# Basic X-Ray Safety

PRESENTED BY

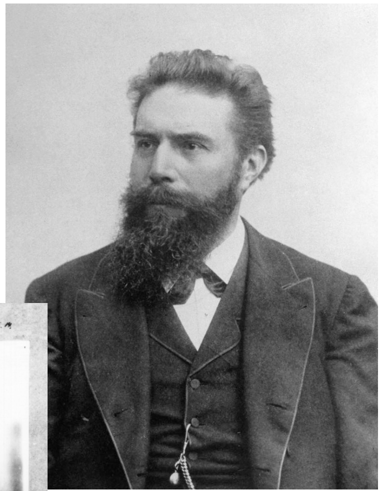
RADIOLOGY TRAINING ASSOCIATES
Anywhere. Anytime. It's that simple.

# Outline

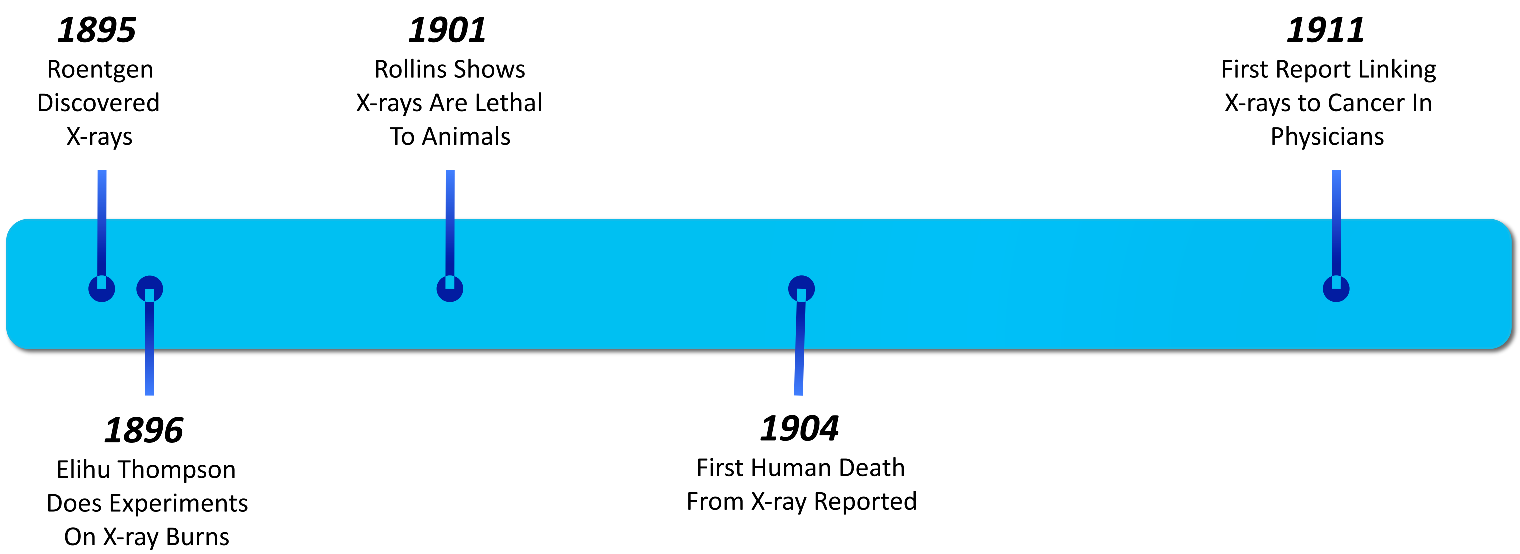
- Discovery of X-Rays
- Radiation Dose & Biological Effects of Radiation
- Radiation Dose Limits & Dosimetry
- ALARA Philosophy – Protecting Yourself from Radiation
- Shielding for X-Rays
- X-Ray Production & Technical Factors
- Beam Hardening & Filtering
- Automatic Exposure Control
- Film vs. CR vs. DR
- Technique Factors & Radiation Dose
- Image Quality & Radiation Dose
- Protecting Your Patients
- X-Ray Room Design & Layout
- Practical Tips for Optimizing Patient & Staff Safety

# A Brief History of Radiation

- Wilhelm Roentgen
  - 1895 – Discovery of X-rays

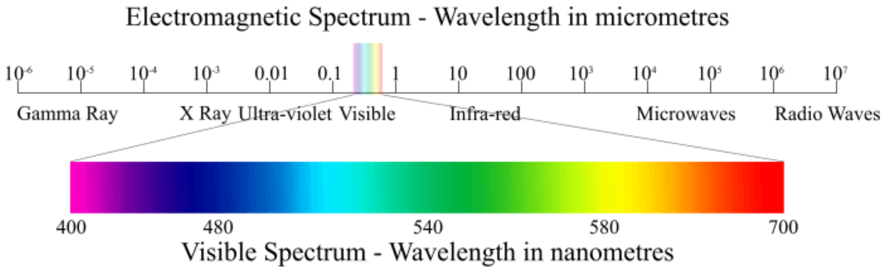


- The history of radiation biology goes back almost as far as the discovery of X-rays

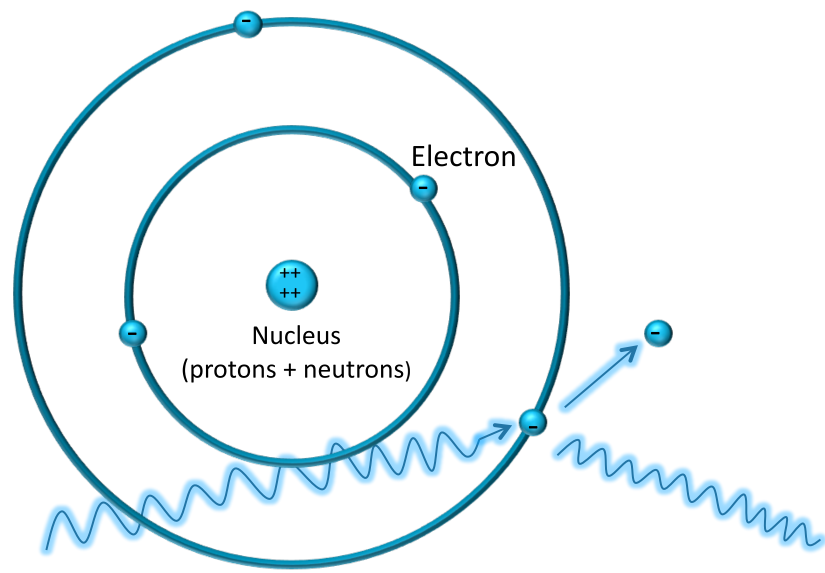


# What is Radiation?

- Transfer of energy through space

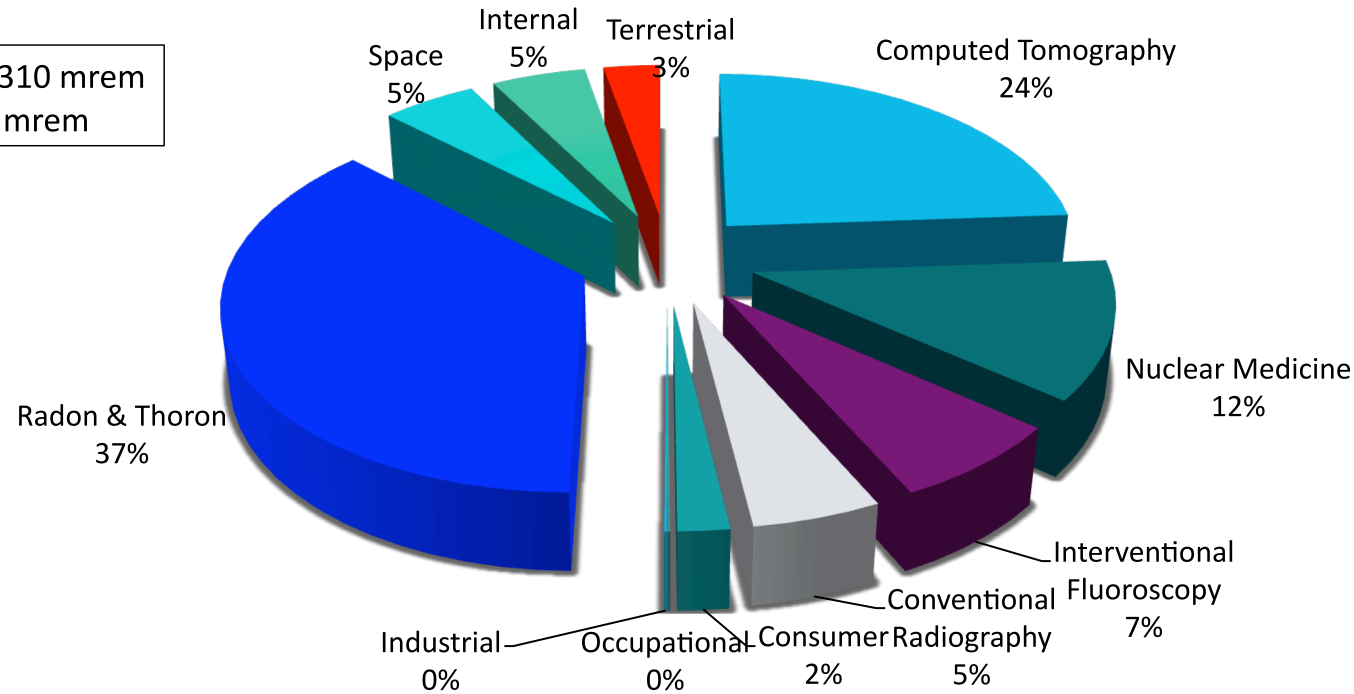



- Radiation can be ionizing or non-ionizing
  - Ionizing radiation can knock electrons off of an atom



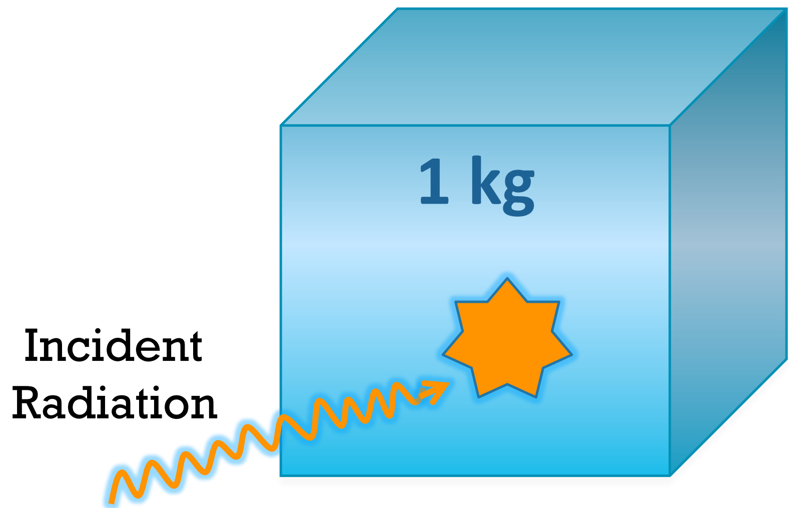
# Exposure Sources for Effective Dose

Background – 310 mrem
Medical – 300 mrem



# What is Dose?

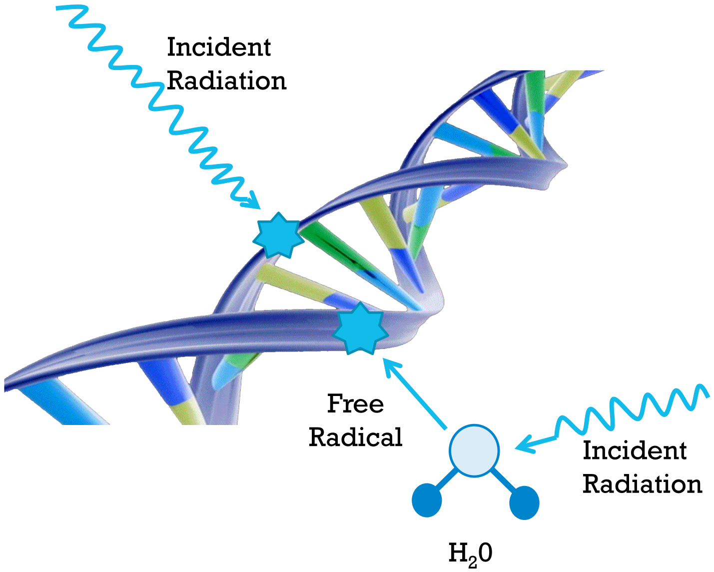
- Dose is defined as the energy deposited per unit mass
  - 1 J/kg = 1 Gray
- Rem, Rad, & Roentgen (R)
- Measured in units of
  - Gy ➔ absorbed dose
  - Sv ➔ dose equivalent
  - 100 rad = 1 Gy
  - 100 rem = 1 Sv




$1.6 \times 10^{-19}$ Joules = 1 eV

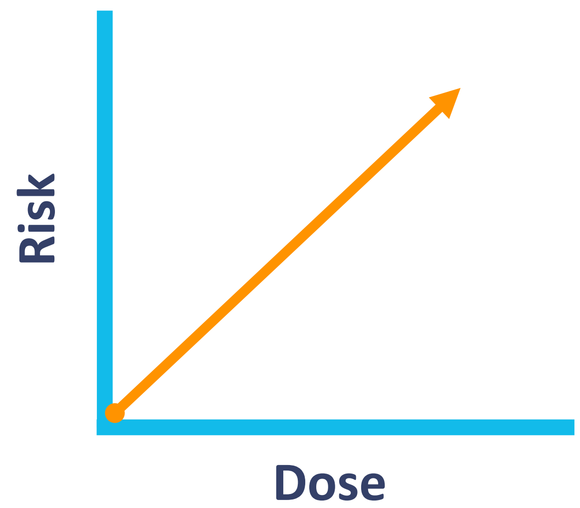
# How Does Radiation Cause Damage?

- Indirect Damage vs. Direct Damage
  - Single Strand Breaks & Double Strand Breaks
- 3 Stage Model of Cancer Formation
  - Initiation – mutational event
  - Promotion – functional change
  - Progression – tumor invasion
- Radiation is a weak carcinogen because it acts only as an initiator



# Non-Stochastic vs. Stochastic

- Non-Stochastic Effects (Non-Probabilistic)
  - A threshold dose exists!
  - Erythema
  - Epilation
  - Dermal Necrosis
- Stochastic Effects (Probabilistic)
  - A threshold does (might) not exist – LNT
  - Most common stochastic effect – cancer
  - Stochastic effects have a latency period
    - Most cancers ~ 20 – 40 years



# Non-Stochastic Effects In Action

6 – 8 weeks

On March 29, 1990, a 40-year-old male underwent coronary angiography, coronary angioplasty and a second angiography procedure (due to complications) followed by a coronary artery by-pass graft. Total fluoroscopy time estimated to be > 120 minutes. The injury was described as "turning red about one month after the procedure and peeling a week later."

www.fda.gov

# Non-Stochastic Effects In Action

16 – 21 weeks

At 16 – 21 weeks post procedure, the radiation induced injury appears to be healing.

# Non-Stochastic Effects In Action

18 – 21 months

In fact, only the superficial dermal layers were able to heal while the deep dermal layers went untreated.

# Non-Stochastic Effects In Action

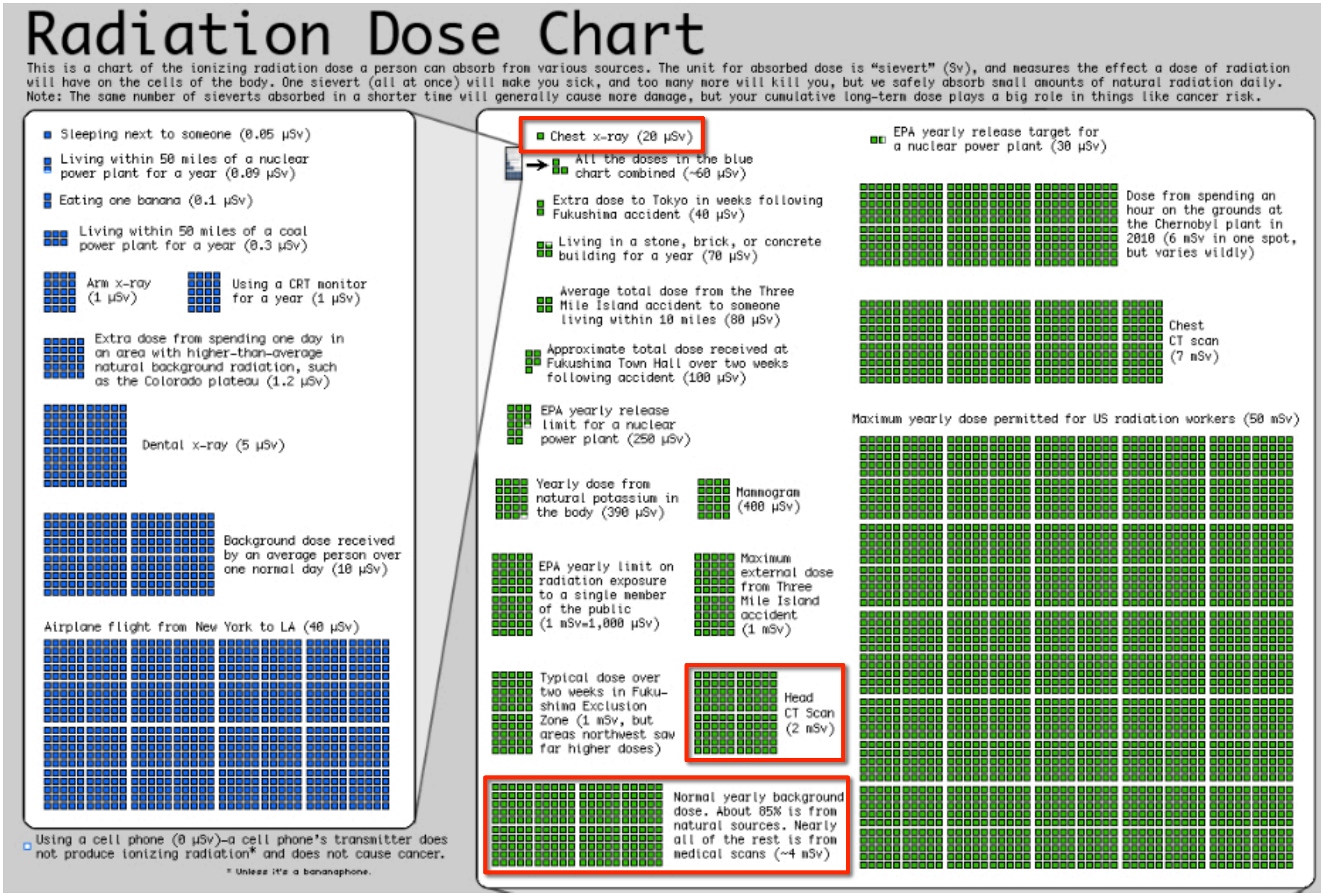
18 – 21 months

Post skin grafting

www.fda.gov

# Acute Radiation Effects

| Radiation Effect | Threshold to Produce (rad) | Amount of Fluoroscopy to produce at 5 R/min | Amount of Cine to produce at 30 R/min | Time to Effect |
|---|---|---|---|---|
| Transient Erythema | 200 | 0.7 hours | 0.1 hours | 24 hours |
| Epilation | 300 | 1 hour | 0.2 hours | 3 weeks |
| Main Erythema | 600 | 2 hours | 0.3 hours | 10 days |
| Dermal Necrosis | 1800 | 6 hours | 1 hour | >10 weeks |


Radiation Dose Chart
This is a chart of the ionizing radiation dose a person can absorb from various sources. The unit for absorbed dose is "sievert" (Sv), and measures the effect a dose of radiation will have on the cells of the body. One sievert (all at once) will make you sick, and too many more will kill you, but we safely absorb small amounts of natural radiation daily. Note: The same number of sieverts absorbed in a shorter time will generally cause more damage, but your cumulative long-term dose plays a big role in things like cancer risk.
Sleeping next to someone (0.05 µSv)
Living within 50 miles of a nuclear power plant for a year (0.09 µSv)
Eating one banana (0.1 µSv)
Living within 50 miles of a coal power plant for a year (0.3 µSv)
Arm x-ray (1 µSv)
Using a CRT monitor for a year (1 µSv)
Extra dose from spending one day in an area with higher-than-average natural background radiation, such as the Colorado plateau (1.2 µSv)
Dental x-ray (5 µSv)
Background dose received by an average person over one normal day (10 µSv)
Airplane flight from New York to LA (40 µSv)
Using a cell phone (0 µSv)—a cell phone's transmitter does not produce ionizing radiation* and does not cause cancer.
* Unless it's a bananaphone.
Chest x-ray (20 µSv)
All the doses in the blue chart combined (~60 µSv)
Extra dose to Tokyo in weeks following Fukushima accident (40 µSv)
Living in a stone, brick, or concrete building for a year (70 µSv)
Average total dose from the Three Mile Island accident to someone living within 10 miles (80 µSv)
Approximate total dose received at Fukushima Town Hall over two weeks following accident (100 µSv)
EPA yearly release limit for a nuclear power plant (250 µSv)
Yearly dose from natural potassium in the body (390 µSv)
Mammogram (400 µSv)
EPA yearly limit on radiation exposure to a single member of the public (1 mSv=1,000 µSv)
Maximum external dose from Three Mile Island accident (1 mSv)
Typical dose over two weeks in Fukushima Exclusion Zone (1 mSv, but areas northwest saw far higher doses)
Head CT Scan (2 mSv)
Normal yearly background dose. About 85% is from natural sources. Nearly all of the rest is from medical scans (~4 mSv)
EPA yearly release target for a nuclear power plant (30 µSv)
Dose from spending an hour on the grounds at the Chernobyl plant in 2010 (6 mSv in one spot, but varies wildly)
Chest CT scan (7 mSv)
Maximum yearly dose permitted for US radiation workers (50 mSv)

# Dose Limits & Dosimetry

| | Annual Limit | |
|---|---|---|
| Whole Body (TEDE) | 5,000 mrem | 50 mSv |
| Extremities & Skin (SDE) | 50,000 mrem | 500 mSv |
| Lens of Eye | 15,000 mrem | 150 mSv |

| | Gestational Limit | |
|---|---|---|
| Declared Pregnant Workers | 500 mrem | 5 mSv |

**This is for occupationally exposed staff only!**

**This does not apply to patients!!!**

| | Limits | |
|---|---|---|
| Members of the Public | 100 mrem* | 2 mrem in any 1 hour |

* Limit goes to 500 mrem when source is an individual administered unsealed byproduct material

# Dosimeters


- May be issued monthly or quarterly
- TLD vs. Film
- Practical Tips
  - Store in a low background area
  - Wear outside of your lead, if applicable
  - Only wear your badge!

# ALARA

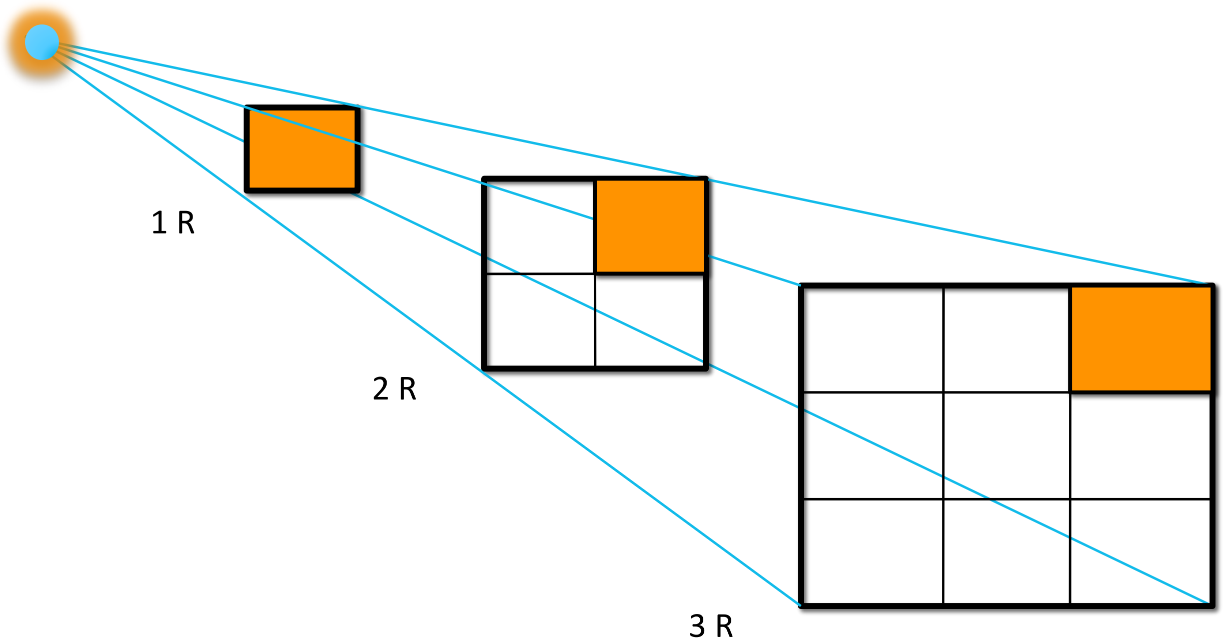
- As Low As Reasonably Achievable
  - Reasonable efforts should be made to keep occupational doses as far below regulatory limits as possible
- Fundamentals of radiation protection
  - Time, Distance, & Shielding
- Sources of exposure in a hospital
  - Radiology (X-Ray, CT, NM)
  - Radiation Therapy
  - Cath Lab, GI Lab, Pain Clinics, etc

☑ Time

☑ Distance

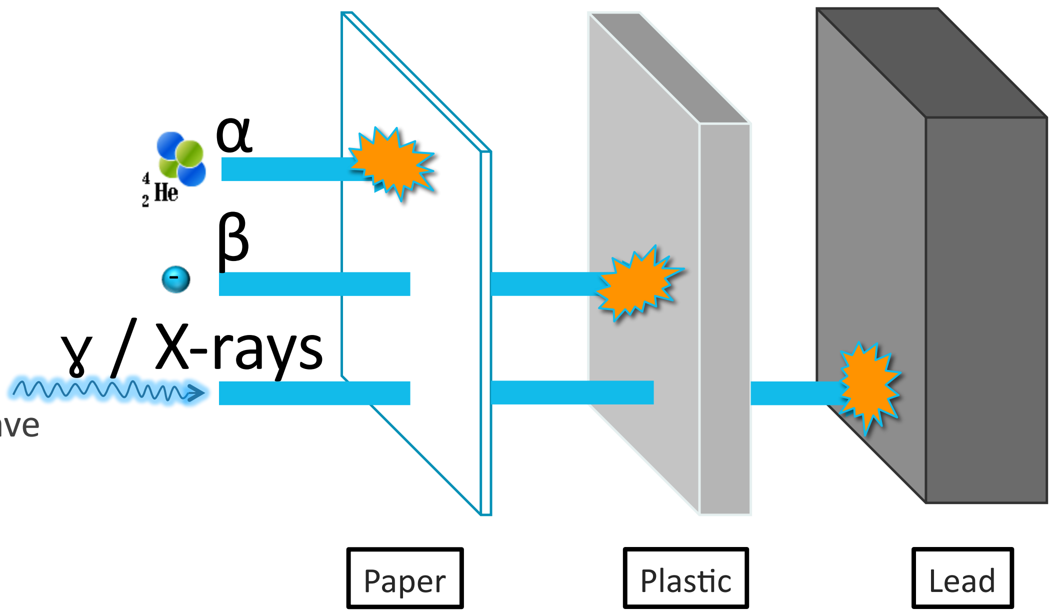
☑ Shielding

# Distance

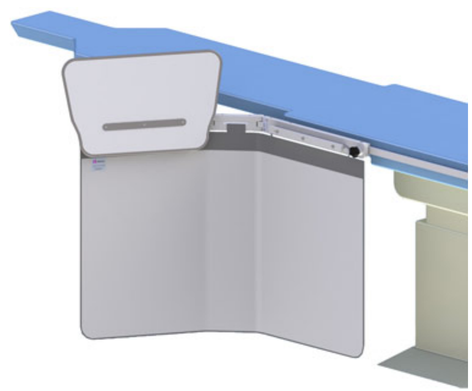


# Shielding

- Particles
  - Alpha, beta, protons, neutrons
- Gamma & X-rays
- Some Considerations
  - What types of radiation are you shielding?
  - What is the energy and activity?
  - What shielding material do you have available?

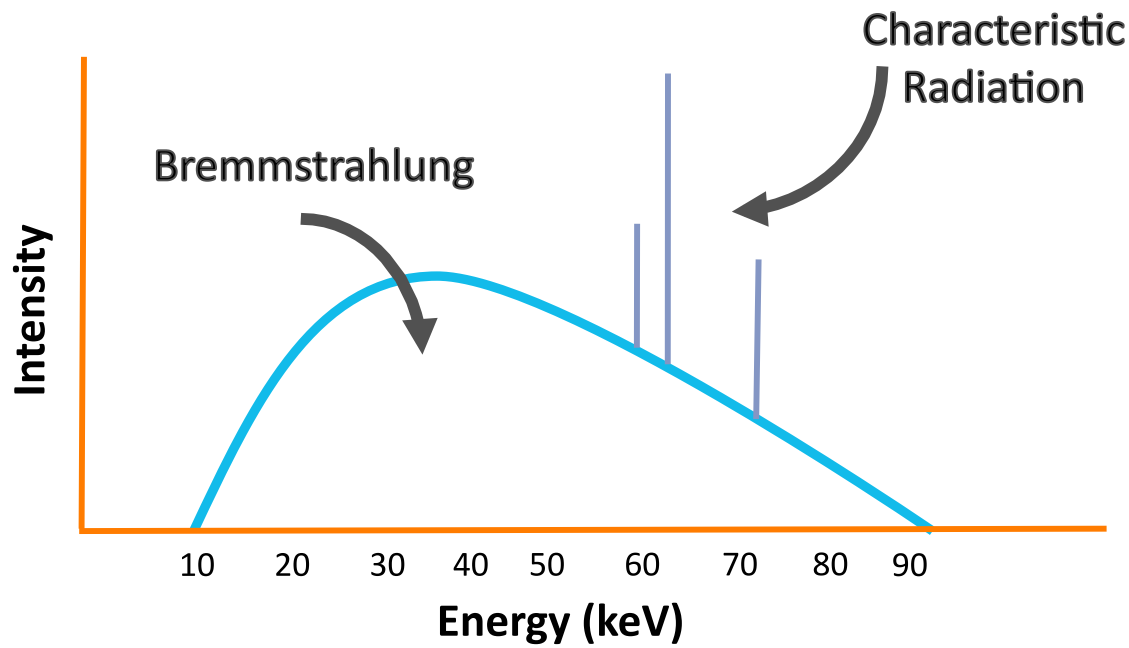


# Shielding Examples

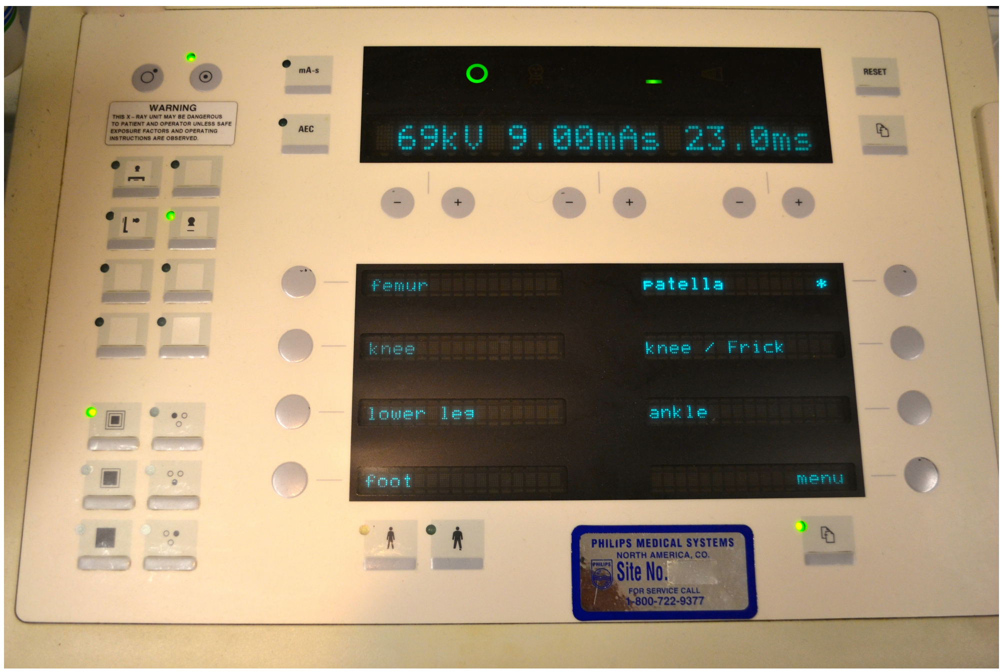


# Where Do X-Rays Come From?

- Two Sources
  - Characteristic Radiation
  - Bremmstrahlung
- Anode
  - Tungsten (High Z)



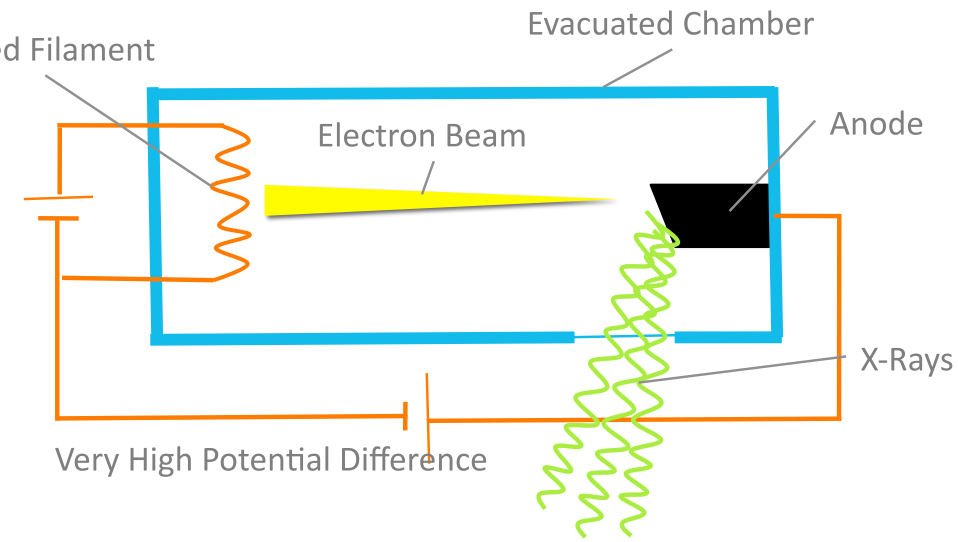
# Basic X-Ray Tube Control




- Tube Potential (kVp)
- Tube Current (mA)
- Timer (sec or ms)
- Other Considerations
  - SID (40" vs 72")
  - AEC
  - Focal Spot Size
  - Collimation & PBL
  - Detector Type (CR/DR)
  - Grids

# X-Ray Tube Control

- Tube Potential (kV or kVp)
  - Electrical potential applied across the X-Ray tube to accelerate electrons towards the target



# X-Ray Tube Control

- Tube Current (mA)
  - Number of electrons accelerated across the X-Ray tube
- Timer (sec)
  - Amount of time the beam is “On”
- Tube Current Time Product (mAs)
  - Determines the total number of electrons accelerated across the X-Ray tube during the exposure
  - X-Ray Fluence → $\Phi$
  - Radiation Dose is directly proportional to mAs

mAs = milliampere*seconds

$$\not{m}A \bullet s = A \bullet s$$

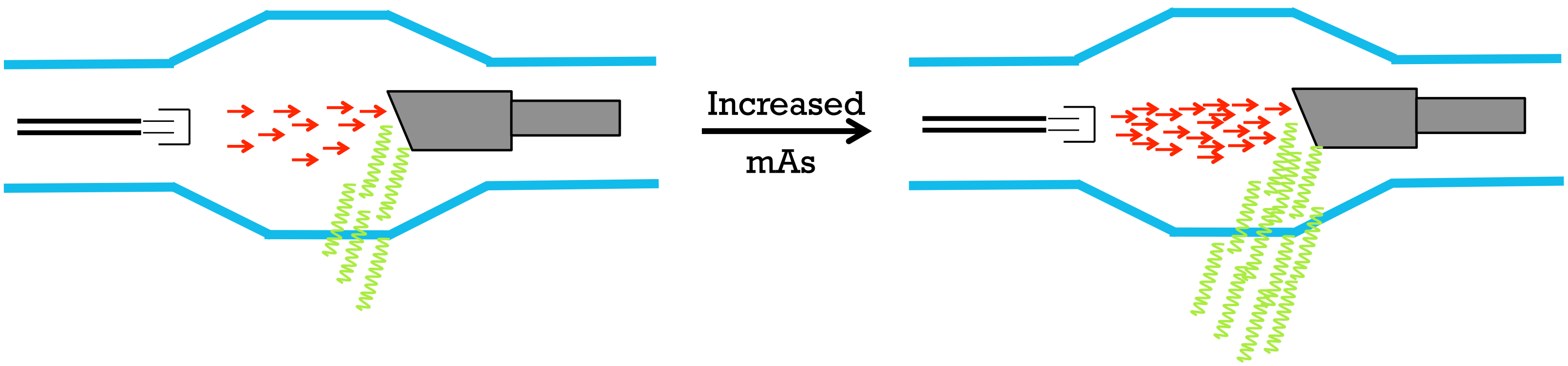
Q: What is an Amp (A)?
A: An Amp is a coulomb/second (C/s)

Q: What is a Coulomb?
A: A coulomb is a unit of charge….and electrons carry charge!!!

THEREFORE

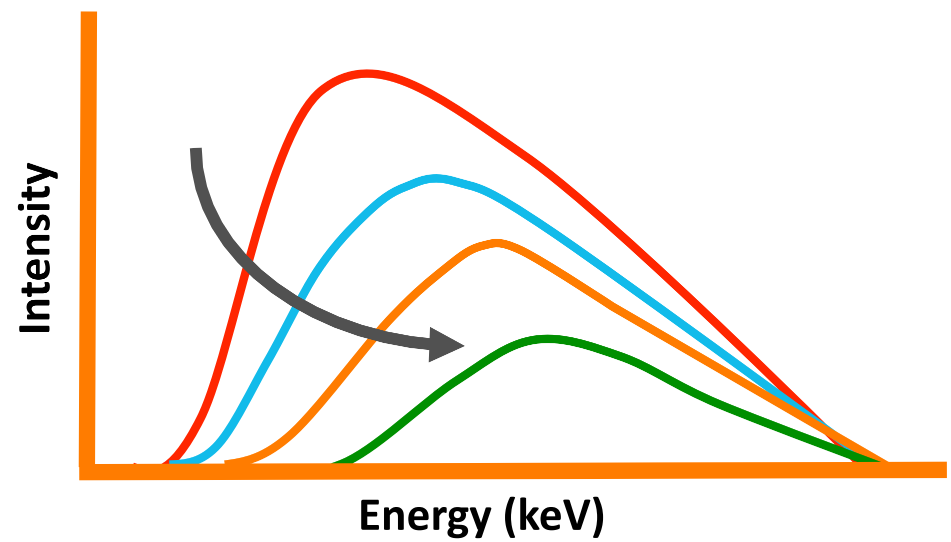
$$
\begin{aligned}
Amp * sec &= \frac{C}{\not{s}} * s\not{e}c \\
&= Coulombs \\
&\propto number\ of\ electrons \\
&\propto number\ of\ Xrays!!!
\end{aligned}
$$

# X-Ray Tube Control



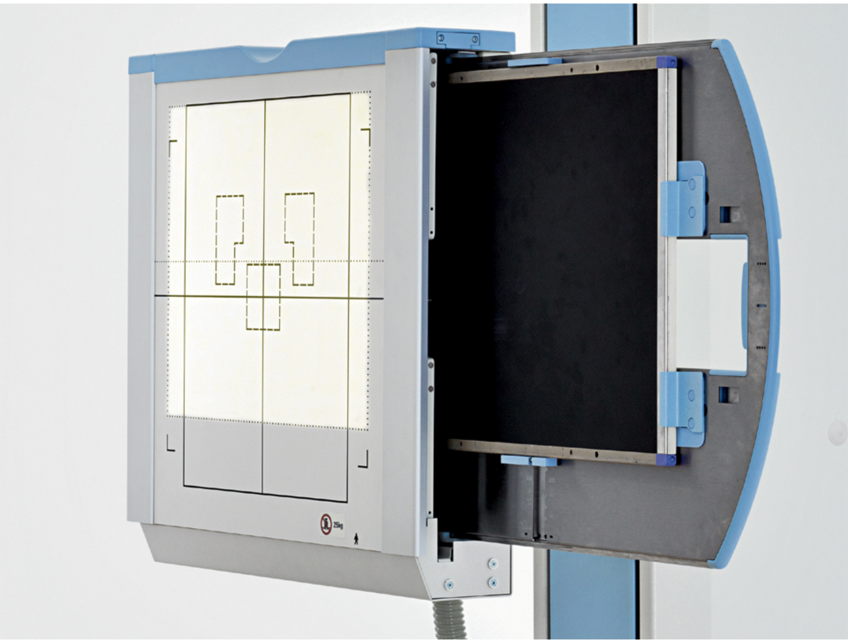
# Beam Hardening & Filtration

- Removal of low energy X-Rays that will not contribute to image formation
- Filtration "hardens" the X-Ray beam
  - Reduces number of X-Rays
  - Increases the *effective energy*
- Reduces radiation dose to the patient
- Inherent & Added Filtration
  - Glass Port
  - Oil surround
  - Aluminum
- Beam quality measured by HVL and compared to FDA and/or state guidelines



# Automatic Exposure Control (AEC)

- AEC is useful in place of manual techniques
- Ion chambers measure amount of radiation at the detector and terminates exposure when preset value is reached
  - Use of comparator circuits
- Accounts for attenuation to give adequate image quality
- Reduces repeat rate



# Collimation and PBL

- Collimation
  - Limiting the field size to only the region of interest with lead collimators
  - Evaluated via collimator light and reflective mirror
  - Reduces radiation dose to anatomy outside of the FOV
- Positive Beam Limitation
  - Collimator electronically linked to bucky tray through sensors
- Still can have scatter, off focus radiation, and penumbra

# Film vs. CR vs. DR

- Film
  - Intensifying screen – scintillates when activated by X-Rays
  - Visible light exposes silver halide on film
  - More X-Rays ➔ More visible light (linear response) ➔ Darker Film (logarithmic response)
- Computed Radiography (CR)
  - Uses *photostimulable phosphor detector*
  - X-Rays absorbed and energy is trapped
  - Energy is “released” by a laser light
  - Light is collected and electronic signal is recorded as a digital image using pixels
- Digital Radiography (DR)
  - Use of an intensifying screen & CCD chip with an array of dexels (detector elements)
  - Forms images from visible light by collecting and reading out electrical charge

# Technique Factors & Dose

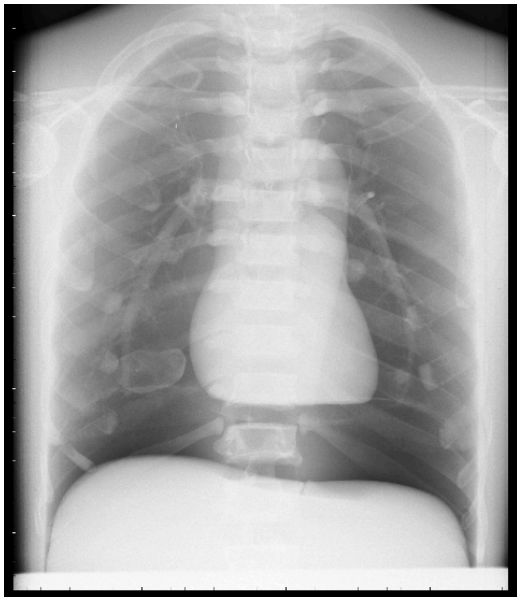
- Lower kV = Higher patient dose
  - Need enough X-Rays to reach detector
  - Must be balanced with contrast needs
  - Can use higher kV with CR/DR than with Film
- mAs
  - Directly proportional to radiation dose
  - mAs has different effects in Film than in CR/DR
- Generally, use high kV and low mAs to reduce patient dose
  - "Wastes" less radiation

# Image Quality & Radiation Dose

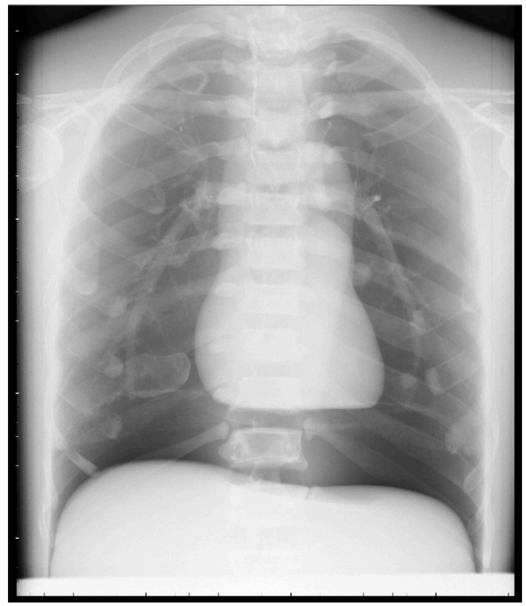
- CR/DR is quite different from film
  - mAs doesn't control OD in the same fashion
  - Use of post processing algorithms
  - Automatic & Manual Rescaling
- How low can you go?
  - Avoid noise and quantum mottle
- Exposure Index (EI, S, F#, REX)
  - Can be used as a general guide
  - Varies based on manufacturer – not linear!
- Dose Creep
  - CR/DR excel with more radiation
  - Can use 10 – 50 times more mAs

Exposure Index

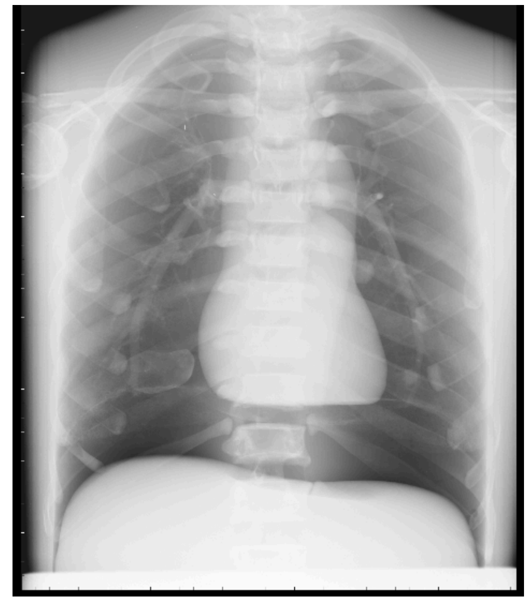
| Manufacturer | 50 µGy | 100 µGy | 200 µGy |
|---|---|---|---|
| Fuji (S) | 400 | 200 | 100 |
| Kodak (EI) | 1700 | 2000 | 2300 |
| Canon (REX) | 50 | 100 | 200 |
| Siemens (EI) | 500 | 1000 | 2000 |



110 kV @ 2 mAs
EI 1460



110 kV @ 12.5 mAs
EI 2320



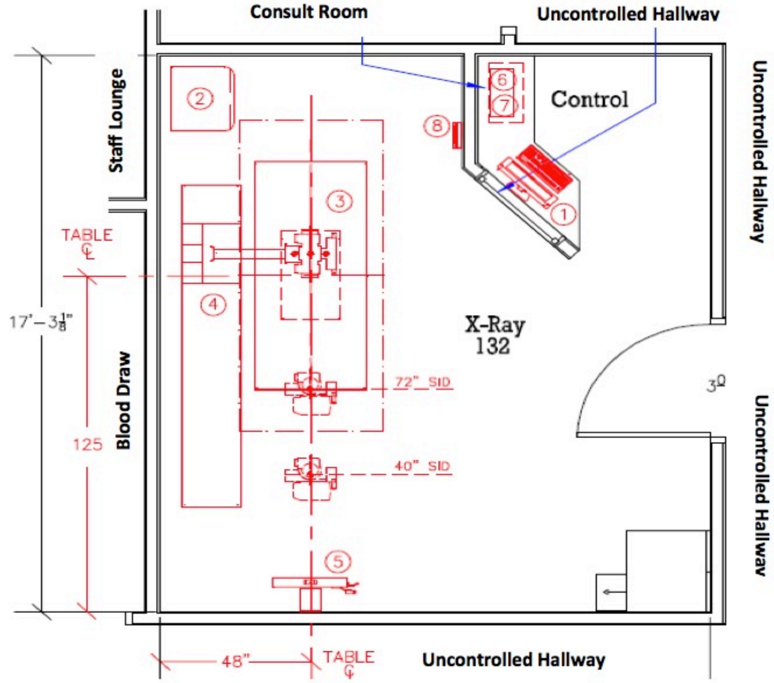
110 kV @ 100 mAs
EI 3210

# Use of Patient Shielding

- Gonadal Shields & Contact Shields
- Never place a shield in the area of interest!
- Required by many states and possibly other regulatory and/or accrediting agencies
- But the reality is....
  - Somatic radiation effects have never been observed in humans....EVER!
  - Sterility has a threshold of 2500 – 6000 mGy
  - Radiation induced malformations (pregnant patients)
    - Threshold is 100 – 200 mGy, not considered "significant" risk until > 1000 mGy
  - An X-Ray of the pelvis is ~ 1.1 mGy

# X-Ray Room Design

- What gets shielded?
- Primary vs. Scattered vs. Leakage
- Factors that affect shielding
  - Design Goal (Dose Limits)
  - Workload
  - Occupancy
  - Distance
  - Use Factor
  - Shielding Material (Concrete, Lead, etc)
- Control Booth Design

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# Practical Tips for Quality Exams

- Periodically review technique charts
- Ensure equipment functions as designed
- Communicate effectively with your patient
- Institute repeat/reject analysis program
  - Technique
  - Patient Motion
  - Positioning & Collimation
- Train your team
  - Image Quality
  - Radiation Dose
  - Positioning

# Final Thoughts

- We can always be better stewards of diagnostic radiation
  - Are we answering the diagnostic question?
  - What is our image quality?  Acceptable?
  - What is our radiation dose?
- Understanding technical parameters is key to delivering the best care to your patients
- Radiation dose awareness is everyone's responsibility
  - Image quality is the highest priority