Colorado State University

Radiation Control Office

Radiation Safety Training

Module 8 - X-Rays

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Module 8 Outline

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  B. Types of Radiation
  C. X-Ray Production

II. Dosimetry Units and Definitions
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Module 8 Outline

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Module 8 Outline

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Module 8 Outline

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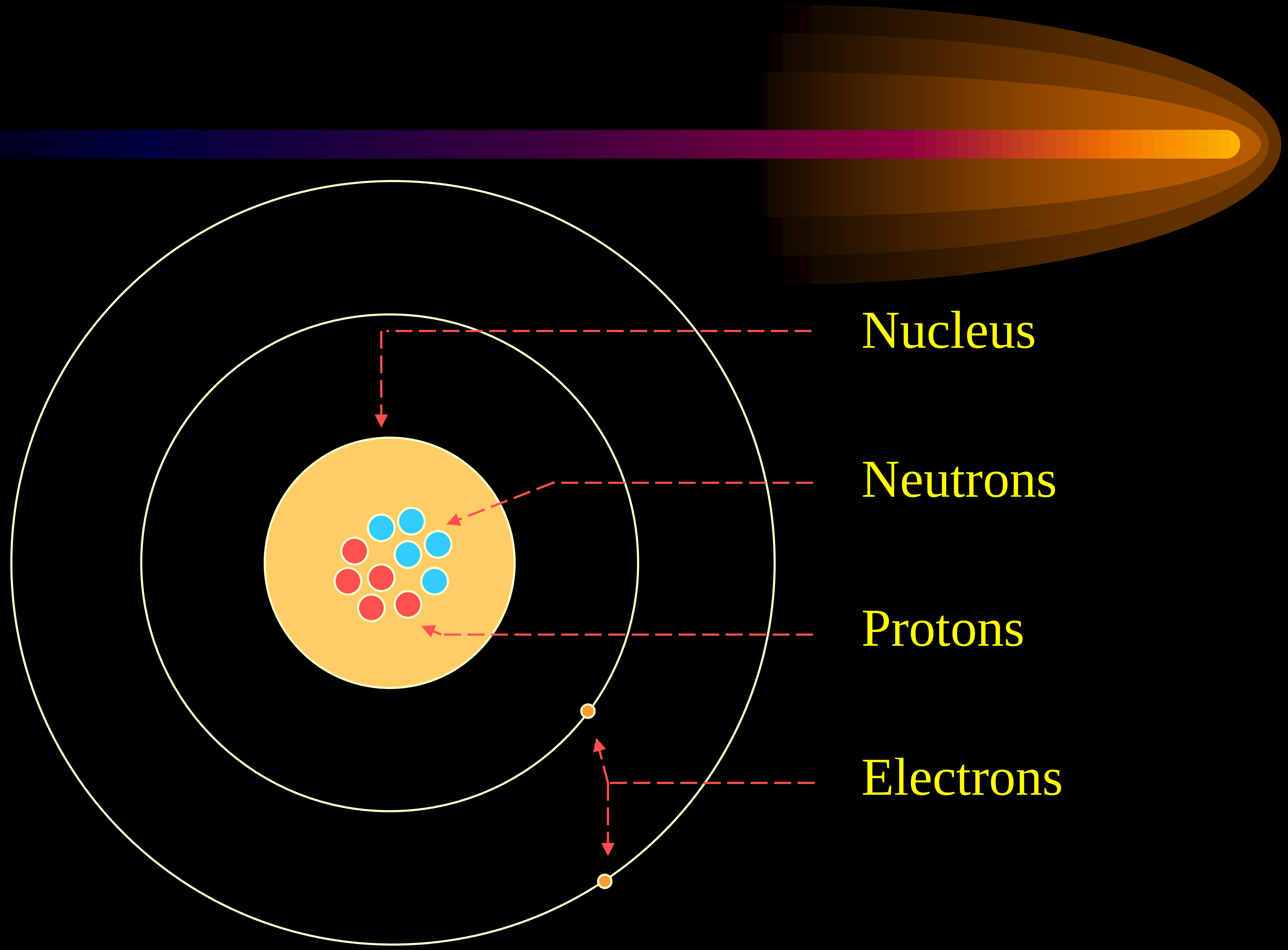
XI. Monitoring Radiation Dose at CSU

- A. Personnel Dosimetry
- B. Requirements

Structure of the Atom



Radioactivity

Definition.

Any spontaneous change in the state of a nucleus accompanied by the release of energy.

Major types

Alpha (α) decay

Beta (β) decay: β^-, β^+ and electron capture

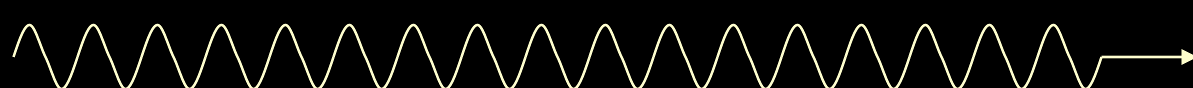
Gamma (γ) decay including internal conversion

X-rays have the same physical form as gamma photons

Ionizing Radiation

Definition - Any type of radiation possessing enough energy to eject an electron from an atom, thus producing an ion.

X-Rays and Gamma photons are both electromagnetic radiations that have the energy to ionize atoms



X-Ray

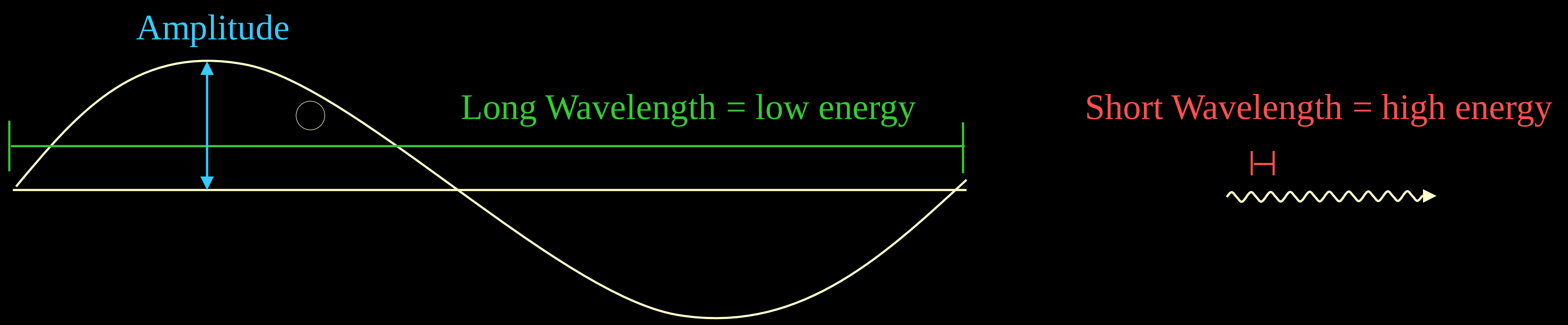
Electromagnetic Radiation

Definition - An energy packet of waves created by an electromagnetic field.

Mass = 0

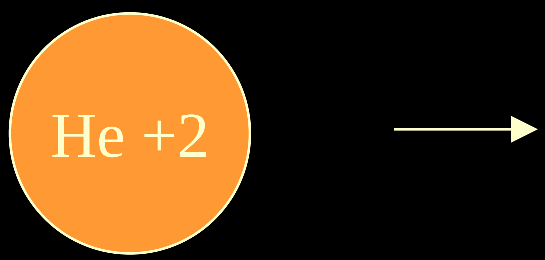
Travels at the speed of light ~ 300,000 km/s

Types - Radio waves, visible light, infra-red, ultraviolet, x-rays, gamma photons



Major Types of Ionizing Radiation
Alpha, Beta, Gamma

Alpha Particle

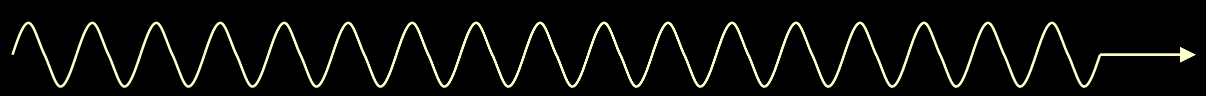


Large Mass (nuclei)

Beta Particle

Small Mass
(subatomic particle)

Gamma Photon
and X-Rays



Radiation Dosimetry Units
Exposure, X:

amount of charge produced anywhere in air by the complete stoppage of all electrons liberated by photons in an incremental volume of air per unit mass of air in that volume.

Standard International (SI) unit: C/kg

traditional unit: roentgen (R) 1 R = 2.58×10^{-4} C/kg

Exposure definition applies only to photons of energy less than or equal to 3 MeV interacting in air.

Radiation Dosimetry Units
Absorbed dose:

is the energy deposited by any type of ionizing radiation in a volume element of mass.

SI unit: gray (Gy)
traditional unit: rad 1Gy = 100 rad

Absorbed dose definition applies to all forms of ionizing radiation in any material.

Relative Biological Effectiveness and Quality Factor

Relative Biological Effectiveness (RBE)

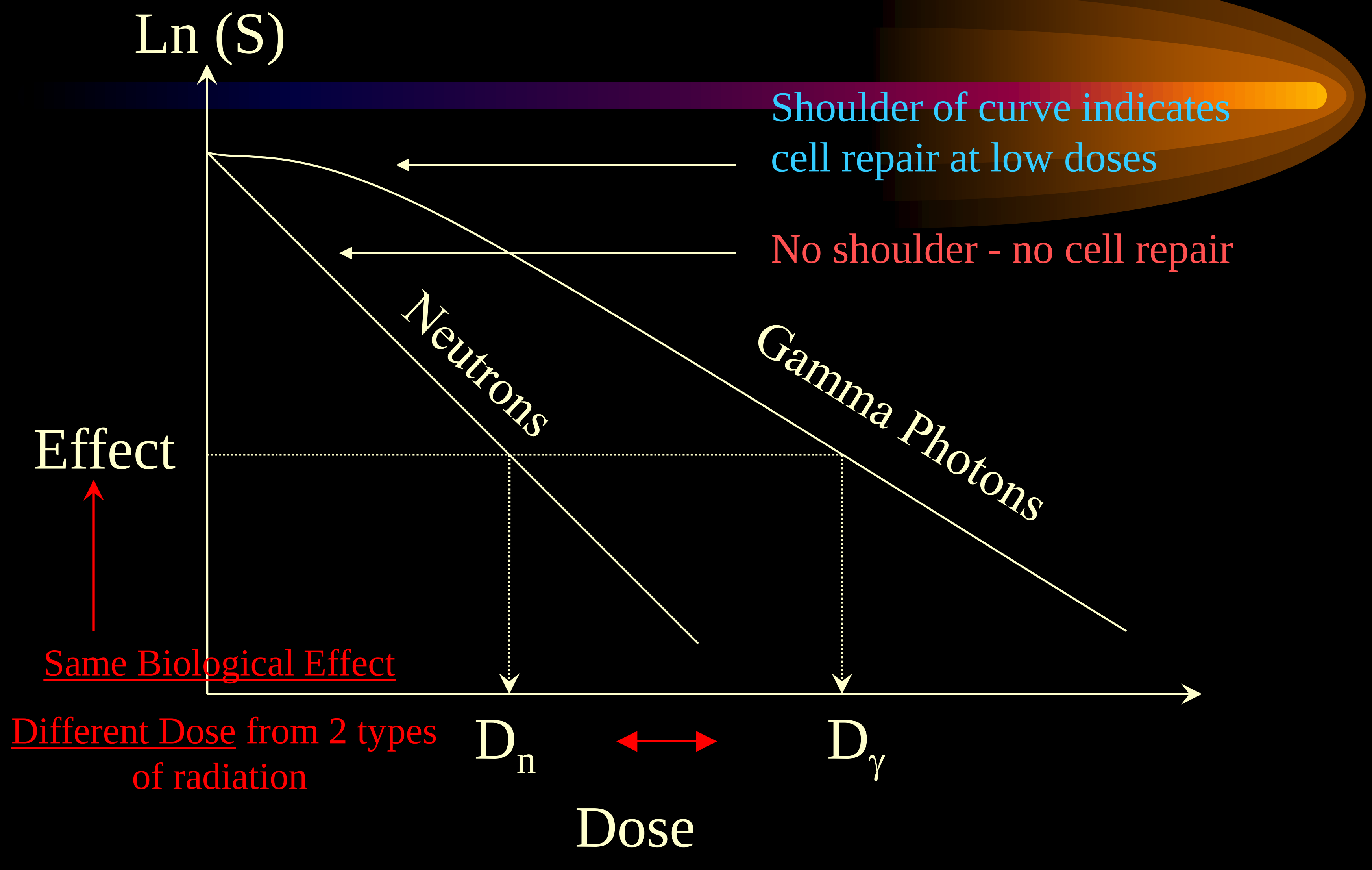
$$\left(\frac{\text{Absorbed dose from standard 250 kVp x-rays}}{\text{dose from a radiation of interest}} \right)$$

Both produce the same biological effect.

Quality factor (Q)

radiation	Q
photon, β	1
proton, neutron	10
alpha	20

Relative Biological Effectiveness



Radiation Dosimetry Units
Dose Equivalent

Dose equivalent: allows the description of the biological effect of an absorbed dose of a particular type of radiation or mixed radiations for the Human Body.

$$H = D\,Q$$

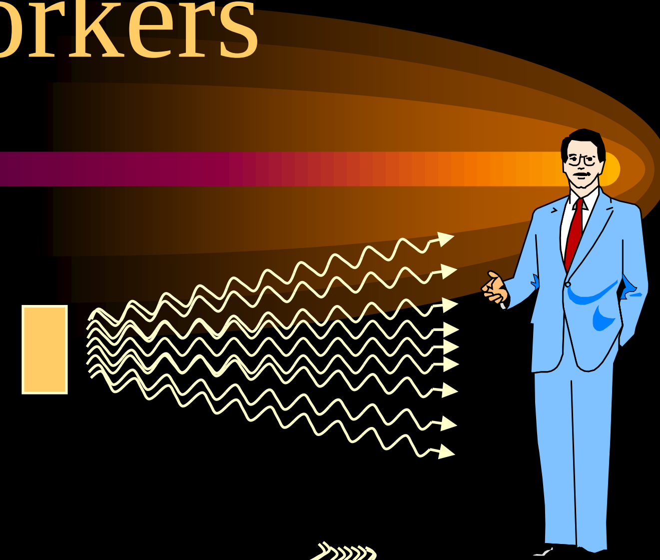
SI unit:		sievert (Sv)
traditional unit:	rem	1 Sv = 100 rem

For photons:

$1\ \text{R} \approx 1\ \text{rad} = 1\ \text{rem}$

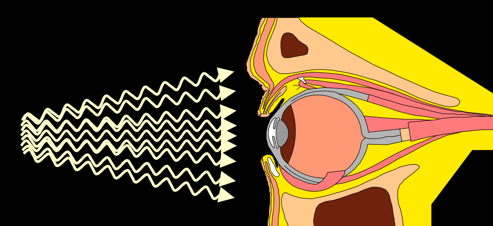
Occupational Dose Limits for Radiation Workers

Whole Body Dose Limit = 5 rem or 5000 mrem

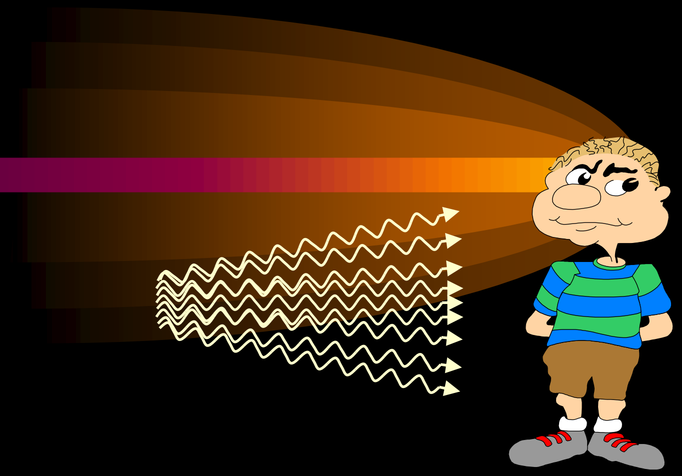


Extremity or Skin Dose Limit = 50 rem or 50,000 mrem

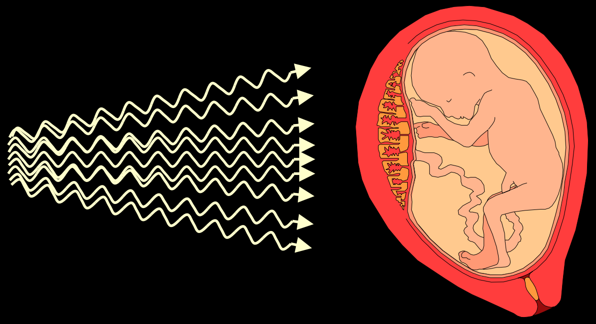
Lens of the Eye Limit = 15 rem or 15,000 mrem



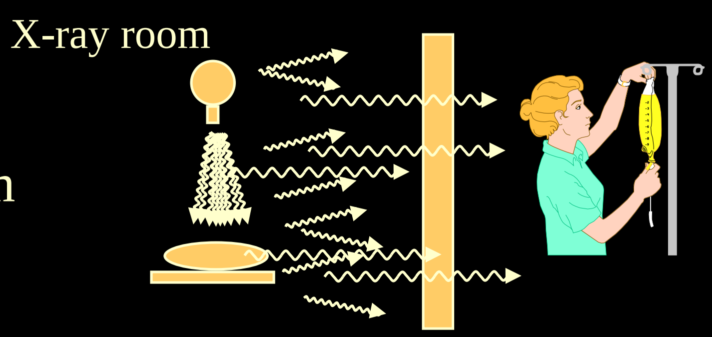
Occupational Dose Limits



Dose Limit for Minors – Under 18 = 500 mrem



Dose Limit for Unborn Fetus = 500 mrem



Dose Limit for General Member of Public = 100 mrem

U.S. Regulatory Limits

Radiation worker:	5 rem/yr	50 mSv/yr
Individual in general population:	0.1 rem/yr	1 mSv/yr
Compare to Background average	0.36 rem/yr	3.6 mSv/yr
$LD_{50/30}$	450 rad	4.5 Gy

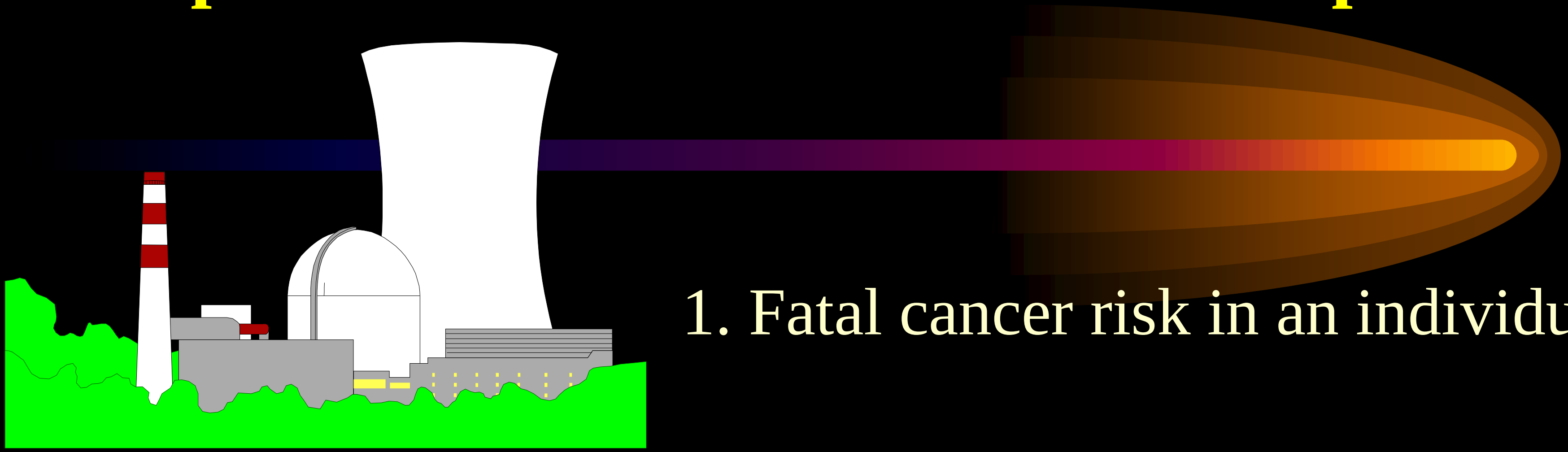
Risk Factors

For fatal cancer induction, whole-body irradiation:	0.0005/rem/person
Compare to non-radiation cancer fatality risk (U.S.A.):	0.223/person/lifetime
For hereditary effects expressed in the first two generations:	0.0001/rem/person
Compare to single generation non-radiation risk:	0.09/person

Some Risk Comparisons
One-in-a million chances of dying

Situation		Cause of death
2.0 mrem	→	cancer from radiation
travelling 700 miles by air	→	accident
crossing the ocean by air	→	cancer from cosmic rays
traveling 60 miles by car	→	accident
living in Denver for 2 months	→	cancer from cosmic rays
living in a stone building for 2 months	→	cancer from radioactivity
working in a factory for 1.5 wks	→	accident
rock-climbing for 1.5 minutes	→	accident
smoking 1-3 cigarettes	→	cancer; heart-lung disease
working in a coal mine for 3 hr	→	accident
20 min being a man aged 60	→	mortality from all causes
living in New York City for 3 days	→	lung cancer air pollution

Using Risk Coefficients
Example: Three Mile Island Accident exposures.



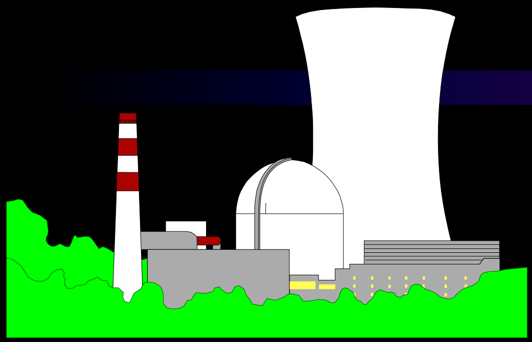
1. Fatal cancer risk in an individual.

Highest dose to a member of the public was 70 mrem.

$P_{\text{fatal cancer}}$=(0.0005/person x rem)(1 person)(70 mrem)(1 rem/1000mrem) = 0.000035

Compare to the probability of fatal cancer from other causes: 0.223/person/lifetime.

Using Risk Coefficients - Three Mile Island (continued)



2. Number of radiation induced fatal cancer in a population.

Average dose within 50 mile radius was 1.5 mrem. Population within 50 miles was 2,163,000.

$$N_{\text{fatal cancer}} = (0.0005/\text{persons x rem})(2,163,000 \text{ persons})(1.5 \text{ mrem})(1 \text{ rem}/1000 \text{ mrem})$$

$$= 1.62 \text{ fatal cancers}$$

Compare to the number of fatal cancers expected from other causes: 482,000.

Long Term Consequences of the Accident at the Chernobyl Nuclear Power Station on 26 April 1986

Location	Population	Average Dose (rem)	Predicted Fatal Cancers	Background Fatal Cancers	% due to Chernobyl
On-site after accident	600,000	25 (?)	7500	72,000	10.42
Off-site within 30 km	135,000	12	810	16,200	5.00
Ukraine Belarus and Russia	75 million	0.67	25,125	9 million	0.279
Other Europe	350 million	0.06	10,500	70 million	0.015
TOTAL	426 million	0.206	43,935	79 million	0.056

Radiation Syndromes and Injury

At low doses, Radiation Injury is a Statistical Probability

In all cases, the effects of radiation injury will be delayed

Somatic and genetic effect of low level radiation
stochastic and non stochastic biological effects

Primary stochastic somatic biological effect of radiation is cancer.

Radiation Syndromes and Injury (continued)

Law of Bergonie and Tribondeau

The radiosensitivity of a population is directly proportional to their mitotic rate and inversely proportional to their degree of differentiation.

In other words, the more frequently cells divide, the more sensitive they are to radiation injury. The more specialized the cells are, the less sensitive they are to radiation injury.

Acute Radiation Syndromes

(Very high radiation doses)

Between 0 and 100 rads
Generally there is no clinically observable changes
Some nausea at the high end of range in more susceptible persons
Some blood changes above 25 rads

100 - 400 rads
The hematopoietic system is affected
Blood cell precursors are very radiosensitive
Gradual depression in blood count over days or weeks
Increased susceptibility to infection and hemorrhage
Most recover at lower end of range with some medical care

Acute Radiation Syndromes

(Continued)

400-1400 rads
Gastrointestinal system is affected
Cells lining the intestinal track are radiosensitive
Bacteria and toxic material gain entry into the bloodstream
Diarrhea, dehydration, infection, toxemia
Survival is unlikely at the upper end of range

Above 1400 rads
Cardiovascular and Central Nervous System is affected
Blood supply is impaired leading to nausea, vomiting, convulsions, or unconsciousness. There is no hope for survival

$LD_{50/30}$ is approximately 450 rads with modest medical treatement

Radiation Risk in Perspective

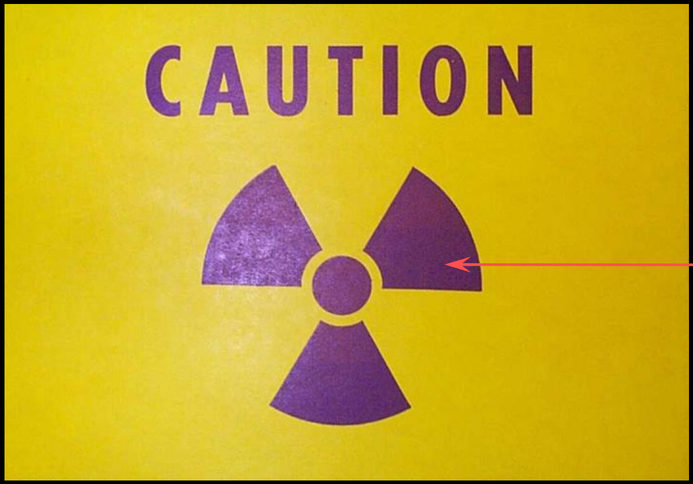
Health Physics Society Position Statement (March 1996):

- Radiogenic health effects (Primarily cancer) are observed in humans only at doses in excess of 10 rem delivered at high dose rates.

- Below this dose, estimation of adverse health effects is speculative since risk of health effects are either too small to be observed or are non-existent.

- Epidemiological studies have not demonstrated adverse health effects in individuals exposed to small doses (less than 10 rem) delivered in a period of many years

Warning Sign
Standard Radiation Symbol



Standard Radiation Symbol

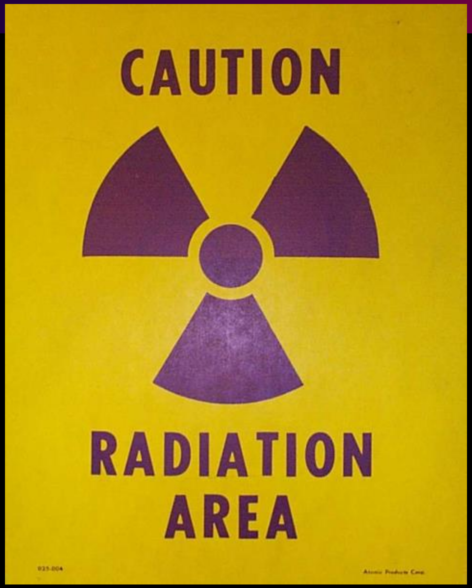
Meaning:
Ionizing Radiation Present in some Form

Warning Sign:
Caution Radioactive Materials
Danger, Radioactive Materials

Meaning:

Any “area or room in which there is used or stored an amount of licensed or registered material exceeding 10 times the quantity of such material specified in Appendix C”

Warning Sign: Caution, Radiation Area



Reach your yearly whole body limit of 5 rem in ~1000 hours (42 days)

Meaning:

"Any area, accessible to individuals, in which radiation levels could resulting an individual receiving a dose equivalent in excess of 5 mrem (0.05 mSv) in 1 hour at 30 centimeters from the source of radiation or from any surface that the radiation penetrates."

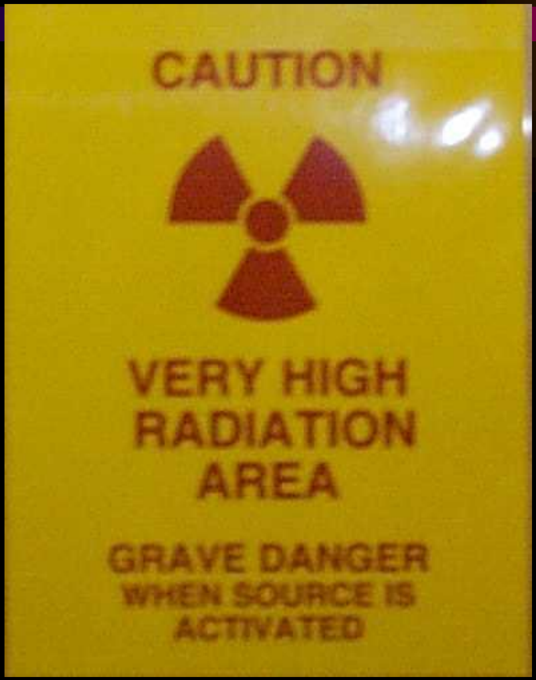
Warning Sign:
Caution, High Radiation Area
Danger, High radiation Area

Reach your yearly whole body limit of 5 rem in ~50 hours (2.1 days)

Meaning:

"an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 100 mrem (1 mSv) in 1 hour at 30 centimeters from any source of radiation or from any surface that the radiation penetrates."

Warning Sign:
Grave Danger, Very High Radiation Area

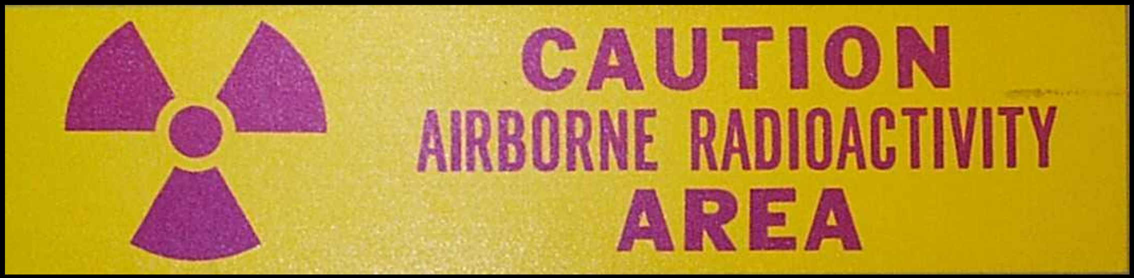


Reach your yearly whole body limit of ~5 rem in < 36 seconds

Meaning:

"an area, accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rem (5 Gy) in 1 hour at 1 meter from a source of radiation or from any surface that the radiation penetrates."

Warning Sign:
Caution, Airborne Radioactivity Area
Danger, Airborne Radioactivity Area



Meaning:

Any area with airborne activity

Photon Interactions with Matter

Radiation and Radioactivity
Radioactivity is a spontaneous change in the state of a nucleus with the release of energy.

Radiation refers to the particle(s) and photons emitted in the process of radioactive decay.

The radiation emitted carry the energy released in radioactive decay.

When radiation(s) interact with matter they may deposit all or part of their energy.

There are four types of photon interactions with matter

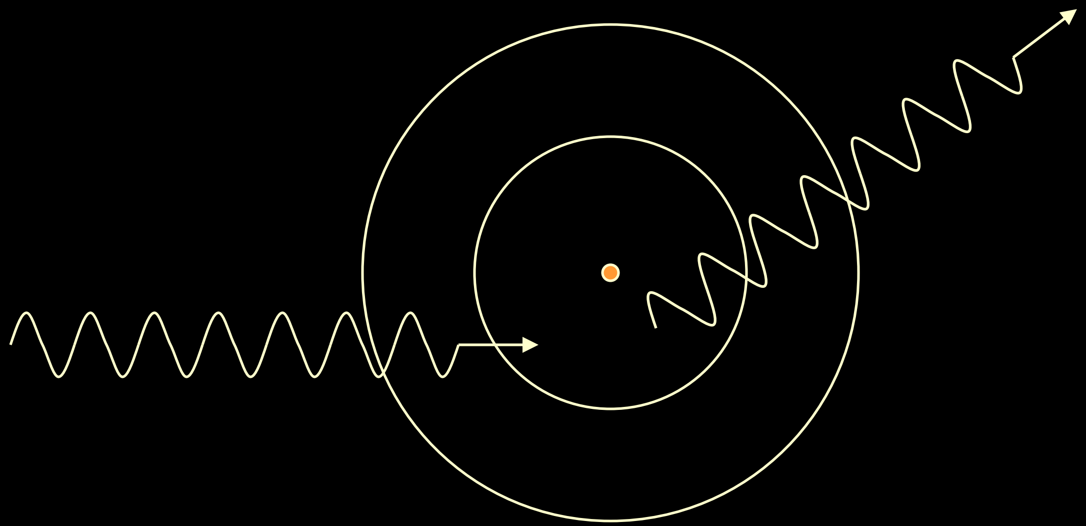
Coherent scattering (Rayleigh scattering)

Incoherent Scattering (Compton scattering)

Photoelectric Effect

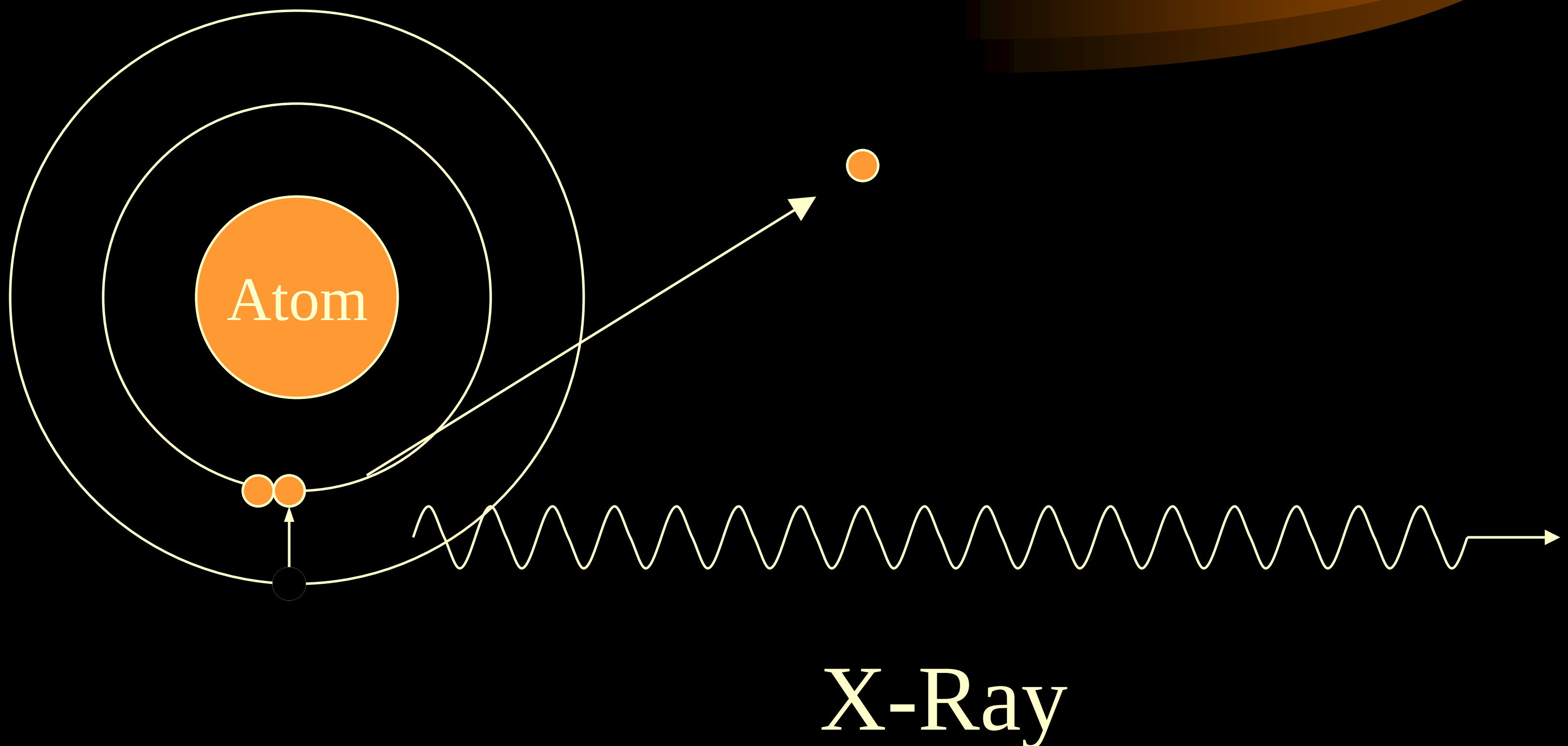
Pair Production

Coherent Scattering (Raleigh Scattering)

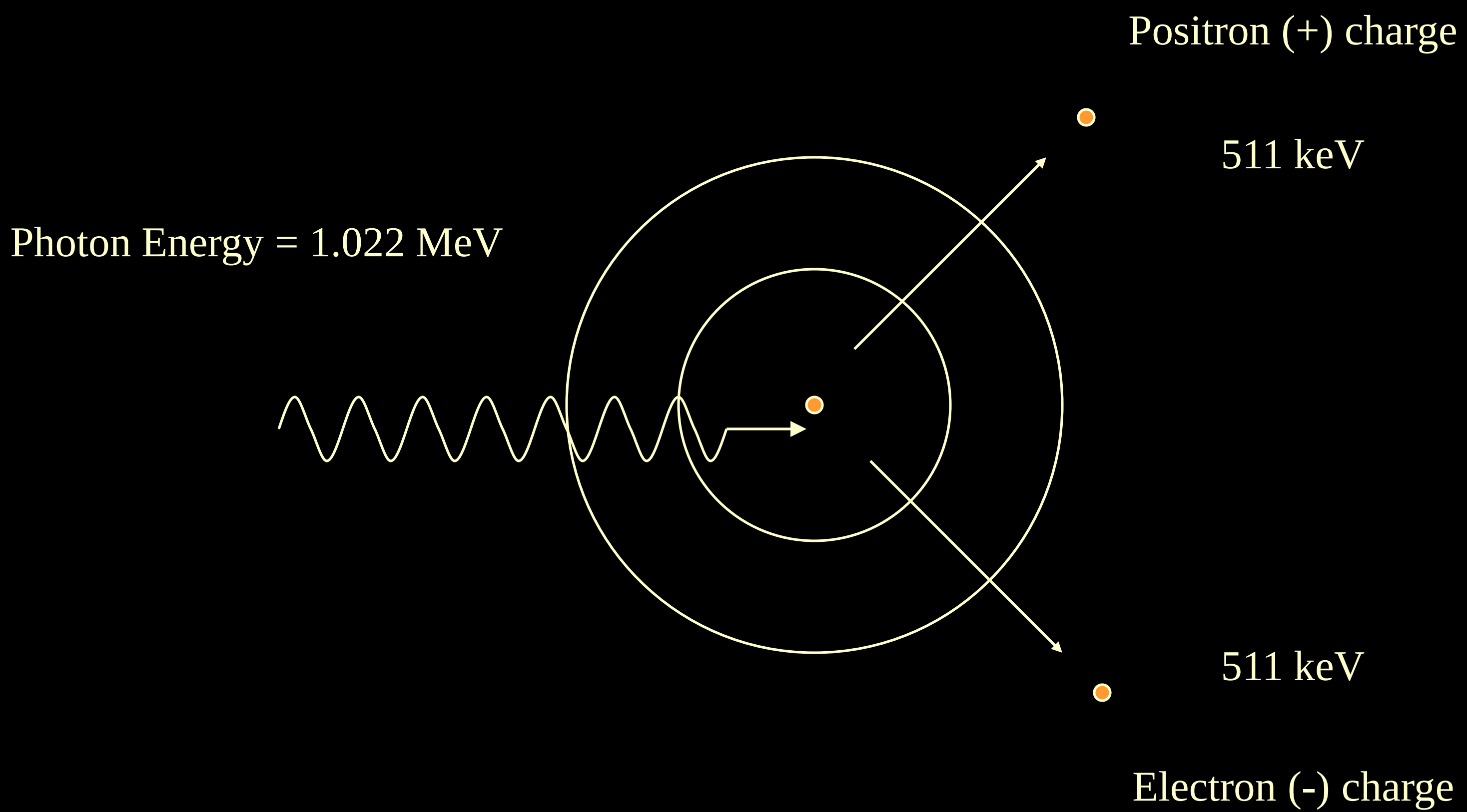


Incoherent Scattering (Compton Scattering)

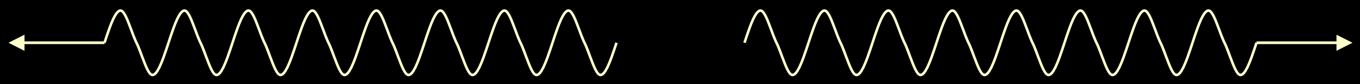
Photoelectric Effect
Production of X-Rays



Pair Production



Pair Production



511 keV

Two photons
travel in exactly opposite
directions

511 keV

$$E = mc^2$$

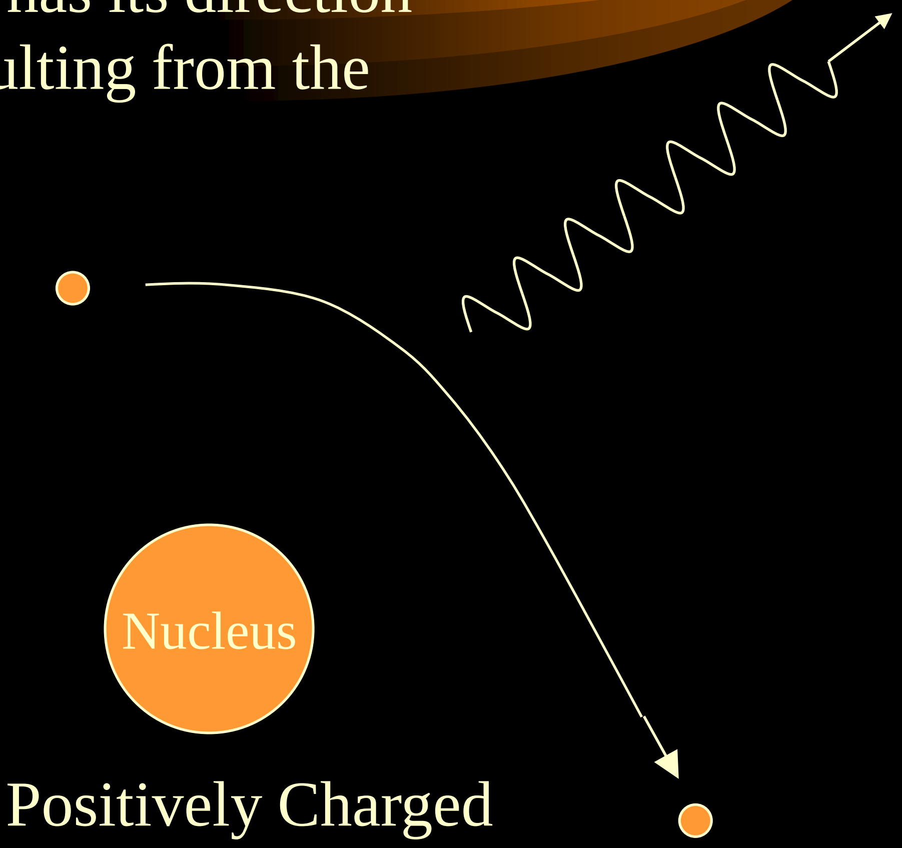
Main Production of X-Rays

Bremsstrahlung Radiation

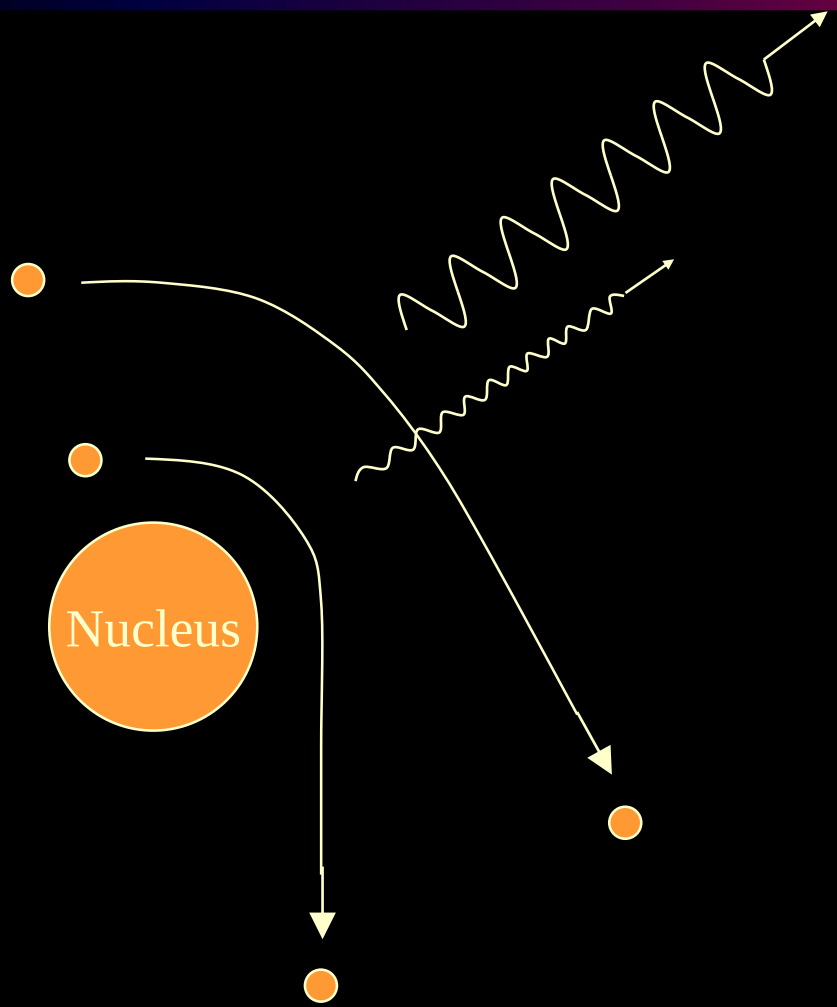
An electron passing near a nucleus has its direction altered by the Coulombic force resulting from the positively charged nucleus.

A change in direction of motion is equivalent to a change in energy and momentum of the electron

Accelerated electrons may lose energy by emitting electromagnetic energy **(X-Rays)**



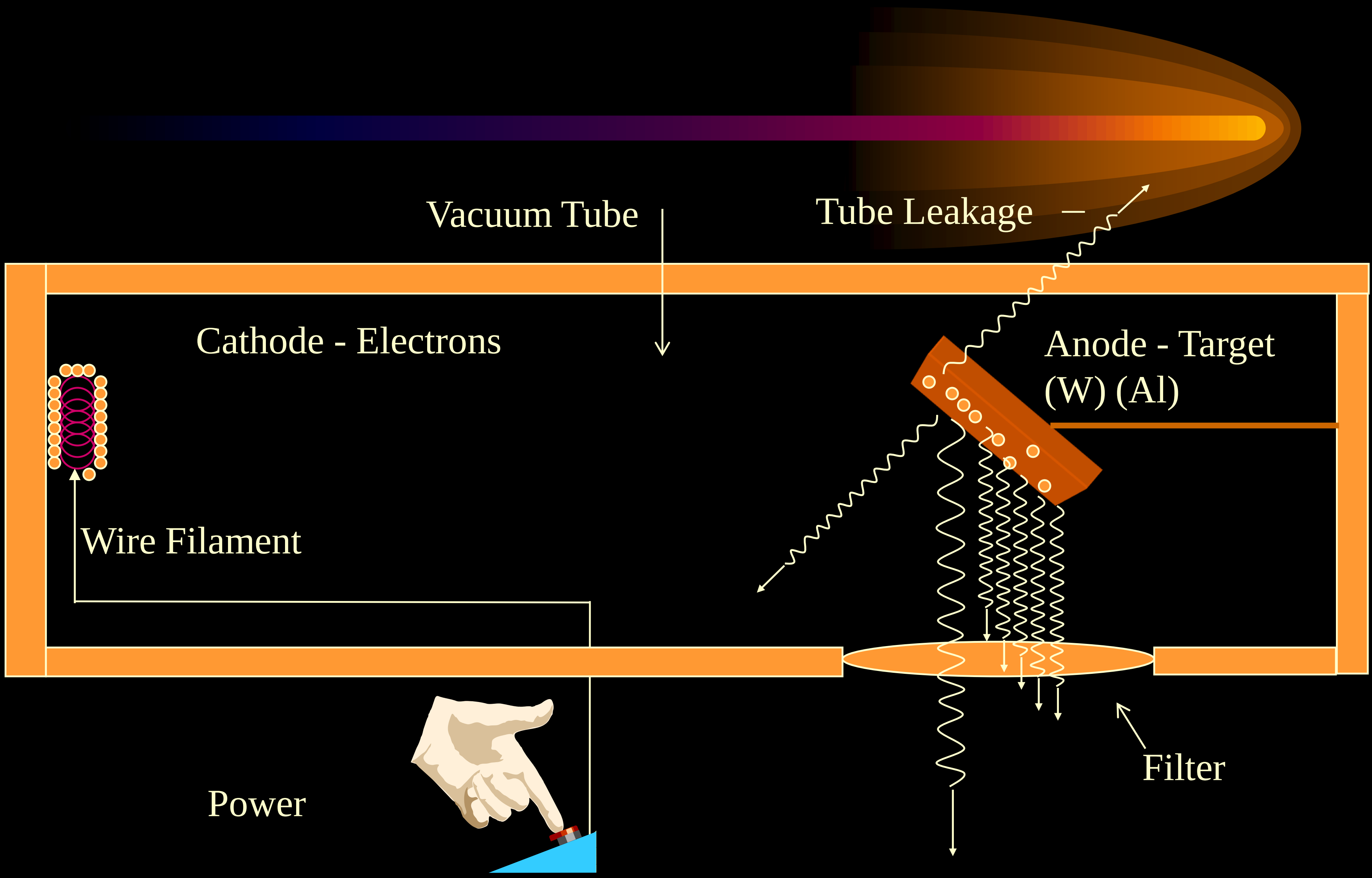
Bremsstrahlung Radiation



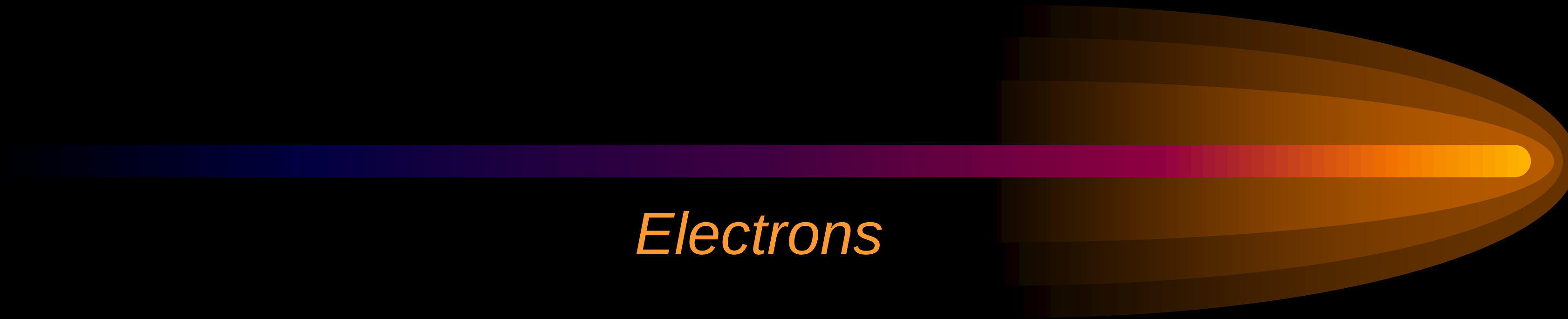
Electron further away from nucleus
Coulombic force is weak
Less energy is released in photon
Longer wavelength

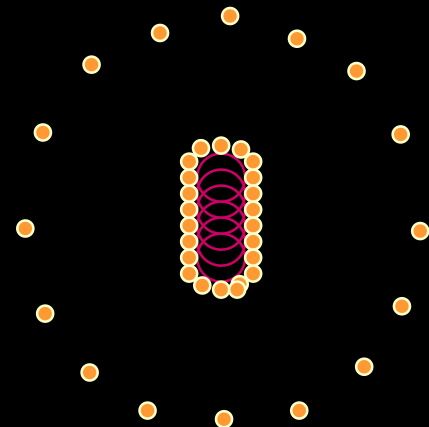
Electron passes closer to nucleus
Coulombic force is stronger
More energy is released in photon
Shorter wavelength

How X-Ray Machines Work



Milliamperage- Seconds (mA-s)





Milliamperage (mA)controls the temperature of the filament

As the mA increases, the temperature of the filament increases and the filament produces more electrons

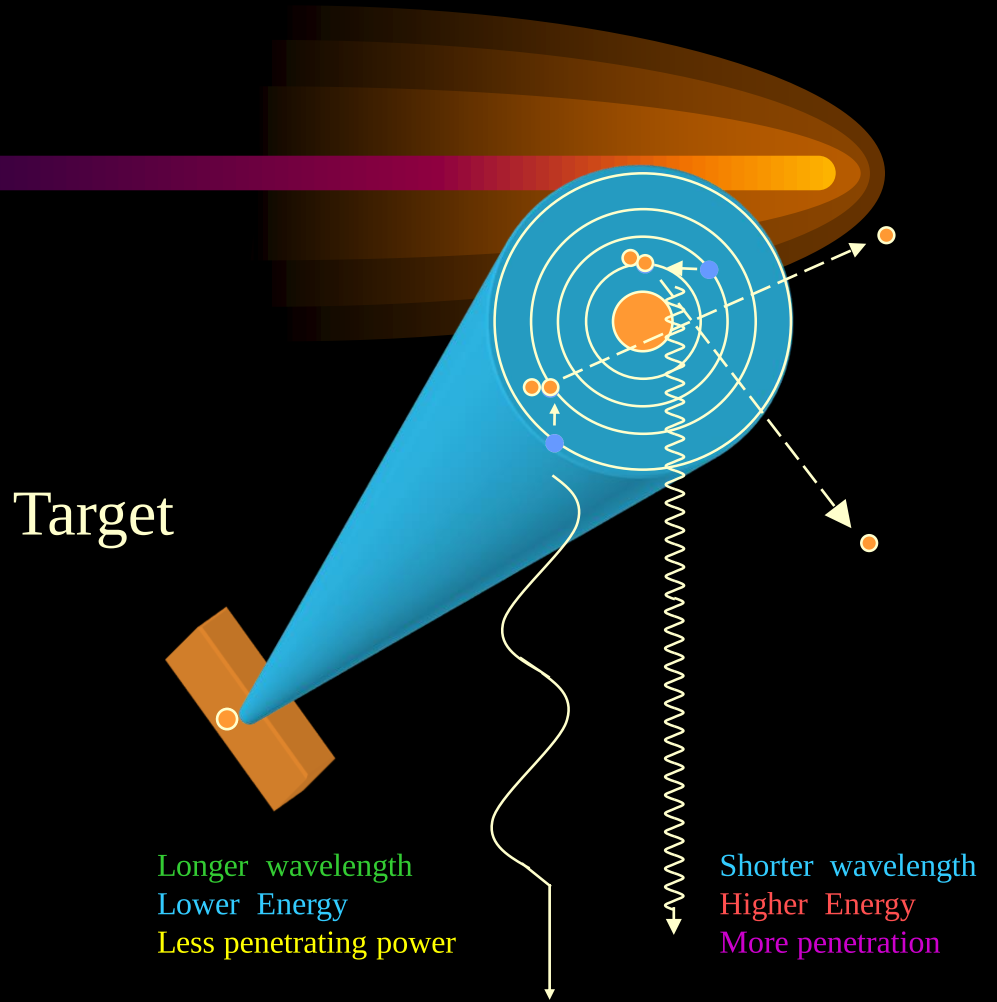
The number of Electrons and the period set for their release determine how many x-rays are available. Thus, the Milliamperage-seconds (mA-s) controls the number of x-rays that are produced

Kilovoltage Peak

Electron *speed* determines the penetrating power of the x-rays

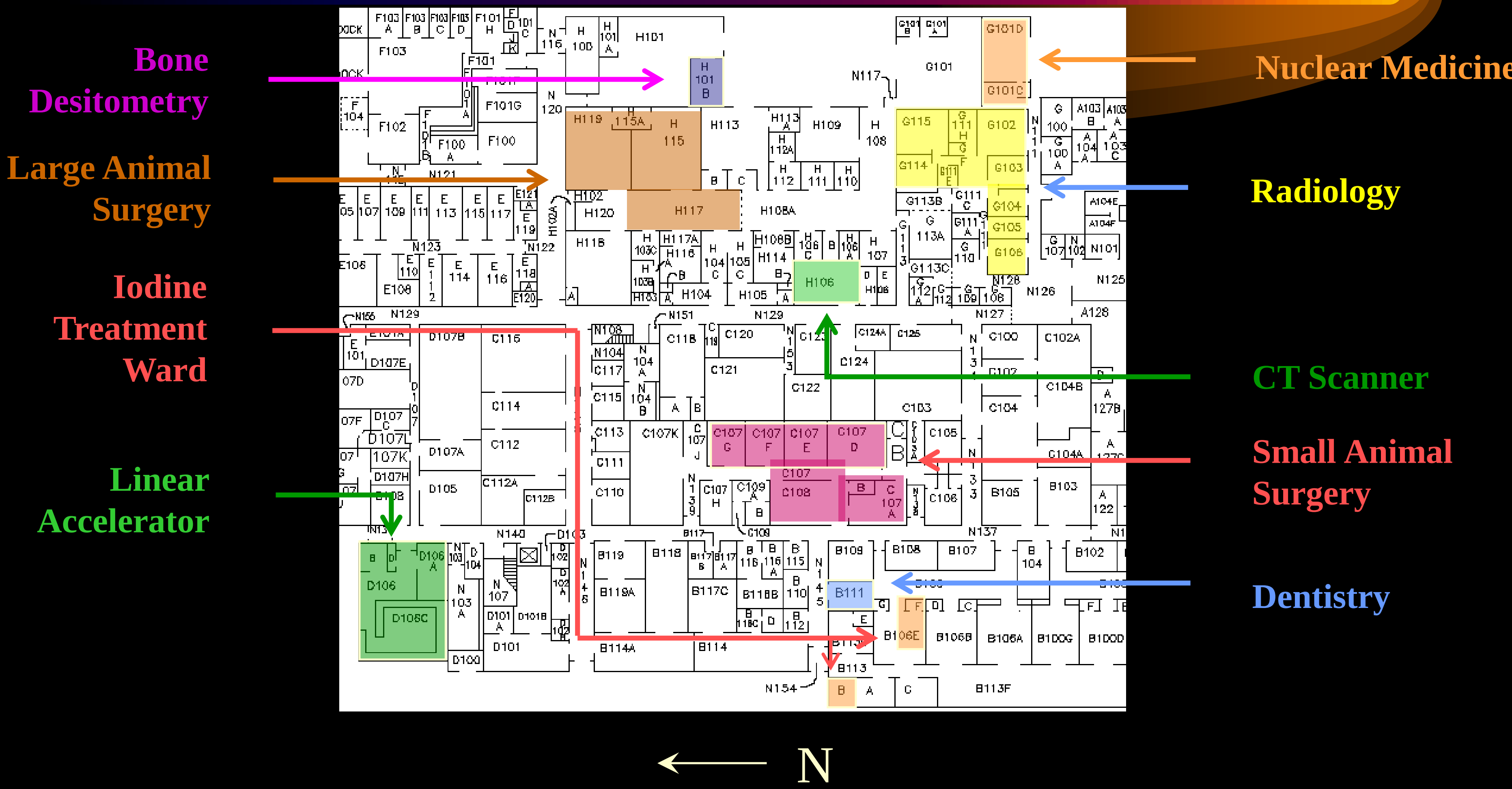
The deeper the penetration of the electron into the (target) electron shell, the higher the energy of the photon released

High voltage produces x-rays with greater penetrating power and intensity



Thus, the penetrating power of x-rays is controlled by the
Kilovoltage Peak (kVp)

Veterinary Teaching Hospital

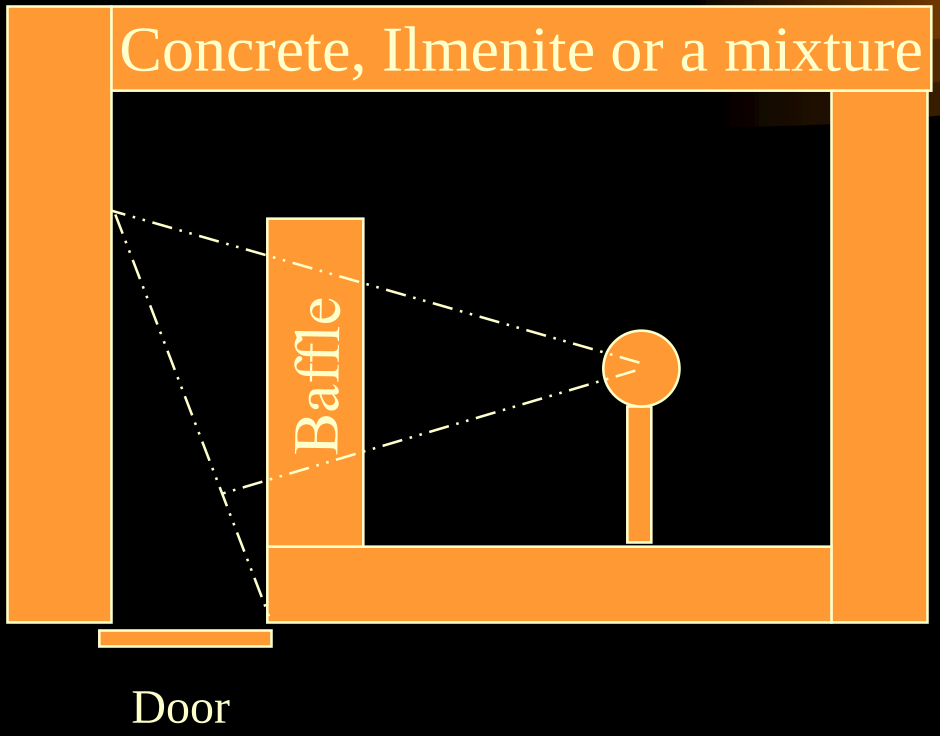


Some VTH Sources

X-Ray Machine

X-Ray Machine

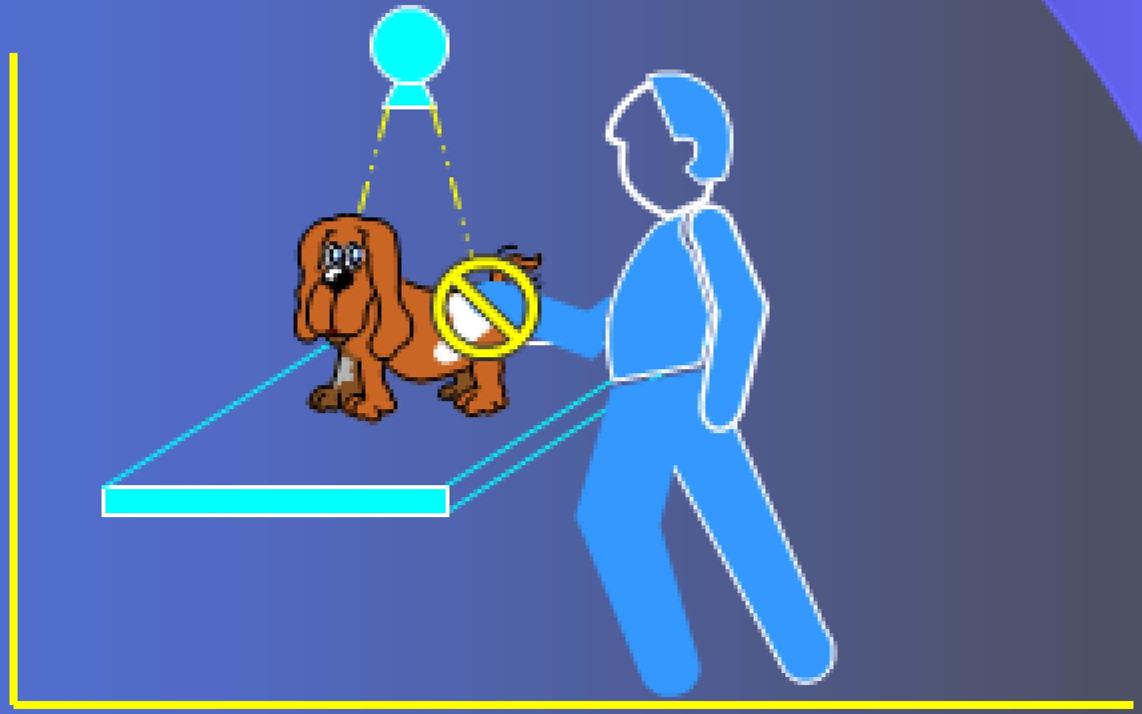
Basic Design of X-ray or Irradiator Facility



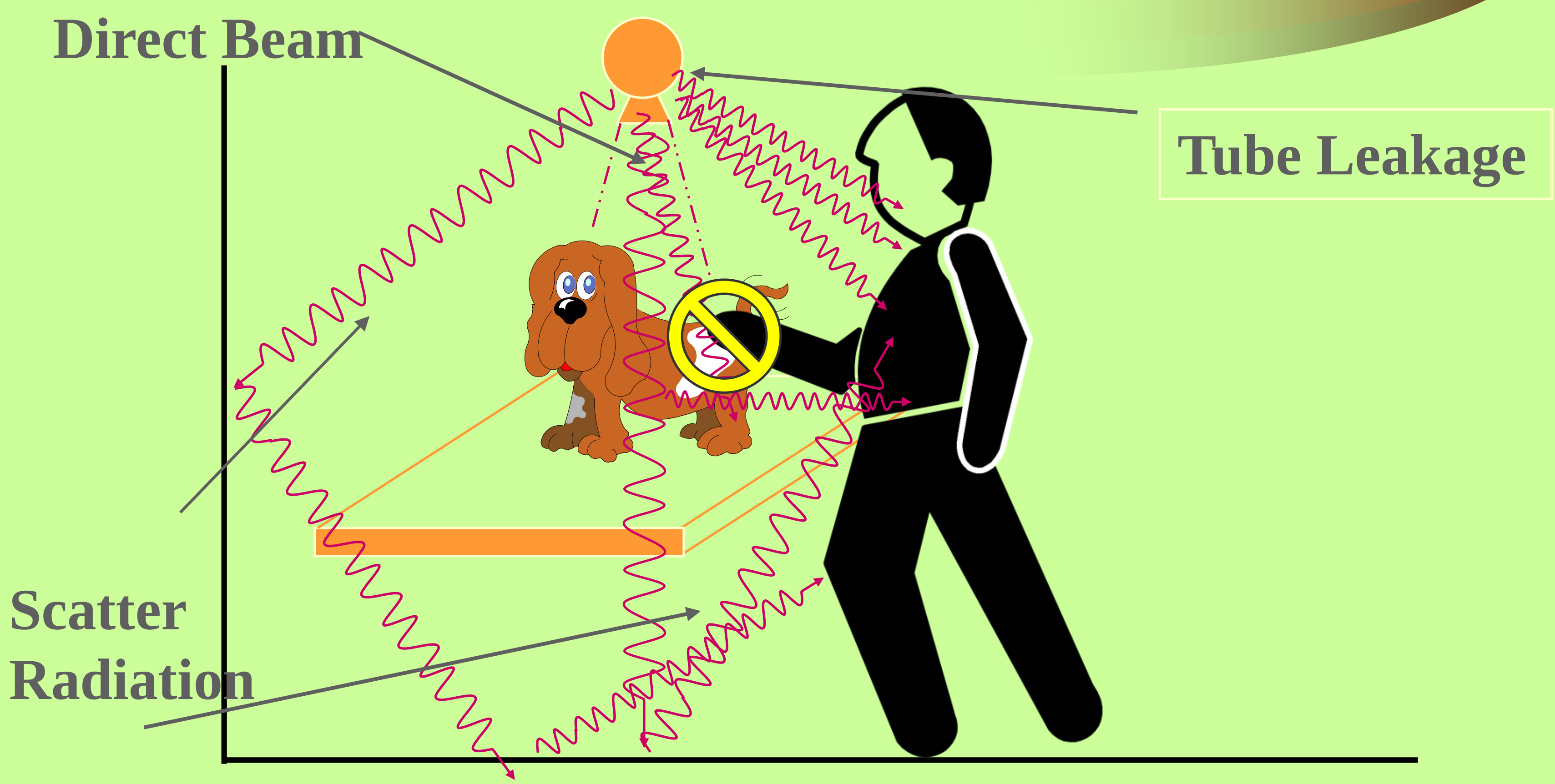
A Baffle protects the occupational worker from scatter radiation by using appropriate shielding geometries

Auxillary Support
Animal Holding

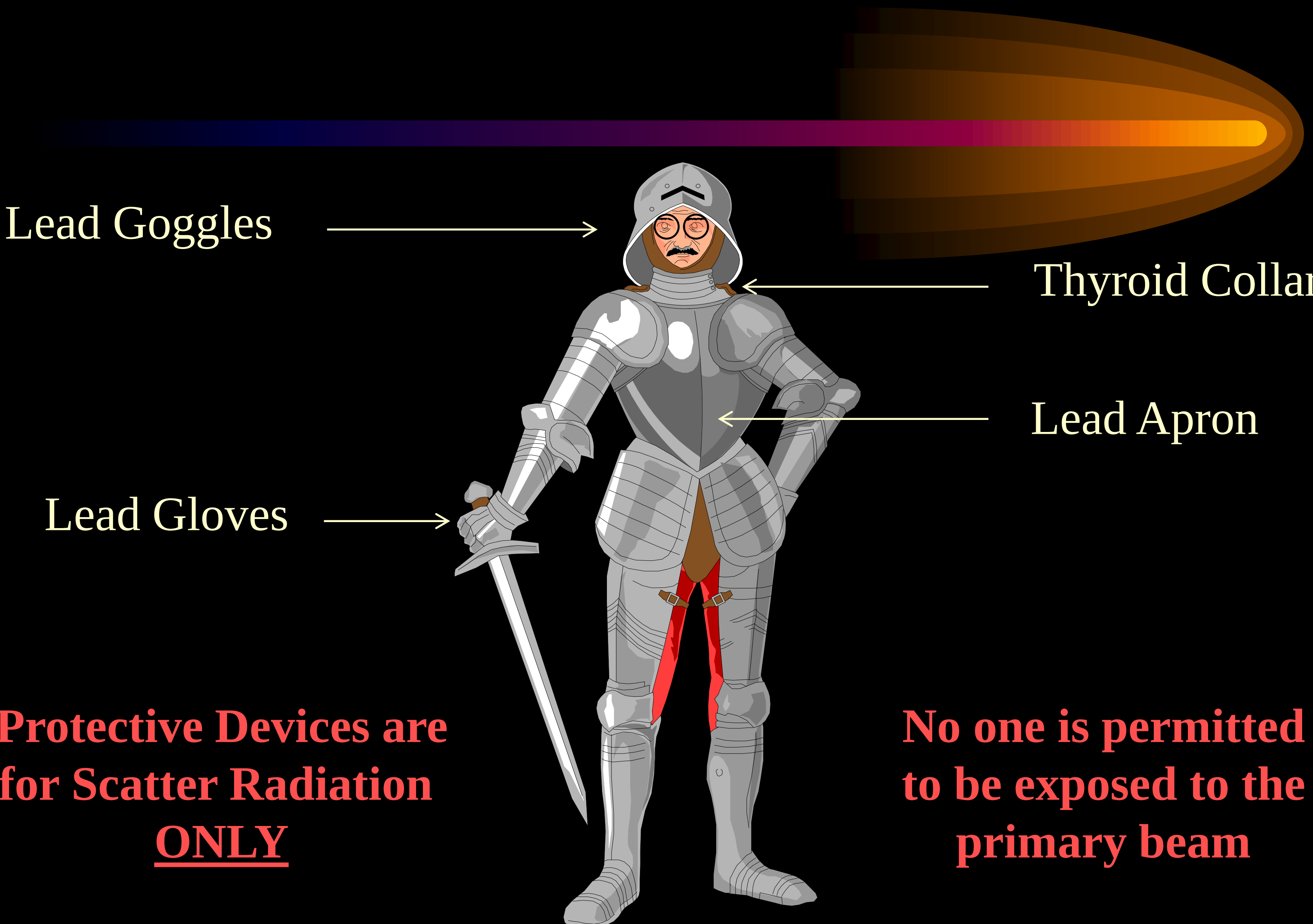
Mechanical holding devices shall be used when the technique permits. The written safety procedures shall list individual projections where holding devices cannot be utilized. Written safety procedures shall indicate the requirements for selecting a holder and the procedure the holder shall follow., The holder has to be protected as required by RH 6.3.1.1.5



Sources of X-Ray Exposure Animal Holding



Personal Protective Equipment



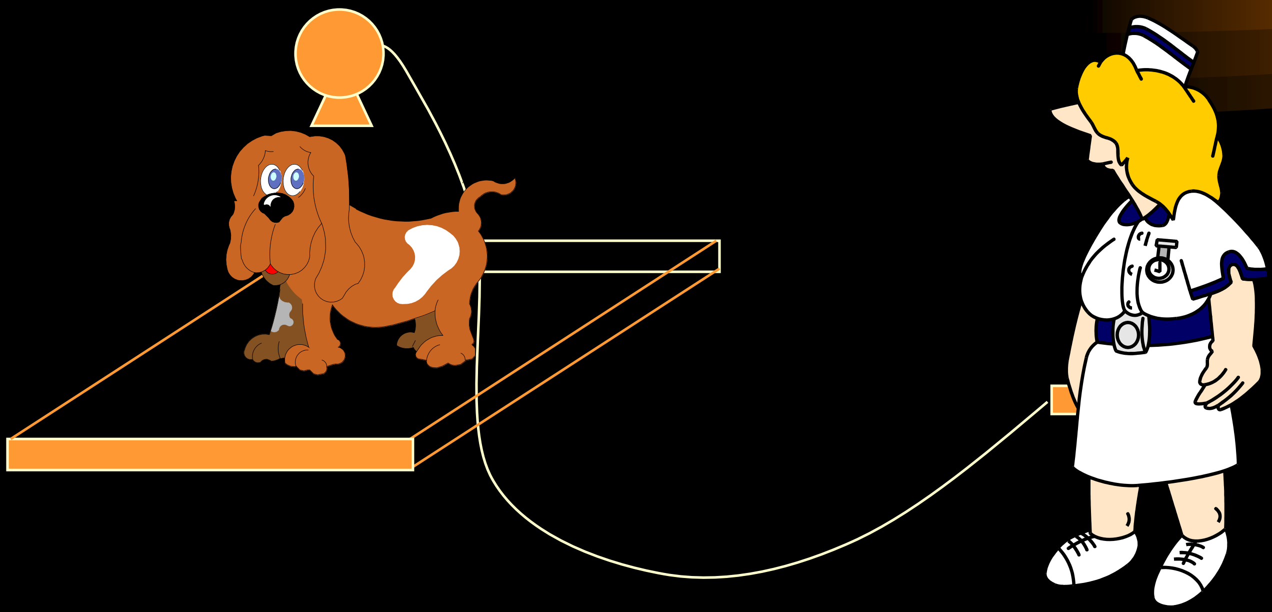
Protective Devices are for Scatter Radiation <u>ONLY</u>

No one is permitted to be exposed to the primary beam

CDPHE - Rules & Regulations

Part 6 - X-Rays in the Healing Arts

State Rules and Regulations



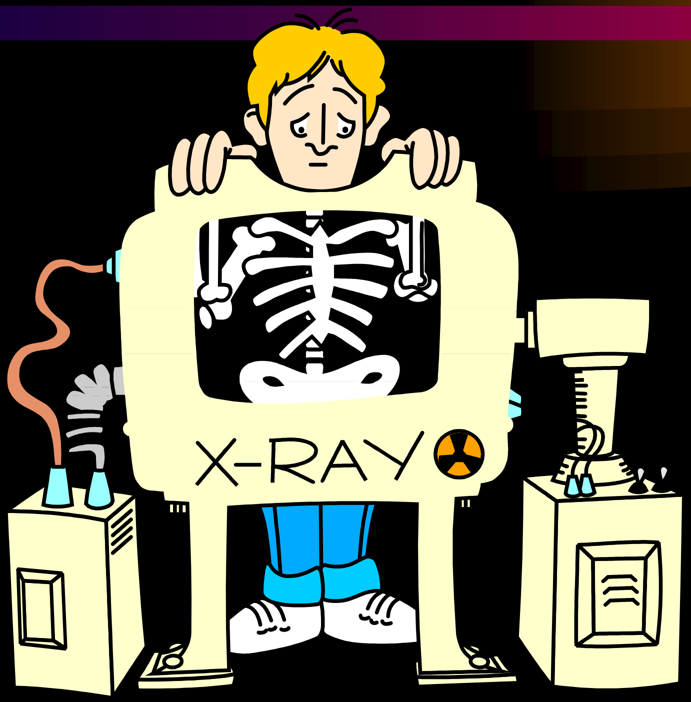
A Technique Chart Must Be in the Vicinity of the Control Panel

If the operator cannot be protected with lead shielding, then the operator must be positioned at least 2 meters (6 feet) from the x-ray tube

This requires a remote cord with exposure control

State Rules and Regulations

Misuse of a
VTH X-Ray
Machine



Human Exposure Is Strictly Prohibited !!!

Misuse of the x-ray machines in this manner will result in Administrative Action against the Individual

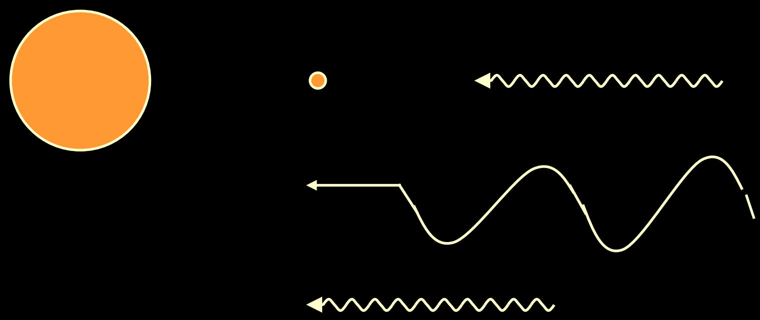
External Radiation Exposure

Definition: Exposure of the body from radiation originating outside of the body

Level of Hazard and Control Depend Upon:

1. Type of Radiation (Alpha, Beta Gamma)

2. Energy of the Radiation (Low or high energy)



3. Dose Rate (Low or high dose rate)

Short period of time can cause cancer

Long period of time can cure cancer

Reducing External Radiation Exposure

- Time:
  - reduce time spent in radiation area
- Distance:
  - stay as far away from the radiation source as possible
- Shielding:
  - interpose appropriate materials between the source and the body

Reduction of Exposure Time

Training

should include a full rehearsal of the procedures outside of the radiation area to improve efficiency and confidence

Power and automated equipment

Lab design

allows easy access to the equipment and components

<u>Reduce the number of shots taken by one person/ Rotate personnel</u>

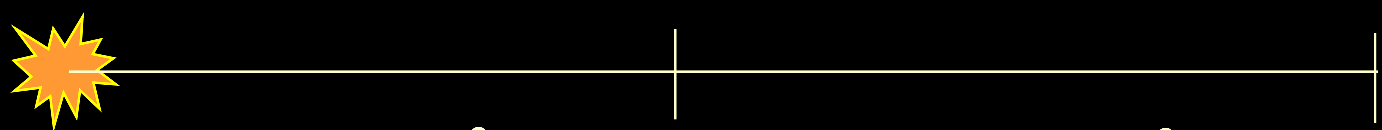
Distance from the Source

Basic principle: Point Source without Shielding

Inverse square law applies:

$$\dot{D}_2 = \dot{D}_1 (d_1^2/d_2^2)$$

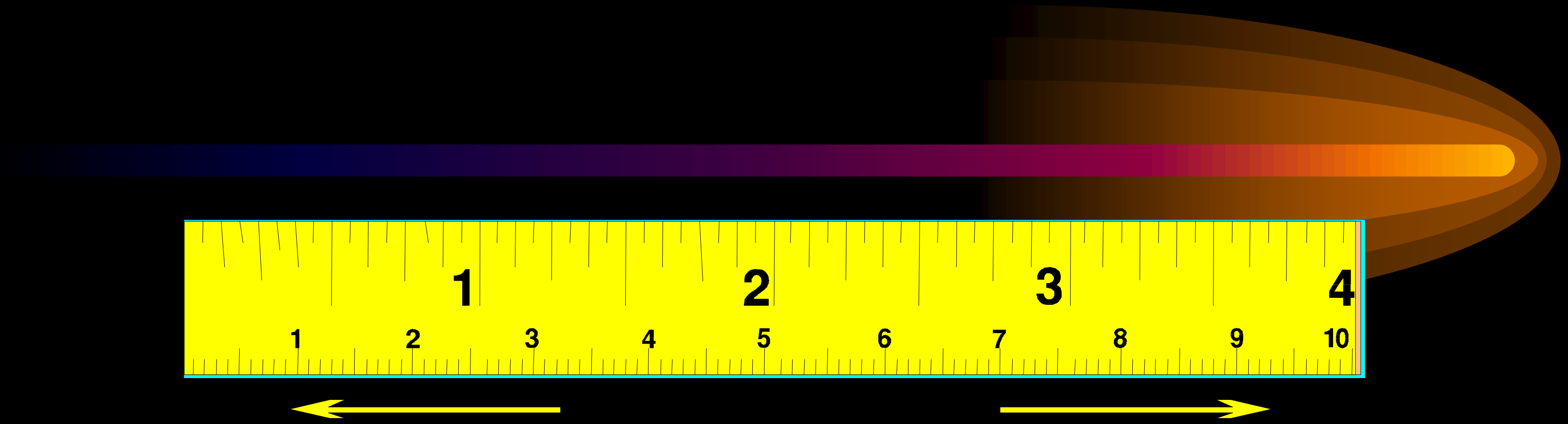
$\dot{D}_1$ and $\dot{D}_2$ = dose rates at distances d_1 and d_2



$\dot{D}_1$, d_1, 10 rem $\dot{D}_2$, d_2, 2.5 rem

Okay if the distance between the source and point of interest is at least five (5) times the greatest dimension of the source.

Control of Distance



•remote operation

manipulating devices, remote handling tools

•moving away from sources

remain near a source only when it is necessary

Leave the x-ray suite if you are not needed for the x-ray procedure

Shielding

Basic principle:
Place materials between the source and person to absorb some or all of the radiation

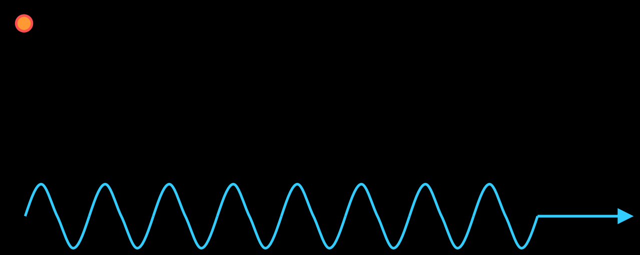
- α radiation: no shield required for external exposures; dead skin layer stops α's

- β radiation: ranges of meters in air; some can penetrate dead skin layer; thin plexiglass shields adequate

- x and γ radiation: highly penetrating, best shields are high atomic number materials (lead)

Radiation Dosimetry - X-Rays

Do not confuse photon energy with kVp



kVp is the potential applied to electrons to give them kinetic energy to create photons

Photons carry energy that is measured in kiloelectron volts or keV

Converting a X-Ray Exposure Rate to Dose Equivalent Dose Rate

Three depths

1.0 cm	used for “Deep” absorbed dose
0.3 cm	used for dose to lens of the “Eye”
0.007 cm	used for “Shallow” or skin dose

Dose Equivalent rate (rem/hr)

$$\dot{H} = C_d \dot{X}$$

Exposure Rate (R/hr)

Conversion factor from table (rem/R)

Rem/R Conversion Factors (C_d)

Photon Energy	Conversion Factors at Depth		
	1.0 cm ("Deep")	0.3 cm (Lens of Eye)	0.007 cm ("Shallow")
15	0.28	0.67	0.9
20	0.58	0.79	0.94
30	1.00	1.07	1.11
40	1.28	1.29	1.34
50	1.46	1.46	1.50
60	1.47	1.47	1.52
70	1.45	1.45	1.50
80	1.43	1.43	1.48
90	1.41	1.41	1.45
100	1.39	1.39	1.43
110	1.37	1.37	1.40
120	1.35	1.35	1.36
130	1.33	1.33	1.34
140	1.32	1.32	1.32
150	1.30	1.30	1.30
662	1.03	1.03	1.03

Worse Case Dose Scenario for X-Rays

$$\dot{H} = C_d \dot{X}$$

From the rem/R conversion factors, a 60 keV photon at shallow depth produces the highest factor of:

1.52

A worse case dose would simply multiply the exposure rate by the conversion factor of 1.52

Example Calculation

What is the deep dose equivalent if a radiation worker is accidentally exposed to 40 keV photons for 2 minutes ? The Exposure rate was measured at 100 R/ hr.

Photon Energy	
	1.0 cm (“Deep”)
15	0.28
20	0.58
30	1.00
40	1.28

$$\dot{H} = C_d \dot{X}$$

$$\dot{H} = (1.28 \text{ rem/R}) \bullet (100 \text{ R/hr})$$

$$\dot{H} = (128 \text{ rem/hr}) \bullet (2\text{m}/60\text{m/hr}) = 4.27 \text{ rem}$$

Monitoring of External Radiation Dose

- Primary CSU dosimeter is the new Luxel crystal
- Sensitive to gamma and hard beta radiations
- Provides CSU RSO dose information on a monthly or quarterly basis
- Does not provide information during an exposure to radiation
- Supplementary dosimeters - pocket dosimeters / radiation survey instruments

Monitoring of External Radiation Dose

•Individual responsibility to change badge

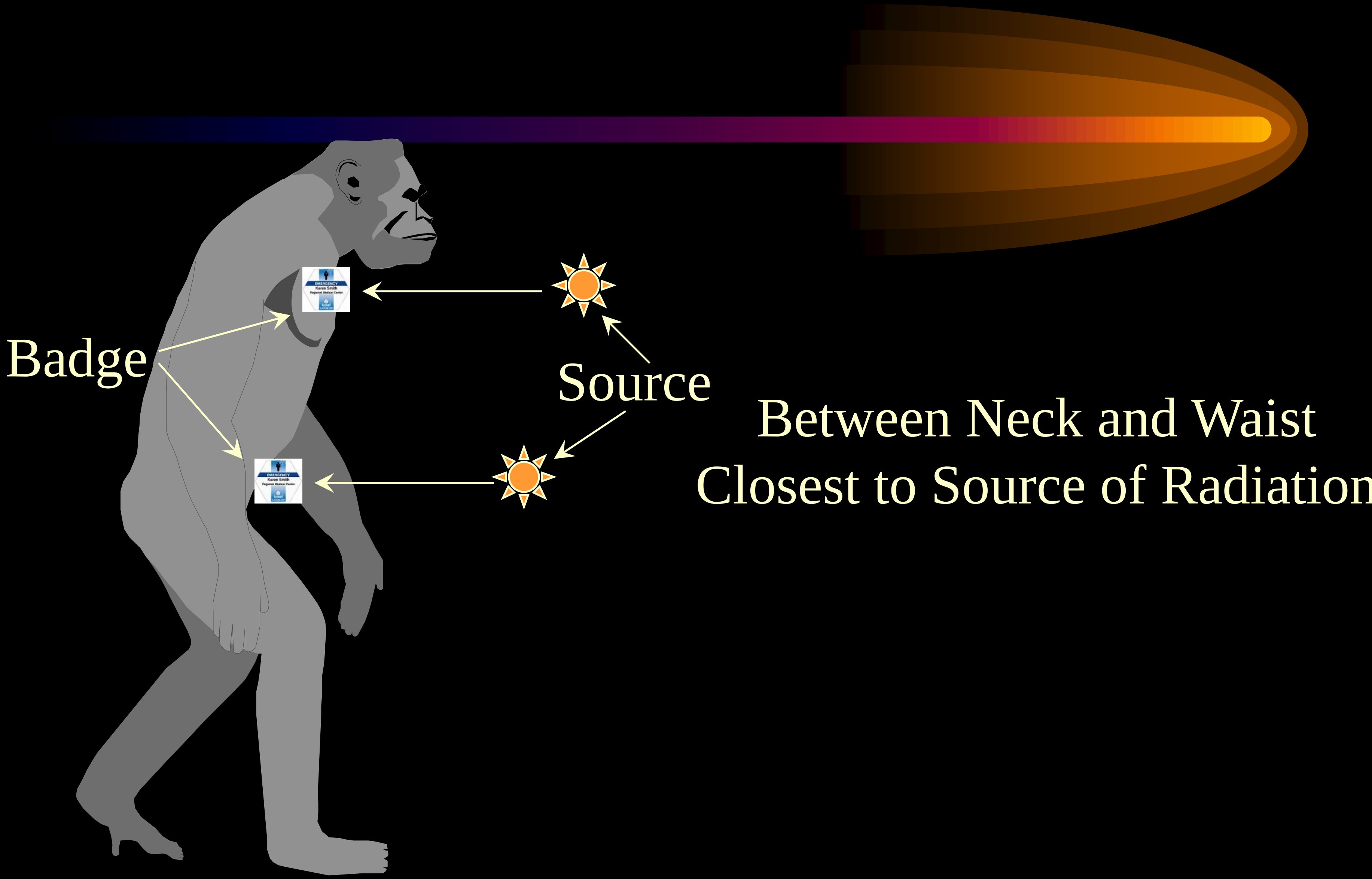
Badge Exchange

•Not Contaminated

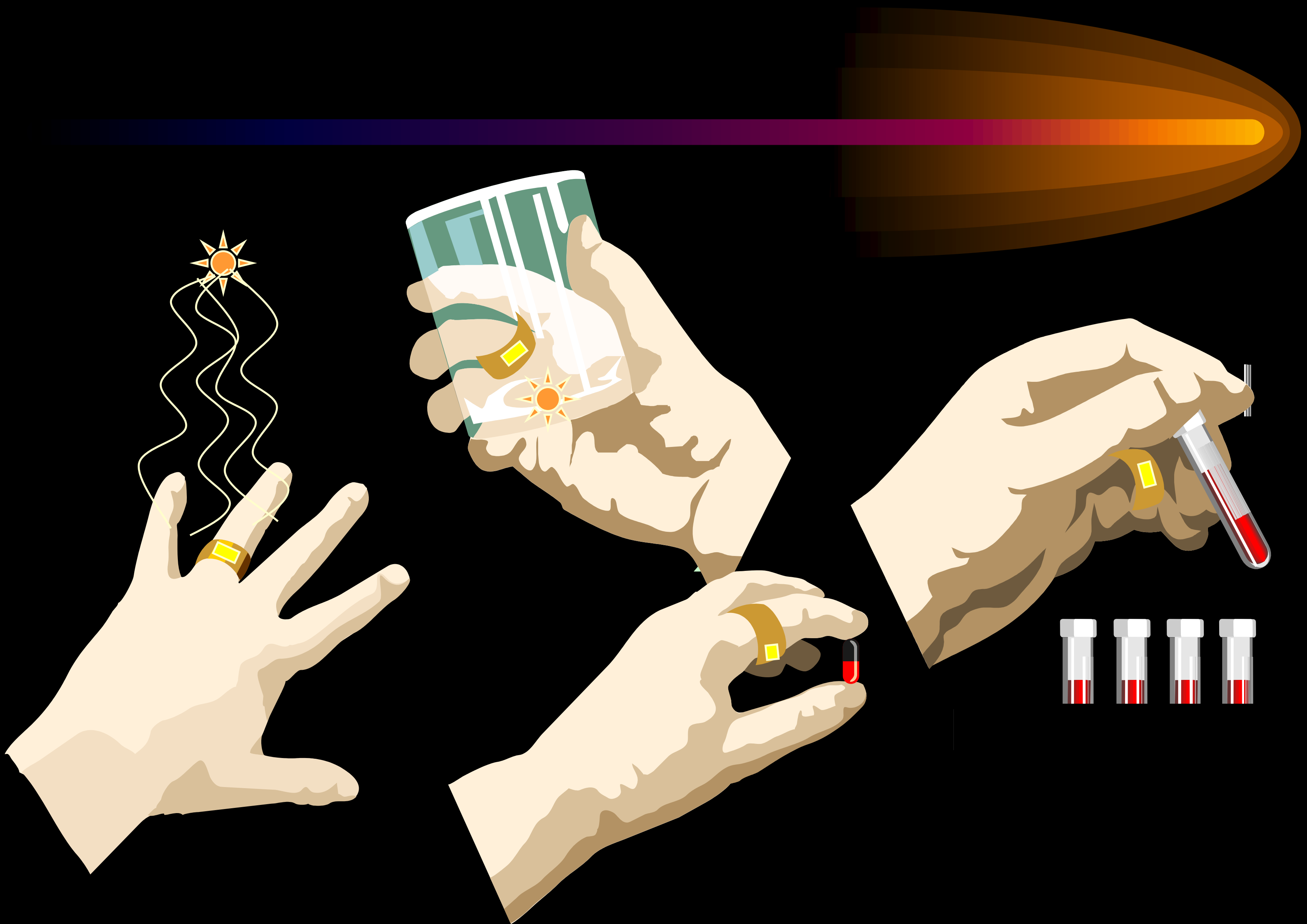
•Badge Book Location

•Change Out Procedure

Body Badge Location



Ring Badge Location



Pocket Dosimeter

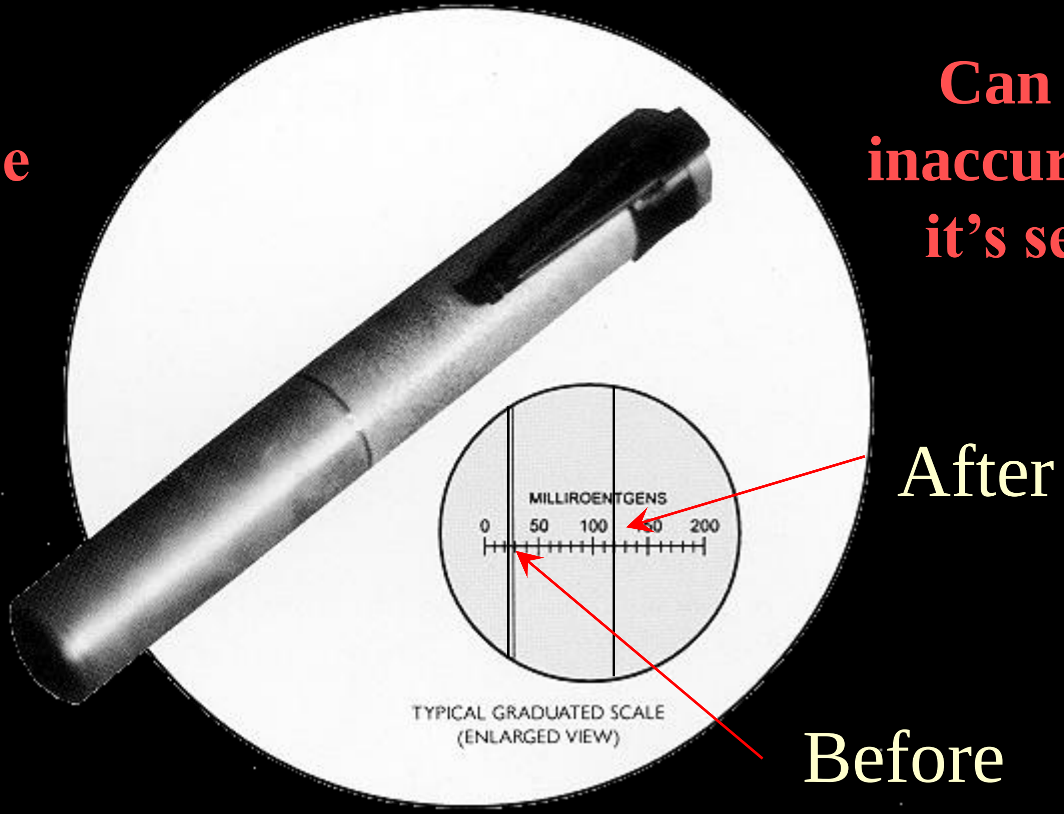
Same Location As Body Badge

Always wear in conjunction with body badge

Shock sensitive

Allows for a "real" time dose reading

Can be very inaccurate due to it's sensitivity



Questions ???

Please Feel Free to Contact: The Radiation Control Office

133 General Services Bld.
CSU Main Campus
Fort Collins, CO. 80523-6021

Environmental Health Sevices: 491-6745

Radiation Safety Officer: 491-3736

Alt. Radiation Safety Officer: 491-3928

Radiation Control Technician: 491-4835

VTH Radiation Technician: 491-4439

Module 8: X-Rays

Prepared by James P. Abraham, Alternate R.S.O.
Radiation Control Office
Environmental Health Services