use dose-sparing techniques


A
B
C
HD



Different styles of lead eyewear, including the newer lightweight (A), sportswrap (B), and classic (C) models. D,E) Fit of eyewear in a normal position (D) and with a slight inferior tilt (E) of the eyewear along the zygoma, decreasing scatter radiation incident on the lens. *Images A, B, C reproduced with permission from* Sturchio et al. “Protective eyewear selection for interventional fluoroscopy.” *Health Phys*. 2013;104(2 Suppl 1):S11-S16.

What lead to buy?

What lead to buy?

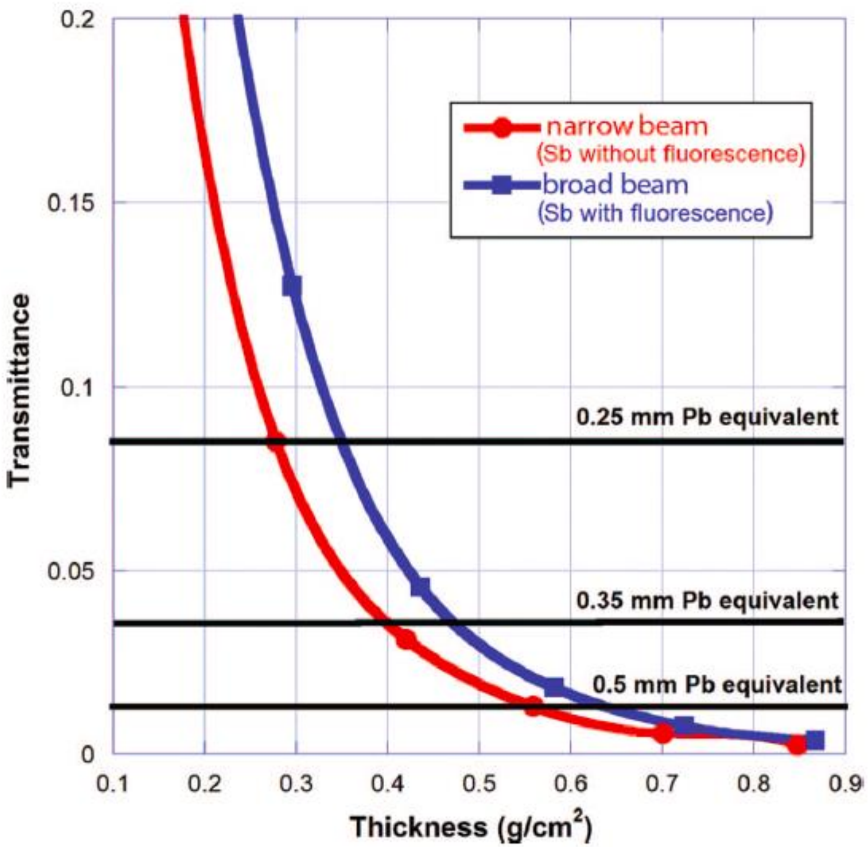


FIG. 7. Commercial Sb-loaded radiation attenuating material irradiated with the 70 kVp ASTM x-ray quality and measured in the narrow beam (without fluorescence) and broad beam (with fluorescence) geometries.

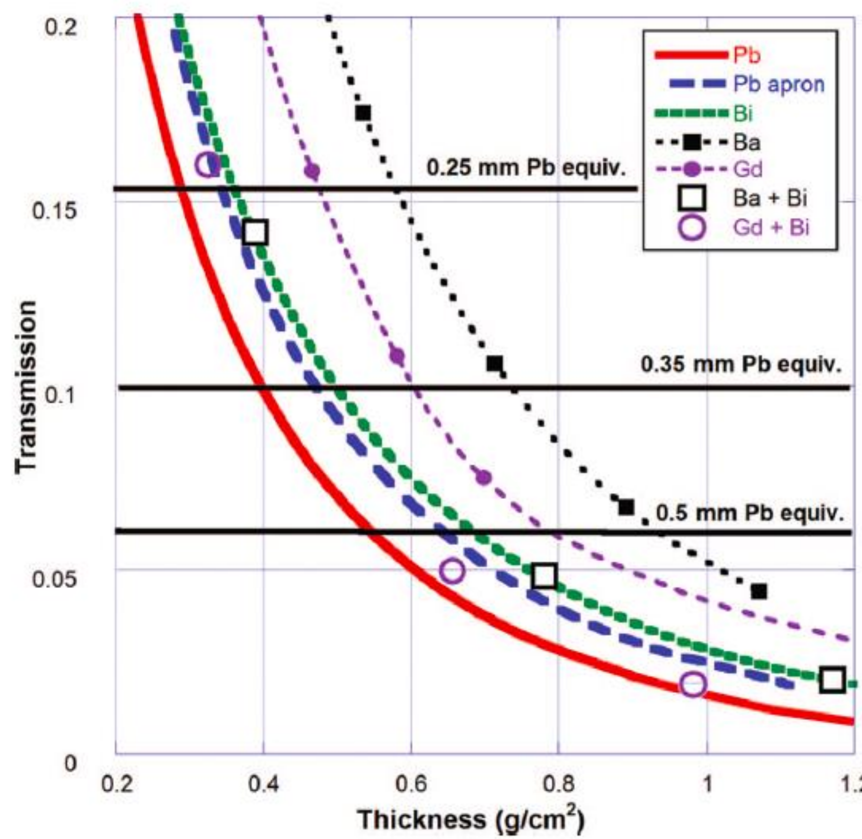
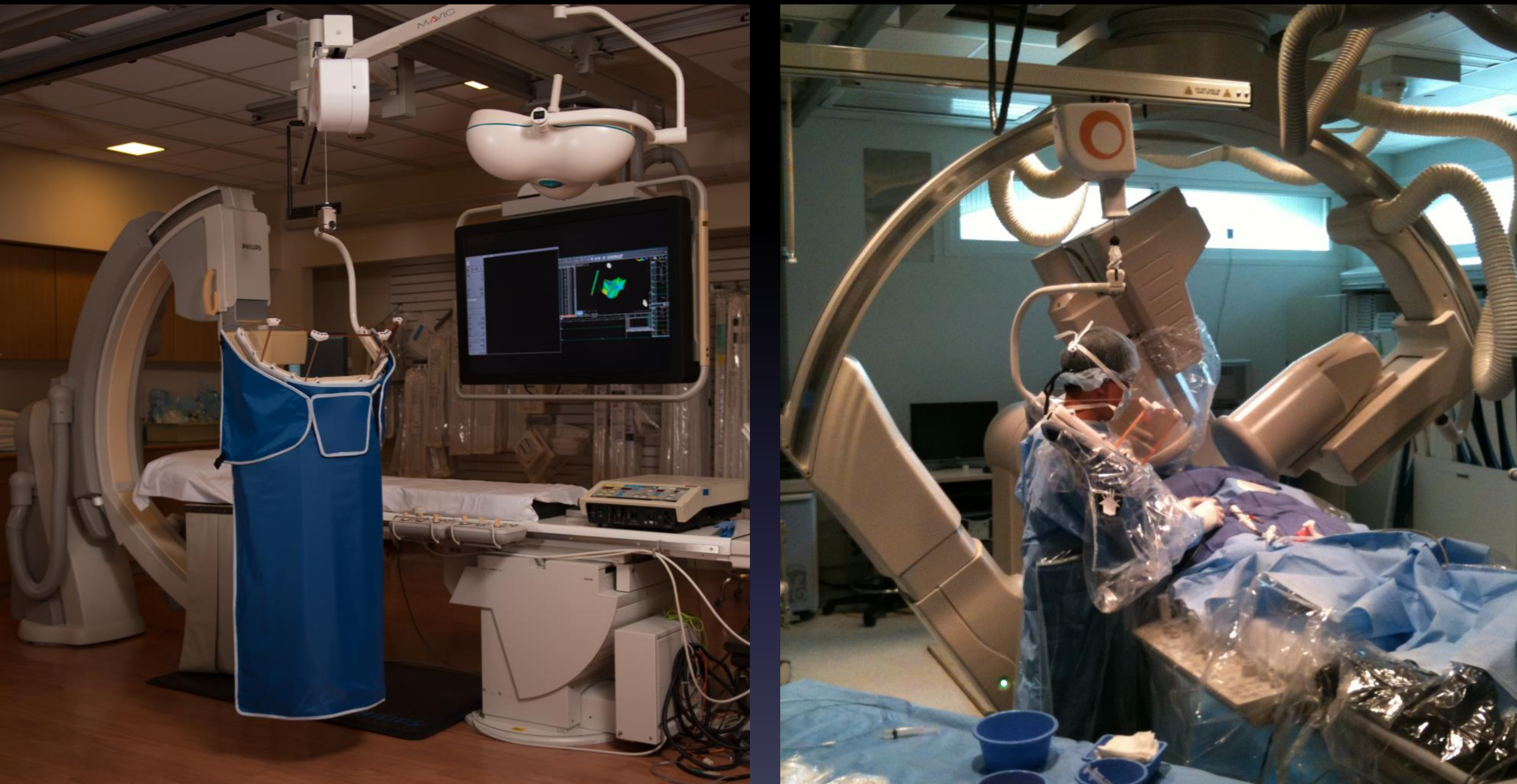


FIG. 8. Transmission vs thickness measurements of several experimental materials and bilayers, irradiated in the broad beam geometry with the 100 kV ASTM x-ray quality.

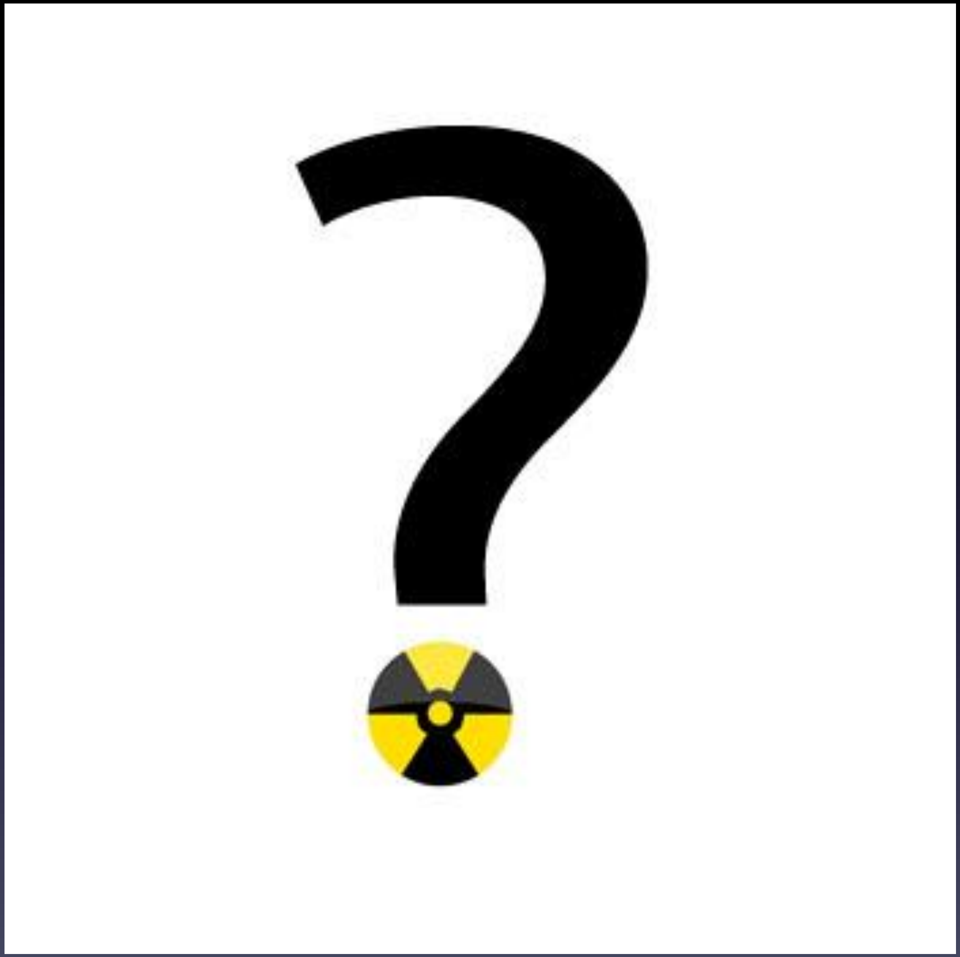


Ceiling-suspended radiation protection is designed to minimize exposure while eliminating body strain. *Photographs courtesy of CFI Medical Zero Gravity™.*

Not Awesome

…unless you hope to become this

Any questions?



Have you paid attention?

- Lightning round!!

Question 1

Which is TRUE of “deterministic effects of radiation” (DER)?

A. DER are unavoidable effects of the medical use of radiation

B. DER are independent of absorbed dose

C. DER can occur at any dose, however small

D. DER can be reversible

E. The probability of developing DER increases with dose

Question 1

Which is TRUE of “deterministic effects of radiation” (DER)?

A. DER are unavoidable effects of the medical use of radiation

B. DER are independent of absorbed dose

C. DER can occur at any dose, however small

D. DER can be reversible

E. The probability of developing DER increases with dose

Question 2

Which is NOT an example of a deterministic effect of radiation?

A. Erythema
B. Cancer
C. Cataracts
D. Infertility
E. Hair loss
F. Death

Question 2

Which is NOT an example of a deterministic effect of radiation?

A. Erythema
B. Cancer
C. Cataracts
D. Infertility
E. Hair loss
F. Death

Question 3

Which statement is true regarding skin effects of radiation exposure?

A. Transient erythema can occur at a dose of 2 Gy, epilation at 3 Gy, and ischemic dermal necrosis at doses over 15 Gy.

B. Inspecting the skin before the patient leaves the fluoroscopy suite is the best way to rule out skin effects.

C. If after a skin dose of 10 Gy the patient experiences no skin irritation at 10 days, the skin is not at risk.

D. Skin ulceration is an early complication, while erythema is seen later.

Question 3

Which statement is true regarding skin effects of radiation exposure?

A. Transient erythema can occur at a dose of 2 Gy, epilation at 3 Gy, and ischemic dermal necrosis at doses over 15 Gy.

B. Inspecting the skin before the patient leaves the fluoroscopy suite is the best way to rule out skin effects.

C. If after a skin dose of 10 Gy the patient experiences no skin irritation at 10 days, the skin is not at risk.

D. Skin ulceration is an early complication, while erythema is seen later.

Question 4

Which is FALSE regarding "stochastic effects of radiation" (SER)?

A. The higher the absorbed dose, the higher the probability of developing SER
B. SER can occur at any dose of radiation, however small
C. SER usually manifest with a few days to weeks after radiation exposure
D. Genetic mutations are an example of SER
E. A person who develops leukemia after exposure to radiation from a nuclear bomb could be said to suffer from a SER

Question 4

Which is FALSE regarding "stochastic effects of radiation" (SER)?

A. The higher the absorbed dose, the higher the probability of developing SER
B. SER can occur at any dose of radiation, however small
C. SER usually manifest with a few days to weeks after radiation exposure
D. Genetic mutations are an example of SER
E. A person who develops leukemia after exposure to radiation from a nuclear bomb could be said to suffer from a SER

Question 5

During fluoro procedures, radiologists can decrease the radiation dose to the patient and themselves by doing all of the following EXCEPT:

A. Magnifying the image to improve visibility
B. Using collimation
C. Moving the patient away from the source
D. Using the shield
E. Changing the pulse rate from 15 to 7 pulses/second

Question 5

During fluoro procedures, radiologists can decrease the radiation dose to the patient and themselves by doing all of the following EXCEPT:

A. Magnifying the image to improve visibility
B. Using collimation
C. Moving the patient away from the source
D. Using the shield
E. Changing the pulse rate from 15 to 7 pulses/second

Question 6

Where is the highest level of scatter radiation found?

A. Near the x-ray source

B. Close to the beam entry point on the patient's skin

C. At the image receptor

D. At the head of the patient table

Question 6

Where is the highest level of scatter radiation found?

A. Near the x-ray source

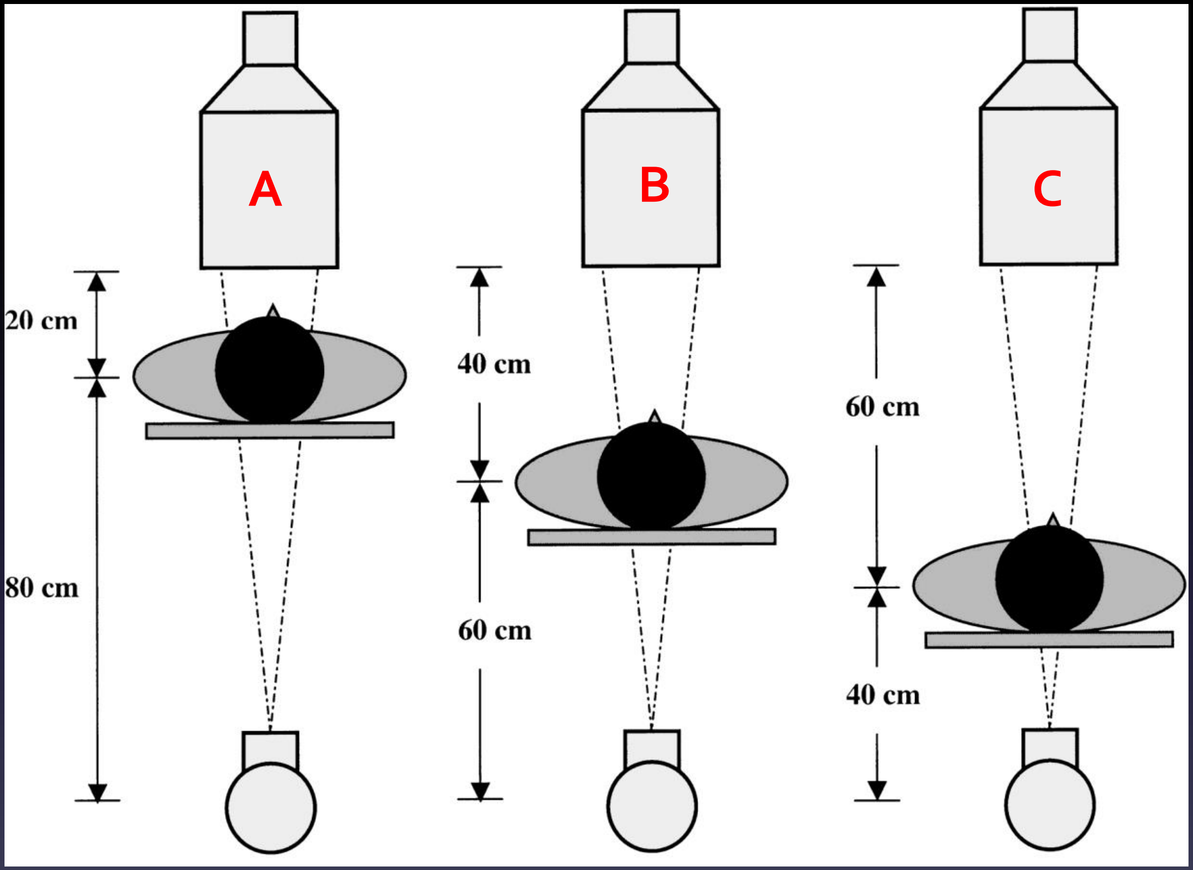
B. Close to the beam entry point on the patient's skin

C. At the image receptor

D. At the head of the patient table

Questions 7 & 8

Image intensifier (detector)



Source

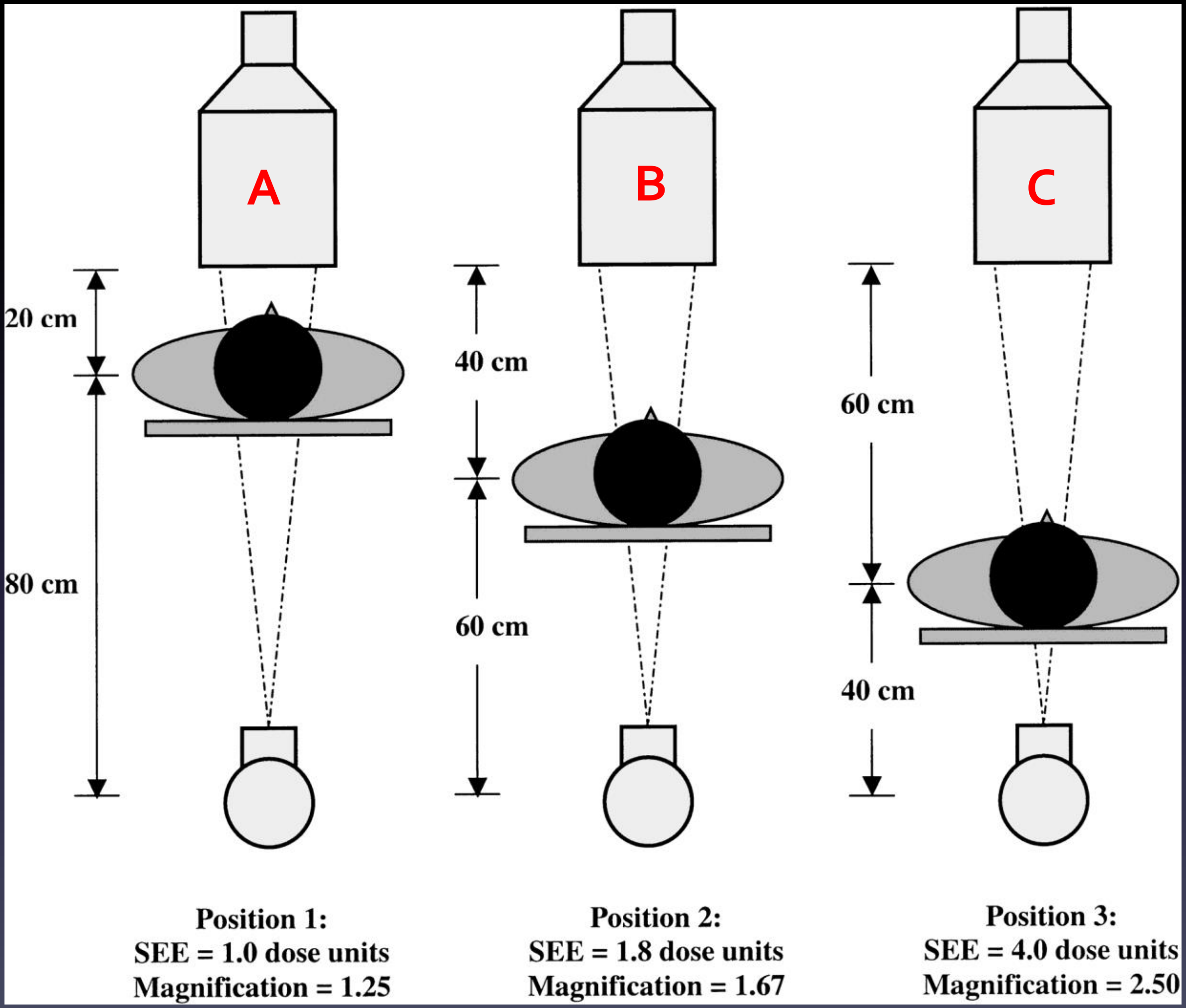
7. Which of the following configurations results in the HIGHEST dose to the patient?
8. Which configuration results in the LARGEST field of view?

Mahesh M Radiographics 2001;21:1033-1045

RadioGraphics

Questions 7 & 8

7. Which of the following configurations results in the HIGHEST dose to the patient? C
8. Which configuration results in the LARGEST field of view? A

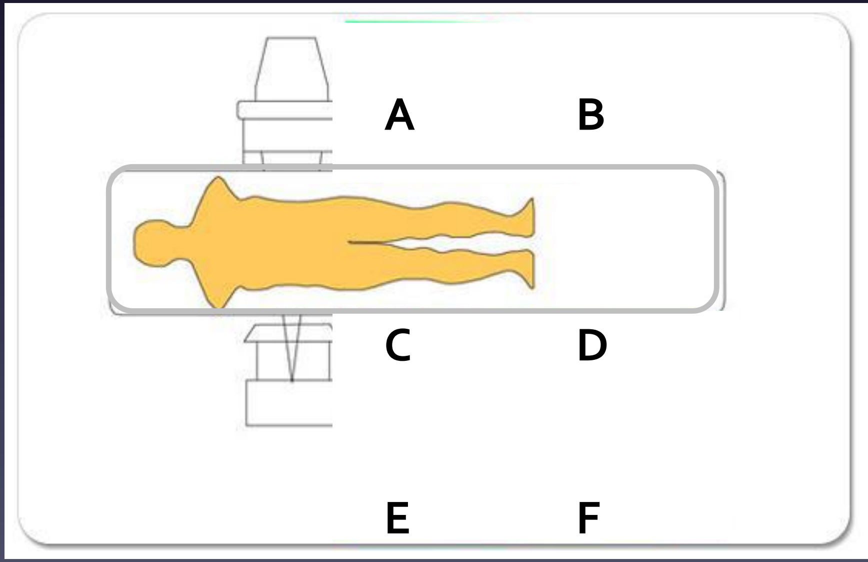


Mahesh M Radiographics 2001;21:1033-1045

RadioGraphics

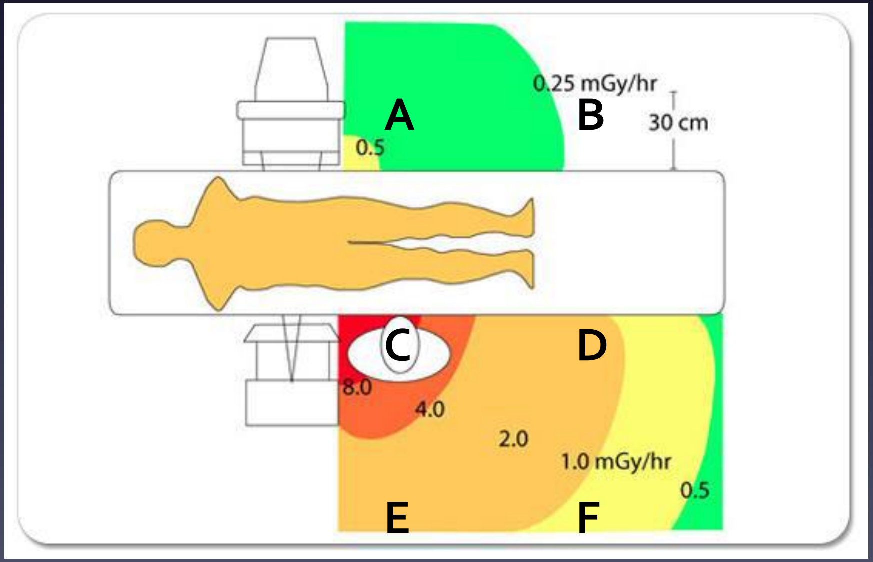
Question 9

When obtaining a lateral view, where is the worst place you can stand in terms of radiation dose?



Question 9

When obtaining a lateral view, where is the worst place you can stand in terms of radiation dose?



Question 10

Which is the best predictor of skin injury?

A. Pulse rate

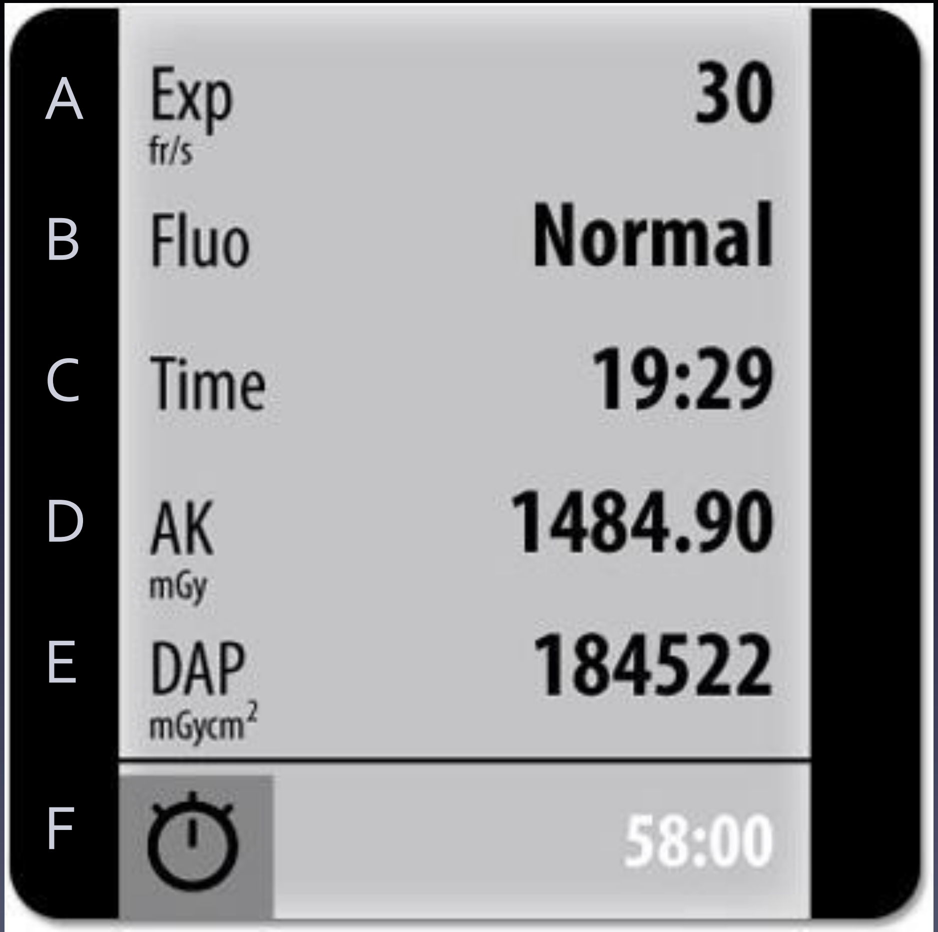
B. Normal vs boost

C. Fluoro time

D. Air Kerma

E. DAP

F. Exam time



Question 10

Air kerma is an expression of *radiation at a point*, so it would best predict deterministic effects of radiation.

Which is the best predictor of skin injury?

A. Pulse rate

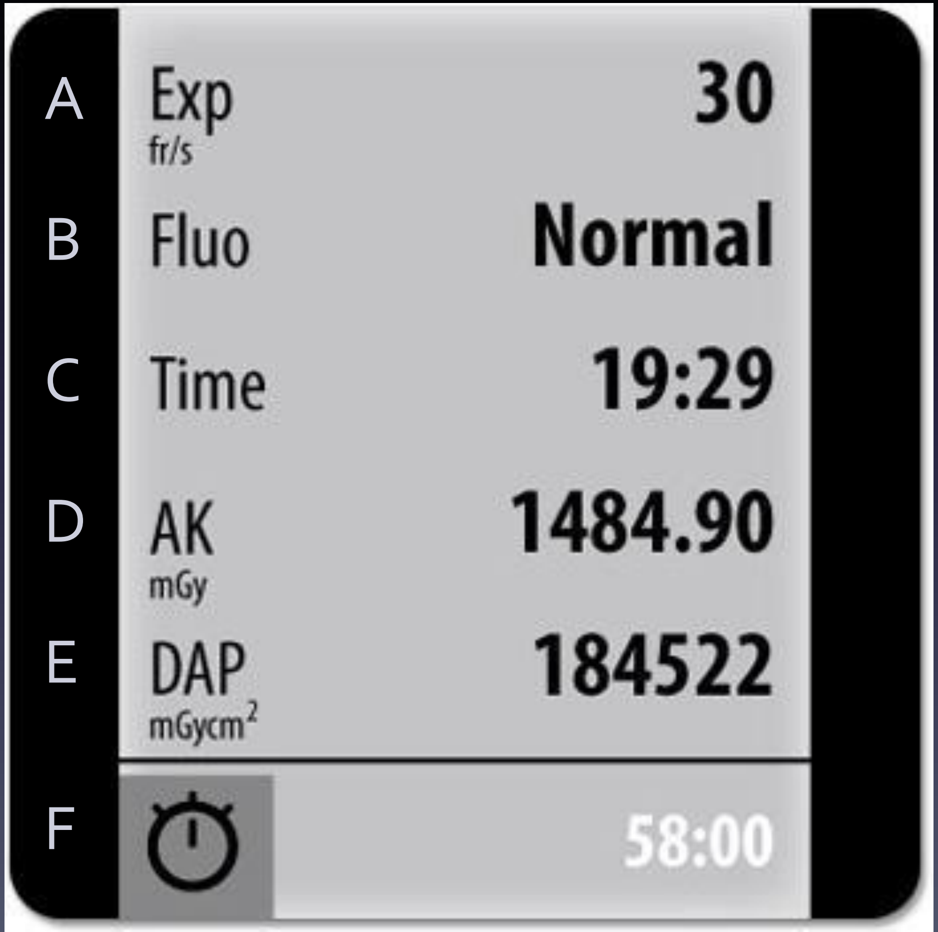
B. Normal vs boost

C. Fluoro time

D. Air Kerma

E. DAP

F. Exam time



Question 11

Which is the best predictor of risk of radiation-induced cancer?

A. Pulse rate

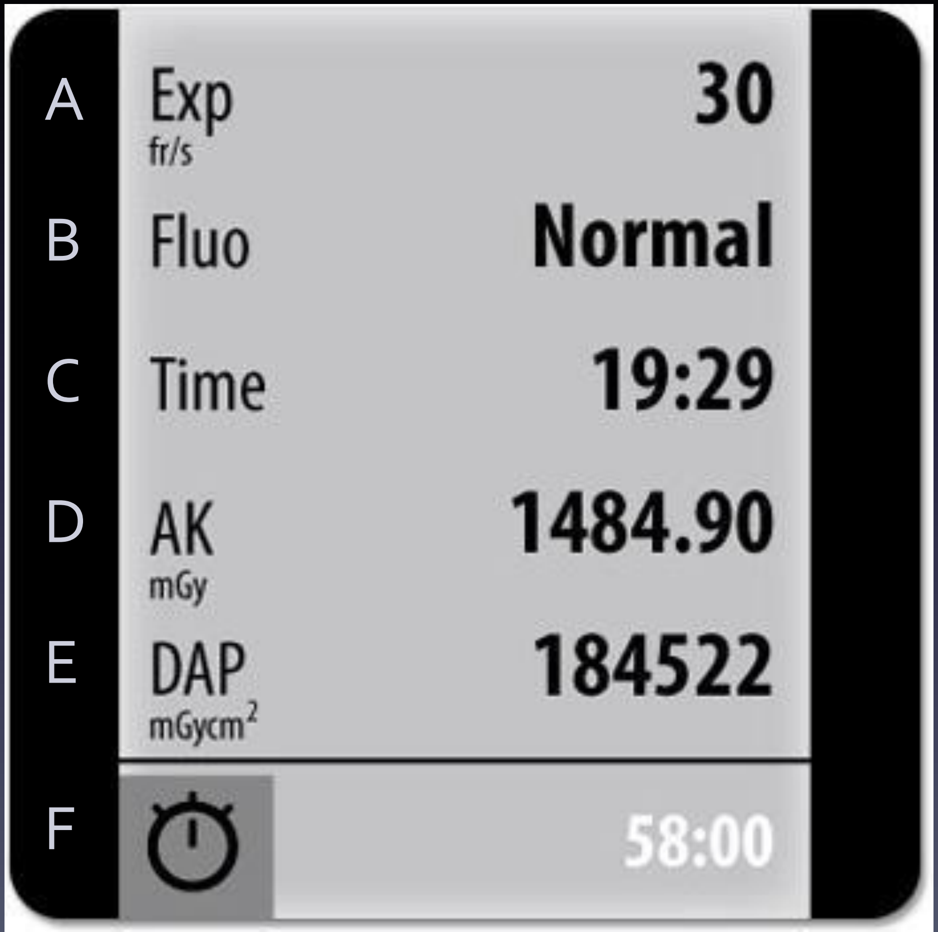
B. Normal vs boost

C. Fluoro time

D. Air Kerma

E. DAP or KAP

F. Exam time

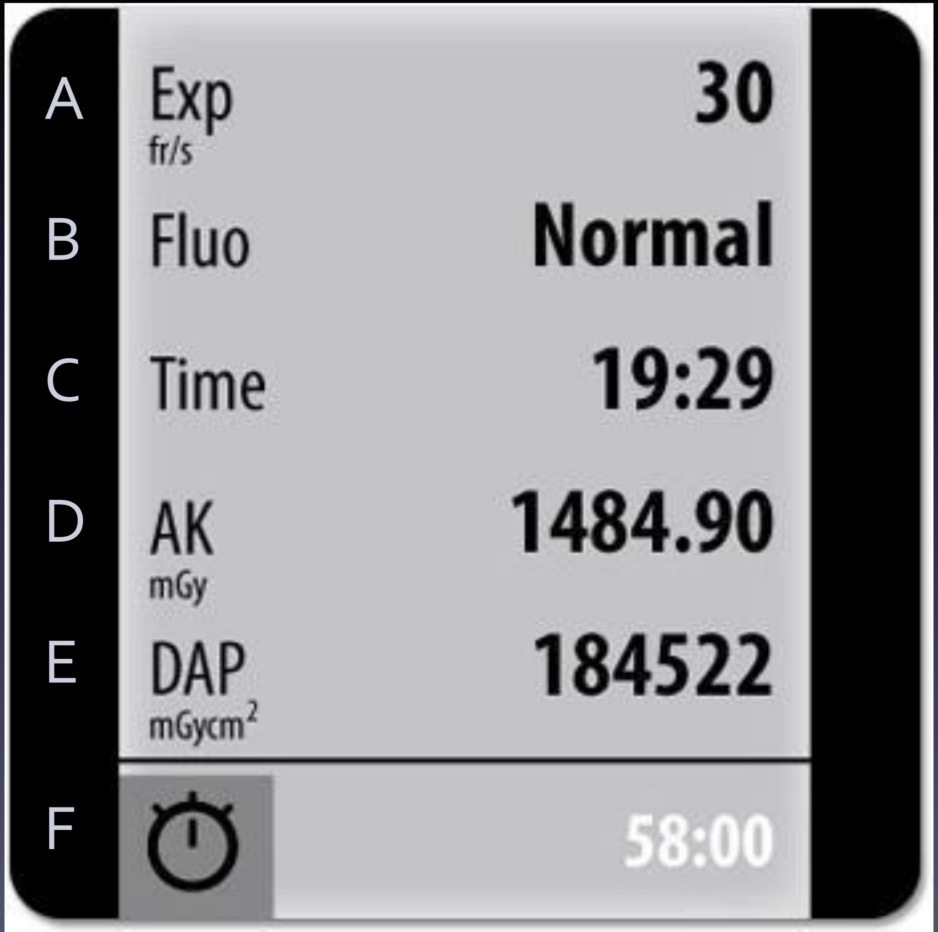


Question 11

Kerma area product is an expression of *total energy deposition across the entire exposed skin* so it would best predict stochastic effects of radiation

Which is the best predictor of risk of radiation-induced cancer?

A. Pulse rate
B. Normal vs boost
C. Fluoro time
D. Air Kerma
E. DAP or KAP
F. Exam time



Question 12

Of the methods below, which is most accurate for measuring skin dose?

A. Noting the total beam on time and comparing it with published reference values

B. Multiplying the beam on time by the value in the phantom dose rate table corresponding to the same size patient and imaging mode

C. Noting the cumulative air kerma on the fluoroscopy console at the end of the procedure

D. Placing dosimeters directly on the patient's skin

Question 12

Of the methods below, which is most accurate for measuring skin dose?

A. Noting the total beam on time and comparing it with published reference values

B. Multiplying the beam on time by the value in the phantom dose rate table corresponding to the same size patient and imaging mode

C. Noting the cumulative air kerma on the fluoroscopy console at the end of the procedure

D. Placing dosimeters directly on the patient's skin

Question 13

You are issued one of these.

What should you do with it?

A. Wear it on the inside of your lead apron

B. Wear it on your hat

C. Wear it on the outside of your lead apron

D. Wear it on your hand

E. Put it directly on the source once a month then store it the rest of the time

Question 13

You are issued one of these.

What should you do with it?

A. Wear it on the inside of your lead apron
B. Wear it on your hat
C. Wear it on the outside of your lead apron
D. Wear it on your hand
E. Put it directly on the source once a month then store it the rest of the time

Question 14

Collimation does all of the following EXCEPT:

Question 14

Collimation does all of the following EXCEPT:

A. Decrease contrast

B. Decrease dose to the patient

C. Decrease dose to the operator

D. Decrease field of view

Question 15

Which of the following statements is wrong?

A. The tube voltage controls the energy of the electrons, and hence the energy of the x-rays.

B. Radiation dose to the patient increases when either mA or kV is increased.

C. Thicker body parts of the body produce less scatter.

D. Thicker parts of the body remove more x-rays from the beam than do thinner parts.

Question 15

Which of the following statements is wrong?

A. The tube voltage controls the energy of the electrons, and hence the energy of the x-rays.

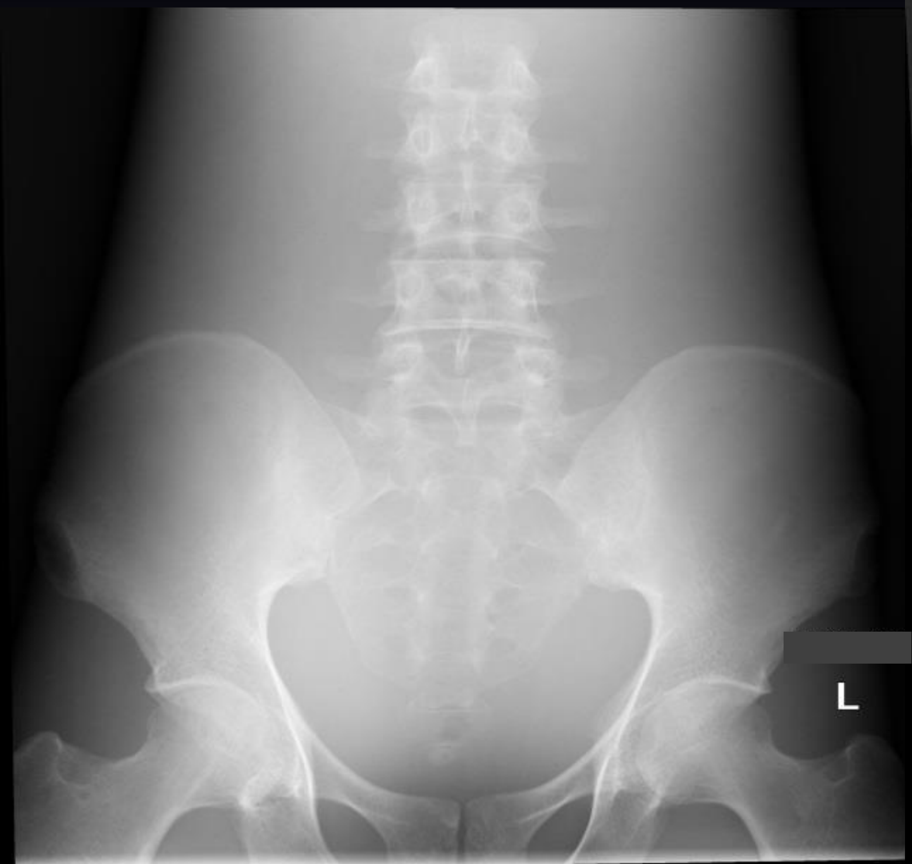
B. Radiation dose to the patient increases when either mA or kV is increased.

C. Thicker body parts of the body produce less scatter.

D. Thicker parts of the body remove more x-rays from the beam than do thinner parts.

Question 16

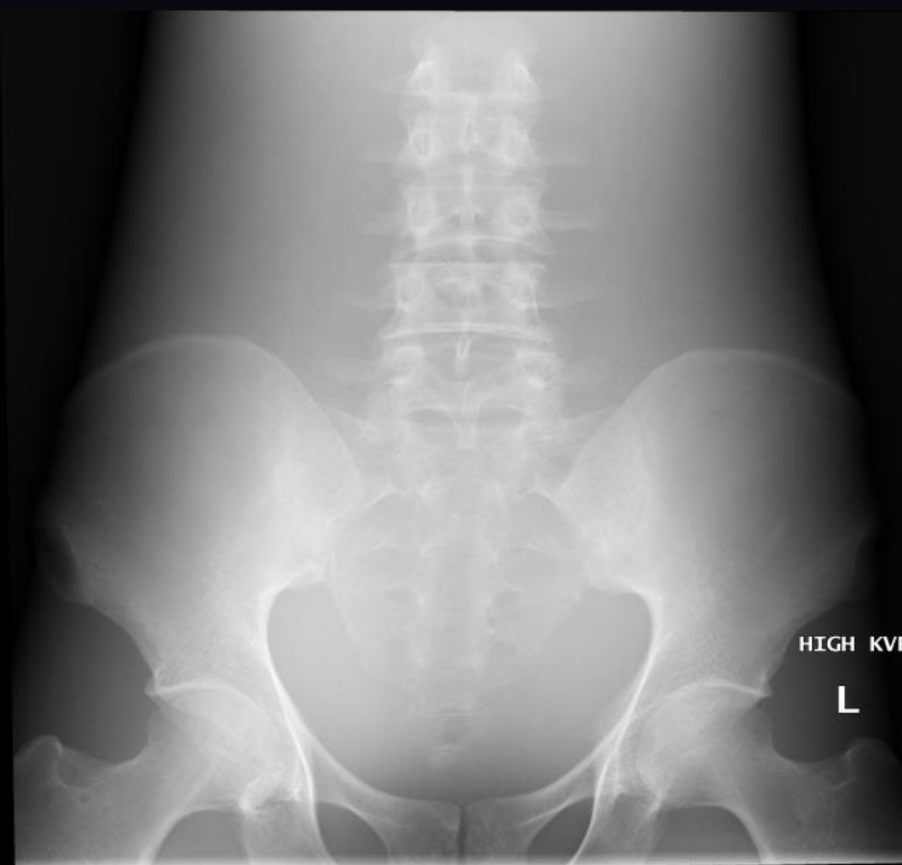
What accounts for the difference in these two images?



Question 16

What accounts for the difference in these two images?

High kV



Low kV

THANK YOU!

Isabel Newton, MD, PhD

inewton@ucsd.edu