Colorado State University

RCO
RADIATION CONTROL OFFICE

Radiation Safety Training

Module 9
VTH Student Orientation

The Operational Physics of X-Rays and Interactions with Matter.

X-ray Safety and Regulations

Topics

Basic Radiation Principles

Types of Radiations

Radiation Dosimetry Units

Occupational Dose Limits

Risk of Cancer

Acute Radiation Syndromes

Photon Interactions w/ Matter

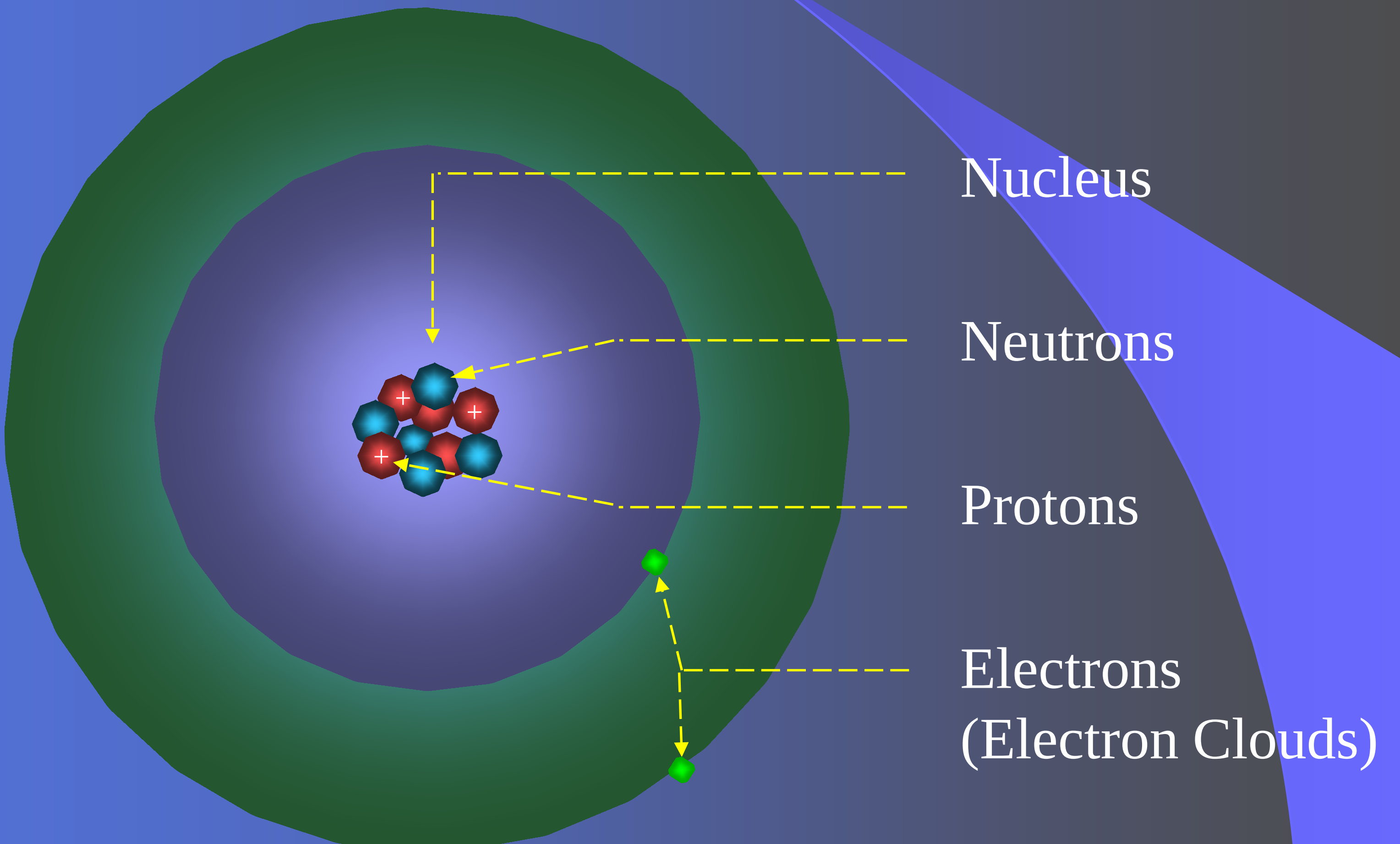
X-Ray machines and Design

VTH and State Regulations

Basic X-ray safety

Dosimetry and Requirements

Structure of the Atom



Units of Measure-Metric System

10^{-18}	10^{-15}	10^{-12}	10^{-9}	10^{-6}	10^{-3}	1.0 Base Unit	10^{3}	10^{6}	10^{9}	10^{12}	10^{15}	10^{18}
atto (a)	femto (f)	pico (p)	nano (n)	micro (μ)	milli (m)	Meters Liters Curies Etc.	kilo (k)	mega (M)	giga (G)	tera (T)	peta (P)	exa (E)

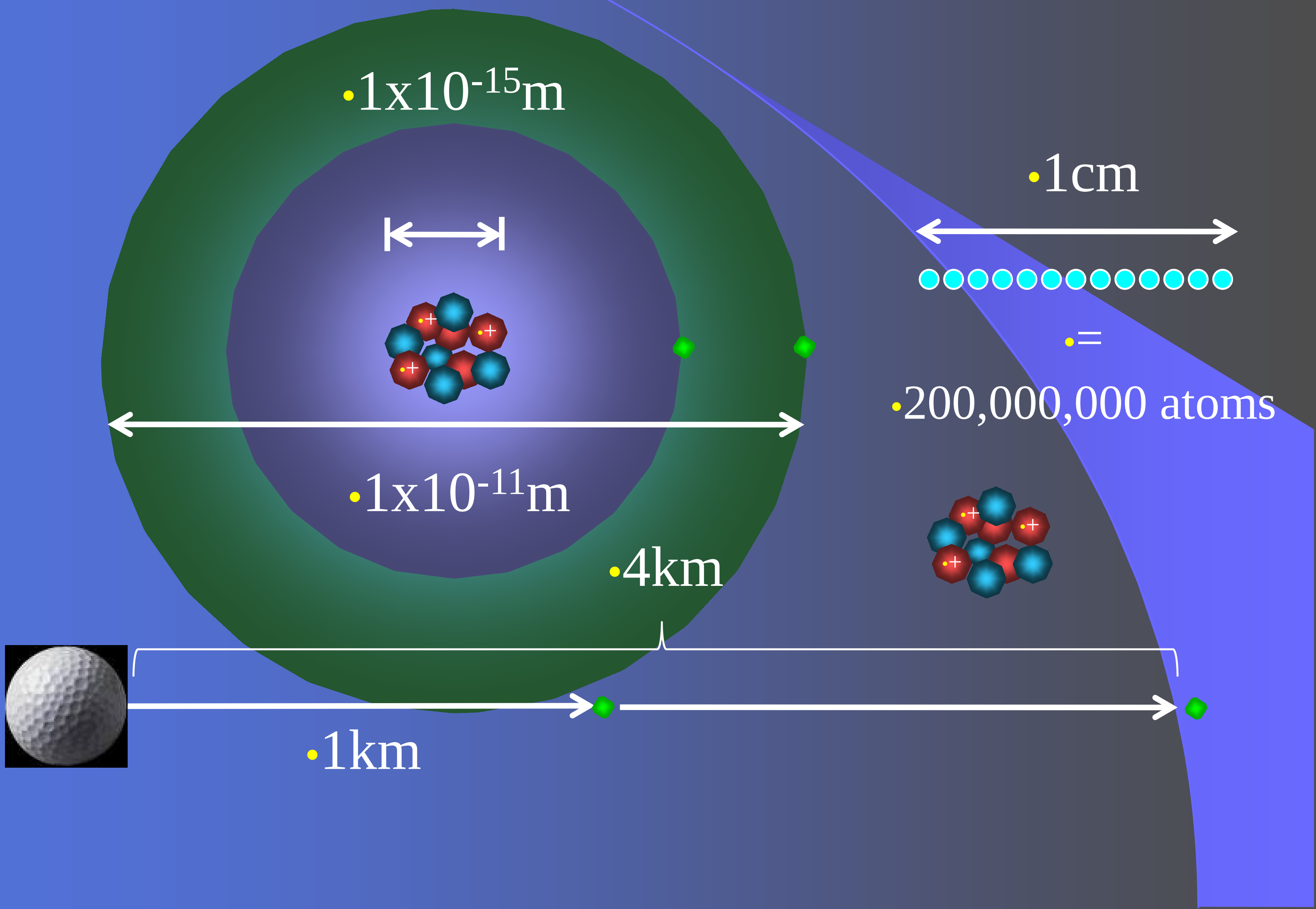
Example – How many meters is a femtometer ?

1fm = 1.0×10^{-15} m = 15 “decimal places” to the left of “1.0”

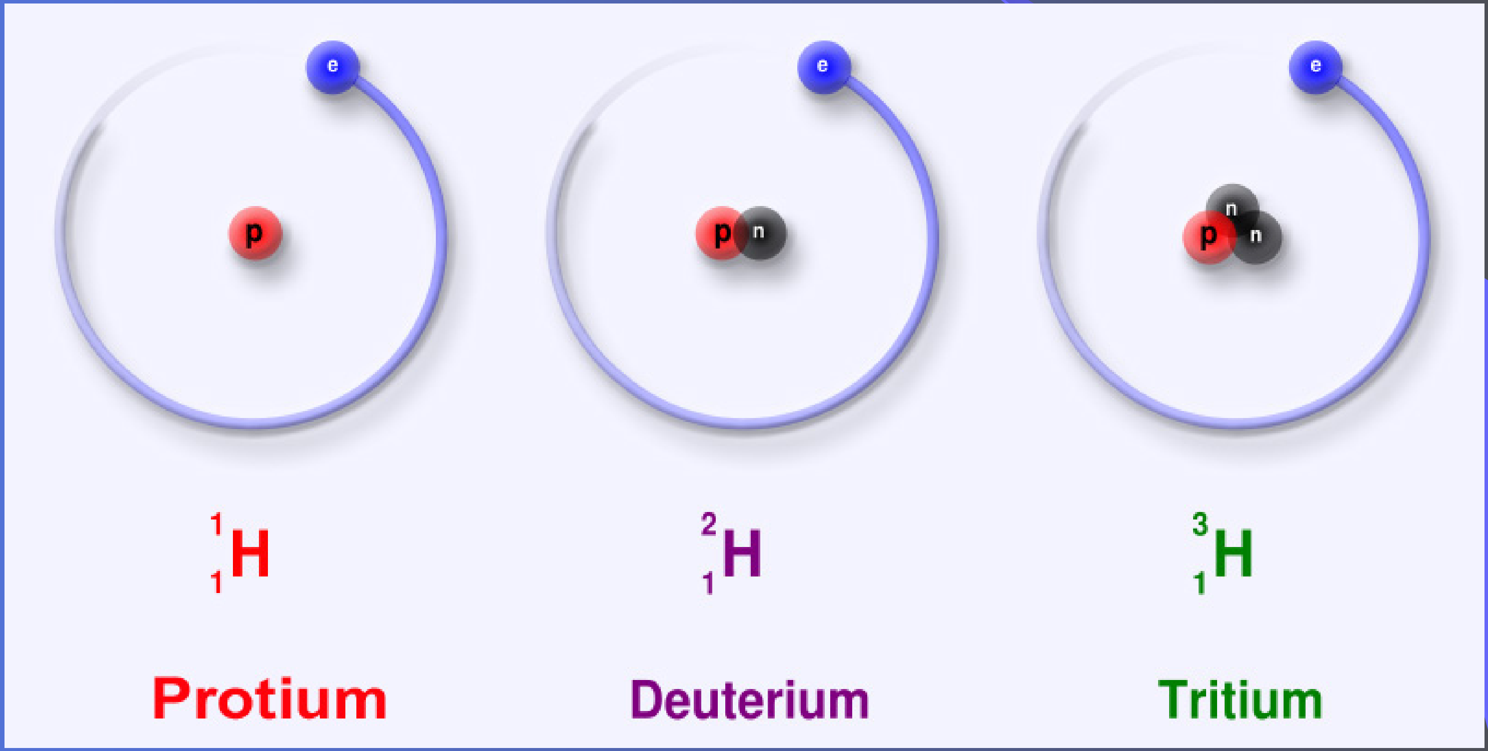
Thus, 1fm = 0.000000000000001 meters

Relative Size of Nucleus

Relative Size of Nucleus



Elements and Isotopes



Elements and Isotopes

Periodic Table of Elements

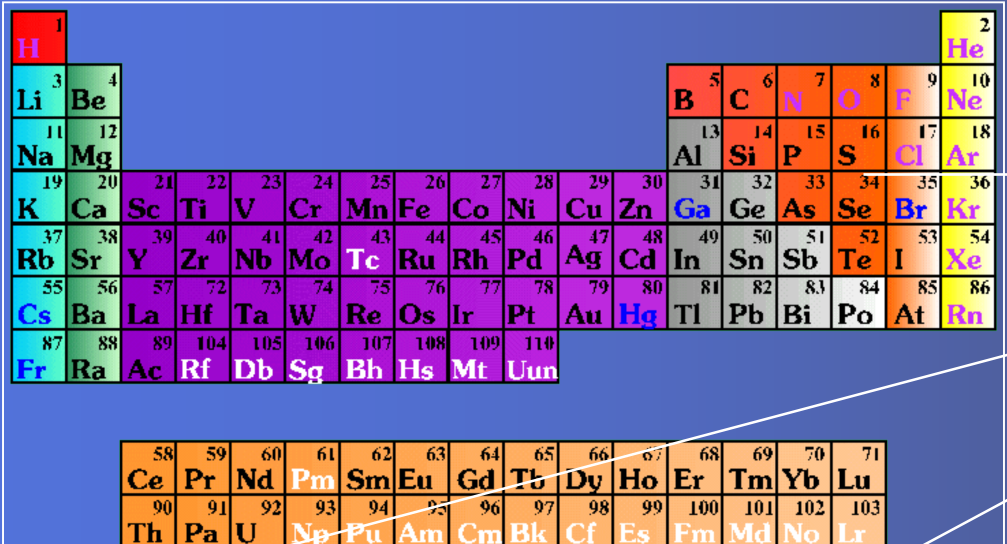
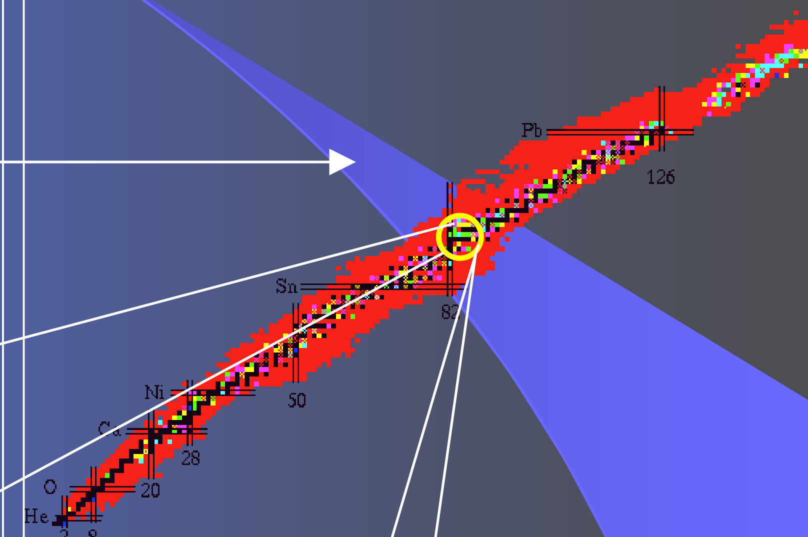


Chart of the Nuclides



				Tc	Tc90	Tc91	Tc92	Tc93	Tc94	Tc95	Tc96	Tc97	Tc98	Tc99	Tc100	Tc101
		Mo	Mo87	Mo88	Mo89	Mo90	Mo91	Mo92	Mo93	Mo94	Mo95	Mo96	Mo97	Mo98	Mo99	Mo100
Nb	Nb84		Nb86	Nb87	Nb88	Nb89	Nb90	Nb91	Nb92	Nb93	Nb94	Nb95	Nb96	Nb97	Nb98	Nb99
Zr82	Zr83	Zr84	Zr85	Zr86	Zr87	Zr88	Zr89	Zr90	Zr91	Zr92	Zr93	Zr94	Zr95	Zr96	Zr97	Zr98
Y81	Y82	Y83	Y84	Y85	Y86	Y87	Y88	Y89	Y90	Y91	Y92	Y93	Y94	Y95	Y96	Y97
Sr80	Sr81	Sr82	Sr83	Sr84	Sr85	Sr86	Sr87	Sr88	Sr89	Sr90	Sr91	Sr92	Sr93	Sr94	Sr95	Sr96
Rb79	Rb80	Rb81	Rb82	Rb83	Rb84	Rb85	Rb86	Rb87	Rb88	Rb89	Rb90	Rb91	Rb92	Rb93	Rb94	Rb95
Kr78	Kr79	Kr80	Kr81	Kr82	Kr83	Kr84	Kr85	Kr86	Kr87	Kr88	Kr89	Kr90	Kr91	Kr92	Kr93	Kr94
Br77	Br78	Br79	Br80	Br81	Br82	Br83	Br84	Br85	Br86	Br87	Br88	Br89	Br90	Br91	Br92	58
42		44		46		48		50			Stable			Natural Radioactive		

Half-Life

- 1 – 10 days
- 10-100 days

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

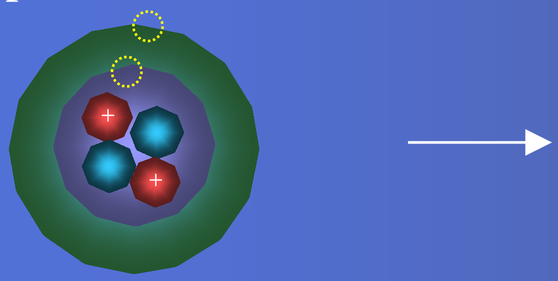
X-rays have the same physical form as gamma photons

Ionizing Radiation

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

Major Types of Ionizing Radiation Alpha, Beta, Gamma

Alpha Particle

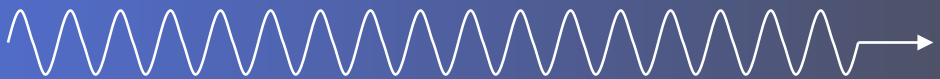


Large Mass (nuclei) – Helium Atom with a +2 charge

Beta Particle

Small Mass - Electron (subatomic particle)

Gamma Photon and X-Rays



No Mass (Electromagnetic Radiation)

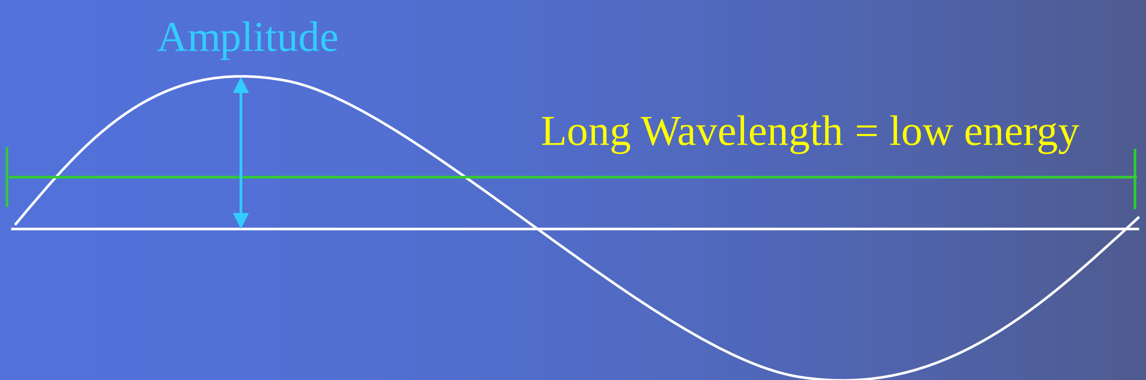
Electromagnetic Radiation

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



Short Wavelength = high energy

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: <u>roentgen</u> (R) $1\ R = 2.58\times10^{-4}\ C/kg$

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

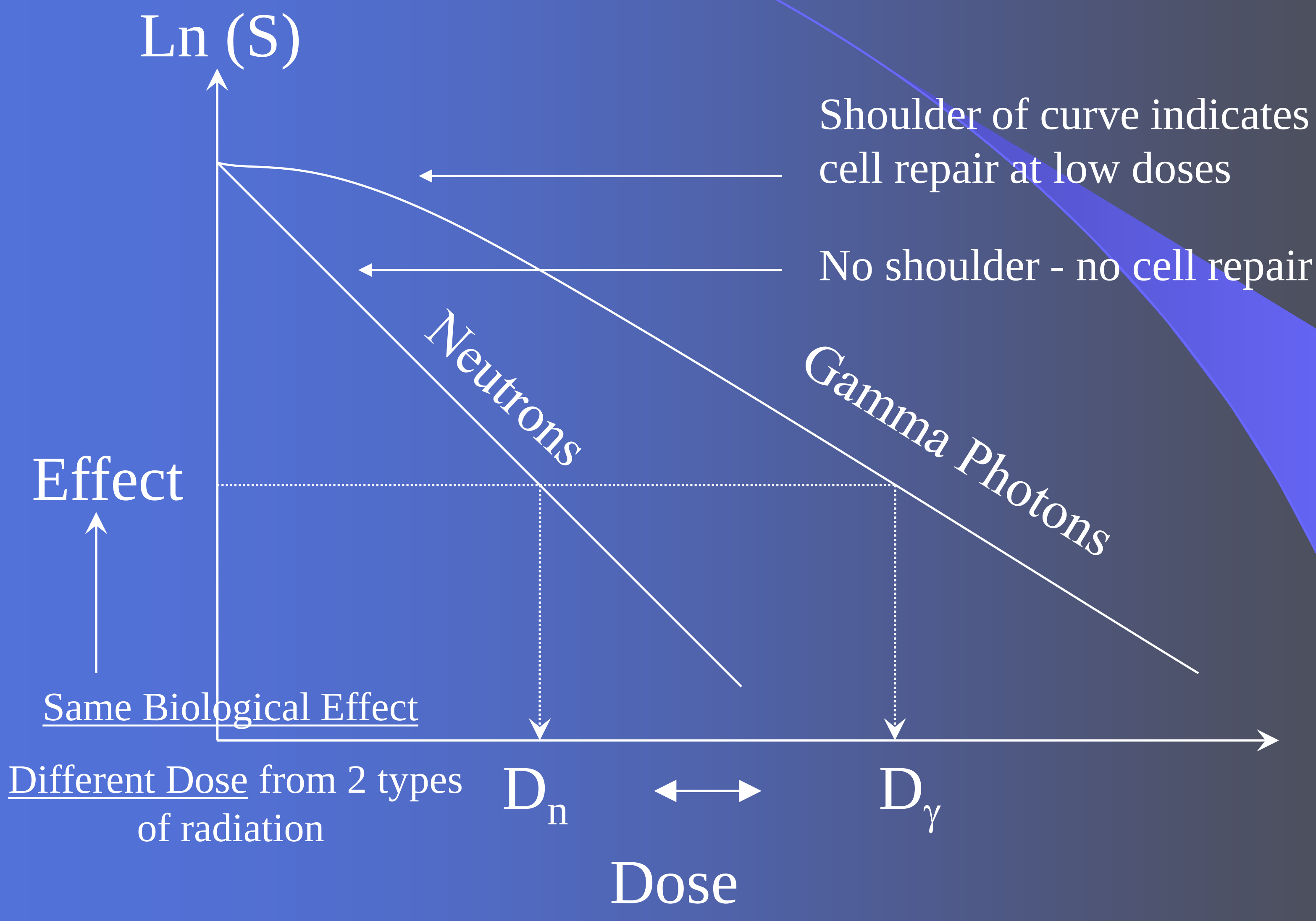
$$\text{Relative Biological Effectiveness (RBE)} = \left(\frac{\text{Absorbed dose from standard 250 kVp x-rays}}{\text{dose from a radiation of interest}} \right)$$

Both produce the same biological effect.

<u>Quality factor (Q)</u>

<u>radiation</u>	<u>Q</u>
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:

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

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

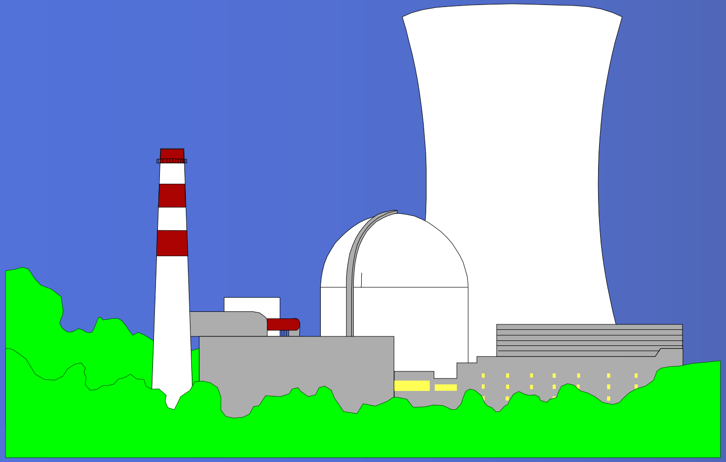
Risk Factors

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.



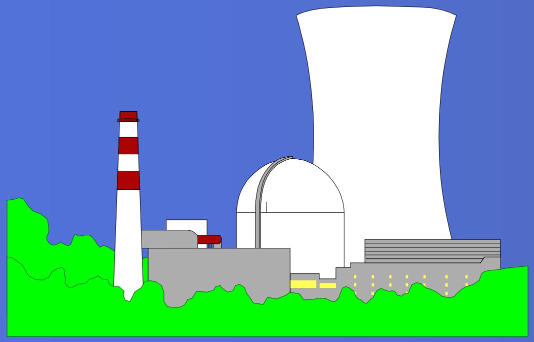
1. Fatal cancer risk in an individual.

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

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

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

In most cases, the primary biological effect of radiation is cancer.

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 in a very short period of time)

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 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

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

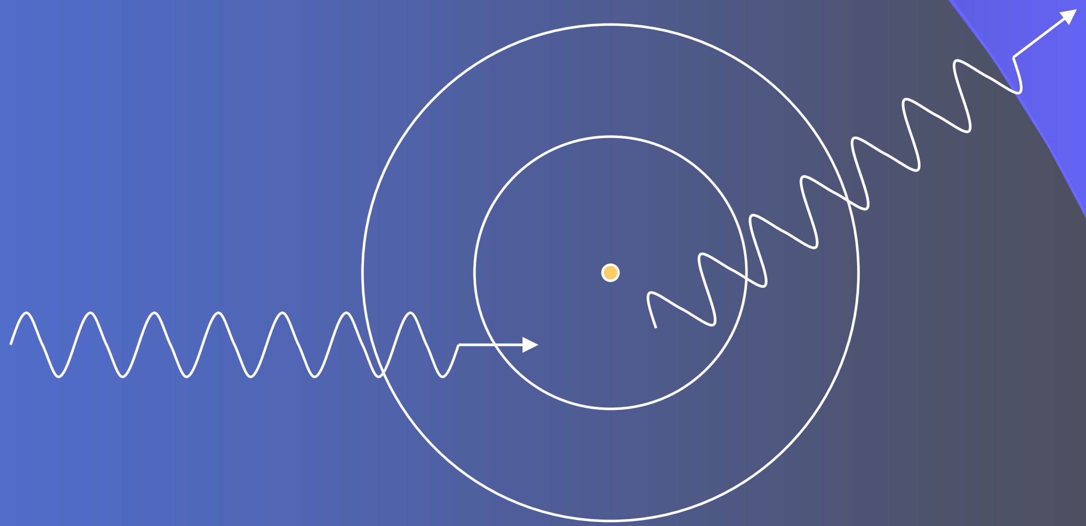
Coherent scattering (Rayleigh scattering)

Incoherent Scattering (Compton scattering)

Photoelectric Effect

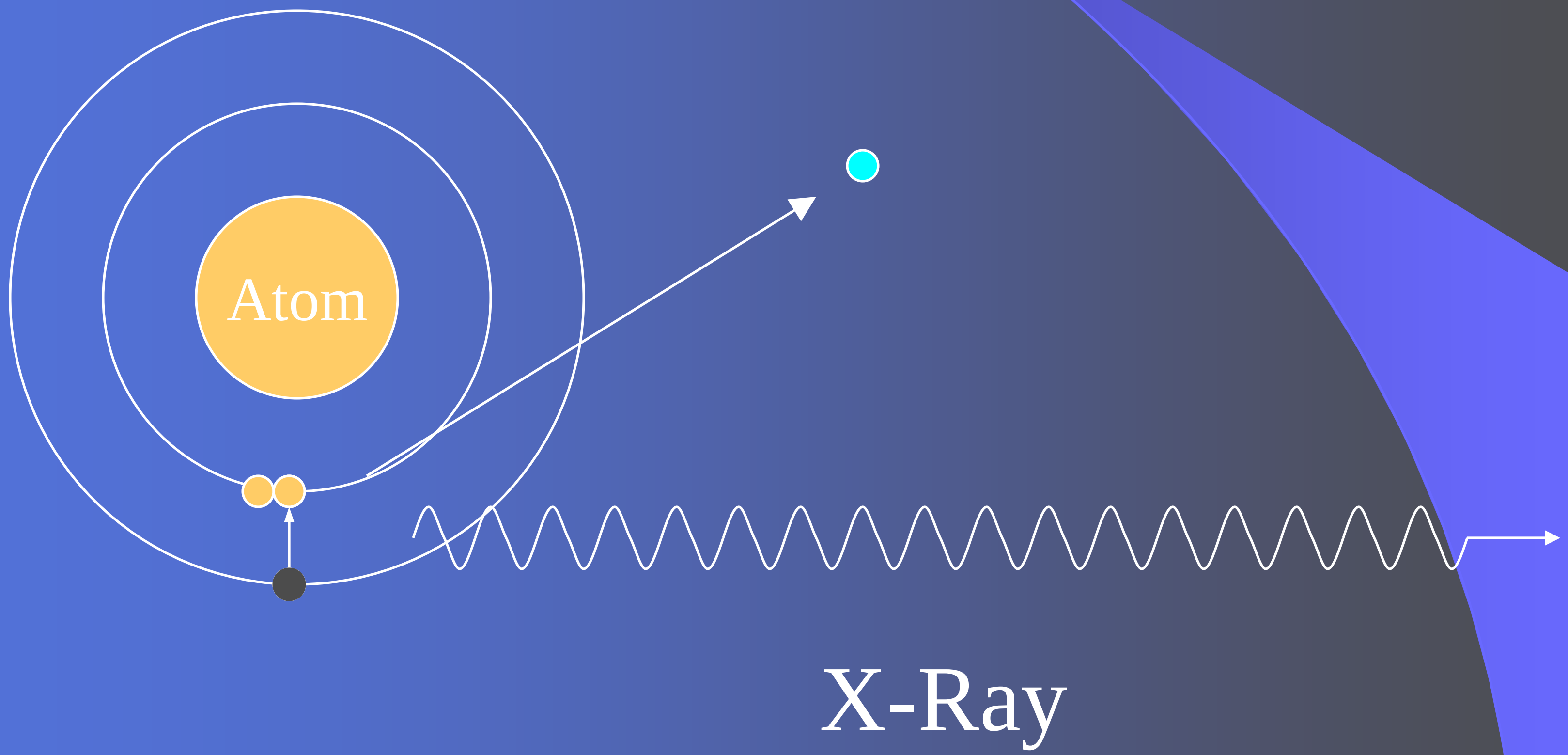
Pair Production

Coherent Scattering (Raleigh Scattering)



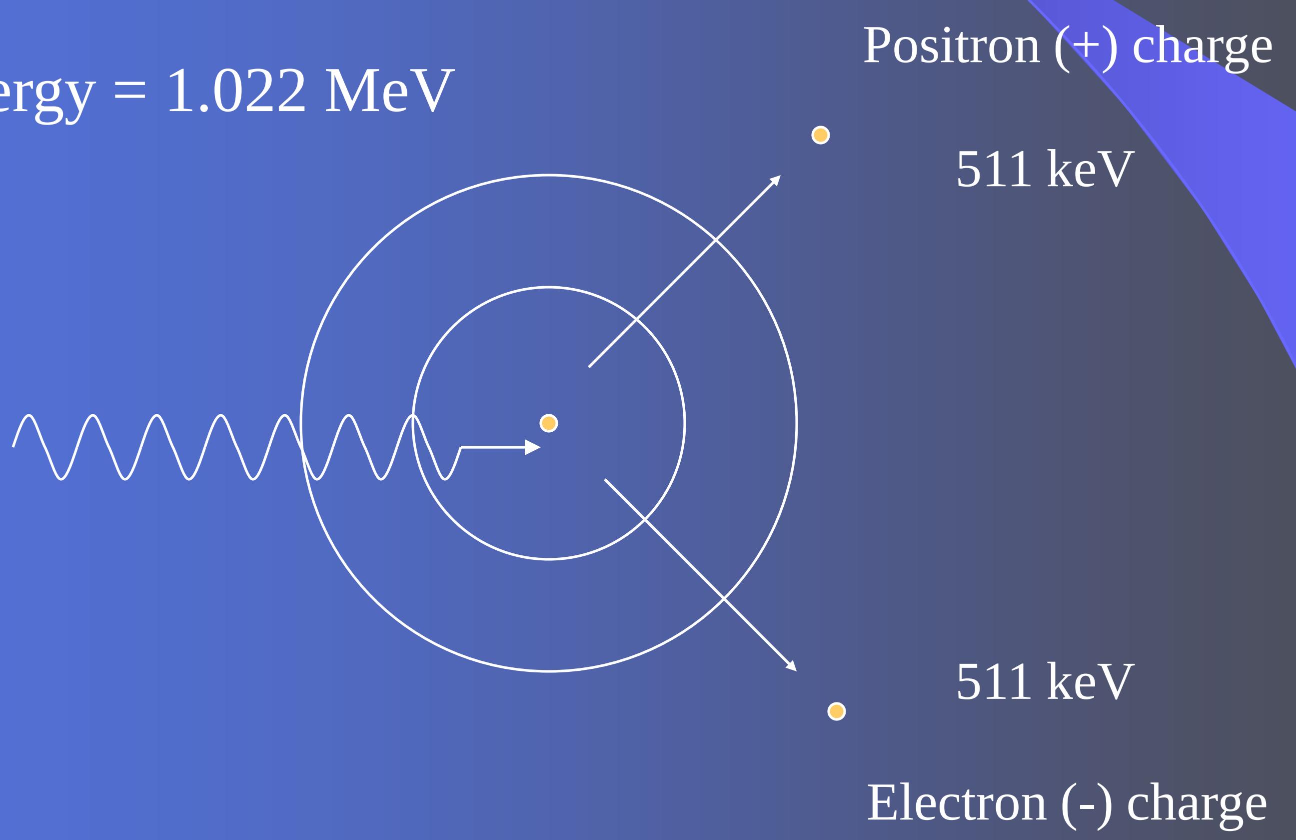
Incoherent Scattering (Compton Scattering)

Photoelectric Effect Production of X-Rays

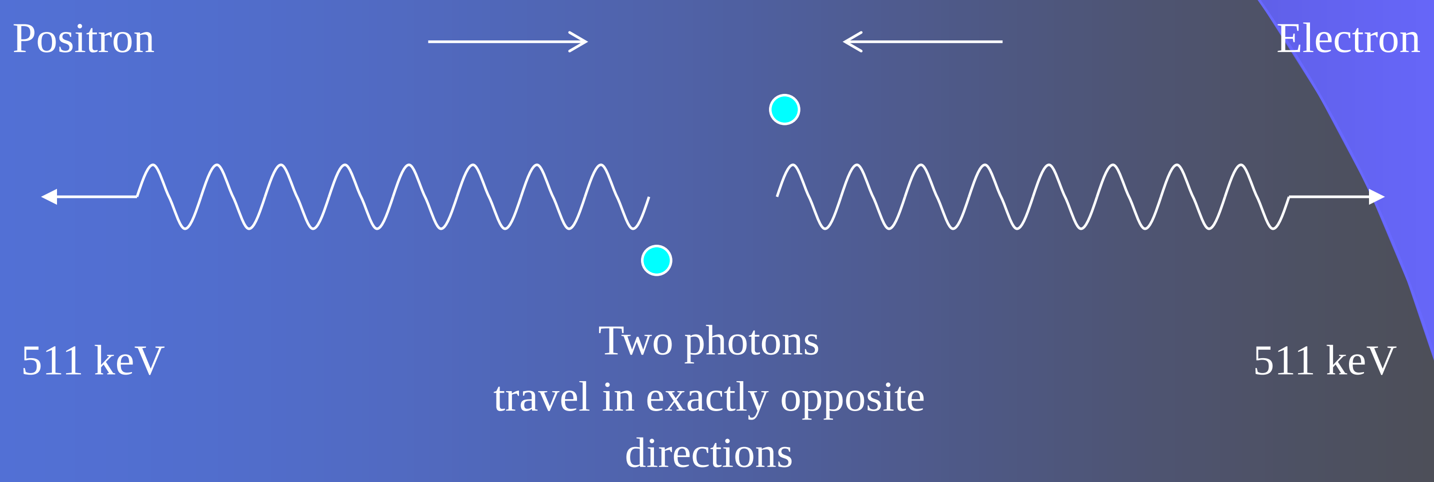


Pair Production

Photon Energy = 1.022 MeV



Pair Annihilation



$$E = mc^2$$

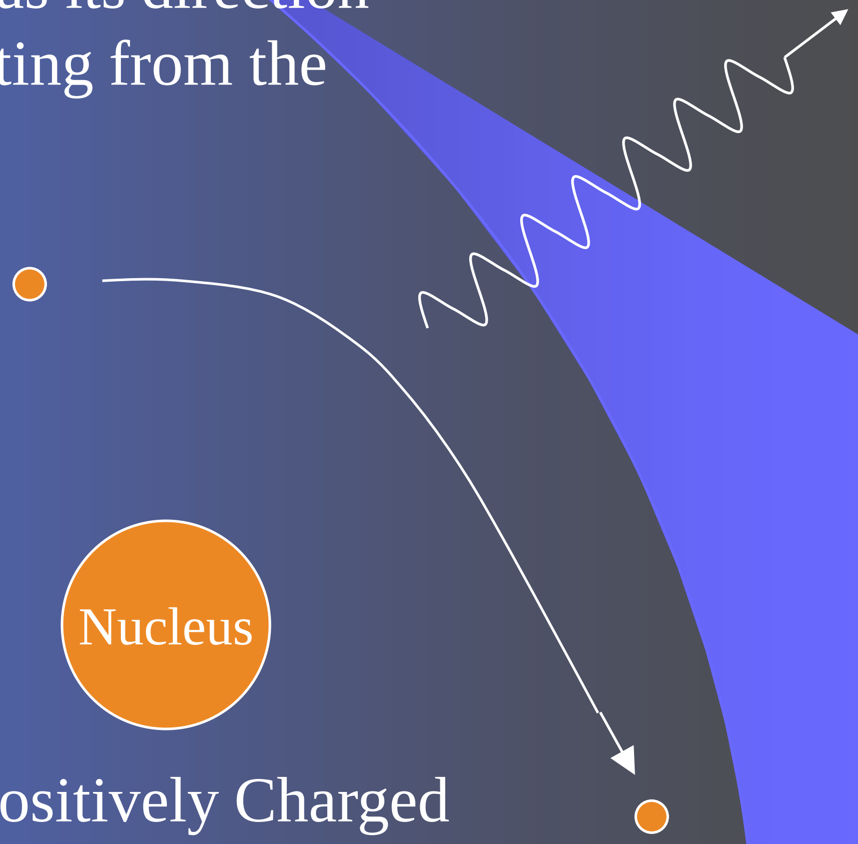
Main Production of X-Rays

Bremsstrahlung Radiation

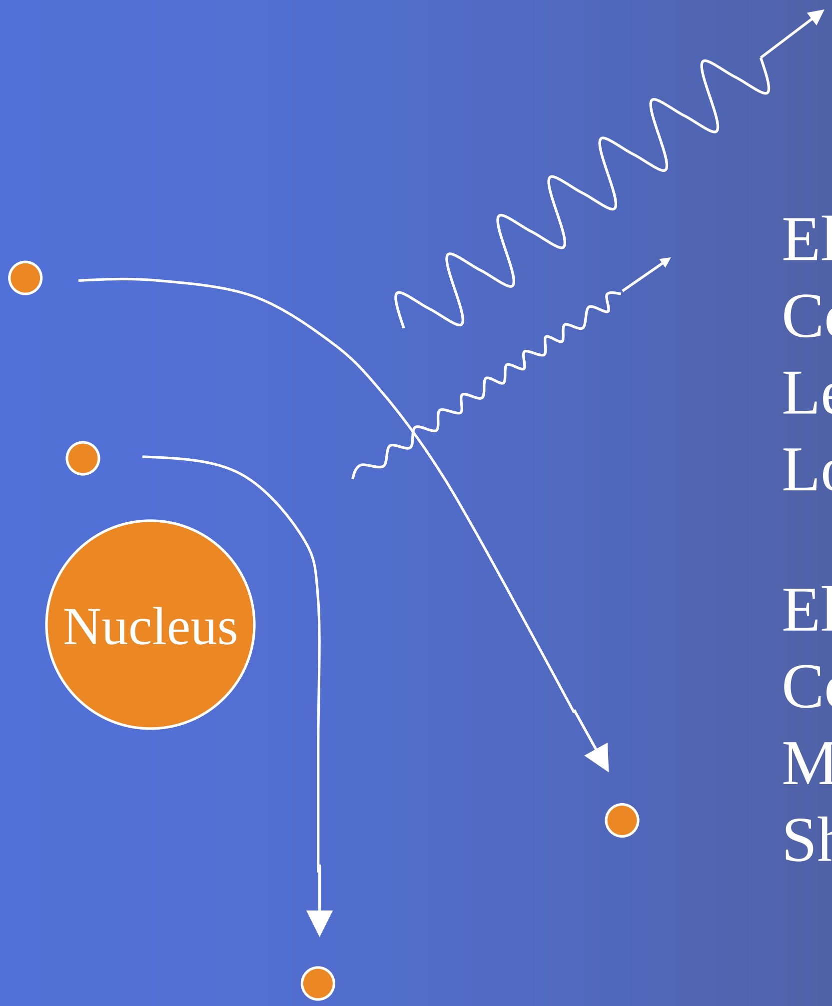
An electron passing near a nucleus has its direction altered by the Coulombic force resulting from the positively charged nucleus.

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 (**<u>X-Rays</u>**)



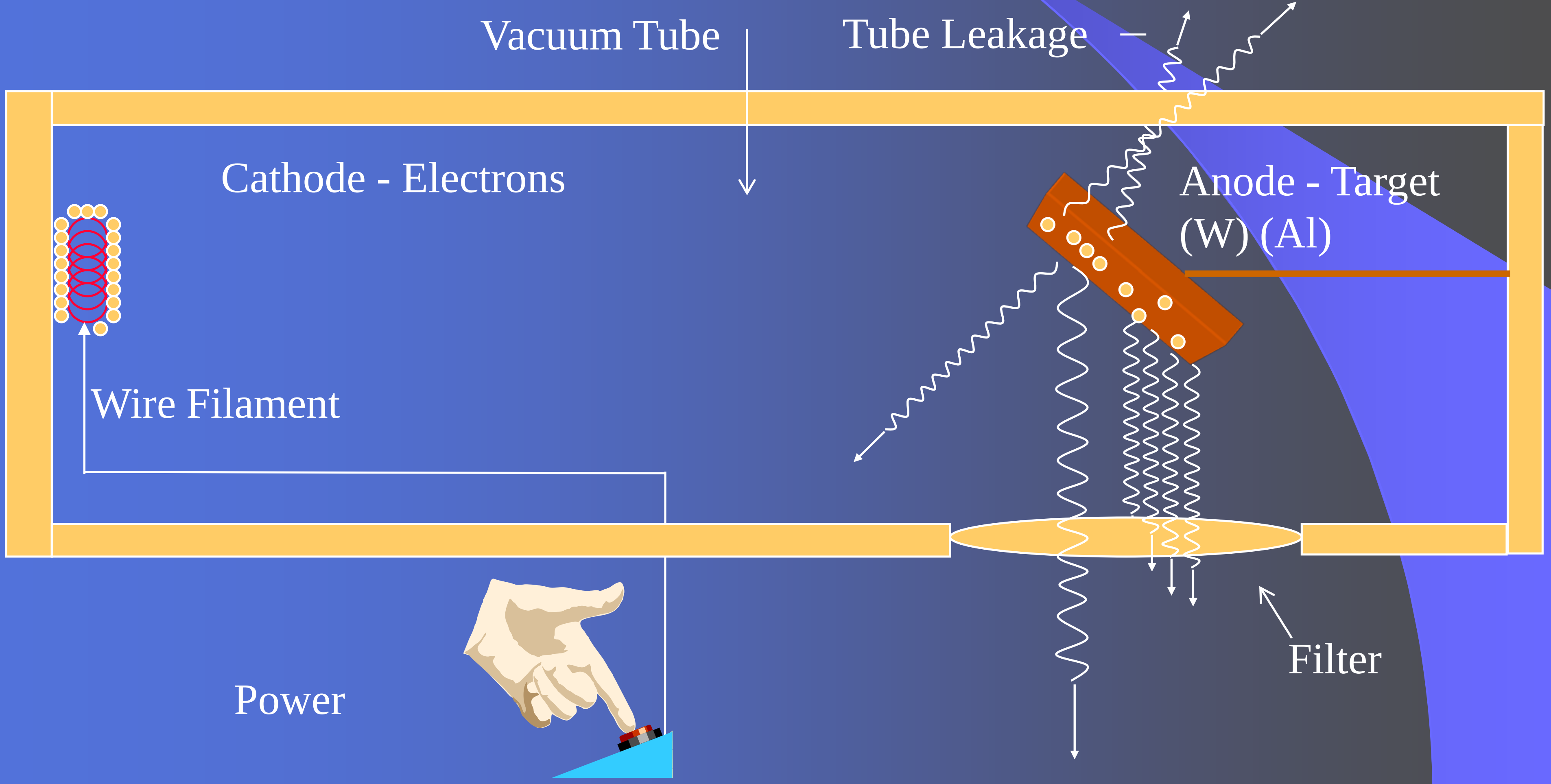
Bremsstrahlung Radiation



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

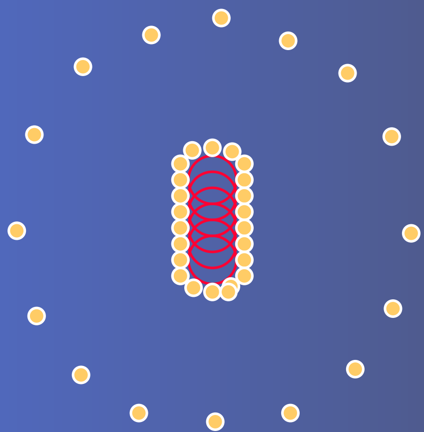
Electron passes closer to nucleus
Coulombic force is stronger
More energy is released in photon
Shorter wavelength

How X-Ray Machines Work



Milliamperage- Seconds (mA-s)

Electrons



Milliamperage (mA)controls the temperature of the filament and Thus the Quantity or Amount of X-rays produced.

As the mA increases, the temperature of the filament increases and the filament produces more electrons More electrons lead to more X-rays.

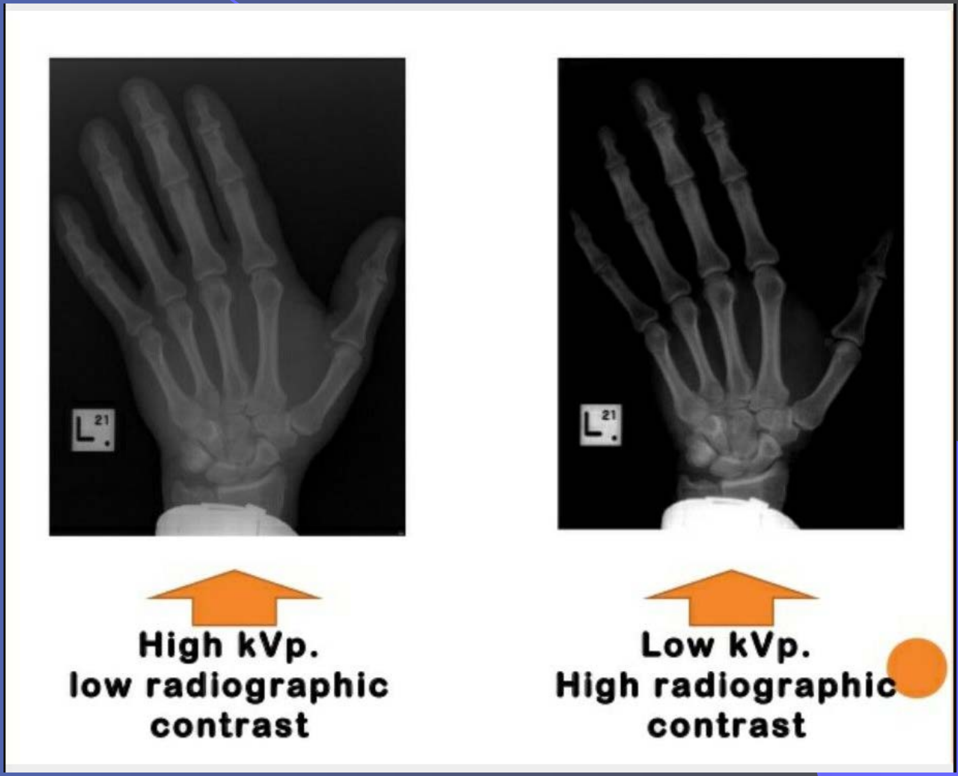
The number of Electrons and the period set for their release determine how many x-rays are available. The mA-s is what controls the blackening or Density on the x-ray film

Kilovoltage Peak (kVp)

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

kVp determines the Quality of the radiograph by affecting the Contrast.

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)

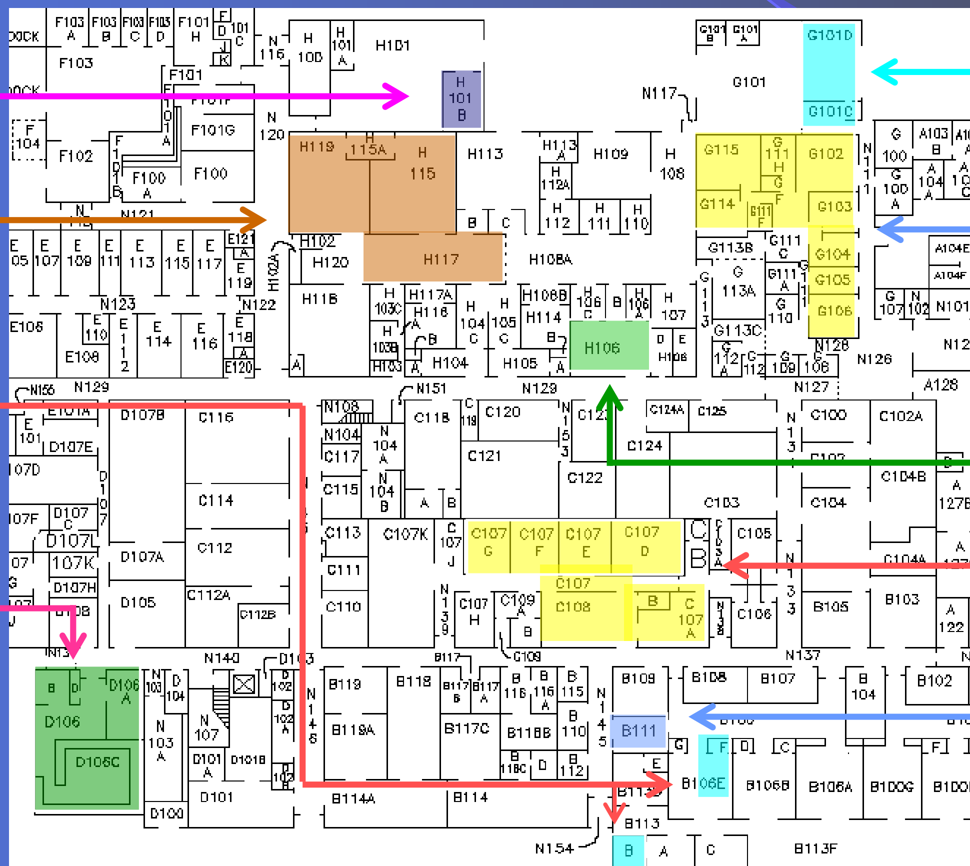
Veterinary Teaching Hospital

Bone Desitometry

Large Animal Surgery

Iodine Treatment Ward

Linear Accelerator



Nuclear Medicine

Radiology

CT Scanner

Small Animal Surgery

Dentistry

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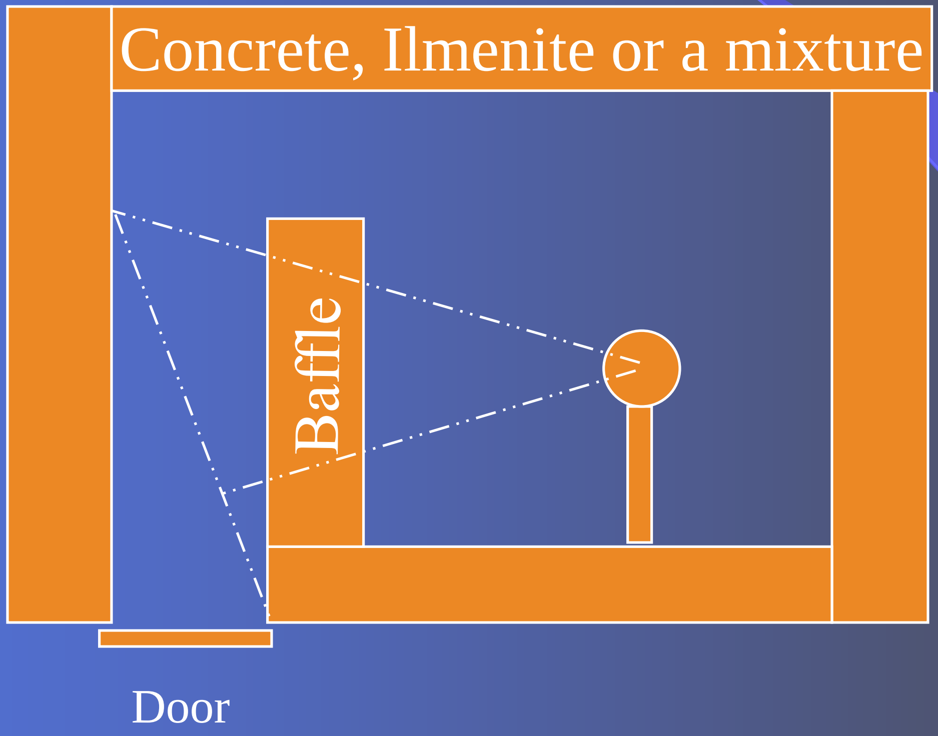
Some VTH Sources

X-Ray Machine

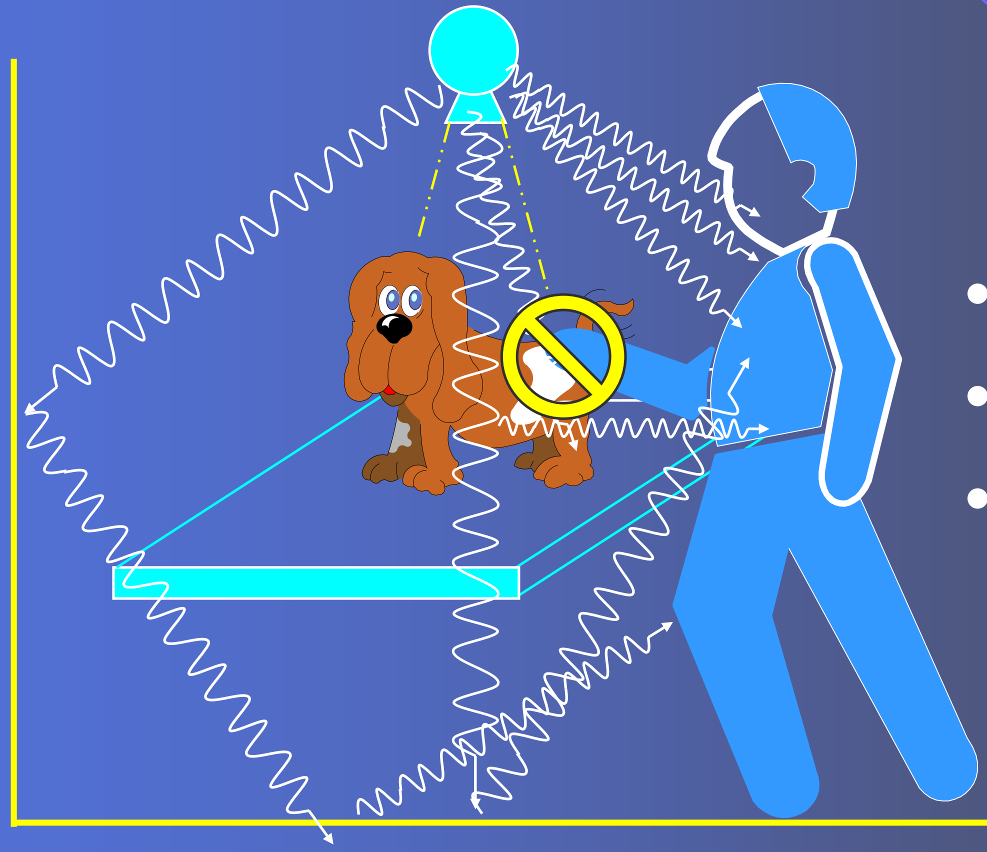
X-Ray Machine

Basic Design of X-ray or Irradiator Facility



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

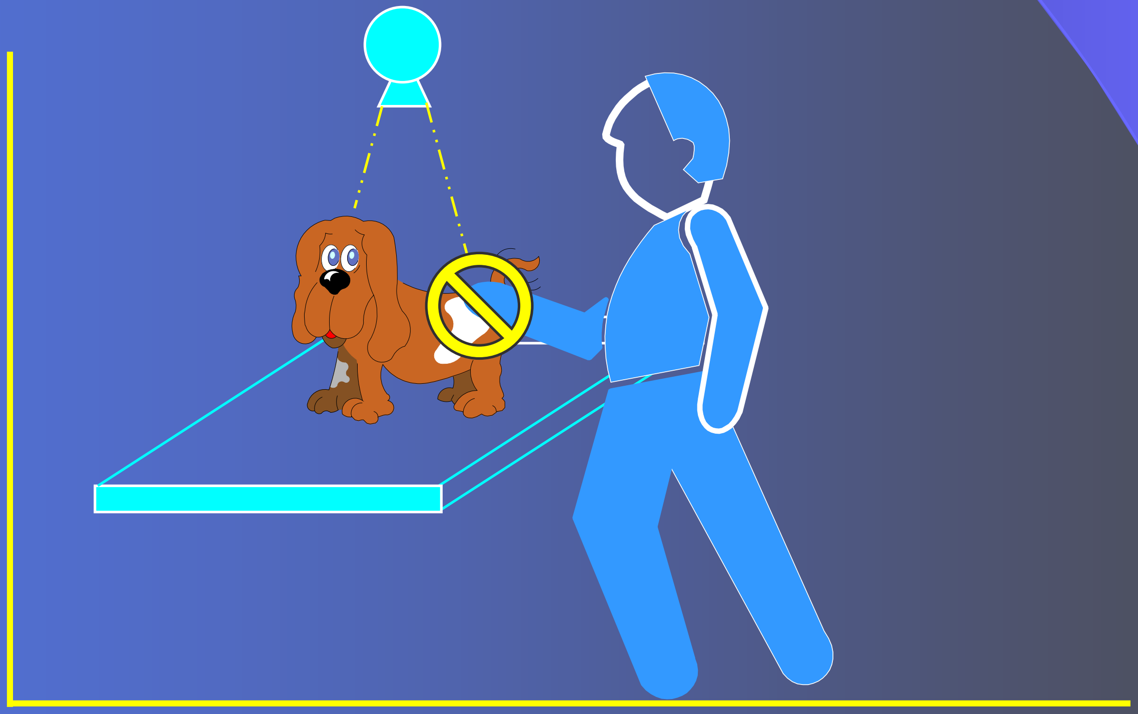
Sources of X-Ray Radiation Exposure - Animal Holding



- Tube Leakage
- Direct
- Scatter

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



Minimum PPE for X-ray

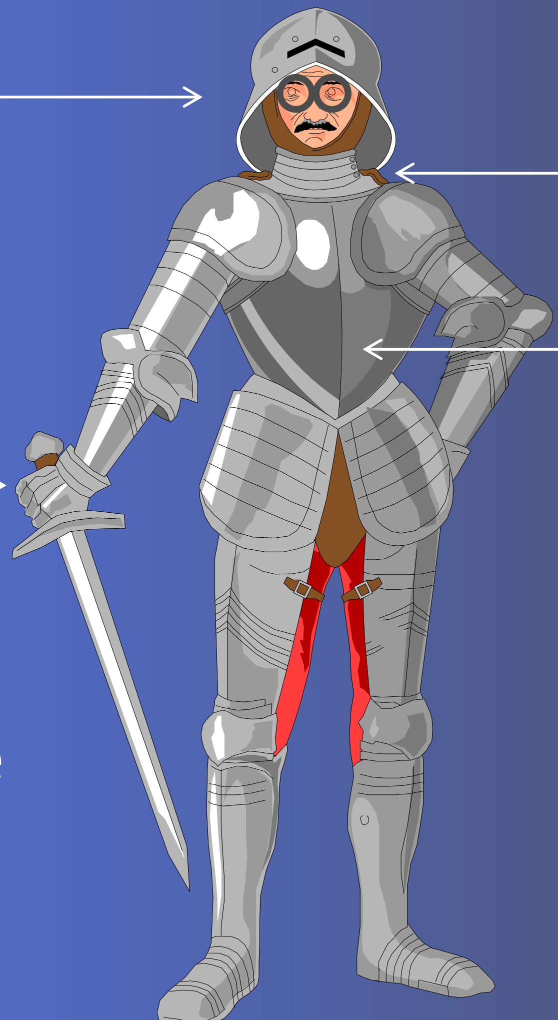
Depending on your work, PPE may include:

Lead Goggles

Thyroid Collar

Lead Apron

Lead Gloves

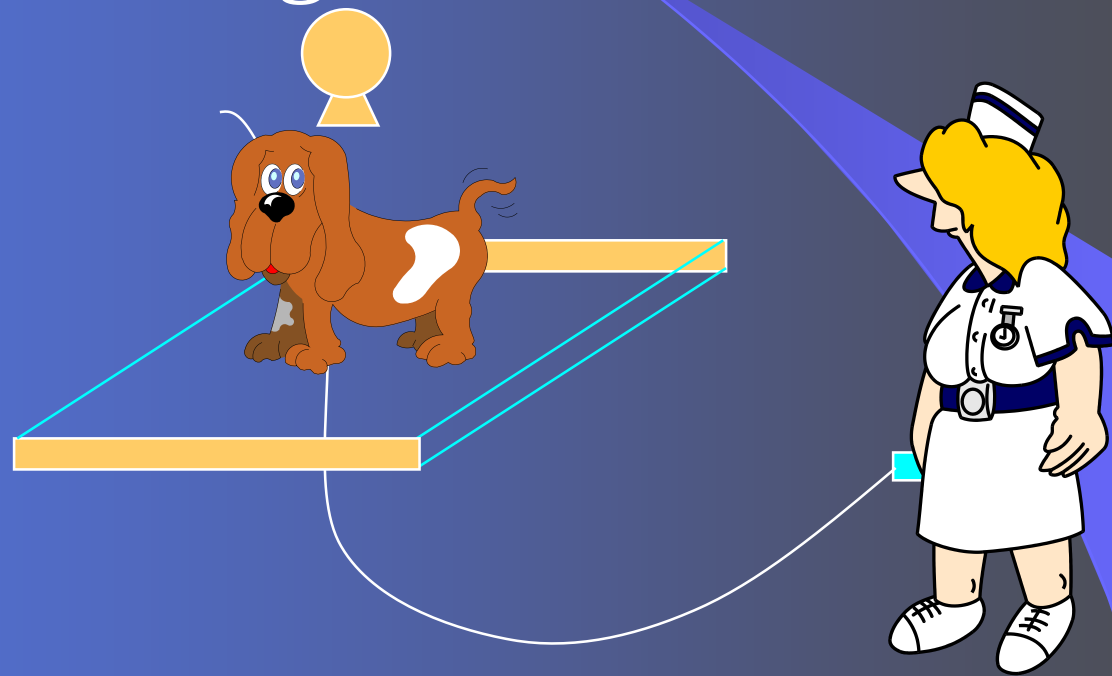


Protective Devices are for Scatter Radiation <u>ONLY</u>

No one is permitted to be exposed to the primary beam

CDPHE - Rules & Regulations

Part 6 - X-Rays in the Healing Arts

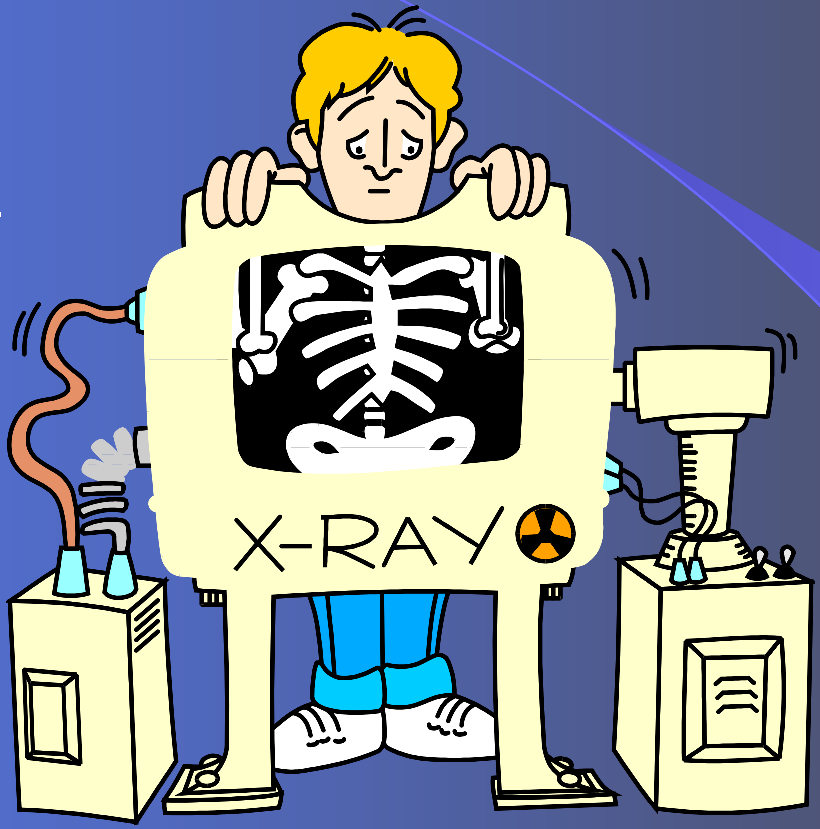


A Technique Chart Must Be in the Vicinity of the Control Panel

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 shutter 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

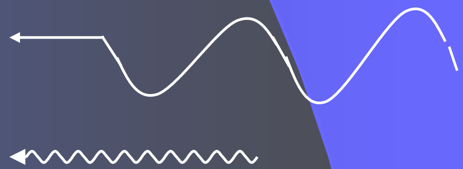
External Radiation Exposure

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>

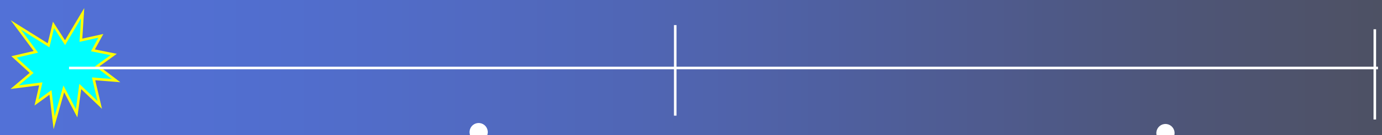
Distance from the Source

Basic principle: Point Source without Shielding

Inverse square law applies:

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

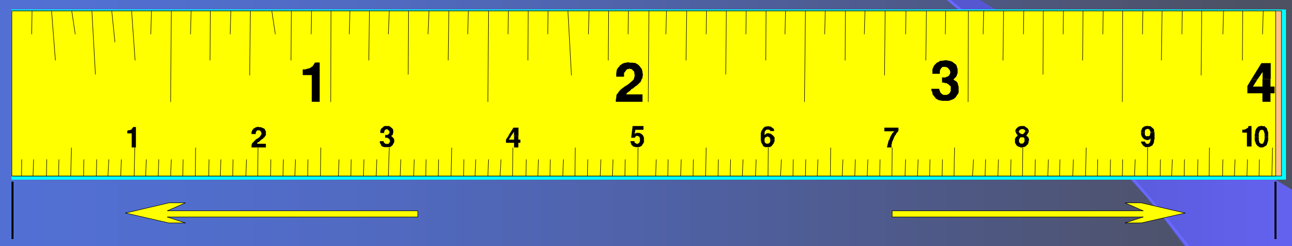
$\dot{D}_1$ and $\dot{D}_2$ = dose rates at distances d_1 and d_2



$\dot{D}_1$, 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)

Recommended Survey Instrument

Ludlum model 3 instrument (Part No. 48-1605) with a 202.2 meter dial and extra cable

Background

What is the background?

High background may indicate:

Radiation Field above background
Light Leak in Probe
Humidity Problems
Contaminated Instrument
Incorrect High Voltage
Not Warmed Up
Intermittent Cable Connection
No Background then Malfunction (Maybe OK for α Probe)

Sensitivity and Energy Response

Sensitivity – how does the instrument respond to the level of radiation

Energy Response – response of instrument may depend on the energy of the radiation

Some instruments over-respond or under-respond to different radiation energies

Try to calibrate the instrument relative to the nuclide of interest.

Calibration

Required annually – CSU performs calibrations every 6 months due to battery condition

Survey Instruments subjected to hard use can out of calibration

Calibration information is attached to the instrument

Calibrate to the nuclide of interest if possible

Other calibration facilities outside of CSU may not provide this

Other calibration facilities may only use a pulse generator for calibration

(check the paperwork provided by the calibration facility)

Some instruments under respond at high exposures – some GM instruments read 0 and some read off scale. What does the instruction manual say?

Environmental Effects

Temperature:

Battery output drops in cold situations

Photomultiplier gain varies

Temperature and Pressure:

Unsealed (vented) ion-chambers

Elevation change may be dramatic

Calibration facility location is important

Time Constant and Survey Speed

Time Constant

Slow setting (s) reduced meter fluctuations, but requires more time to stabilize

Fast setting (f) increases meter fluctuations, but requires less time to stabilize and gives faster readings

Does not change the audible signal

Survey Speed

Basic speed is 1 detector width per second as close to the source as possible without touching the source

VTH Late Charges for Badges

- You will be charged a $15 fee for a lost or late dosimetry badge.

- Badges are to be turned in within the first 10 days of the biannual period. The exchange dates are January 1st thru the 10th and July 1st thru the 10th .
- Failure to turn your dosimetry badge in by the 10th day of the month will result in a charge to your account in the amount of $15 for each late or lost dosimetry badge.

- Badges are kept in a 3 ring binder in the Radiology office. RCO staff will exchange your badge if available on the badge board located at the entrance to radiology. If it is not exchanged, you are required to visit the Radiology office and exchange your badge.

Radiation badges

Radiation badges are not to be worn or taken outside of

Colorado State University

This includes externships, internships etc.

VTH Dose Estimates

- Small Animal Surgery
  - Worst case scenario
    - 6.7 rem/minute at exit port
    - 44.82 seconds to reach 5 rem
    - 7.5 minutes to reach 50 rem

VTH Dose Estimates

- Large Animal Surgery, Ambulatory, Radiology
  - Min X-Ray

KV	mAs	Distance (in)	mrem/shot	Shots for 5 rem	Shots for 50 rem
66	0.08	28	46	109	1,084
66	0.08	6	1,005	5	50

VTH Dose Estimates

- Linear Accelerator
  - 250 rem/min at 1 meter
  - Reach 5 rem in 1.2 seconds at 1 meter

VTH Dose Estimates

- Radiology – G106A

KV	mAs	Distance (in)	mrem/shot	Shots for 5 rem	Shots for 50 rem
102	2.5	37	24	212	2,115
60	125	6	23,826	1	2.1

- Radiology – G106B

KV	mAs	Distance (in)	mrem/shot	Shots for 5 rem	Shots for 50 rem
25	8	18	149	24	335
25	8	6	1,344	4	38

VTH Dose Estimates

- Radiology – G114A

KV	mAs	Distance (in)	mrem/shot	Shots for 5 rem	Shots for 50 rem
60	37.5	40	90	56	555
61	120	6	12,673	1	4

- Radiology – G114B

KV	mAs	Distance (in)	mrem/shot	Shots for 5 rem	Shots for 50 rem
60	13.3	46	16	321	3,211
60	100	6	7,233	1	7

VTH Dose Estimates

- Radiology – G115A

KV	mAs	Distance (in)	mrem/shot	Shots for 5 rem	Shots for 50 rem
96	1.3	40	16	310	3,100
96	1.3	6	717	7	70

- Radiology – G115B

KV	mAs	Distance (in)	mrem/shot	Shots for 5 rem	Shots for 50 rem
96	1.3	46	10	503	5,029
96	1.3	6	584	9	86

VTH Dose Estimates

- Nuclear Medicine

Isotope	Activity (mCi)	Injection Procedure (mrem)	300 Second Spill on Skin rem	Internal Dose (rem)
F-18	2.5	420	135	2.5 (St. Wall)
In-111	5	6.3	2	102 (spleen)
I-131	100	92 (hands) 0.25 (body)	45,667	167,000 (Thyroid)
Y-90	32	3 (hands)	16,133	4,000 (LLI)
Sr-89	10	648 (hands)	4,875	833 (LLI)
Re-186	10	698 (hands)	4,708	25 (Whole Body)
Tc-99	300	569	22,250	18.75 (Whole Body)
Sm-153	100	1,834 (hands)	47,083	2,500 (LLI)

VTH Dose Estimates

- Bone Densitometry

Exam	Scan Time in seconds	Radiation Exposure
Lumbar Spine	30	10 mR
Hip	30	10 mR
Supine lateral whole body bone mineral density	120	35 mR
Single energy lateral spine	10	7 mR
Forearm	30	5 mR
Whole Body	180	1 mR

Requirements for Radiation Badge

In order to receive your radiation badge and began working at the VTH all of the following requirements must be turned in.

- Module 0 Certification
- Module 9 test completed on-line

All students need to have their requirements completed prior to rotating through Radiology or any other radiation work areas.

<u>Contact Deb Liptak or Radiology Office with any questions</u>

Questions ???

Please Feel Free to Contact: The Radiation Control Office

Or visit our office website at :
http://www.ehs.colostate.edu/radiation

rco
RADIATION CONTROL OFFICE

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

Environmental Health Services: 491-6745

Radiation Safety Officer: 491- 3736

Alt. Radiation Safety Officer: 491- 3928

Radiation Control Office: 491- 4835

Colorado State University

Module 9: X-Rays for Veterinary Students

Radiation Control Office
Environmental Health Services