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X-Ray Safety Training

History of X-Ray

- X-ray was discovered by Wilhelm Roentgen in November of 1895.
- He was studying cathode rays from vacuum tube and found paper with barium salt glowing in the dark when tube was powered.
- Unknown signal was called “X-ray”

Roentgen’s initial findings were:

1. X-ray penetrates solid barriers
2. Penetration related to density
3. Produces image on photographic paper

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History of X-Ray

- After initial discovery Roentgen moved into lab to study properties of X-ray for two months.
- He published results in January of 1896.

Results of X-ray study:

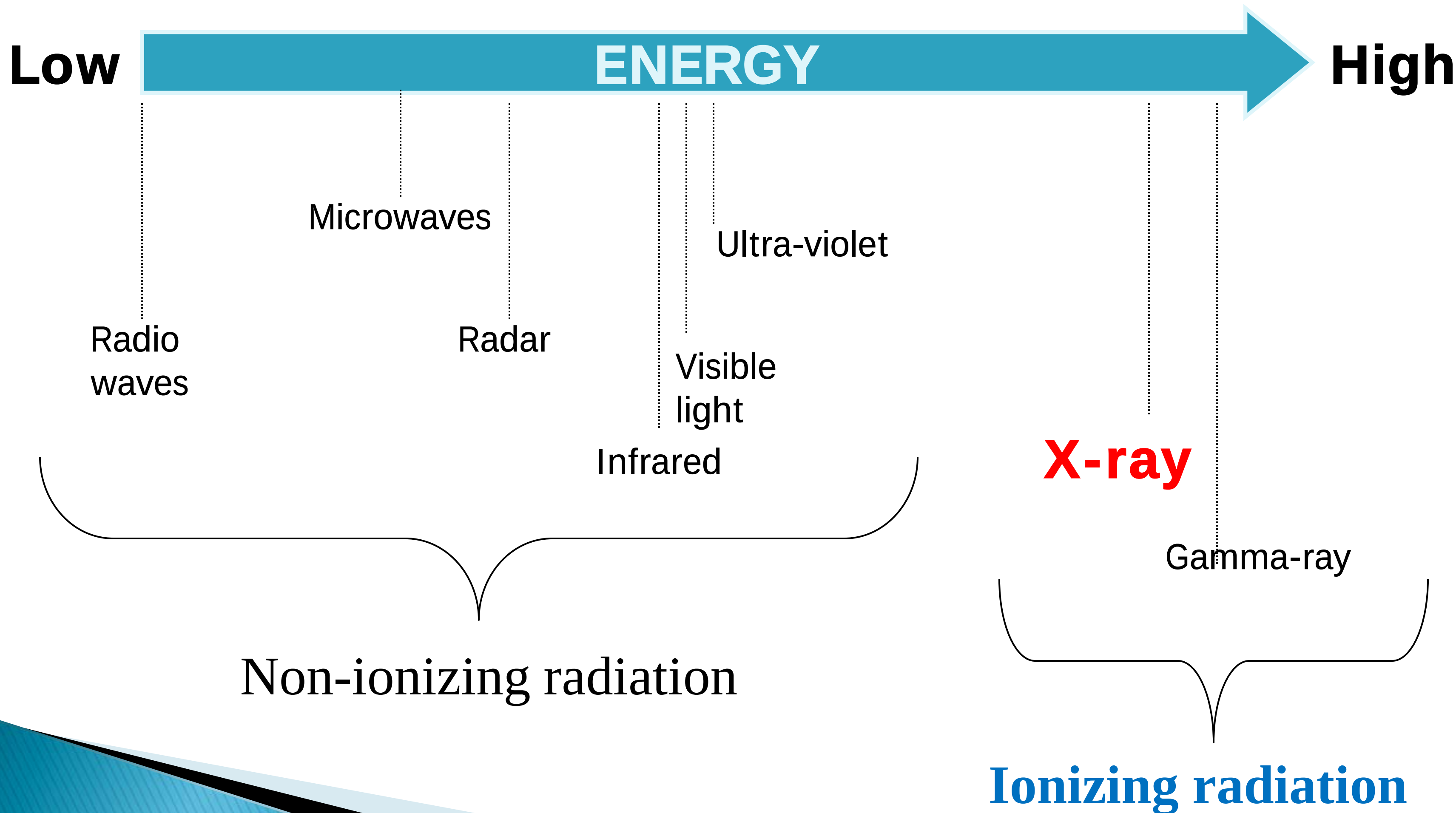
1. Density and thickness reduce penetration
2. Causes florescence in uranium glass
3. Produces image on photographic plate (shadow)
4. Not deflected by a prism, not reflected
5. Rays move with some velocity thru materials
6. Obeys inverse square law

What are X-Rays?

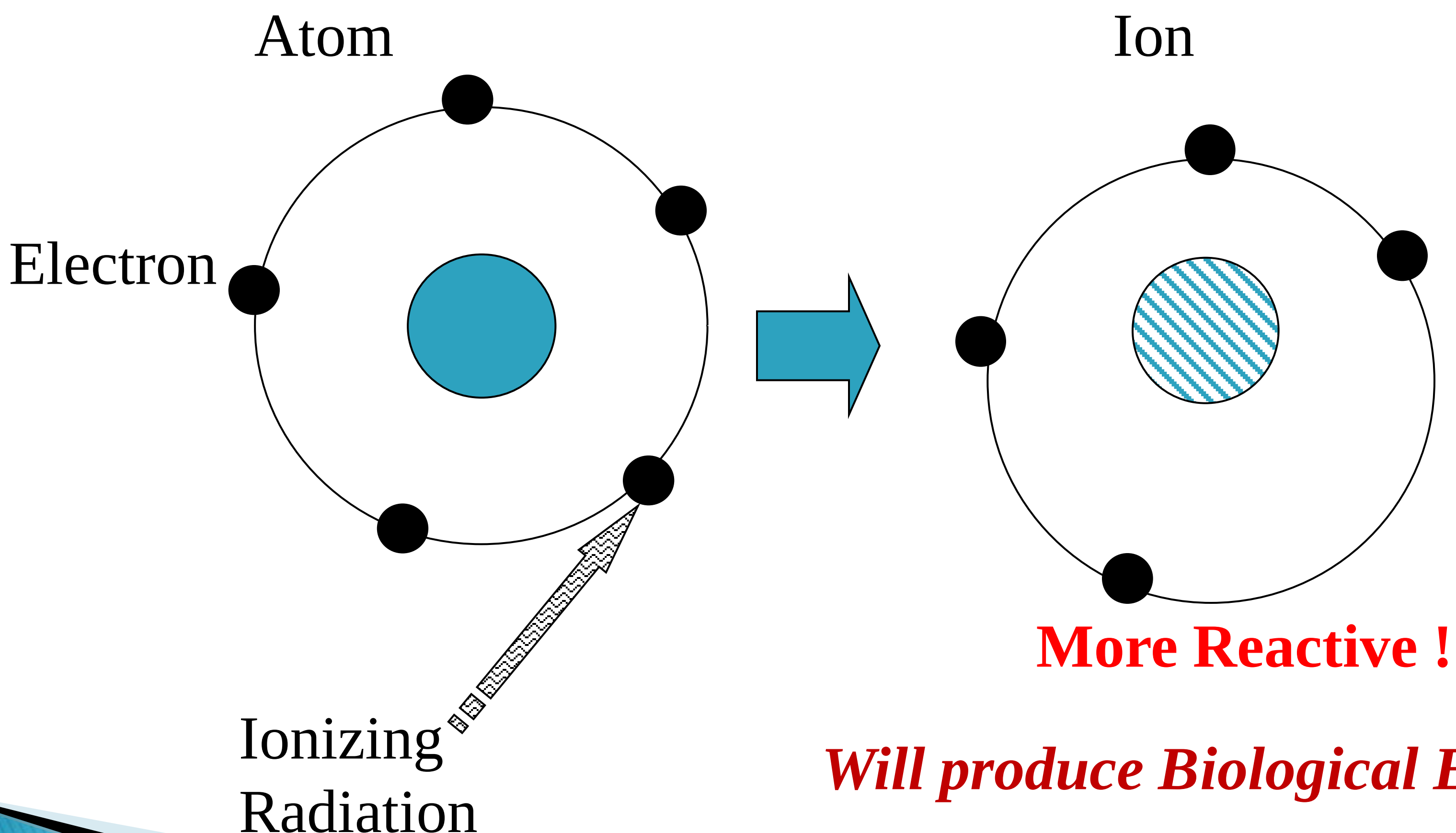
- X-rays are electromagnetic waves generated from the electron cloud orbiting the atomic nucleus.

1. No mass
2. No charge
3. Travel at the speed of light
4. Called a “photon”

Electromagnetic Waves



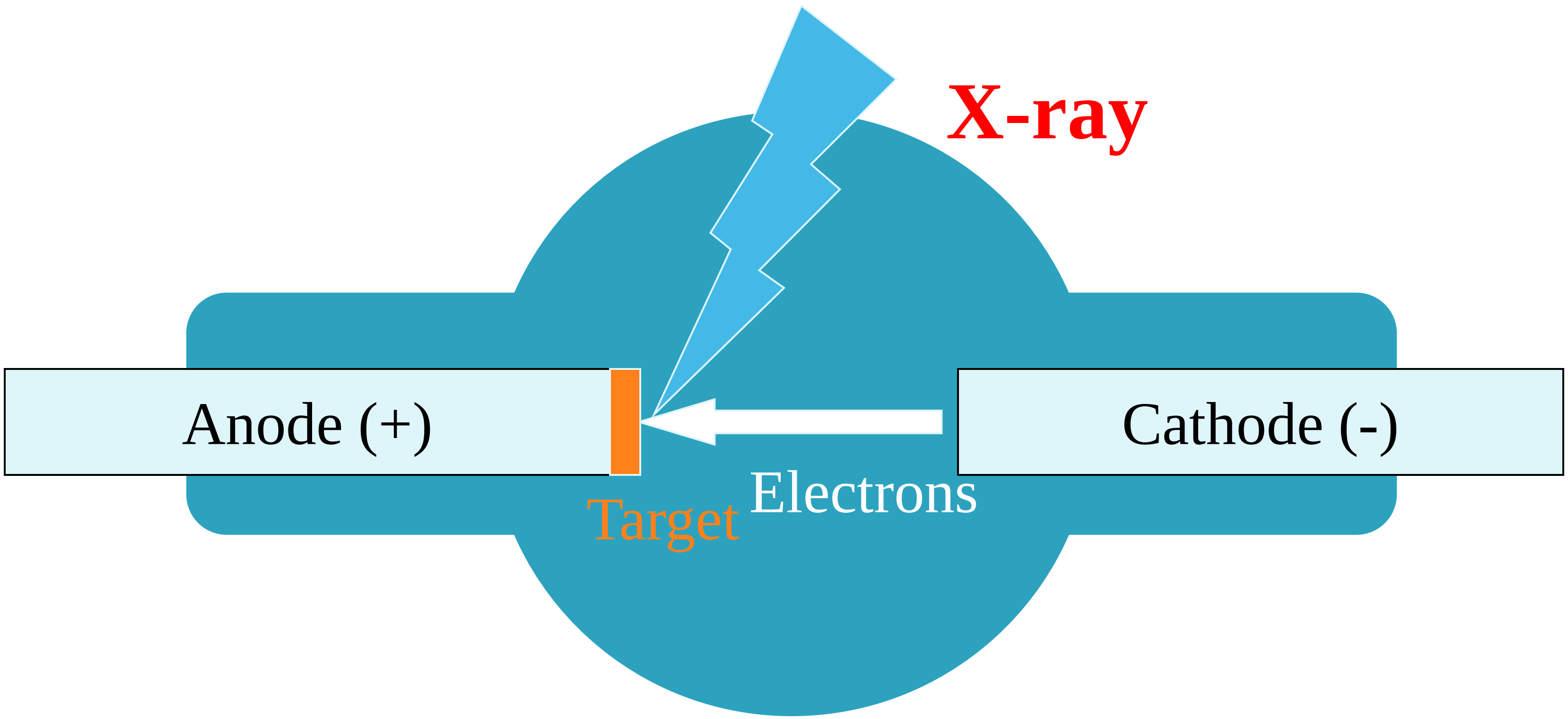
Ionization



More Reactive !!

Will produce Biological Effect

X-ray production



X-ray tube

X-Ray production – cont.

- Most X-ray devices emit electrons from a cathode, accelerated by a voltage
- Electrons strike the anode (often Tungsten)
- Electrons slow down in the anode, and as a result of interaction between the electrons and the atoms of the anode, x-rays are produced.
- The energy of the x-ray shows different distribution depending on the anode material.
- During this process, the device emits two different types of radiation.

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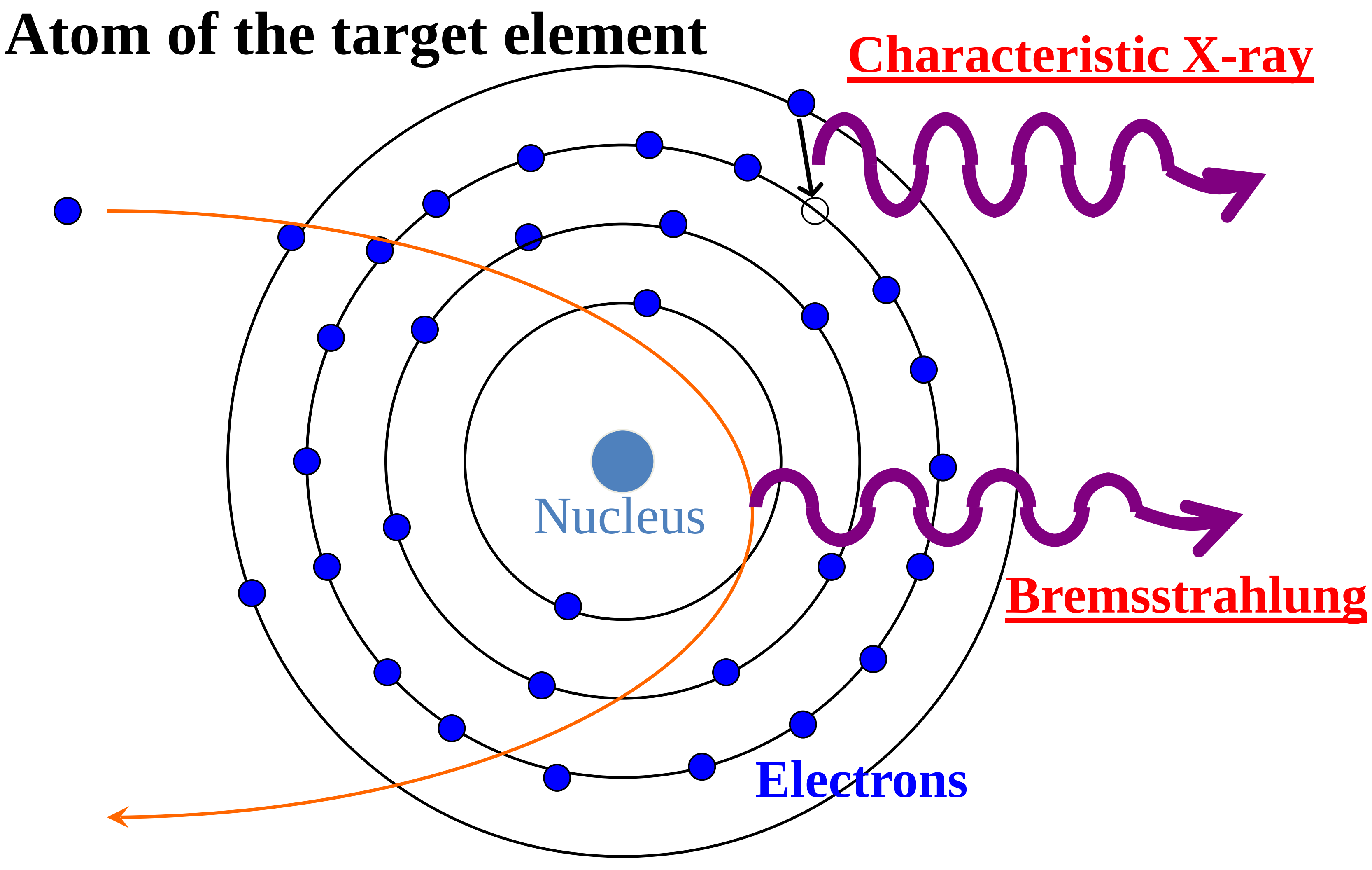
X-Ray Production – cont.



Characteristic X-Ray

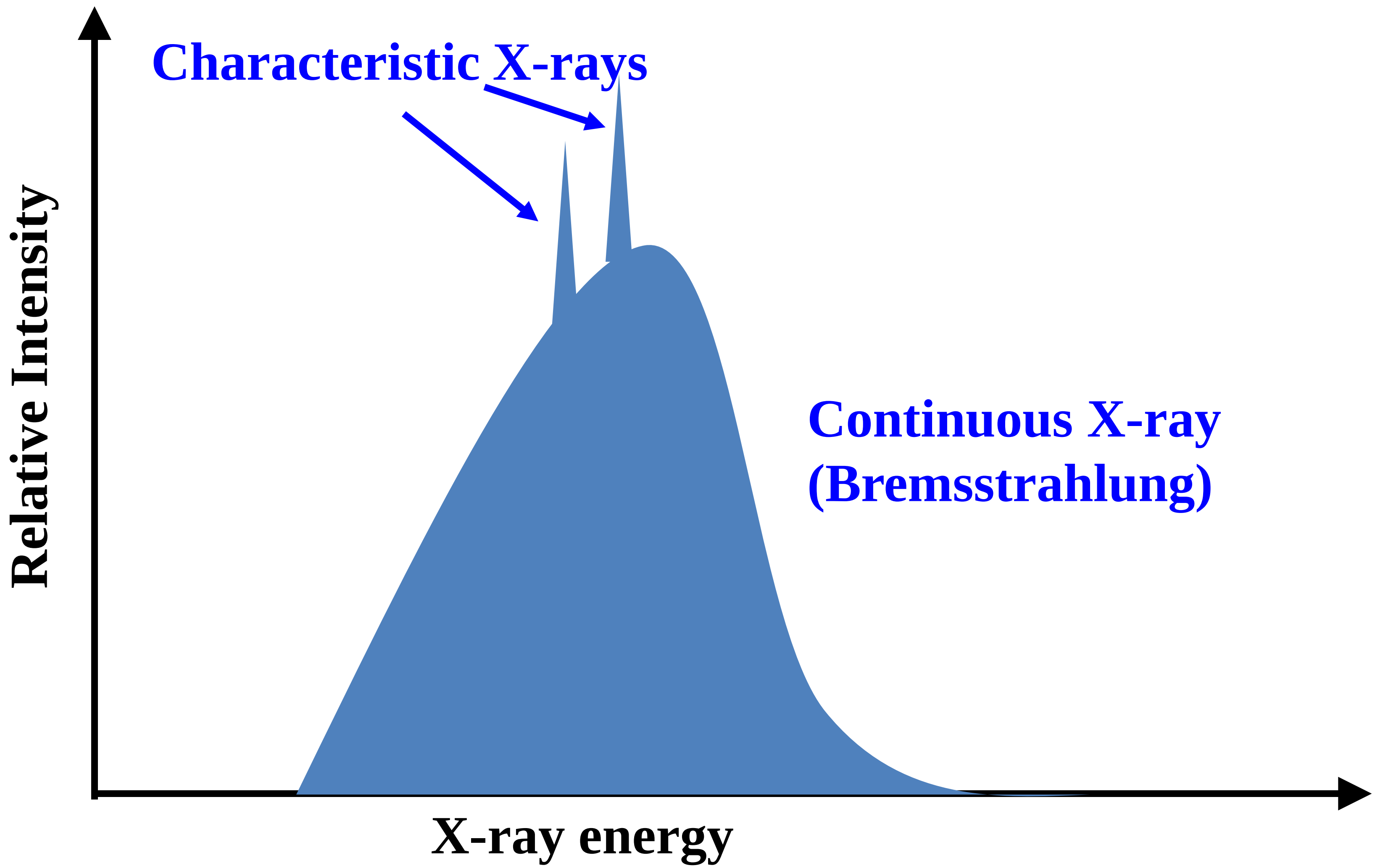
- When the shell of the target (anode) atom has a vacancy, an electron from the outer orbit will fill the spot.
- The energy difference is released as a form of X-ray.
- The energy shows a peak as energy differences between shells are characteristic of each atom.

Bremsstrahlung X-Ray

- Bremsstrahlung means “ **breaking radiation**” in German
- Bremsstrahlung occurs when high energy electrons decelerate when interacting with the electric fields surrounding atomic nuclei. Excess energy is released in the form of an x-ray (photon).
- The energy of the resultant photon is related to the energy of the incident electron as well as the electric field strength.
- These forces are greater in nuclei with higher atomic numbers.
- This shows a continuous spectrum as each electron emits a different fraction of its energy.

X-ray spectrum

Example of energy distribution.



Properties of X-Ray

- Highly penetrating
- Electrically neutral
- Wide range of energies
- Travel in straight line at speed of light
- Cause ionization
- Cause fluorescence in crystals
- Cannot be focus by lens
- Produce photograph images
- Produce scattering

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Physical Characteristics of X-Rays

- **Intensity** (quantity)
  - measured as exposure rate in Roentgens (mR/hr)

- **Control exposure** (mR) **by:**
  - time of exposure - seconds
  - tube current (mA)
  - tube potential (kVp)
  - Filtration (shielding)
  - distance (inverse square law

Physical Characteristics of X-Rays – cont.

- **Quality**
  - ability to penetrate
  - function of X-ray energy
  - high energy means high frequency, short wavelength

- **Energy** of X-ray related to the tube potential
- Quality of X-ray = 1/3 of kVp

X-Ray Devices

Intentional - X-ray for specific use

1. Fixed, interlocked, shielded room
2. X-ray diffraction, fluorescent analysis
3. Medical x-ray, industrial cabinet and not cabinet installations

Incidental – not wanted or used

1. Computer monitors, electron microscopes
2. TV, electron beam welders
3. <0.5 mR/hr

X-ray devices

ATTENTION !!

Application of radioactive materials/ionizing radiation (X-ray and other) to human subjects *is not allowed* at the University of Arkansas.

Researchers who wish to use medical devices for human subject research, should consult the RSO before starting their project.

Analytical X-Ray Devices

- For diffraction or fluorescence

  can be enclosed beam and open beam
- Safety requirements:

  - label – *"Caution –this equipment produces x-ray when energized"*

  - fail-safe light, *"X-Ray On"*

  - fail-safe indicator, *"Shutter Open"*

  - fail-safe interlocks, door/ panels

  - beam stops, shielding

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Cabinet X-Ray

- Tube is in cabinet
- Enclosure contains sample, shielding, and exclusion for persons (baggage inspections)
- Comply with 21 CFR 1020.40
  - dose rate 0.5 mrem/hr at 5 cm
  - safe in a non-controlled area

Enclosed –Beam System

- All X-ray paths enclosed
- No part of body exposed to beam
- Safer than open beam
- X-ray tube, sample, detector, etc.
  - enclosed in chamber
  - shutter or fail-safe interlock to prevent entry
- Dose rate 0.5 mrem in an hour at 5 cm from external surface

Units

R (Roentgen) - unit of radiation exposure in air.

Defined as the amount of X-ray or gamma-ray that will generate 2.58E-4 coulombs/kg-air (STP).

Please note that this unit is only applicable to X-ray/gamma-ray field.

Units

Rad (Radiation absorbed dose)

Rad stands for Radiation Absorbed Dose.

1 rad is the amount of radiation that will deposit 0.01Joules of energy in a kilogram of material (tissue, air, shielding material …etc). This unit can be used for any kinds of radiation.

•Rad is a traditional unit for absorbed dose. International Unit (SI unit) for absorption dose is Gy (gray). Conversion is 1 Gy = 100 rad.

Units

Rem (Roentgen equivalent man)

Rem stands for Roentgen Equivalent Man. It can be obtained by multiplying Rad and weighting factor. Different weighting factor is given for different types of radiation. For X-rays, weighting factor is 1. Thus, for X-rays, 1 rem = 1 rad.

•Rem is also traditional unit. SI unit used instead of rem is Sv (sievert).

Conversion is 1 Sv = 100 rem

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Units

1R = 0.93rad (tissue), 0.97rad(bone), 0.87rad(air)

For a quick estimation of exposure, it is often approximated that

1R=1rad=1rem.

Occupational Exposure Limits

- Whole Body - 5rem/year
- Extremities - 50 rem/year
- Eye – 15 rem/year
- Pregnant workers – 0.5 rem/over whole gestation period.
- General public - limited to 0.1 rem/year (additional to the background radiation)

Shielding and Filtration

- High energy more penetrating than low energy, needs more shielding
- High and low energy called – hard and soft x-ray
- Filters – will harden the beam (Al, Cu, Pb filters)
- Hard x-ray better for radiographs
- Low energy is absorbed in skin

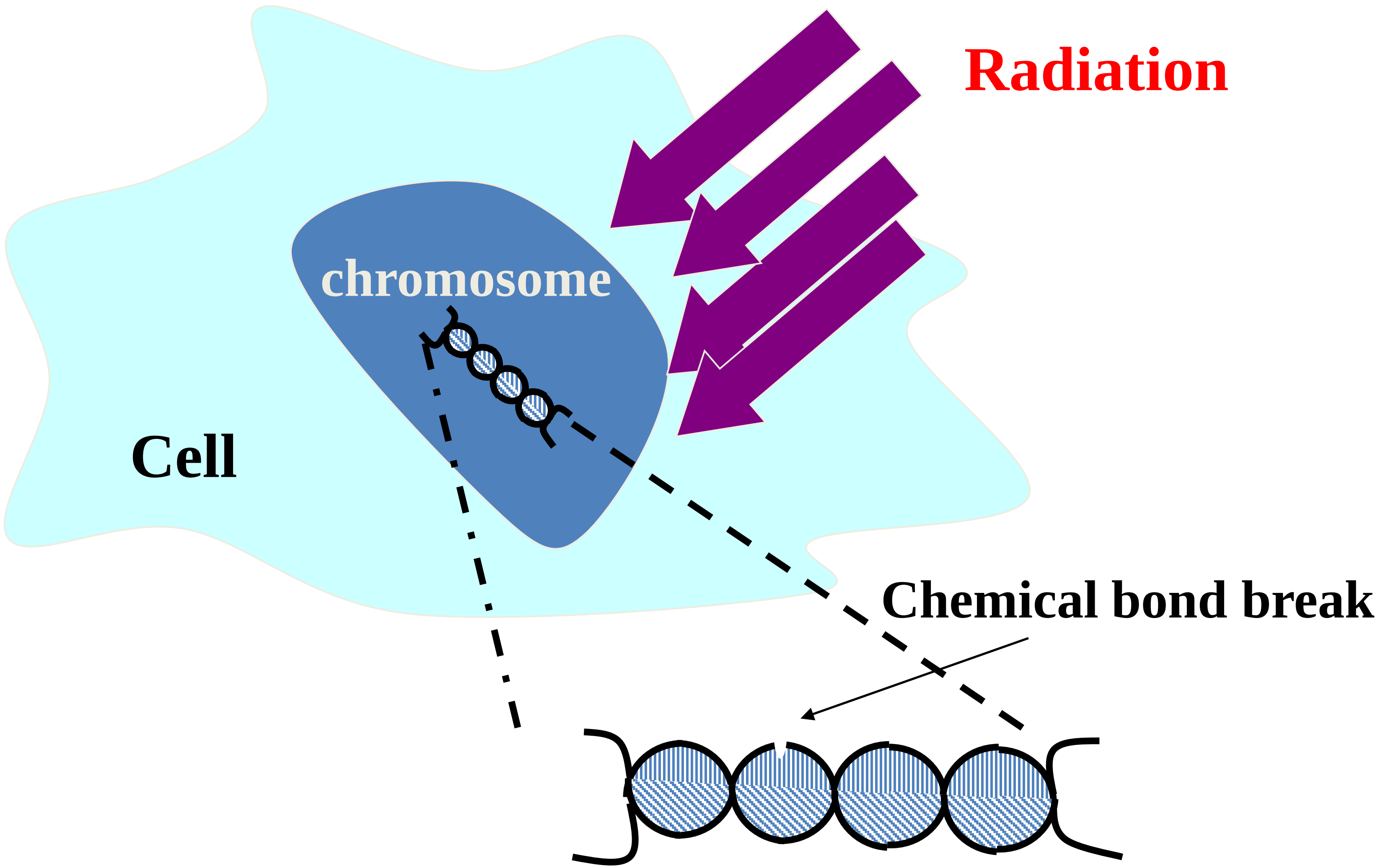
Biological Effects

- X-rays have the capability to go through skin layers and deposit their energy in cells deep inside the body.
- X-rays have enough energy to ionize atoms in deep tissue
- X-rays can break chemical bonds within some critical biological molecules.

Biological Effects – cont.

- In some cases, those damaged cells are able to repair themselves. However, high dose or high dose rate exposure may create non curable damage.
- When cells are not recovered, this damage can cause cell injury or even cell death. The effects may passed to daughter cells (with damaged characteristics). The division of this damaged cell may be the first step in tumor/cancer development.
- If enough cells in a particular body organ are damaged, the function of the organ may be impaired.

Biological Effects – cont.



Direct Beam X-Ray Exposure vs. Thermal Burns

- Thermal Burns – nerve endings on skin surface gives early warning of thermal burns (Expl: immediate withdrawal of the hand from burning flame)

- X-Ray Burns – x-ray penetrate to deeper, basal skin cells, killing germinal cells that are intended to replace surface cells (no immediate pain)

  - Thus, skin may not heal

  - may require grafts or amputation

Acute X-Ray Effects

- **500 rem** (5000,000 mrem all at one time)
  - No immediate pain; warmth and itching may be felt.
  - Reddening after a day, fading in few days.
  - Dry scaling or peeling will follow.
  - Avoid future injuries.
  - Recovery should be complete.

Acute X-Ray Effects – cont.

- **1000 rem** (In a single dose)
  - Serious tissue damage.
  - 2nd degree burns.
  - Reddening, inflammation.
  - Blisters in1-3 weeks, raw open wounds.
  - Hand exposure, fingers stiffness.
  - Need immediate medical attention.

Biological Effects

Exposure (Acute Dose)

<u>500 rem</u>
- No immediate pain
- Warm & itchy first day

<u>1000 rem</u>
- Serious tissue damage
- 2nd degree burn
- Blisters, raw open wound (1-3weeks)

<u>Syndrome</u>

Hematopoietic	**Gastrointestinal**	**Central Nervous**
100 –1,000 rem	1,000-5,000rem	5,000 –10,000 rem

Acute – Low Energy Effects

Low energy - less than 50 keV, easily absorbed by outer layer of tissue, skin

May cause:

- Erythema – skin loss
- Epilation – hair loss
- Pigmentation
- Radiation dermatitis
- Skin ulceration - burns

Acute – High Energy Effects

High energy – greater than 50 keV, may penetrate deep into body and cause internal dose.

May cause:

- Gastrointestinal tract damage
- Bone marrow damage
- CNS damage
- Death

Biological Effects

Typically young and rapidly growing cells are more sensitive to radiation than mature fully grown cells.

Sensitivity

Low

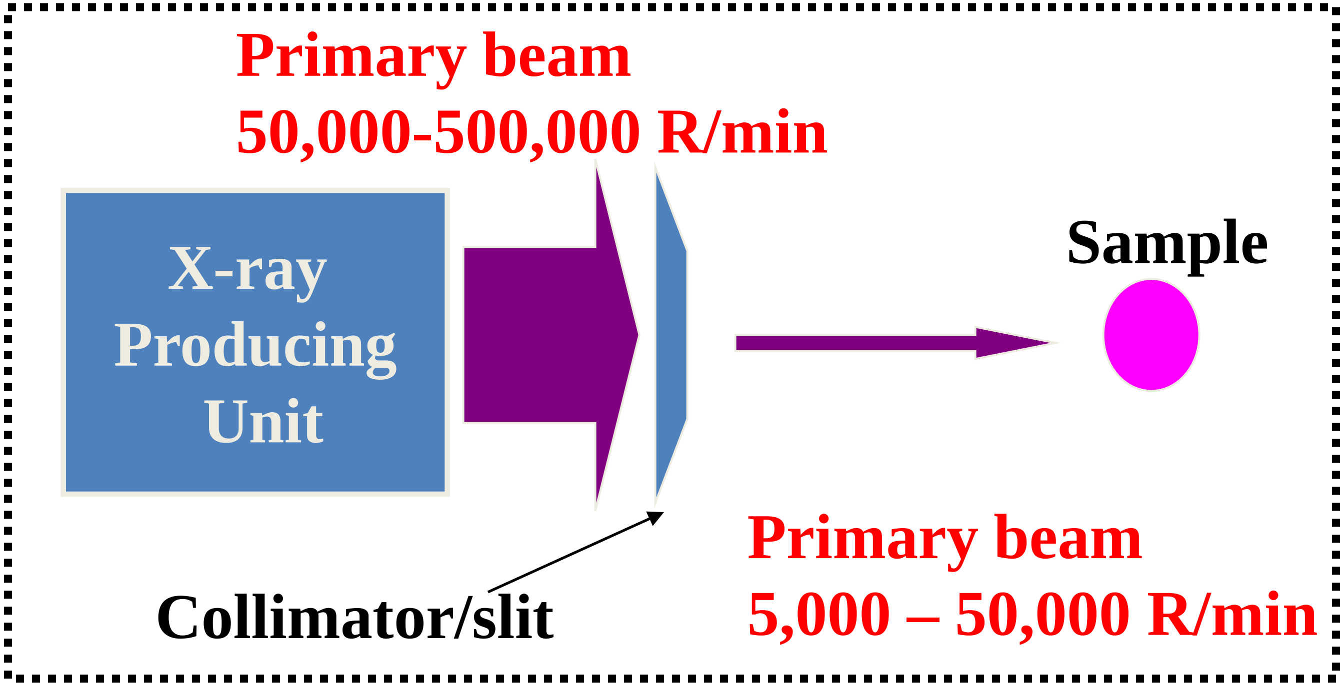
Muscle, Joints, Central nerves, Fat

Skin, Inner-layer of intestines, Eyes

Bone marrow, Lymph system, Reproductive organs

High

Possible Exposure Rate
(X-ray machines)



Secondary beam
Leakage 0.5 - 5 R/hr
Scatter < 10 – 300 mR/hr

Sources of Possible Exposure

- **Primary beam**
  - very intensive exposure in beam
  - could be >100,000 R/min
  - small beam diameter, <1 cm
- **Scattered x-ray radiation – “sky shine”**
  - low intensity
  - large area of exposure
  - from housing leakage
  - from any target material
  - from inadequate shielding

Sources of Possible Exposure – cont.

- **Operator Error**

  - adjustment or alignment of samples/cameras while beam is ON

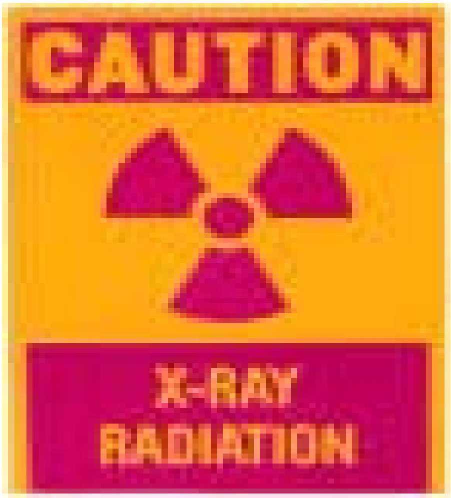
  - not using safety features (bypassing interlocks, shielding of unused port, etc.

  - unauthorized user (untrained user, unsupervised operation)
- **X-ray leakage**
- **Not using protective equipment**

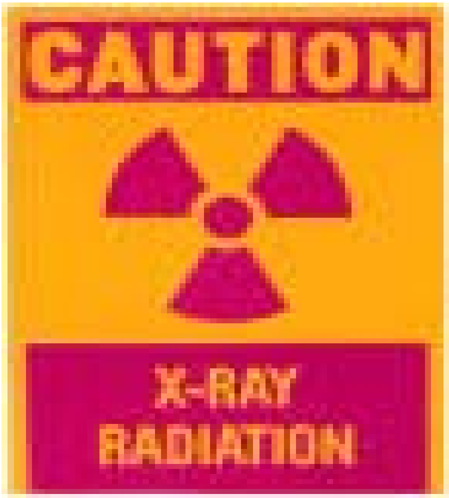
  - lead aprons, etc.

Protective Measures

- Post caution signs.
- Labels – “Caution- this equipment produces x-ray when energized”.
- Know X-Ray beam status at “ALL TIMES”.
- Do not place any part of you body in the direct beam.
- Warning devices:
  - warning signals status of x-ray tube
  - visible indicator of power “ON”
  - warning light near door
  - shutter open indicator
- Interlocks
  - fail-safe interlocks on doors and panels
- Testing
  - leak tests
  - check warning lights , current meter



Warning signs



Door sign

Warning signs

ALARA

ALARA = “As low as reasonably achievable”

- Main objective of the University of Arkansas, Fayetteville, Radiation Safety Program
- Radiation protection philosophy
- **ALARA** should be applied to maintain any dose at levels that are as low as practicable

Personal protection

Time : Shorter usage → Less exposure

Distance : Keep your distance (Inverse square law)

Shielding : Shielding material selection
- Bremsstrahlung

Monitoring : Survey meter selection

PPE (Personal Protective Equipment)

Time

- Planning of experiment
- Cold run
- Written procedure

Distance

Distance is a major factor for reducing exposure

Inverse Square law

“ When you double the distance the exposure rate is decreased by 4 times ”

“ Triple the distance? Half the distance?”

Proper equipment (*e.g.*, tongs)

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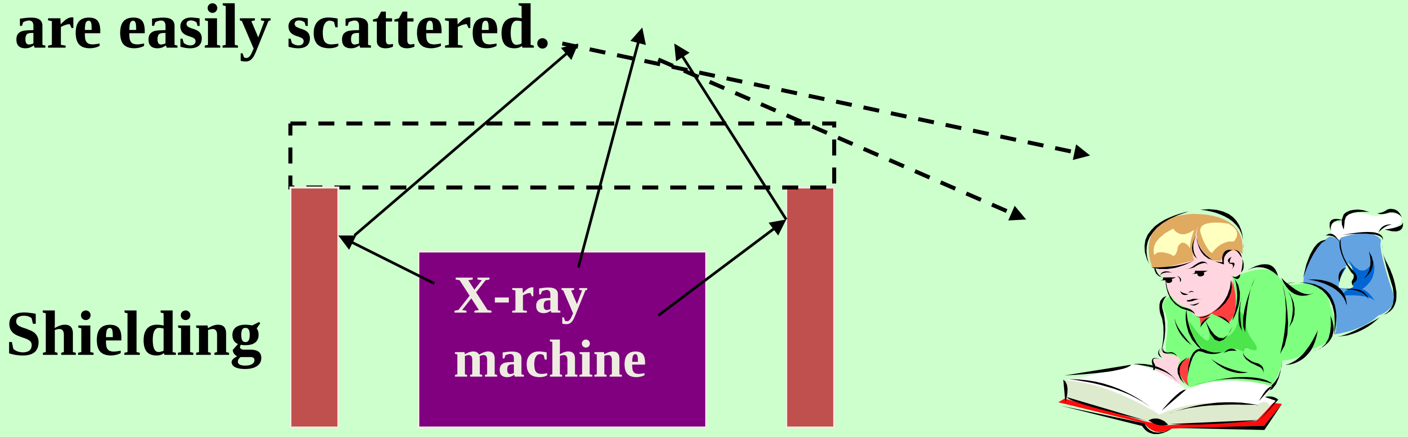
Shielding

Increasing the amount of shielding around a source of radiation will decrease the amount of radiation exposure.

Be sure to shield all directions.

X-rays are easily scattered.



Rooms

Security

Limit access to authorized personnel only

Notification of hazard presence

Signs, Posting, Warning signs (see next page)

Protection

Shielding, Warning signs

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Surveys

- **Frequency of Surveys**

  - quarterly
  - upon installation
  - upon changes/re-location
  - maintenance requirements
  - observed unsafe conditions

- **Survey Meters**

  - Thin window Geiger-Muller (GM) counter may be used to check for leakage (to find where leakage occurs), indicate x-ray production (to verify if beam is "on" or "off") , monitor routine operation. GM meters count individual photons (x-ray, gamma) in counts per minute.

  - Ion chamber can be used to determine dose rate at the x-ray field (how much). The ion chamber response in R/min (hour) and can be used to measure radiation dose rate.

Monitoring

- X-Ray operators must use personal dosimeter provided by RSO.
- Body badge type TLD (Thermo Luminescence Dosimeter) is provided for the main users of the X-ray machines. This is sensitive to about 10 mrem or higher exposure. TLD’s are personal dose monitoring device and do not provide any protection.
- Control area dosimeters will be provided whenever needed.

X-Ray Safety Features

- **Shielding**
  - For analytical x-ray machines the manufacturer provides shielding in accordance with ANSI standard N43.2. However, it is important to survey the adequacy of the shielding before initial operation. This should be done routinely.
- **ANSI N43.2**

Anode Current (mA)	Millimeters of Lead		
	50kVp	70kVp	100kVp
20	1.5	5.6	7.7
40	1.6	5.8	7.9
80	1.6	5.9	
120	1.7		

X-Ray Safety Features

- **Shutter**

  X-ray machine will not generate X-ray when the shutter is open. (Avoid accidental exposure while changing samples)
- **Safety Key/Interlock**

  To prevent unauthorized use, x-ray machine operation requires several steps (key(s) to be in place to switch on the device, etc)
- **Warning sign**

  Indicates on/off status of the X-ray machine

X-ray device user

Responsible for:

- **Notifying the RSO of any changes**
  (addition, removal, location change, authorized user change … etc)
- **Inspection**
  (according to the manufacturers guideline)
- **Ensuring security**
- **Compliance**
  (Federal, State, Institution policies)

Contacts

- **Office of Environmental Health & Safety**
  575-5448 (M-F, 7:30am – 4:00pm)
- **University of Arkansas Police Department (UAPD)**
  575-2222 (After hours & Holidays)
- **Radiation Safety Officer**
  575-3379
- **Assistant Radiation Safety Officer**
  575-8473