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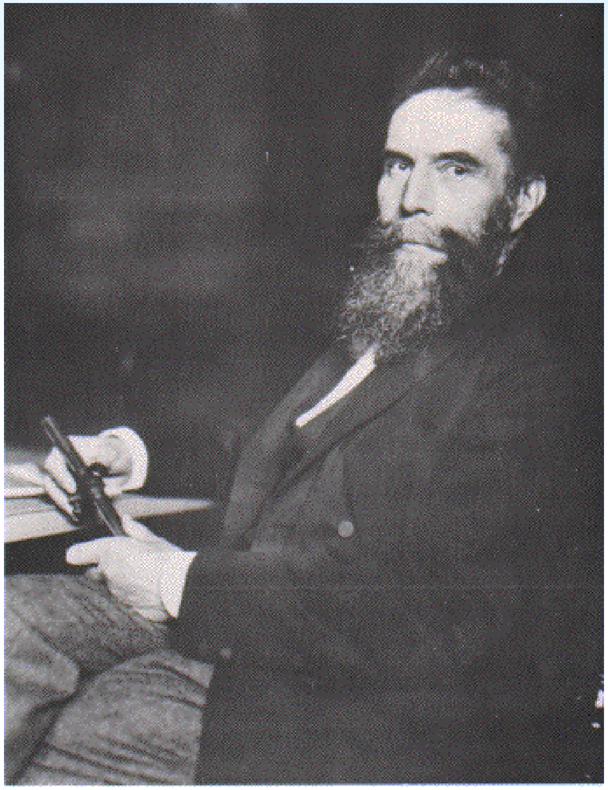
# Analytical X-Ray Systems:

## Radiation Safety for X-ray Machines

Special Thanks to Sharron Daly, Radiation Safety Officer
UW-Milwaukee for use of this presentation

# 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



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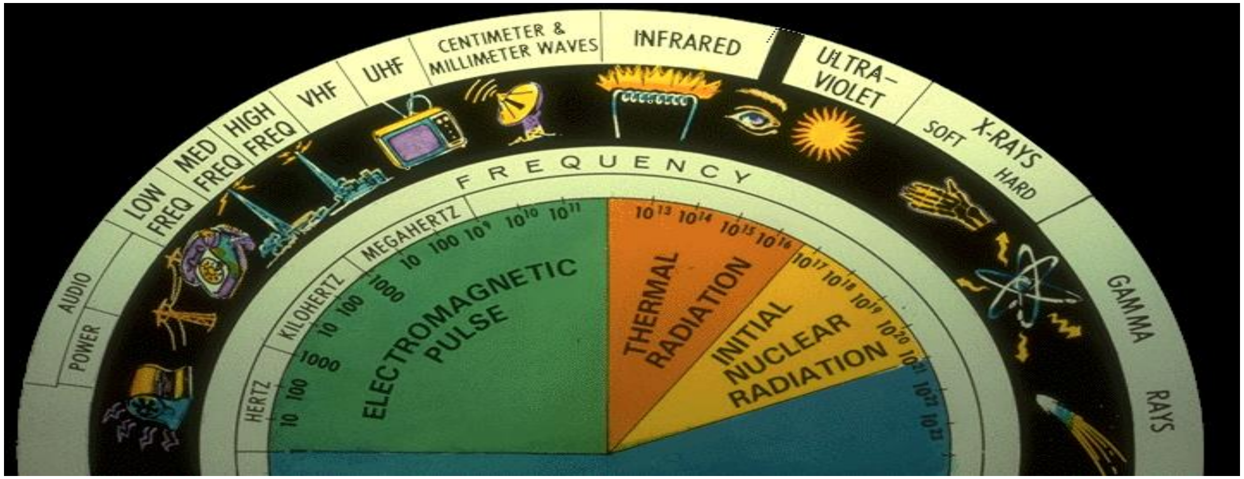
# What is an X-Ray?

- 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

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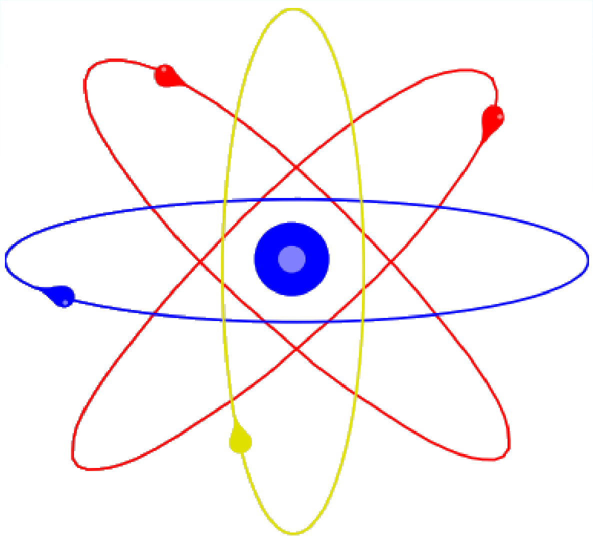
# What is an X-Ray?

- 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.



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# 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***.

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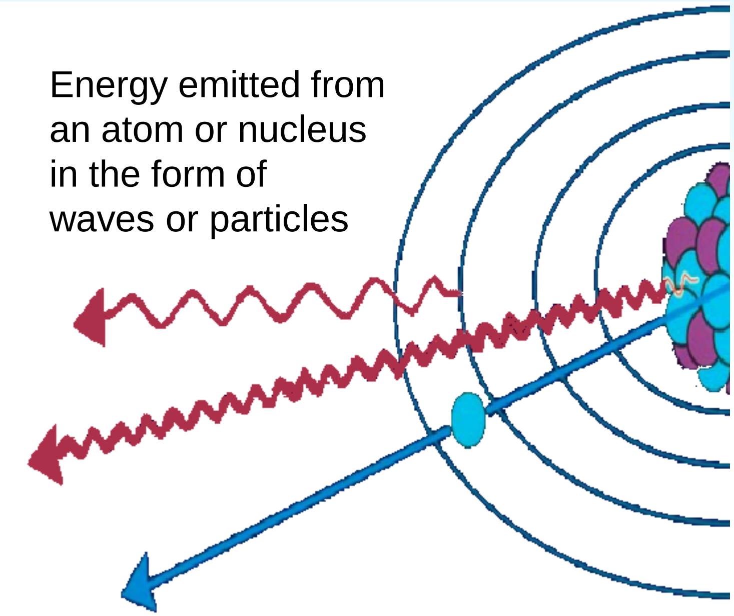
# Radiation Physics

- 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

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# 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 |

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# X-Ray and Gamma Ray Properties

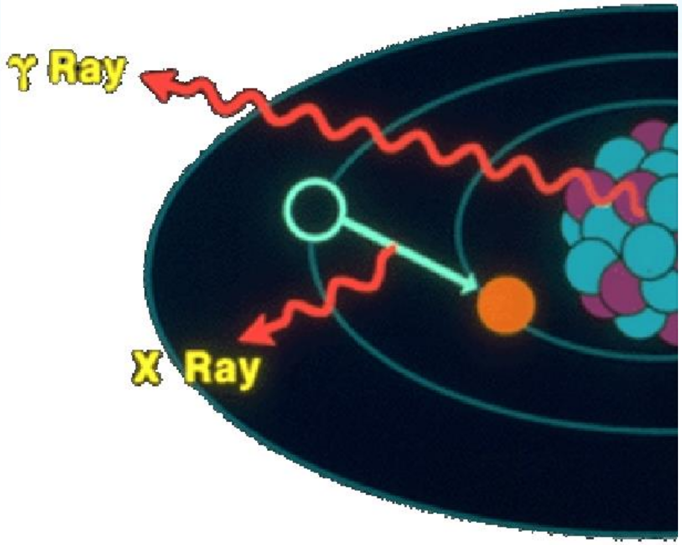
Charge:   None
Mass:     None

Velocity: 3 x 108 m/s

Origin:

  ***Gamma Rays***:  Nucleus

  ***X Rays***:  Electron Cloud
  & Bremsstrahlung

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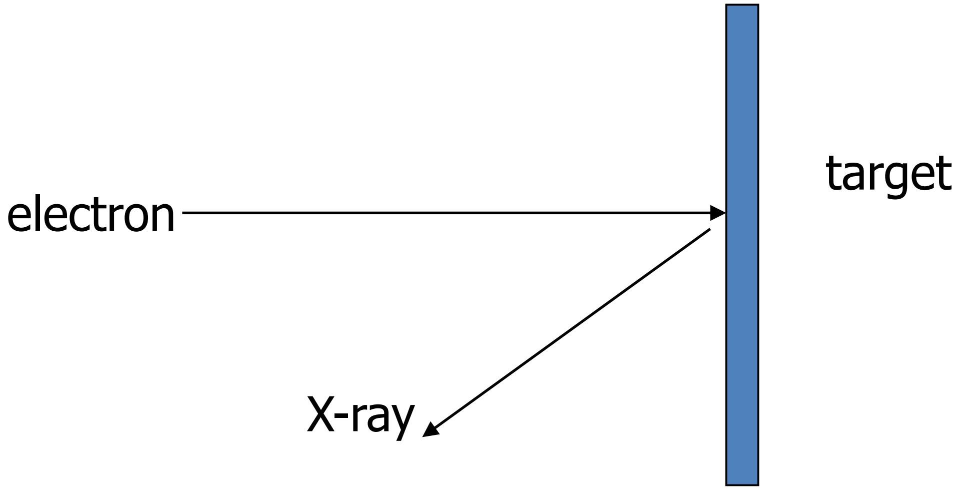
# X-rays

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

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# 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).

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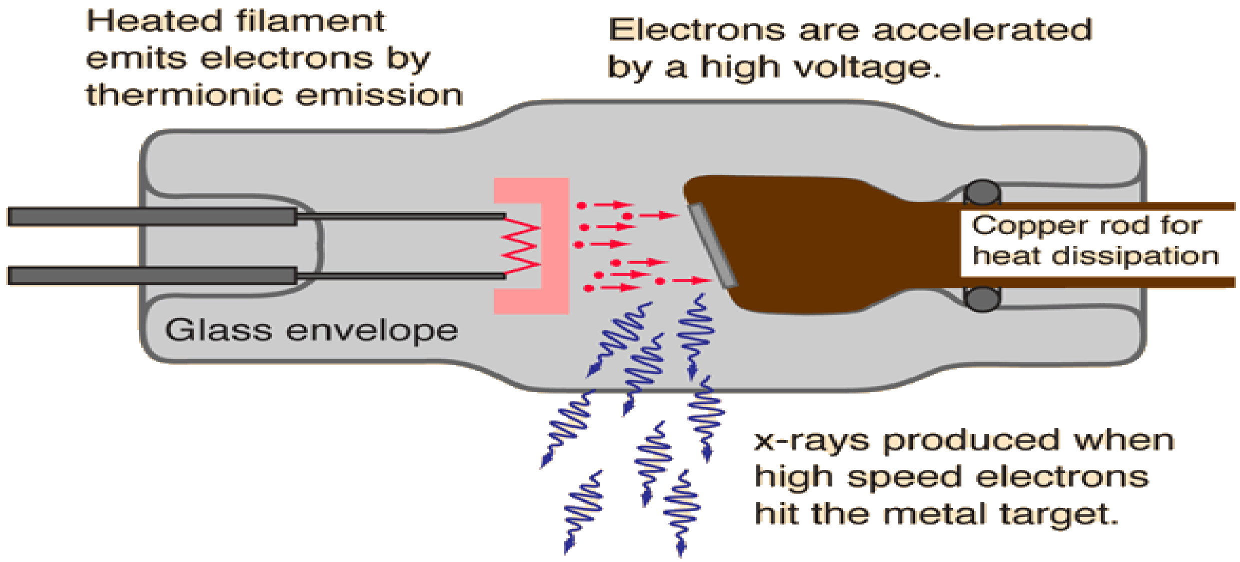
# How X-rays are Produced?

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

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# X-Ray Equipment

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

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# 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

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# 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 x $10^{-4}$ Coulombs of charge produced per kilogram of air*

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# 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

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# 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

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# 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

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# 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.

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# 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.

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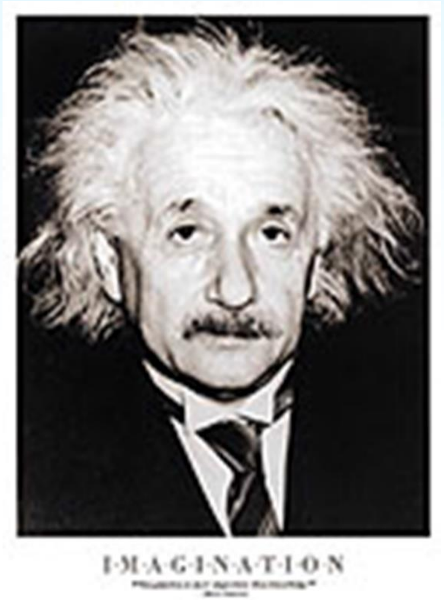
# Prompt Effects

- 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.

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# 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.

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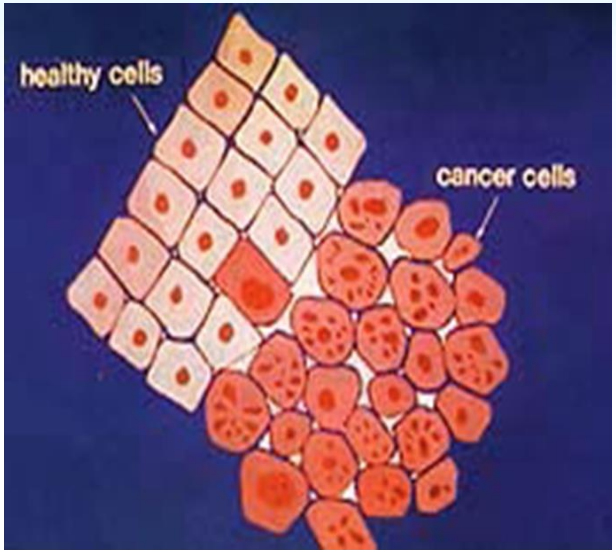
# Delayed Effects

- 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.

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# 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***)

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# 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<br>(5000 mrem/yr) |
| ***Extremities*** – Radiation Workers | 50 rem/year<br>(50,000 mrem/yr) |
| ***General Public*** | 0.1 rem/year<br>(100 mrem/yr) |

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# 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*

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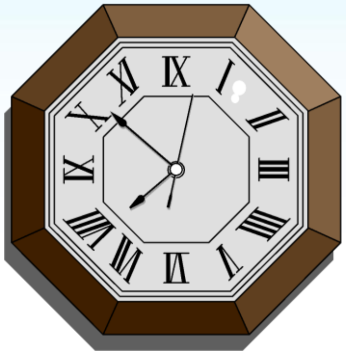
# Radiation Protection Techniques

- **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



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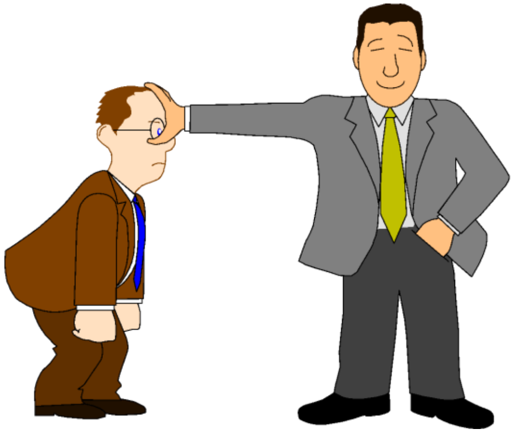
# Radiation Protection Techniques
# ***DISTANCE***

- 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!



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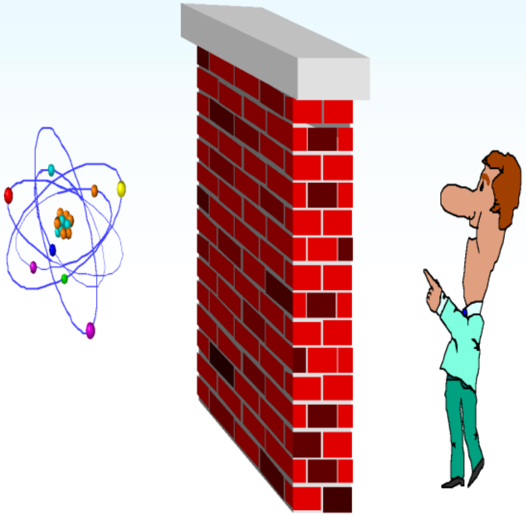
# Radiation Protection Techniques SHIELDING

- 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



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# 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.

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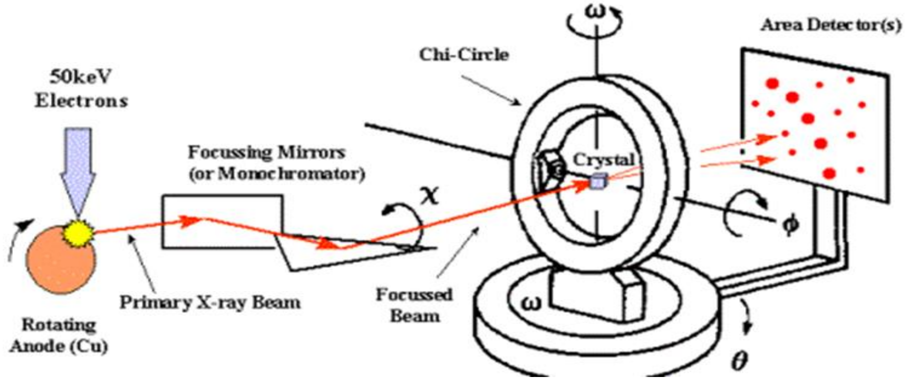
# Analytical X-ray Systems

- 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

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# 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

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# 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*


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# 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!

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# 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.

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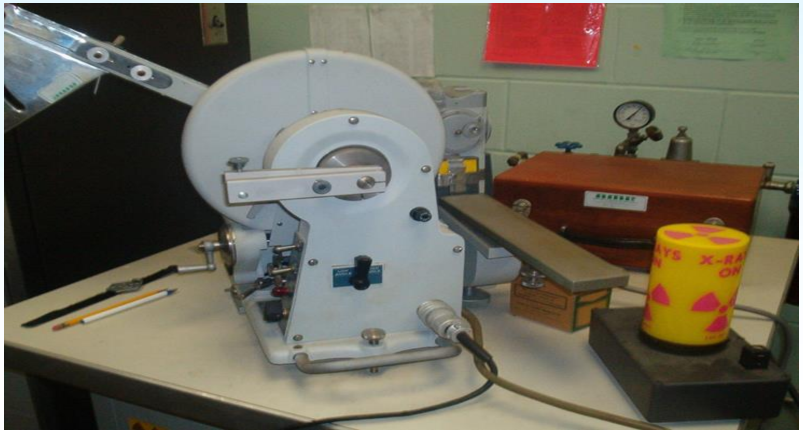
# Open Beam XRD Unit



- 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.

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# 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.

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# 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 |

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# 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

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# 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)


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# 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*"


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# 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

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# 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.

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# 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

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# 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*"


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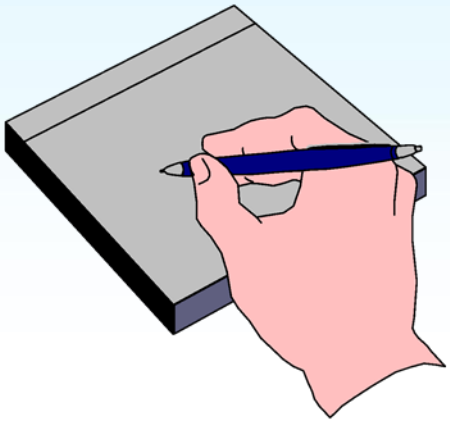
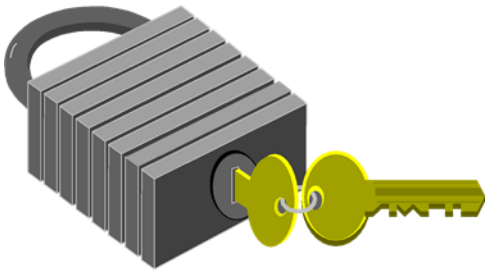
# Analytical X-Ray Equipment Radiation Safety Requirements

- 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.



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# 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

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# 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.

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# 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

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# 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 256-824-3544
  - After hours – 256-824-6596 (UAH Police Department)

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# Acknowledge Training

[Click here to acknowledge receipt of training](#)

[Quiz](#)

**If you have any questions contact:**

Office of Environmental Health and Safety
Physical Plant Building
301 Sparkman Drive
Huntsville, AL 35899
oehs@uah.edu
256-824-6053

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