The New Jersey Section of the American Industrial Hygiene Association

Ionizing Radiation

Michael J. Vala, CHP
Bristol-Myers Squibb
michael.vala@bms.com
732-227-5096

Course Objectives

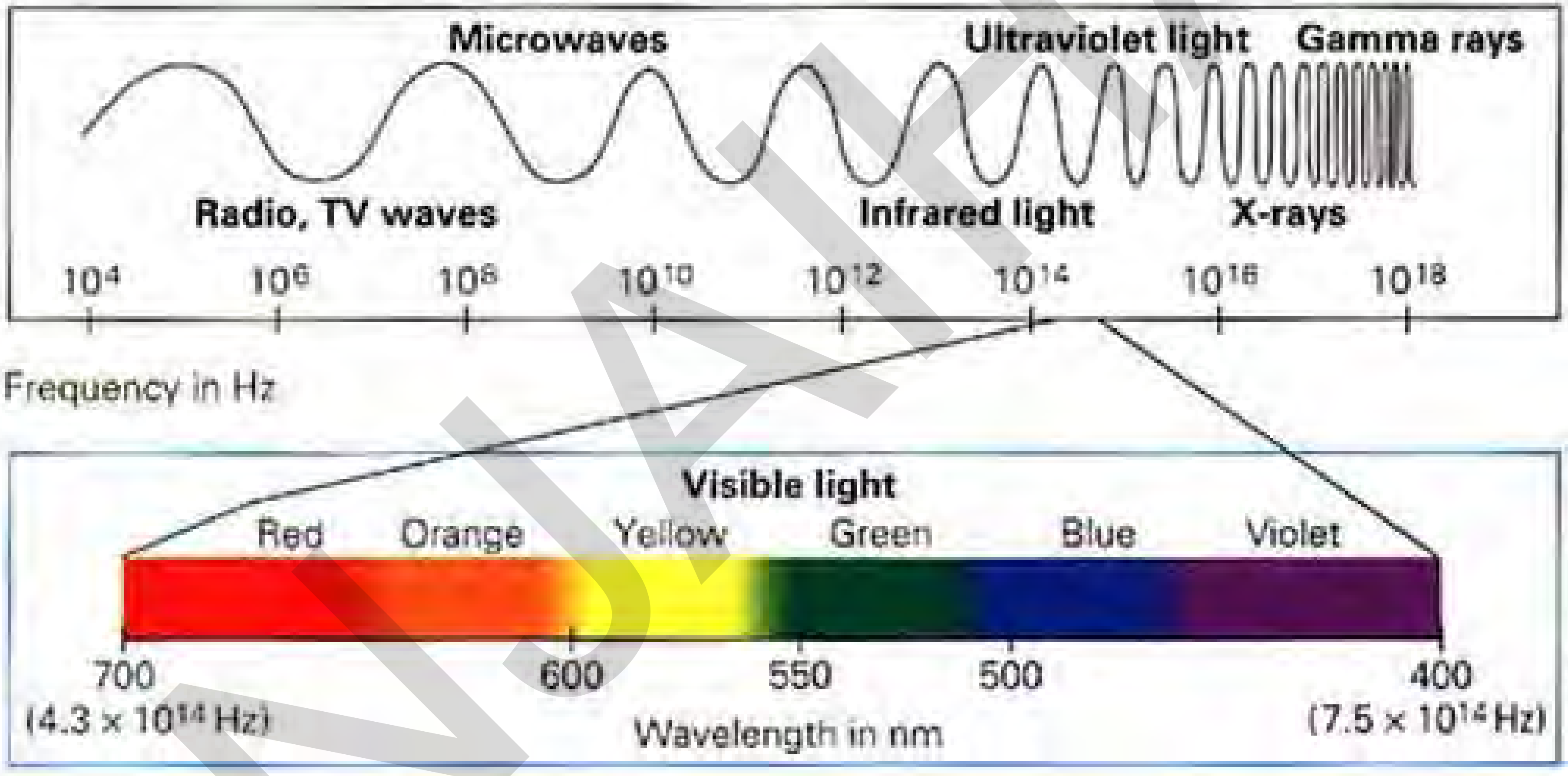
At the end of this course, you should be able to:

- identify sources of ionizing radiation
- understand physical characteristics, e.g. dose, half-life, penetration distance
- evaluate hazards from ionizing radiation, e.g., radiation surveys, dosimeters, bioassay
- know methods of protection from ionizing radiation

Discovery of Radiation

- Roentgen discovered x-ray tube, December 1895.
- Becquerel discovered the radioactivity of uranium, 1896
- Marie Curie discovered radium and polonium, late 1890's.

Electromagnetic Spectrum



We Are All Irradiated

- Natural Radiation

- Man-Made Radiation

Natural and Man Made Population Radiation Exposures

	US Population Radiation Dose	mrem/y	mrem/y
	Cosmic	30	
	External gamma	25	
Natural	Internal (mostly K-40)	30	350
	Radon (lung dose)	250	
	Medical diagnostic	270	
	Occupational	1	
Man Made	Fallout	0.4	272
	Reactors	1	
	Consumer products	0.03	

Sources of Ionizing Radiation

- Radioactive material (radionuclides)
- Radiation producing machines
  - X-ray diffraction instruments
  - X-ray fluorescence analyzers
  - Radiographic x-ray machines
  - Medical x-ray machines
  - Accelerators

Sealed Source Level Gauge

Lab Use of Radionuclides

Nuclear Reactor

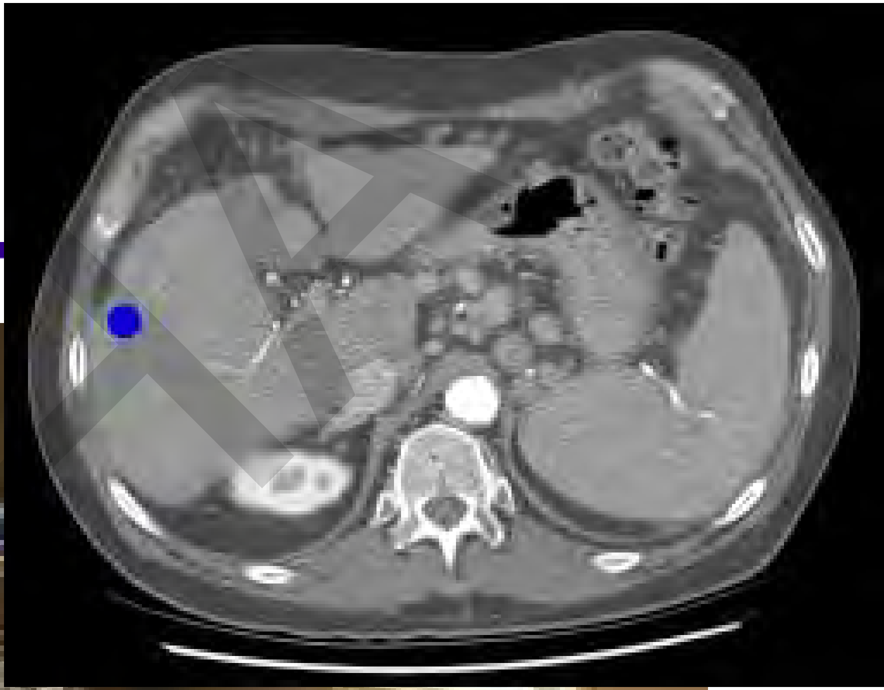
X-Ray Diffraction

Portable X-Ray Diffraction

Portable X-Ray Fluorescence Analyzer (“ray-gun style”)

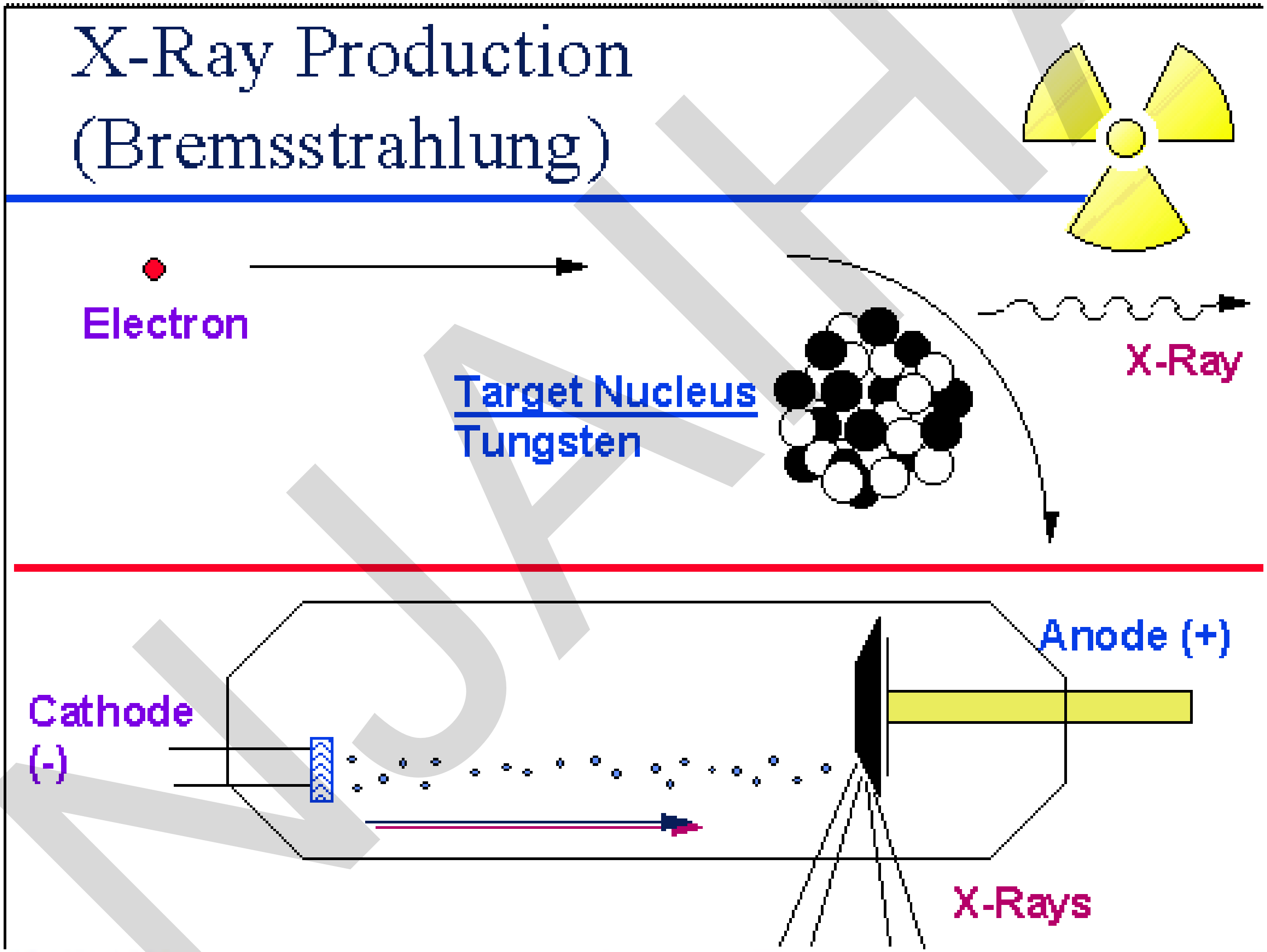
Medical X-Ray

CT Scan



X-Ray Tubes

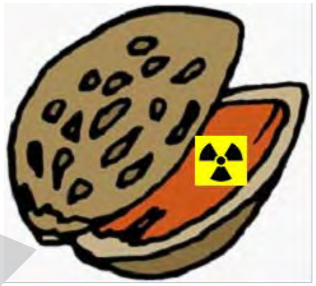
X-Ray Production



Acute X-Ray Burns

- Very intense beams of x-rays.
- Acute skin burns possible.
- Shielding and safety interlocks prevent exposure.

Nuclear Physics and Radiation Biology in a Nutshell

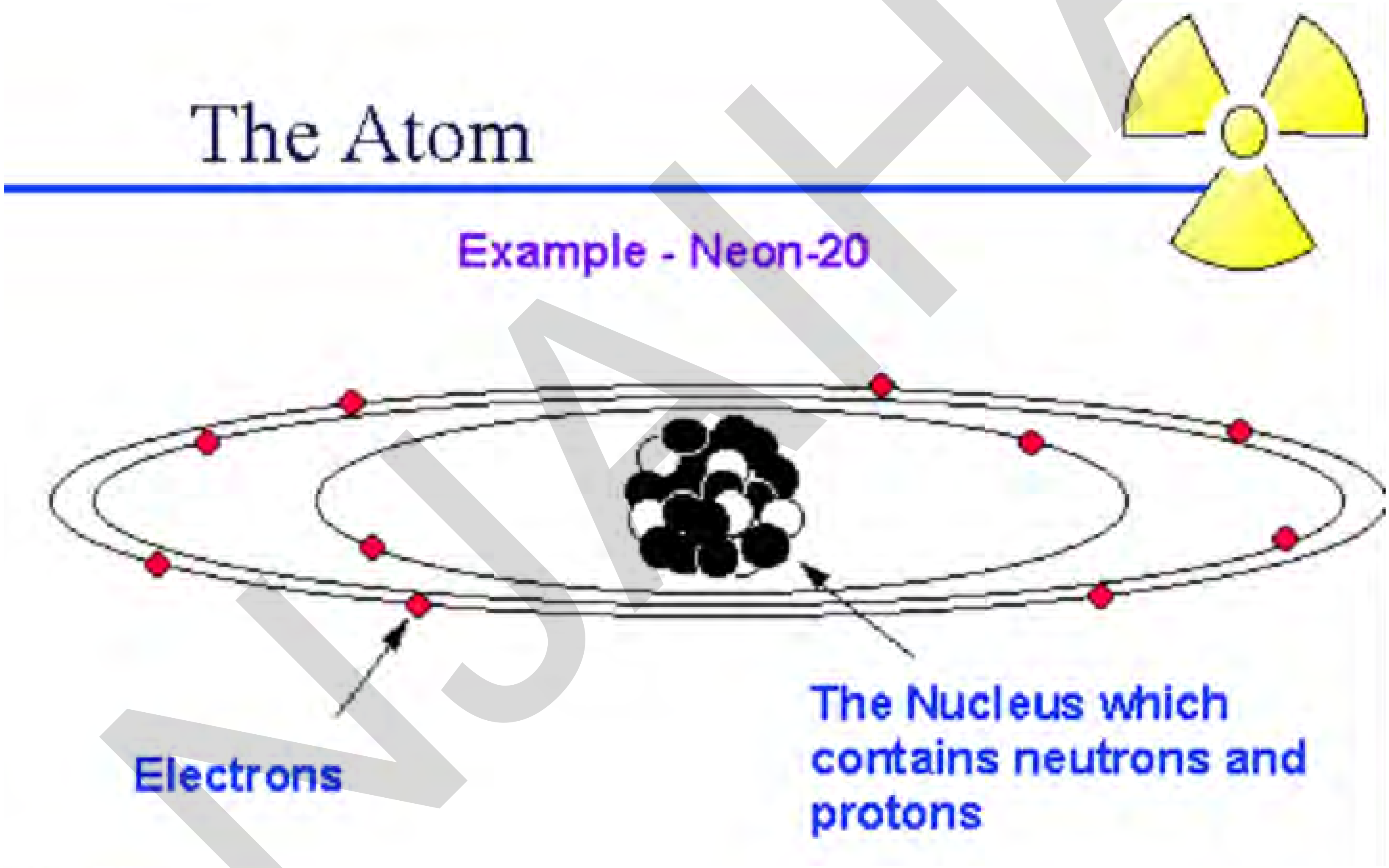


- Radioactive material emits radiation.
- Radiation cannot be detected by human senses.
- Radiation exposure can be harmful.
- The “harm” is proportional to the dose.
- Radiation can be detected with radiation monitoring instruments.

Radiation and Radioactivity

- Radioactivity is matter which decays spontaneously emitting radiation.
- Radiation is ionizing emissions.

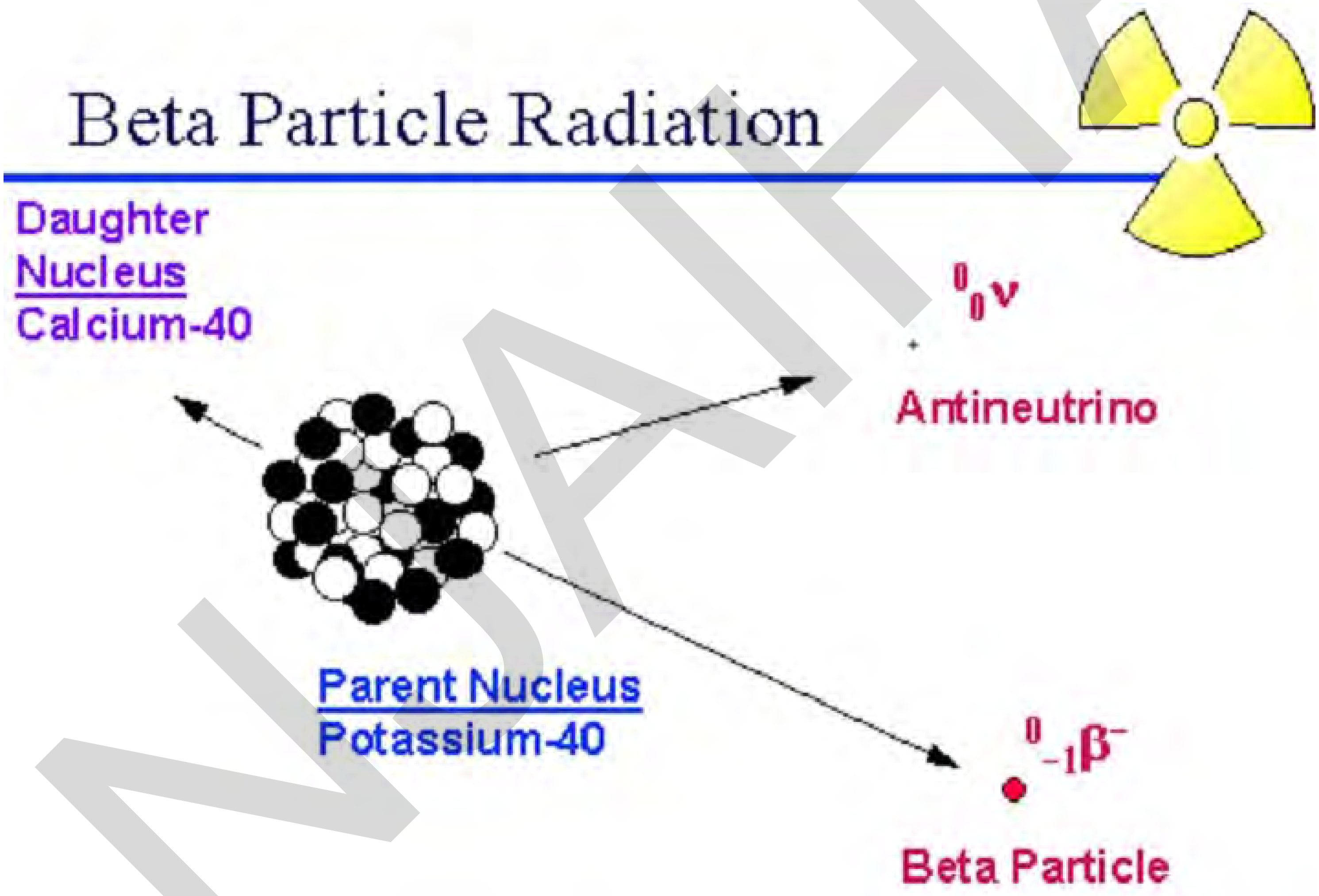
Radioactive Atoms Decay Spontaneously, Emitting Radiation



Types of Radioactive Decay

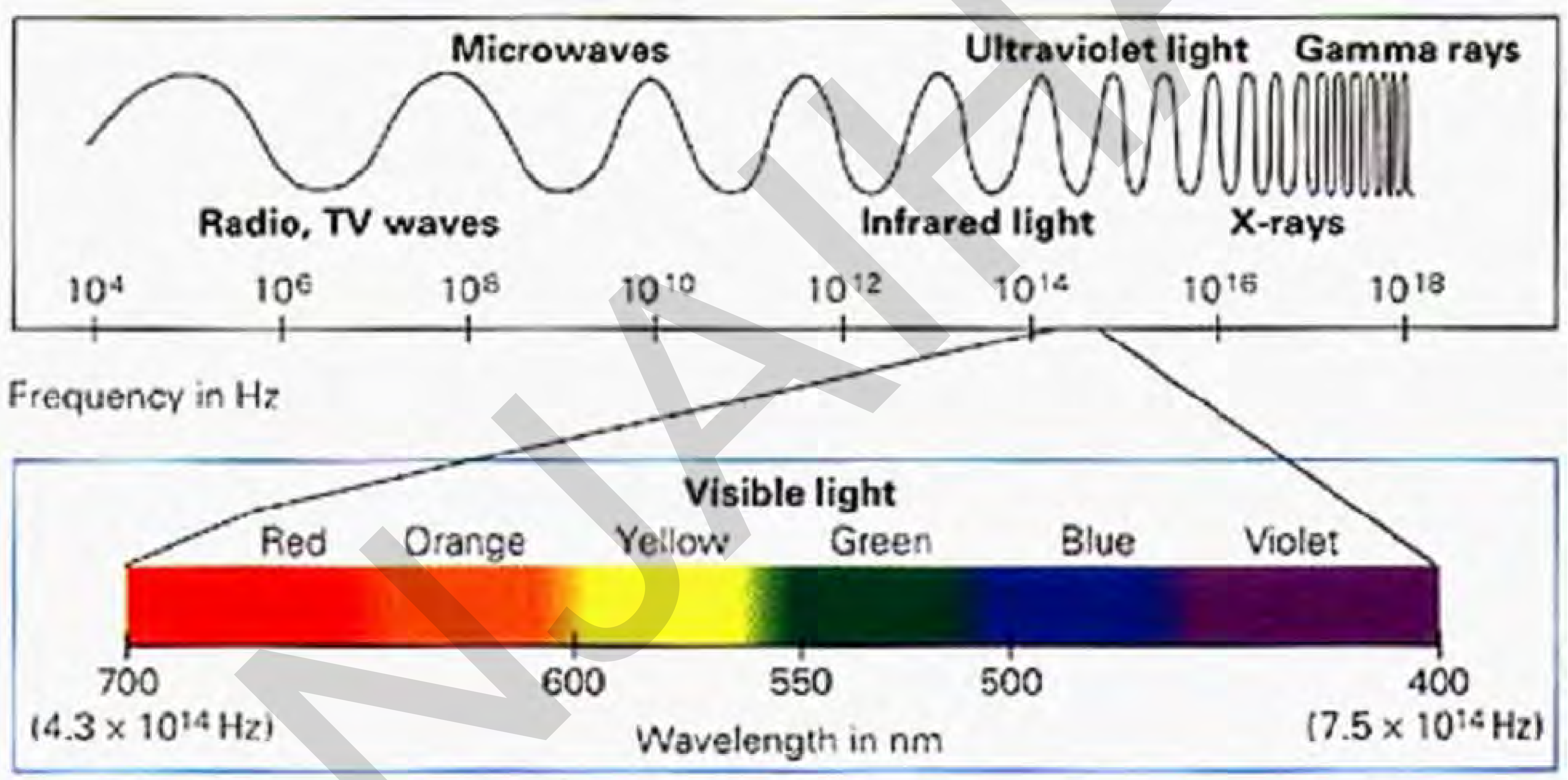
Type of Radioactive Decay	Examples of Radionuclides	
Alpha decay	Polonium-210, Americium-241	α
Beta decay		
pure beta emitters	C-14, H-3, S-35, P-32, P-33	β
beta-gamma emitters	Cesium-137, Iodine-131, Cobalt-60	β γ
Electron capture	Iodine-125, Chromium-51	EC
Isomeric transition	Tc-99m	γ

Beta Decay

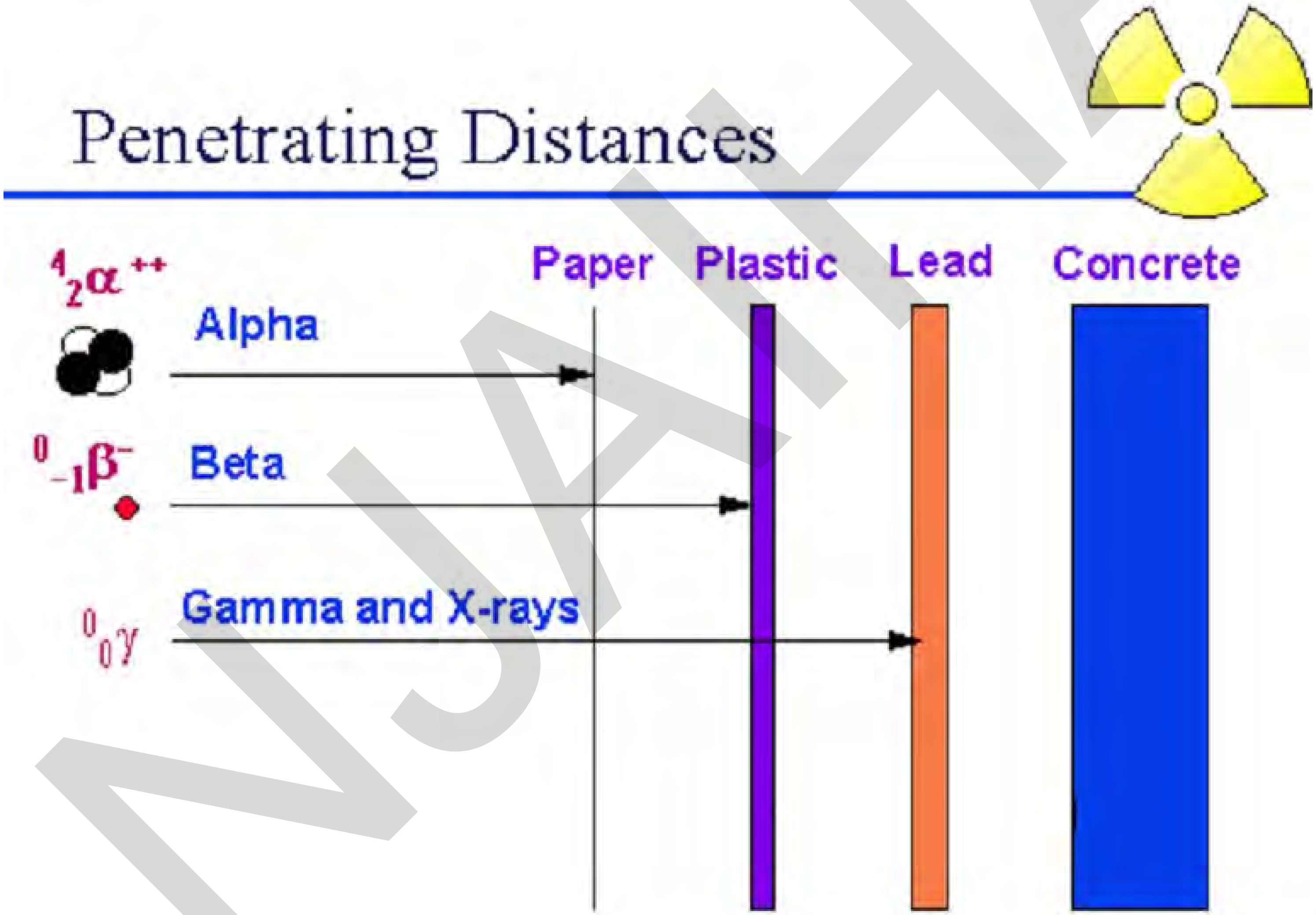


Beta Particle Radiation
Daughter Nucleus
Calcium-40
$^{0}_{0}\nu$
Antineutrino
Parent Nucleus
Potassium-40
$^{0}_{-1}\beta^{-}$
Beta Particle

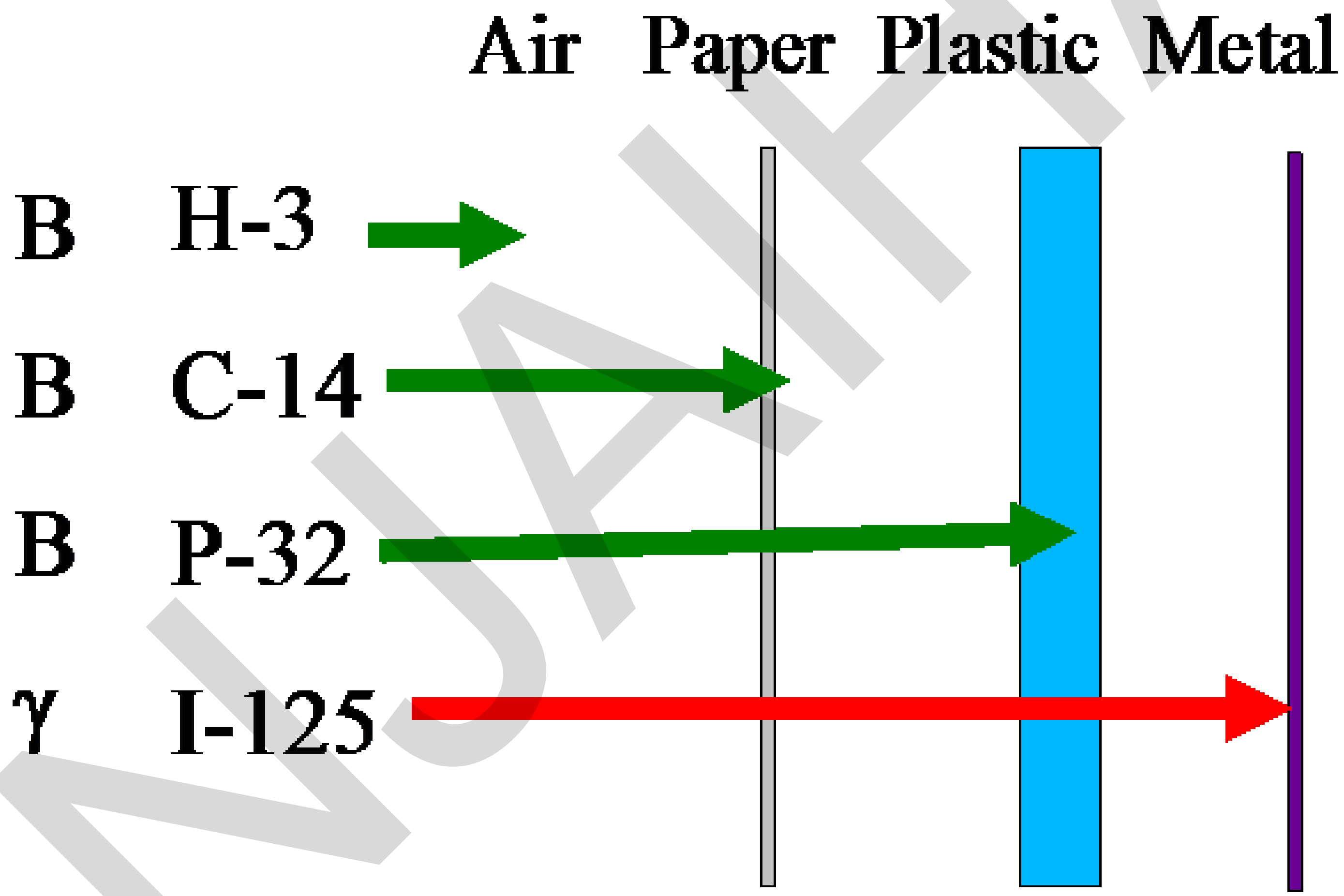
Gamma Radiation (ionizing photons)



Penetrating Distances



Penetration of Common Radiation



Amount of Radioactivity

Measures of Radioactivity

Activity: The quantity of radioactive material present at a given time:

- Curie (Ci): 3.7×10^{10} disintegration per second (dps)

or

- Becquerel (Bq): 1 dps

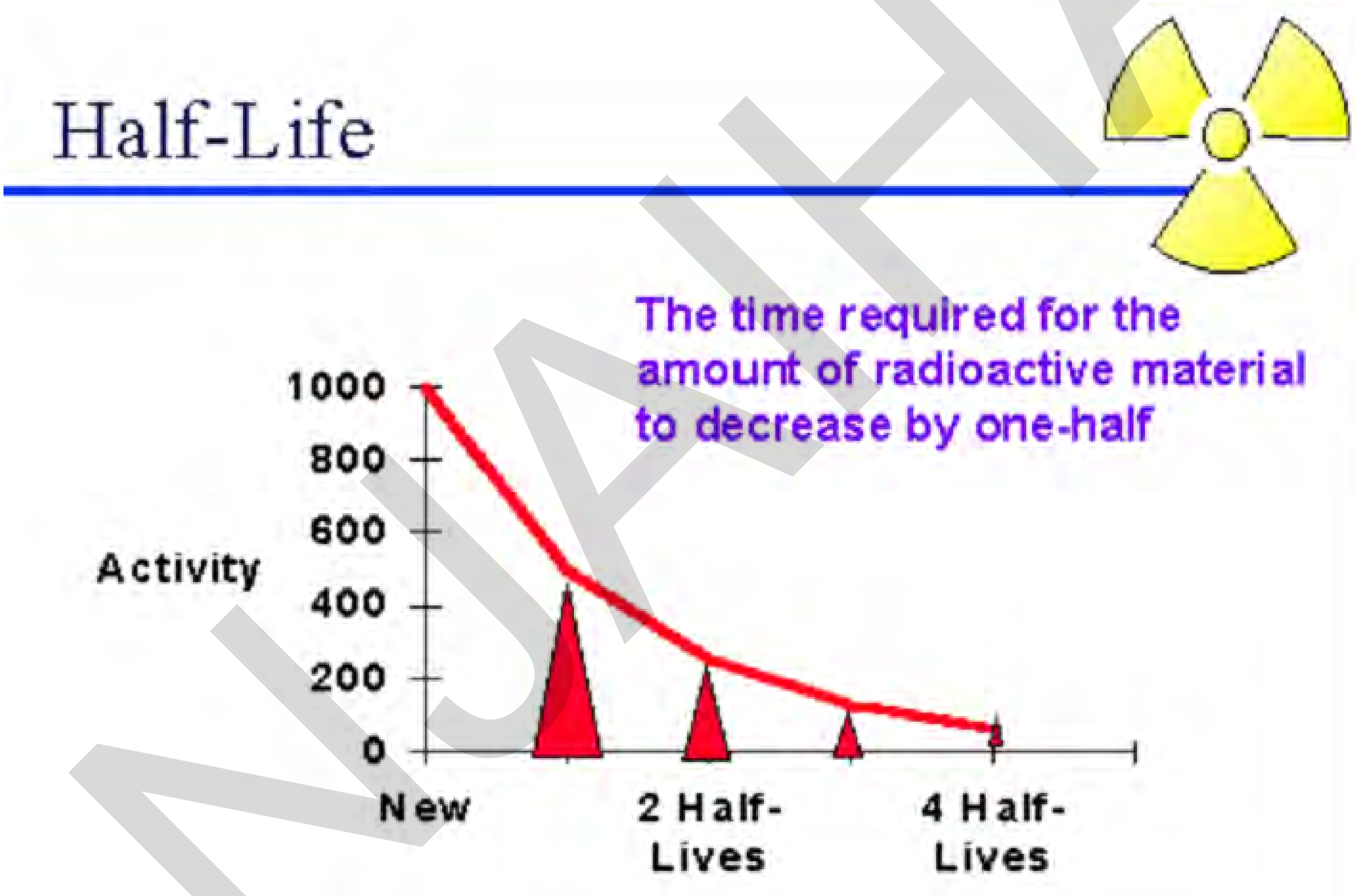
For example:

Equal Amounts of Radioactivity	
1	microcurie (uCi)
2,220,000	Disintegrations per minute (dpm)
37,000	Disintegrations per second (dps)
37,000	Becquerel (Bq)
0.037	MegaBecquerel (MBq)

Units of Measure

Measure	Unit	Abbreviation	Definition	Note
Amount of Radioactivity	Curie	Ci	3.7×10^{10} decay/sec	1 g of radium = 1 Ci
	Becquerel	Bq	1 decay/sec	new SI unit
Exposure	Roentgen	R	2.58×10^{-4} Coulomb/kg of air	only for gamma or x-rays in air
Absorbed Dose (a physical unit)	rad	rad	rad = 100 ergs/gram absorbing material	
	Gray	Gy	1 Gy = 100 rads	new SI unit
Dose Equivalent (proportional to biological effect of absorbed dose)	rem	rem	rem = rad x QF	QF=1 for gamma QF=1 for beta QF = 10 for neutron QF = 20 for alpha
	Sievert	Sv	1 Sv = 100 rem	new SI unit

Half Life


Half-Life
The time required for the amount of radioactive material to decrease by one-half
Activity
1000
800
600
400
200
0
New
2 Half-Lives
4 Half-Lives

Half Life Equation

$$A = A_o \cdot \left(\frac{1}{2}\right)^{t/h}$$

time

half-life

final amount

initial amount

This is the split factor... After a half-life, one pound becomes ½ pound.

Half Lives of Common Nuclides

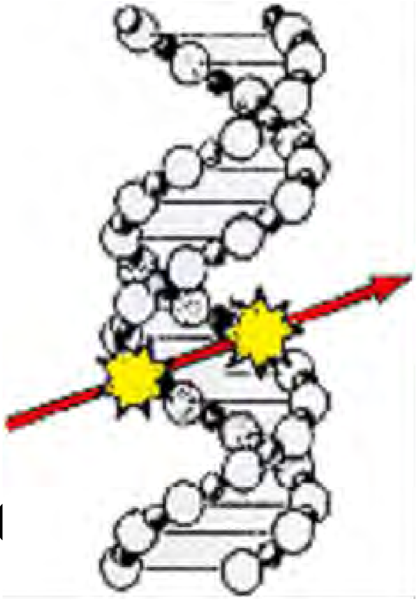
Radioisotope	Half-Life
Hydrogen-3	12.3 years
Carbon-14	5730 years
Phosphorus-32	14.3 days
Phosphorus-33	25.3 days
Sulfur-35	87.6 days
Iodine-125	60.1 days
Technetium-99m	6.02 hours
Technetium-99	213,000 years

Biological Effects

BIOLOGICAL EFFECTS	Non-Stochastic	Stochastic (probabilistic, "all or nothing")
Examples:	skin reddening, skin burns, sterility, cataracts, death	cancer
Threshold dose below which no effect occurs?	Yes	No
Time to occurrence:	acute (minutes, days, weeks)	long term (years)
Radiation dose is proportional to:	severity of effect	probability of effect
Typical doses	High, >100 rem	Medium, 1-100 rem
At the effective dose:	nearly everyone in a population has same effect.	only a fraction of a population has effect.

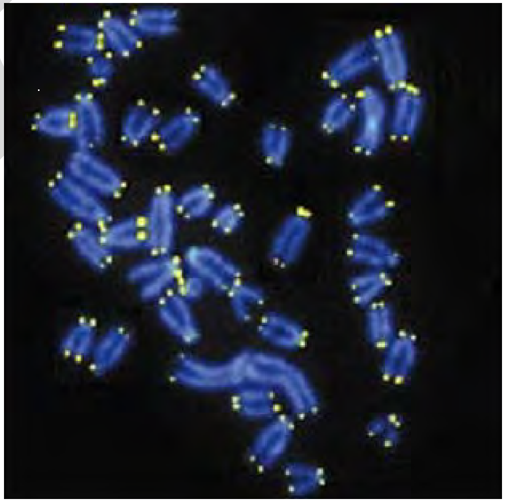
Radiation Interactions with Matter

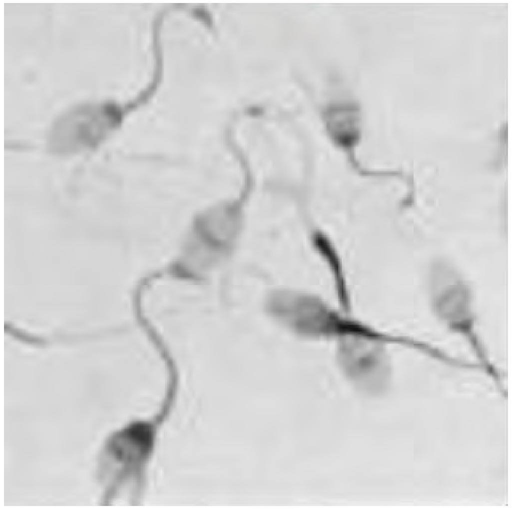
- Produce free radicals
- Break chemical bonds
- Produce new bonds and crosslinks between macromolecules
- Damage molecules vital to cell processes (e.g., DNA, RNA, proteins)



Minimum Dose for Clinical Effects

- Chromosomal damage (deletions, rings and dicentrics)
- Depressed sperm count
- Approximately 10 rad (0.1 Gray)





Biological Effect at Threshold Dose

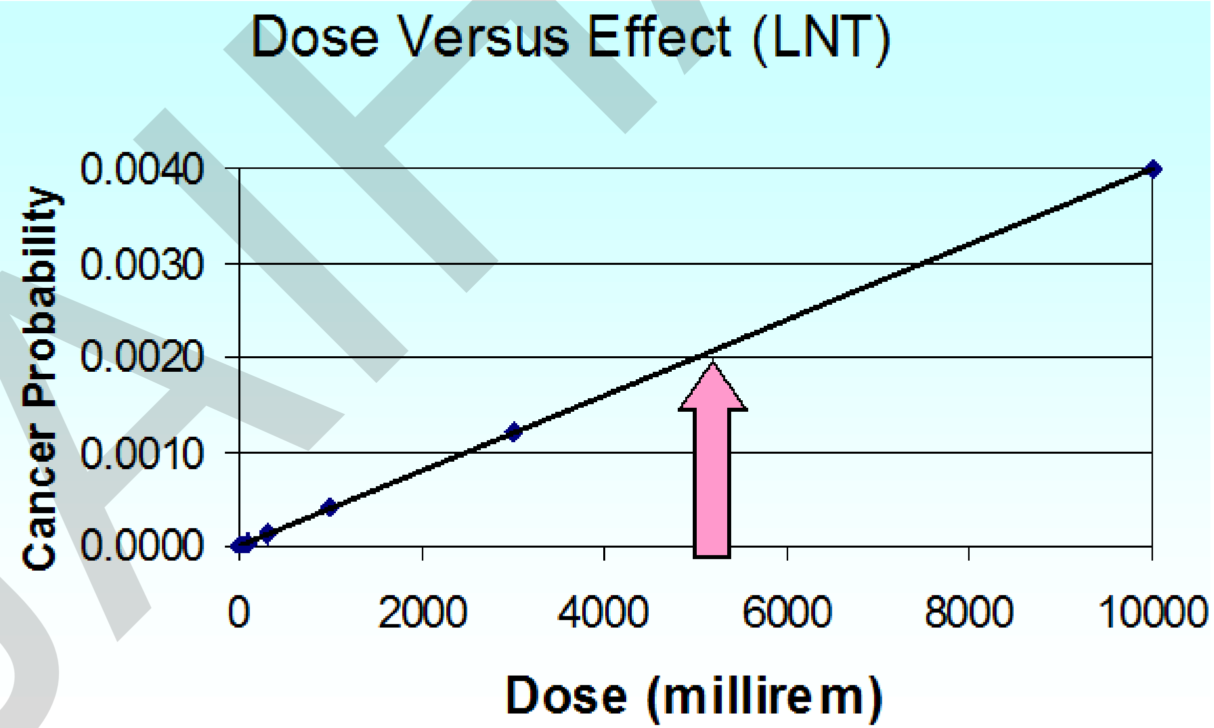
Effect	Dose (rem)
Blood count changes	50
Vomiting (threshold)	100
Mortality (threshold)	150
$LD_{50/60}$ (with minimal supportive care)	320 – 360
$LD_{50/60}$ (with supportive medical treatment)	480 – 540
100% mortality (with best available treatment)	800

Evidence for Carcinogenicity of Radiation

- Animal studies
- Epidemiological studies of Japanese atomic bomb survivors
- Epidemiological studies of patients receiving medical radiation therapy
- Types of cancer: leukemia, bone, breast, GI track, lung, thyroid, etc.

Linear Non-Threshold Theory

- Radiation effects are assumed to be linear with radiation dose, even at small doses.
- Radiation effects below about 5-10 rem are too small to be observed in populations.



Radiation Dose Limits

Body Part	Occupational Dose Limit
Total Effective Dose Equivalent (external plus internal dose)	5 rem/year
Sum of deep dose equivalent and committed dose equivalent to <u>any individual organ</u>	50 rem/year
Lens of eye	15 rem/year
Skin or extremities (hands, feet)	50 rem/year

Internal Radiation (inhalation and ingestion)

- Annual Limit on Intake (ALI).
- ALI is the amount of radioactivity which, if taken internally, would result in the maximum permissible internal dose.

Nuclide	H-3	C-14	S-35	P-32	I-125	Tc-99m
ALI (mCi)	80	2	20	0.9	0.06	80

Radiation Protection Instrumentation

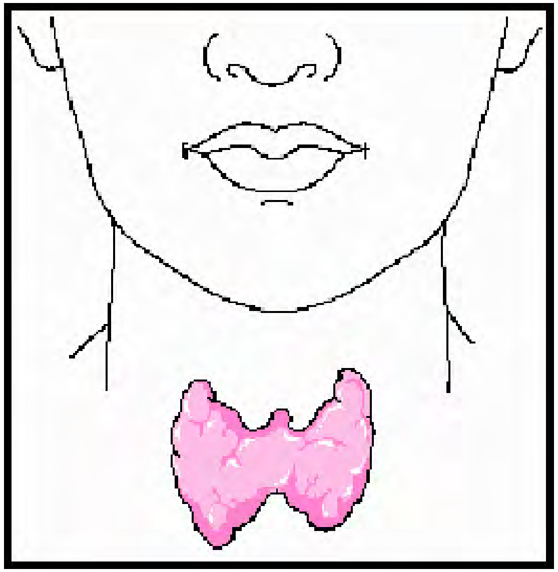
- Geiger-Mueller detector (GM probe)
  - General purpose probe
  - Measures dose rate (e.g., mR/h)

Badge and Ring Dosimeters

- "Film badge"
- Measures cumulated radiation dose (mrem, mSv)
- Body and hand dose
- Usually monthly or quarterly cycle

Bioassay for Radioactivity in the Body (Internal Radiation Dose)

- Urine analysis for tritium and carbon-14
- Thyroid bioassay for iodine-125 and iodine-131



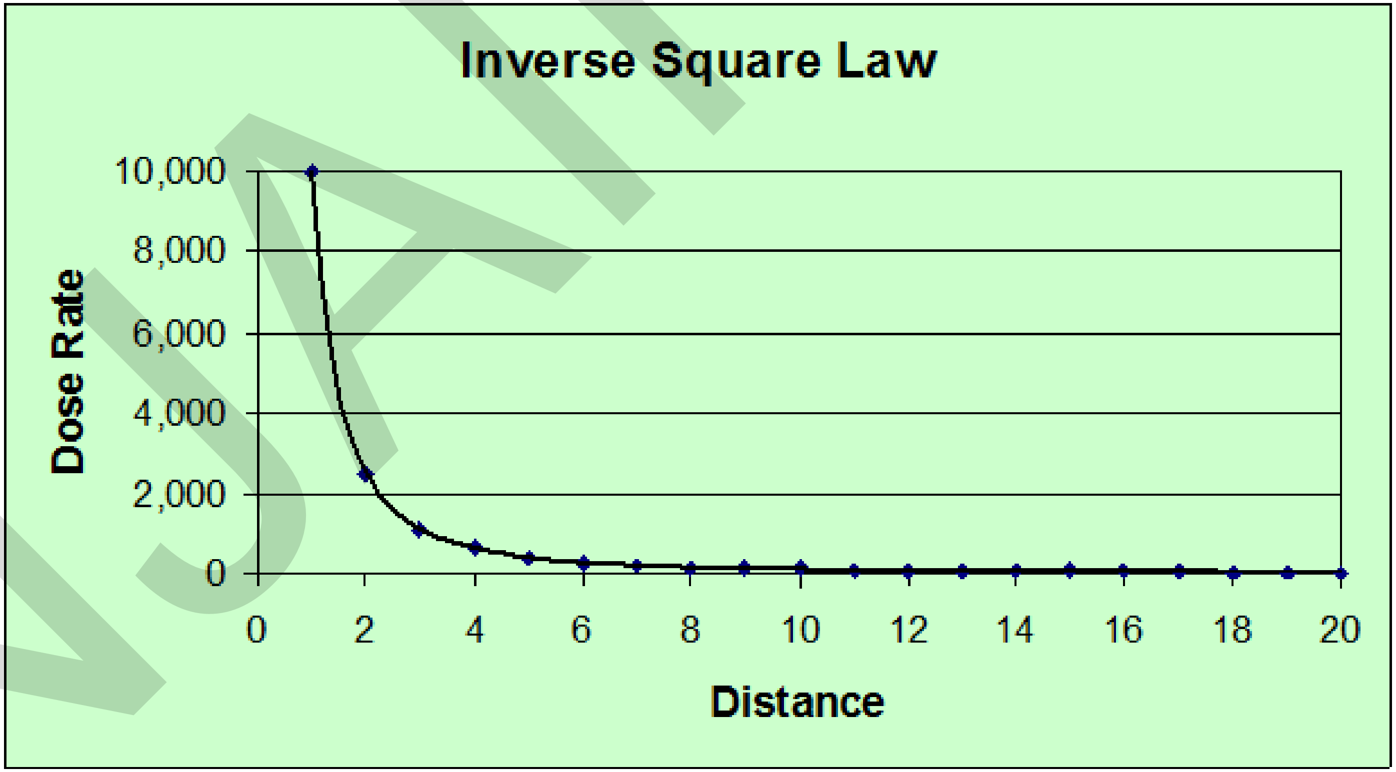
Radiation Protection Techniques

- Minimize exposure **time.**
- Maximize **distance** to radiation source.
- Use radiation **shielding**.

Inverse Square Law

- Dose rate decreases as the square of the distance.

$$\frac{1}{r^2}$$



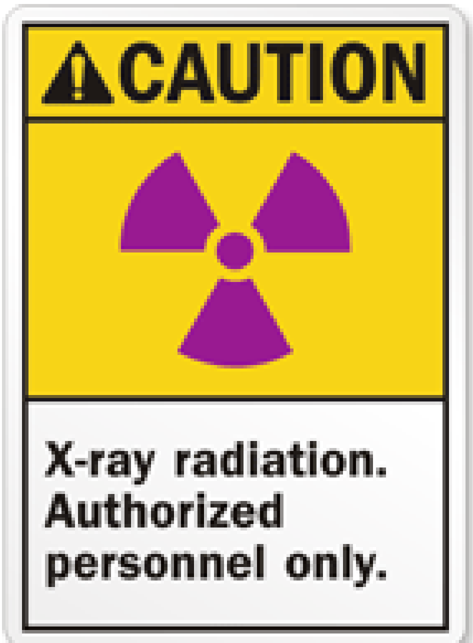
ALARA

- As Low as Reasonably Achievable (ALARA):
  - Keep radiation dose to a minimum
  - A regulatory requirement
  - Based on Linear Non-Threshold (LNT) theory of radiation damage

Regulation in United States

- Radioactive material (byproduct, source, and special nuclear material)
  - Nuclear Regulatory Commission, or
  - Agreement States
- Machine-generated radiation
  - States
  - OSHA ?

Warning Signs and Labels



Questions?

Bibliography / References

- Introduction to Health Physics: Fourth Edition, Herman Cember and Thomas Johnson, McGraw Hill, 2008.
- Atoms, Radiation, and Radiation Protection, Third Edition, James E. Turner, Wiley-VCH, 2007
- Physics for Radiation Protection, Third Edition, James E. Martin, Wiley-VCH, 2013.
- Radiation Protection: A Guide for Scientists, Regulators and Physicians, Jacob Shapiro, Harvard University Press, 2002.
- Basic Health Physics, Second Edition, Joseph John Bevelacqua, Wiley-VCH.
- Health Physics and Radiological Health, Fourth Edition, Thomas E. Johnson and Brian K. Birky, Lippincott, 2012.
- Environmental Radioactivity from Natural, Industrial & Military Sources, Fourth Edition, Merrill Eisenbud and Thomas F. Gesell, Academic Press,1997.
- US Nuclear Regulatory Commission, Code of Federal Regulations, Title 10, Part 20, Radiation Protection.