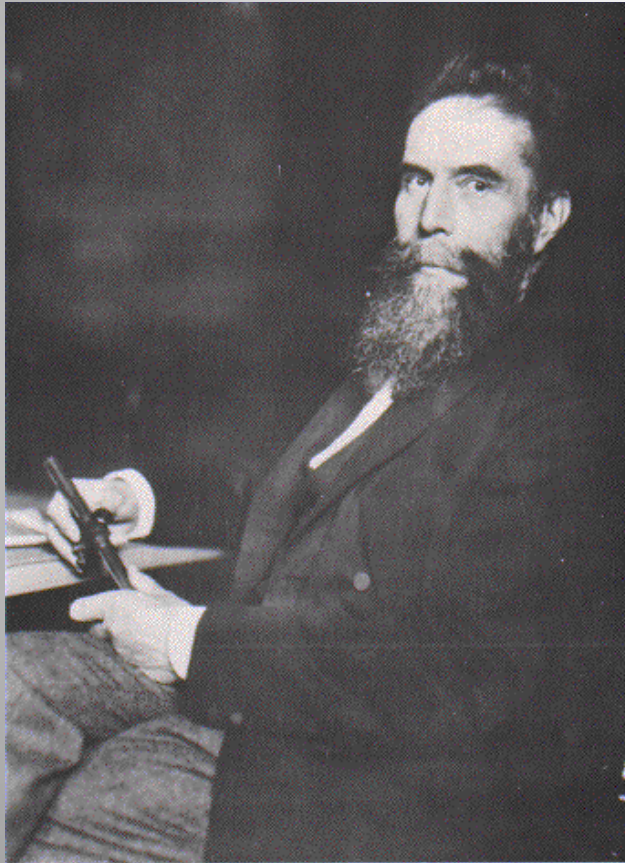


# Analytical X-Ray Systems:

## Radiation Safety for X-ray Machines

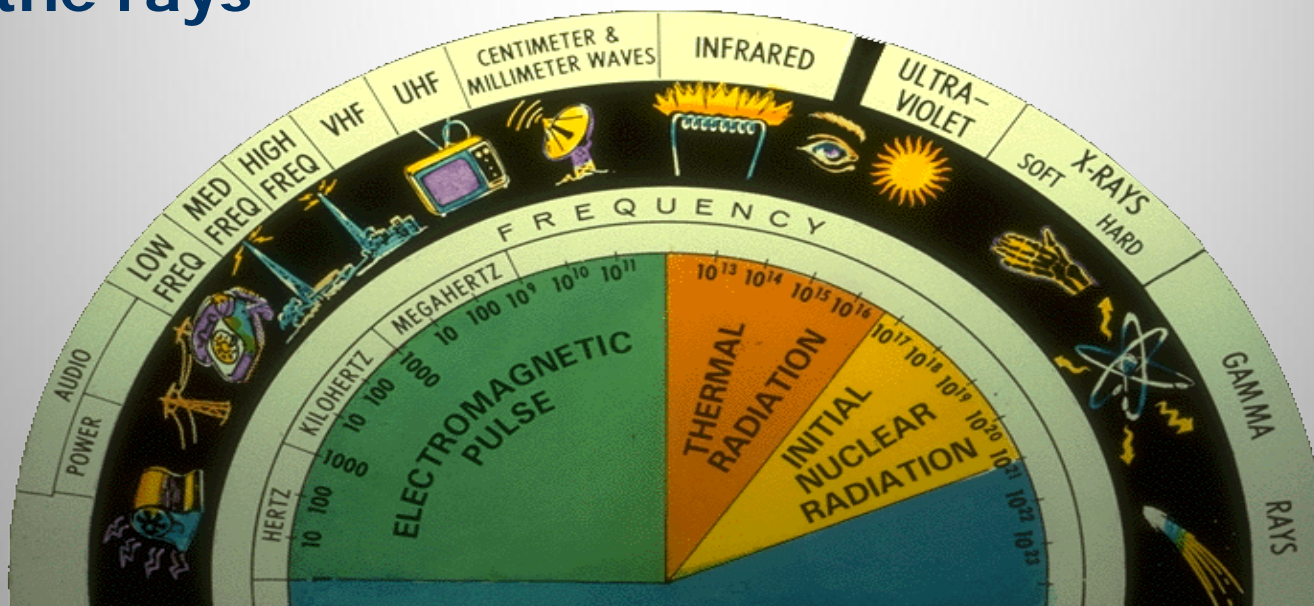
# Who Discovered X-rays?



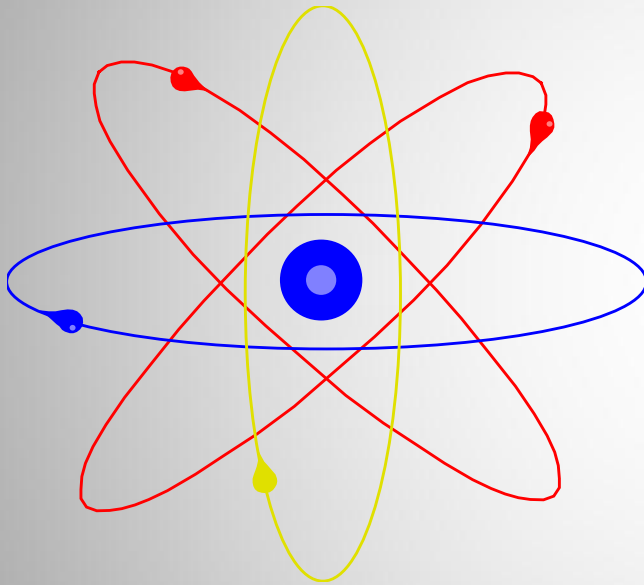
- 1895 – Wilhelm Roentgen discovered X-rays while studying luminescence produced by cathode tubes.
- Because he didn't know what they were he called them **X-rays** (X for unknown)
- He also noticed that the rays caused photographic plates to darken
- X-ray photographs revealed the inner structure of objects

# What's an X-Ray?

- Basically the same thing as visible light rays
- Both are wavelike forms of electromagnetic energy carried by particles called photons
- The difference is the **energy level** of the individual photons - expressed as the **wavelength** of the rays



# What's an X-Ray?



- Visible light and X-ray photons are both produced by the movement of electrons in atoms
- Electrons occupy different energy levels (orbitals) around the atom's nucleus
- When electrons drop to a lower orbital it releases energy in the form of a photon
- The energy of the photon depends on how far the electron dropped between orbitals.

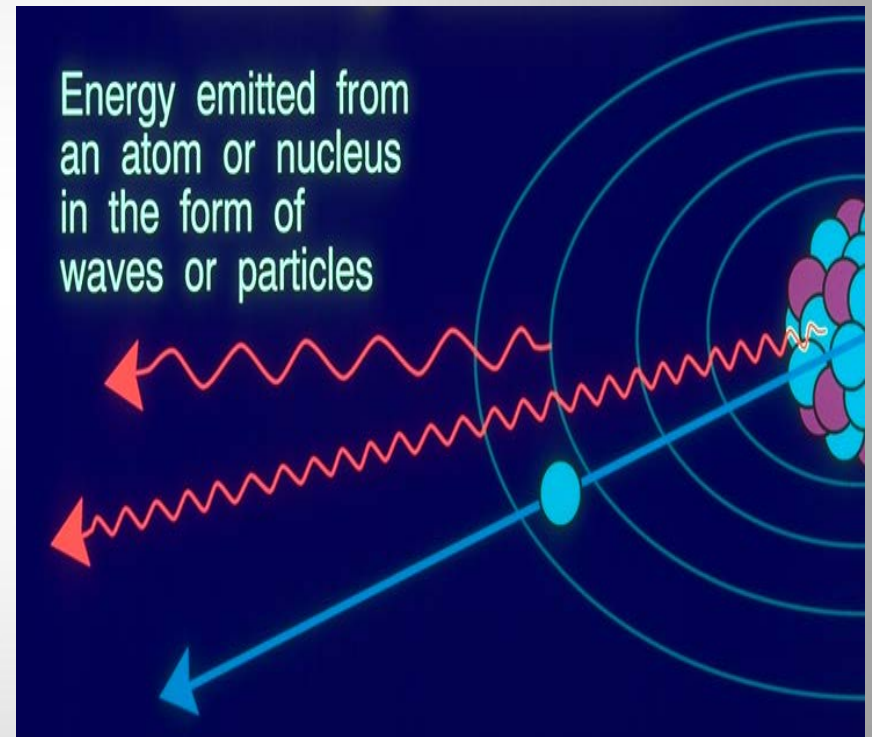
# Radiation Physics

- **Radiation** is “energy in transit” in the form of high speed particles and electromagnetic waves.
- This energy makes up our visible light, radio and television waves, UV light and microwaves
- Because these energies do not carry enough energy to separate molecules or remove electrons from orbits they are forms of **non-ionizing radiation**.



# Radiation Physics

- Ionizing radiation is radiation with enough energy to remove electrons from their orbit
- This causes the atom to become charged or ionized.
- This energy is emitted in the form of waves or particles



# Ionizing Radiation

Kind	Atomic Mass	Electrical Charge	Range in Air	Range in Body Tissue	Attenuation
Alpha	4	+2	< inch	Unable to penetrate skin	Stopped by a sheet of paper or skin
Beta	1/1840	-1	Several feet	1/3 inch	Stopped by a thin sheet of aluminum
Gamma / x-ray	NA	None	Passes through	Passes through	Thick lead or steel
Neutron	1	Neutral	Hundreds of feet	About 10% goes through	Several feet of water or plastic

# X-Ray and Gamma Ray Properties

Charge: None

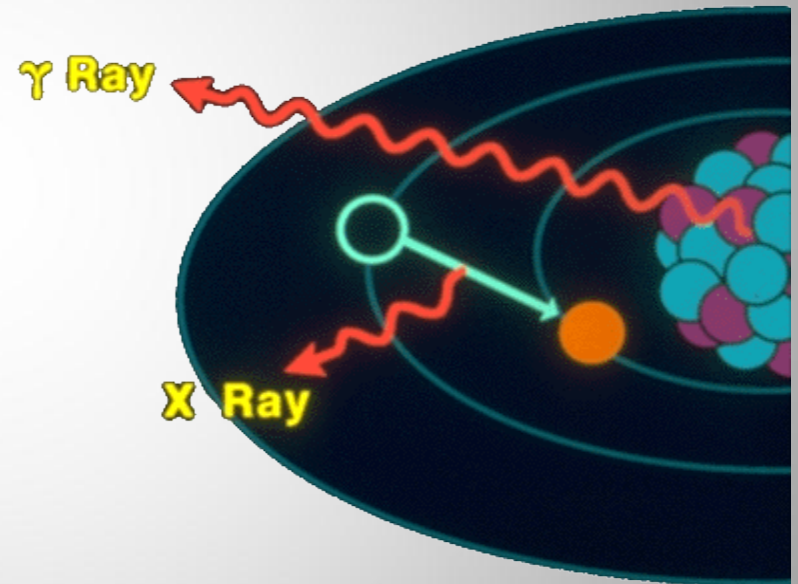
Mass: None

Velocity:  $3 \times 10^8$  m/s

Origin:

Gamma Rays: Nucleus

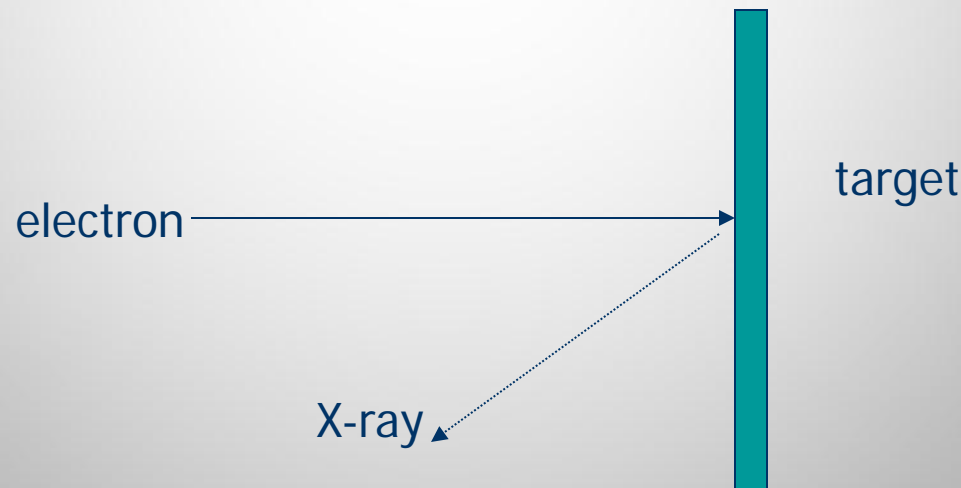
X Rays: Electron Cloud  
& Bremsstrahlung





# X-rays

- Electromagnetic radiation
- Originate in energy shells of atom
- Produced when electrons interact with a target

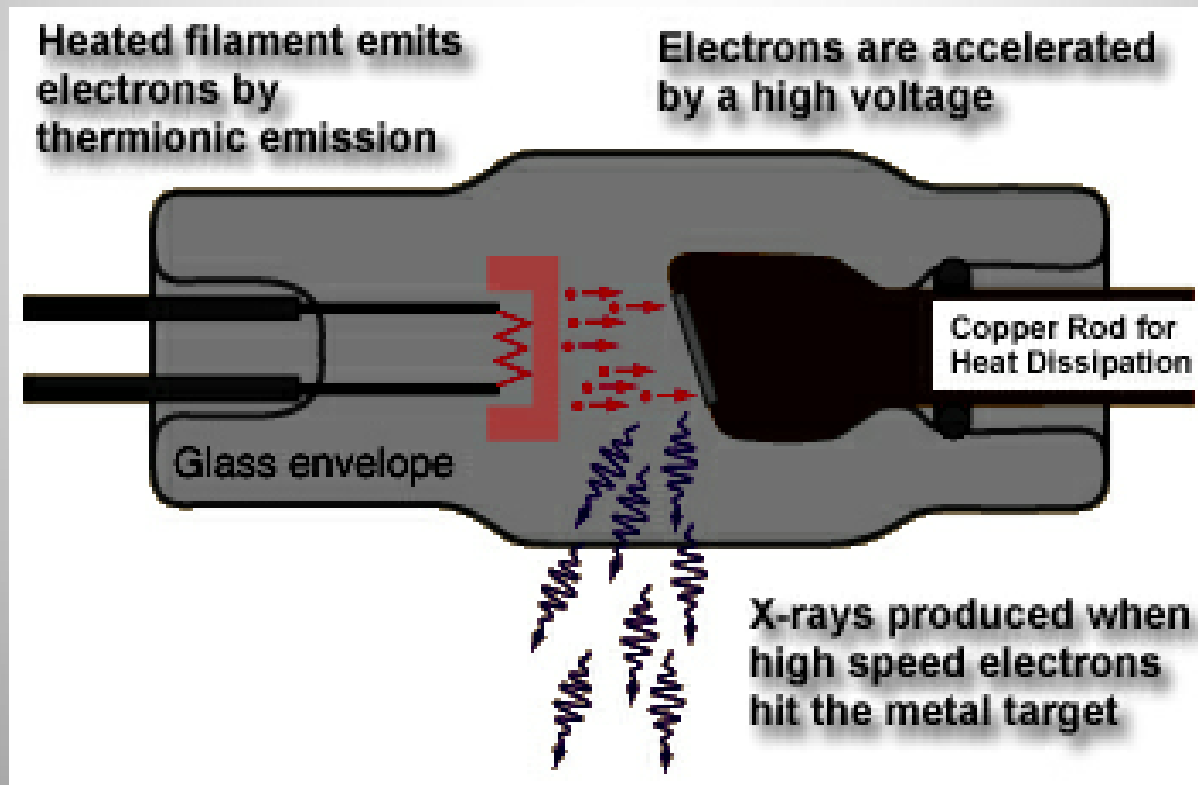


# What are X-Rays?

- X-rays are produced when accelerated electrons interact with a target, usually a metal absorber, or with a crystalline structure. This method of x-ray production is known as *bremsstrahlung*.
- The *bremsstrahlung* produced is proportional to the square of the energy of the accelerated electrons used to produce it, and is also proportional to the atomic number ( $Z$ ) of the target (absorber).

# How X-rays are Produced?

When fast-moving electrons slam into a metal object, X-rays are produced. The kinetic energy of the electron is transformed into electromagnetic energy.



# X-Ray Equipment

- Many different types of machines produce x-rays (intentionally or inadvertently)
  - X-ray Diffractometers
  - X-ray Fluorescence
  - Electron Microscopes
  - Photoelectron spectrometers



# Radiation Basics

- X-rays are known as ionizing radiation because x-rays possess sufficient energy to remove electrons from the atoms with which x-rays interact
- There are three quantities primarily used to describe the intensity of an x-ray beam
  - Exposure
  - Absorbed Dose
  - Dose Equivalent

# Radiation Basics

- **Exposure** is a quantity describing how much ionization is produced (how many electrons are produced as x-rays create ionization) in air by gamma or x-rays.
- Unit of exposure is the **Roentgen**

1 Roentgen (R) =  $2.58 \times 10^{-4}$  Coulombs of charge produced per kilogram of air



# Radiation Basics

- Absorbed dose – quantity describing how much energy is deposited in a material by a beam of radiation
- Unit of absorbed dose is the rad

1 rad = 100 ergs of energy deposited in one gram of material

# Radiation Basics

- **Dose Equivalent** – quantity derived by multiplying the absorbed dose by a quality factor (QF) which depends on the type of radiation being measured.
- Dose equivalent does not reflect the ability of each type of radiation to cause damage
- Unit of dose equivalent is the **rem**

**Dose Equivalent = Absorbed dose x QF**

QF = 1 for gamma and x-rays

# Biological Effects of X-Rays

- Injury to living tissue results from the transfer of energy to atoms and molecules in the cellular structure.
- Atoms and molecules become ionized or excited.
- These excitations and ionizations can:
  - Produce free radicals
  - Break chemical bonds
  - Damage molecules that regulate vital cell processes

# Prompt and Delayed Effects

- Radiation effects can be categorized by when they appear
- Prompt, acute effects – skin reddening, hair loss and radiation burns which develop soon after large doses of radiation are delivered over short periods of time
- Delayed effects –cataract formation and cancer induction that may occur months or years after a radiation exposure.

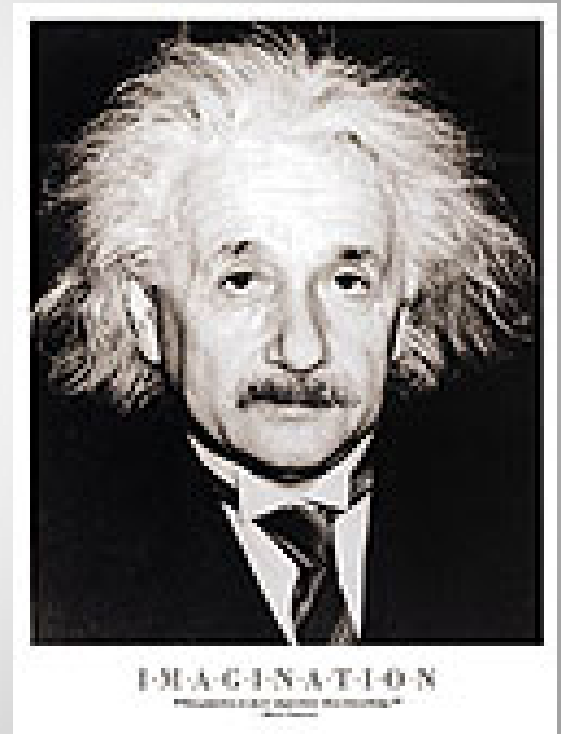
# Prompt Effects

- Will develop within hours, days or weeks depending on the size of the dose. The larger the dose the sooner the effect will occur
- Limited to the site of the exposure.



# Prompt Effects

- The skin does not have receptors that sense radiation exposure. No matter how large a radiation dose a person receives, there is no sensation at the time the dose is delivered.
- Some people who have received large doses claim to feel a tingling at the skin, however it is believed that the tingling is due to static charge at the skin surface rather than the direct sensation of radiation exposure.





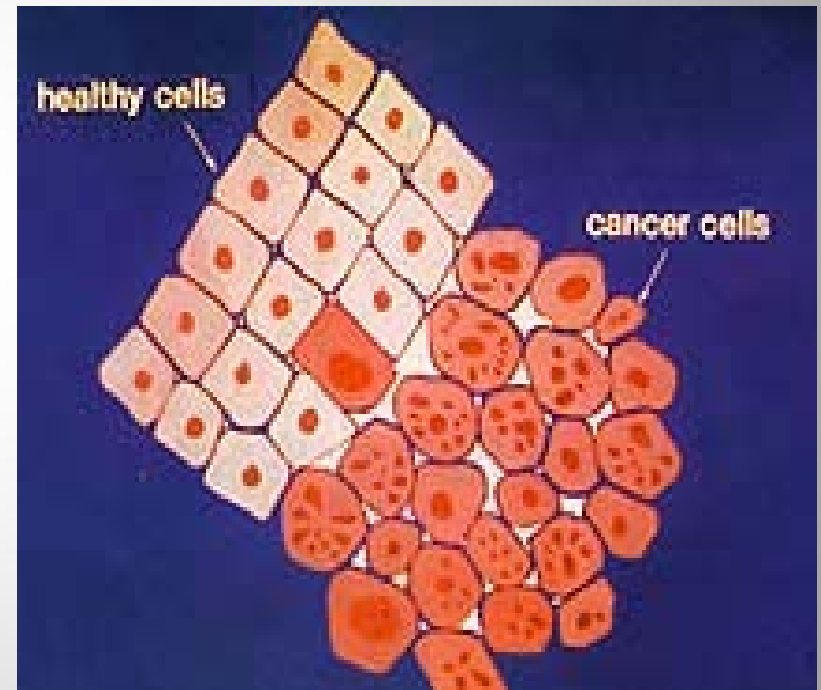
# Delayed Effects

- Cataracts – induced when a dose exceeding 500 rems is delivered to the lens of the eye. Radiation induced cataracts may take months or years to appear.
- Extremely unlikely to receive a substantial dose to the eye working with XRD units.



# Delayed Effects

- Cancer studies of people exposed to high doses of radiation have shown there is a risk of cancer induction associated with high doses.
- Studies demonstrate that cancer risk is linearly proportional to the dose
- Radiation induced cancers may take 10-15 years to appear.



# Cancer Risk Estimates

## Putting Risk into Perspective

- 1 in a Million chance of death from activities common in society
  - Smoking 1.4 cigarettes in a lifetime (lung cancer)
  - Eating 40 tablespoons of peanut butter (aflatoxin)
  - Spending two days in New York City (air pollution)
  - Driving 40 miles in a car (accident)
  - Flying 2500 miles in a jet (accident)
  - Canoeing for 6 minutes (drowning)
  - Receiving a dose of 10 mrem of radiation (cancer)

# Personnel Exposure Limits

- Annual Dose Exposure limits have been established based on the recommendations of national and international commissions.
- Exposures at or below these limits should result in no exposure effects

Whole Body – Radiation Workers	5 rem/year (5000 mrem/yr)
Extremities – Radiation Workers	50 rem/year 50,000 mrem/yr
General Public	0.1 rem/year (100 mrem/yr)

# Exposure Effects

- 1000 rad – second degree burns
- 2000 rad – intense swelling within a few hours
- 3000 rad – completely destroys tissue
- 400 rad – acute whole body exposure is LD 50/30\*

Remember – Multiply the QF and the rad to get rem

\*LD 50/30 – lethal to 50% of population within 30 days if not treated

# Radiation Protection Techniques

Time

Distance

Shielding

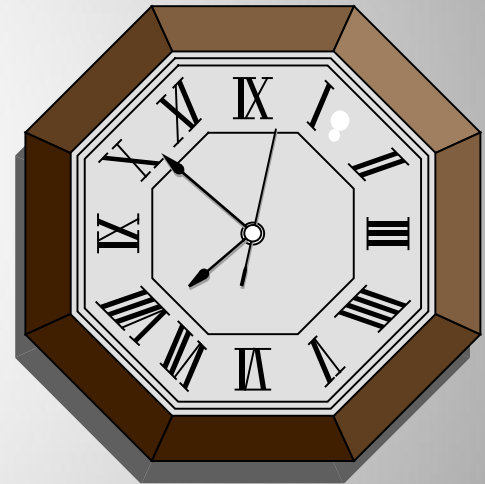


# Radiation Protection Techniques

## TIME

Reduced Time =  
Reduced Exposure

- Work quickly and efficiently
- Plan experiments and rehearse procedures to minimize exposure (beam on) time thus reducing total radiation exposure in room



# Radiation Protection Techniques

## DISTANCE

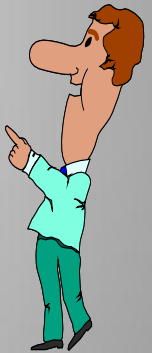
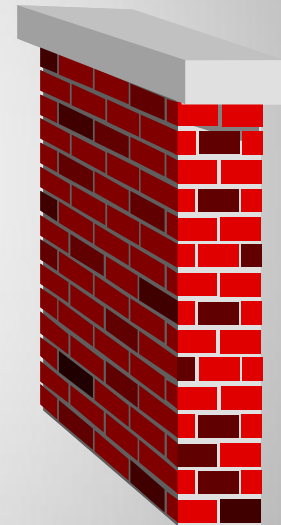
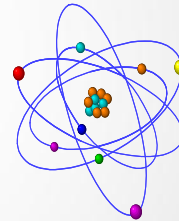
- Increased Distance = Reduced Exposure
  - Radiation exposure is reduced by  $1/\text{distance}^2$
  - When system is being used if you are not required to be near the system, move away!



# Radiation Protection Techniques

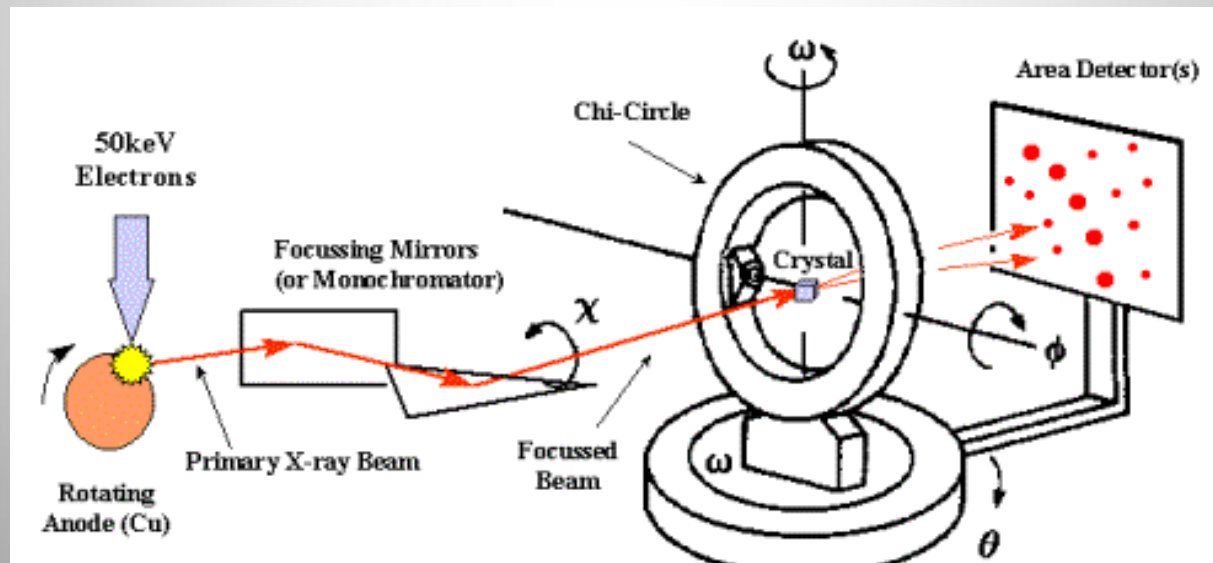
## SHIELDING

- Put appropriate material between you and the source
  - X-ray tubes protected by fixed shielding
  - Don't rely on protective aprons – permanently placed shielding is more effective for reducing exposure
  - Operate systems with all shielding and safety components in place
  - **NEVER** tamper with system interlocks



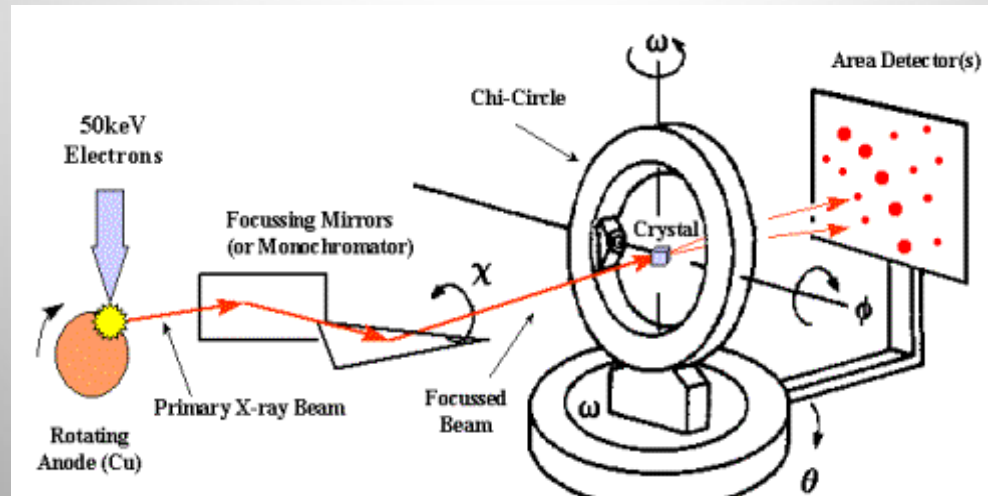
# Analytical X-Ray Systems

- Analytical X-ray machines are used extensively for microstructure analysis
- When a sample is irradiated with a parallel beam of monochromatic x-rays, the atomic lattice of the sample acts as a 3-dimensional diffraction grating, causing the beam to be diffracted to specific angles related to the inter-atomic spacings.



# Analytical X-ray Systems

- This x-ray pattern is recorded by film or angular x-ray detectors.
- By measuring the angles of the diffraction, the inter-atomic spacing of the material can be determined and used to identify the crystallographic structures of the material



# X-Ray Diffraction

X-ray diffraction units consist of:

- X-ray generator
- Goniometer (optical instrument for measuring crystal angles)
- Sample holder
- X-ray detector

X-Ray beam impinges sample and scattered radiation is measured by radiation detectors located at various angles with respect to the sample





# Causes of Accidents

- Poor equipment configuration
- Manipulation of equipment when energized
- Equipment failure – shutter failure/warning light failure
- Inadequate training – incorrect use of equipment
- Violation of procedures – over-riding interlocks



# Preventing Accidents

- Know location and/or presence of primary and diffracted beams at all times
- Provide and inspect shielding
- Do not perform maintenance without confirming the beam is not energized
- Perform routine check of safety devices
- Don't put your body parts in the beam!

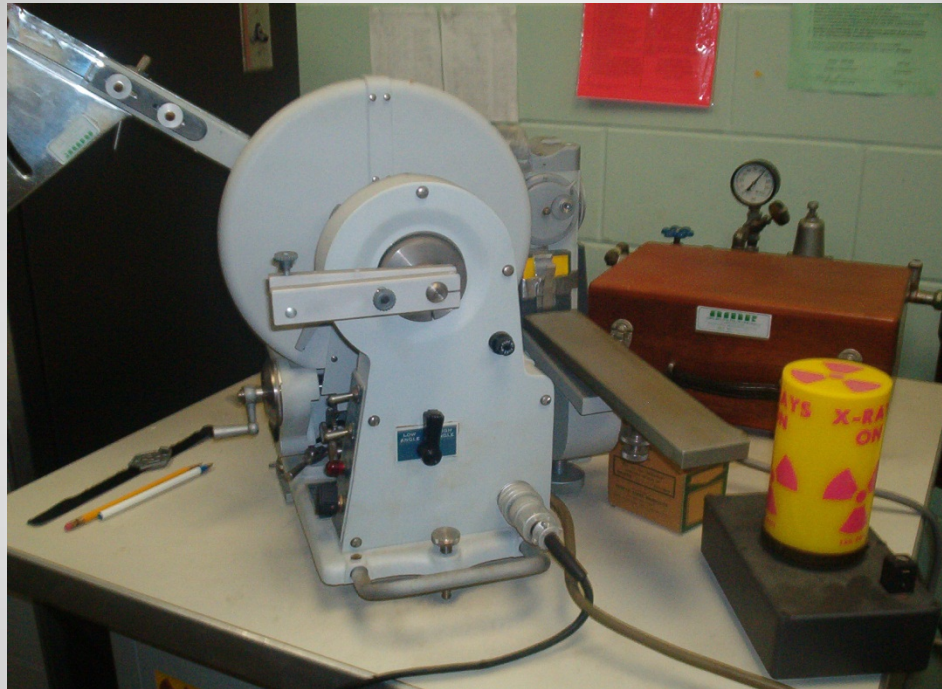
# Principle Hazard

## Analytical XRD Units

- Analytical X-ray units make use of a very narrow collimated x-ray beam.
- Exposure of the skin to the primary beam may result in very high doses within fractions of a second that will result in severe radiation burns.



# Open Beam XRD Unit



This is an OLD open beam X-ray diffraction device. New diffraction X-Ray devices for UAH research must be contained in a fully shielded interlocked cabinet.

# Cabinet XRD Unit



The x-ray tube, detector, sample are contained in a housing that provides shielding to the user and others in the lab. The access doors are interlocked and will shut off the x-rays when opened. The large viewing area is made possible by using leaded glass or Plexiglass

## Possible Radiation Intensity Near Analytical X-ray Equipment

Location	Dose Rate
Primary beam at tube port	Several thousand rems per second
Primary beam at 10 cm collimator	Several hundred rems per minute
Scatter radiation near sample	Hundreds of mrems per hour



# Precautions and Guidelines

- Receive proper training and instruction
- Never assume the unit was left in a safe working condition by the previous user
- Do not by-pass any safety device or interlock
- Know the location and/or presence of primary and diffracted beams at all times
- Do not leave the unit unattended when operational
- Know what you are doing and where to expect problems

# Analytical X-Ray Equipment Radiation Safety Requirements

- Safety device prevents entry of any part of an individual's body into the primary beam or which causes the beam to be shut off immediately upon such entry
- Warning devices must be provided near the source housing which indicates the x-ray tube status (on/off) or shutter status (open/closed)





# Analytical X-Ray Equipment Radiation Safety Requirements

- X-Ray equipment must be labeled with a sign bearing a conventional radiation symbol and the words "Caution – High Intensity X-ray Beam" and "Caution – This equipment produces radiation when energized"



**CAUTION**  
**THIS MACHINE PRODUCES**  
**RADIATION**  
**WHEN ENERGIZED**

# Analytical X-Ray Equipment Radiation Safety Requirements

- Equipment must be equipped with a shutter that cannot be opened unless a collimator is attached
- A warning light labeled "X-ray On" must be located near any switch that energizes the tube and it must illuminate only when the tube is energized



# Analytical X-Ray Equipment Radiation Safety Requirements

- Leakage radiation from the x-ray tube housing, with all shutters closed, must not exceed 2.5 mR/hr at 5 cm from the surface.
- X-ray generators must have a protective cabinet which limits leakage radiation at 5 cm from the surface to 0.25 mR/hr or less.



# Analytical X-Ray Equipment Radiation Safety Requirements

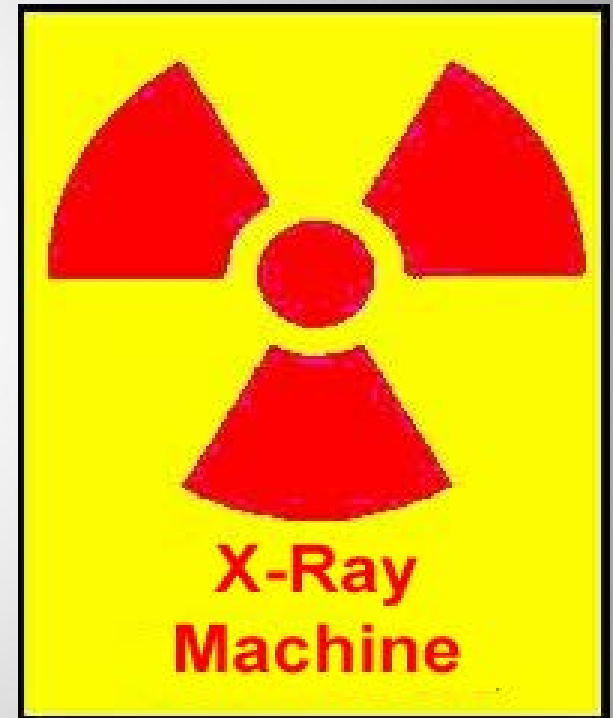
- X-ray generators must be shielded to prevent long-term exposure in excess of statutory limits to any individual.
- Radiation surveys must be performed upon installation of equipment, after modification and after any major repair of the equipment





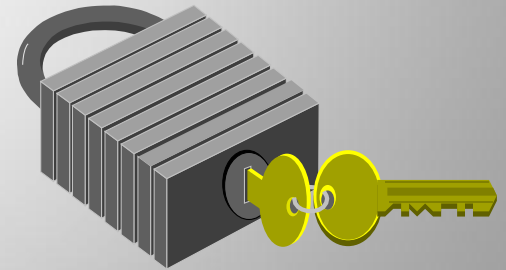
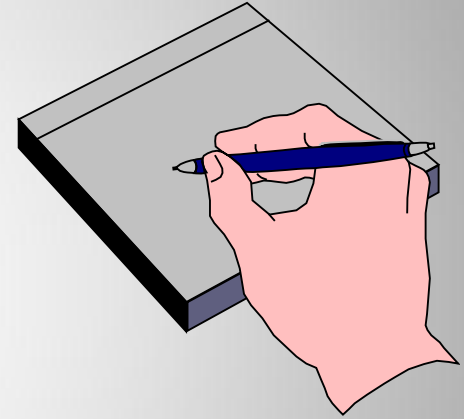
# Analytical X-Ray Equipment Radiation Safety Requirements

- Rooms containing analytical x-ray equipment shall be posted with a sign bearing the radiation symbol and the words "Caution – X-ray Equipment"



# Analytical X-Ray Equipment Radiation Safety Requirements

- Only trained individuals are allowed to operate the equipment and written procedures must be available
- No safety device may be bypassed without approval of the RSO.

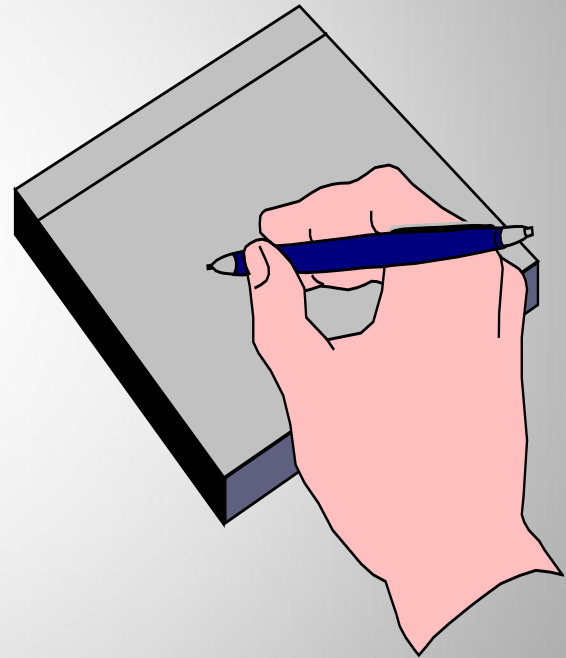


# Analytical X-Ray Equipment Radiation Safety Requirements

- No one is permitted to operate an x-ray machine without receiving instruction on the radiation hazard involved, safety devices, operating procedures, symptoms of acute localized exposure and procedures for reporting a suspected overexposure

# Analytical X-Ray Equipment Radiation Safety Requirements

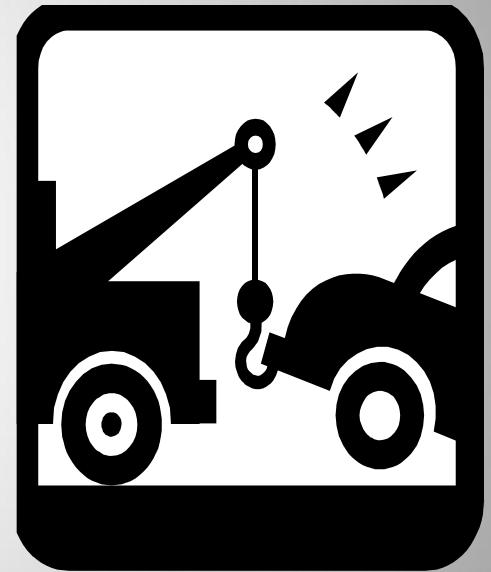
- Records of safety surveys, routine calibrations and maintenance and records of any modifications from the original schematics must be maintained for the life of the equipment.





# How to Recognize Failures

- Interlocks not working
- Radiation is observed during surveys
- Unqualified people operating the system
- Redness of the skin, normally to the hand
- Warning light(s) not operational



# Emergency Contacts

- Should you suspect anything is wrong with the unit immediately halt operations
- Notify the instructor
- Contact the Radiation Safety Officer

Dr. Michael Banish 256-824-6810

After hours – 256-824-6596 (UAH Police  
Department)

# Quiz

