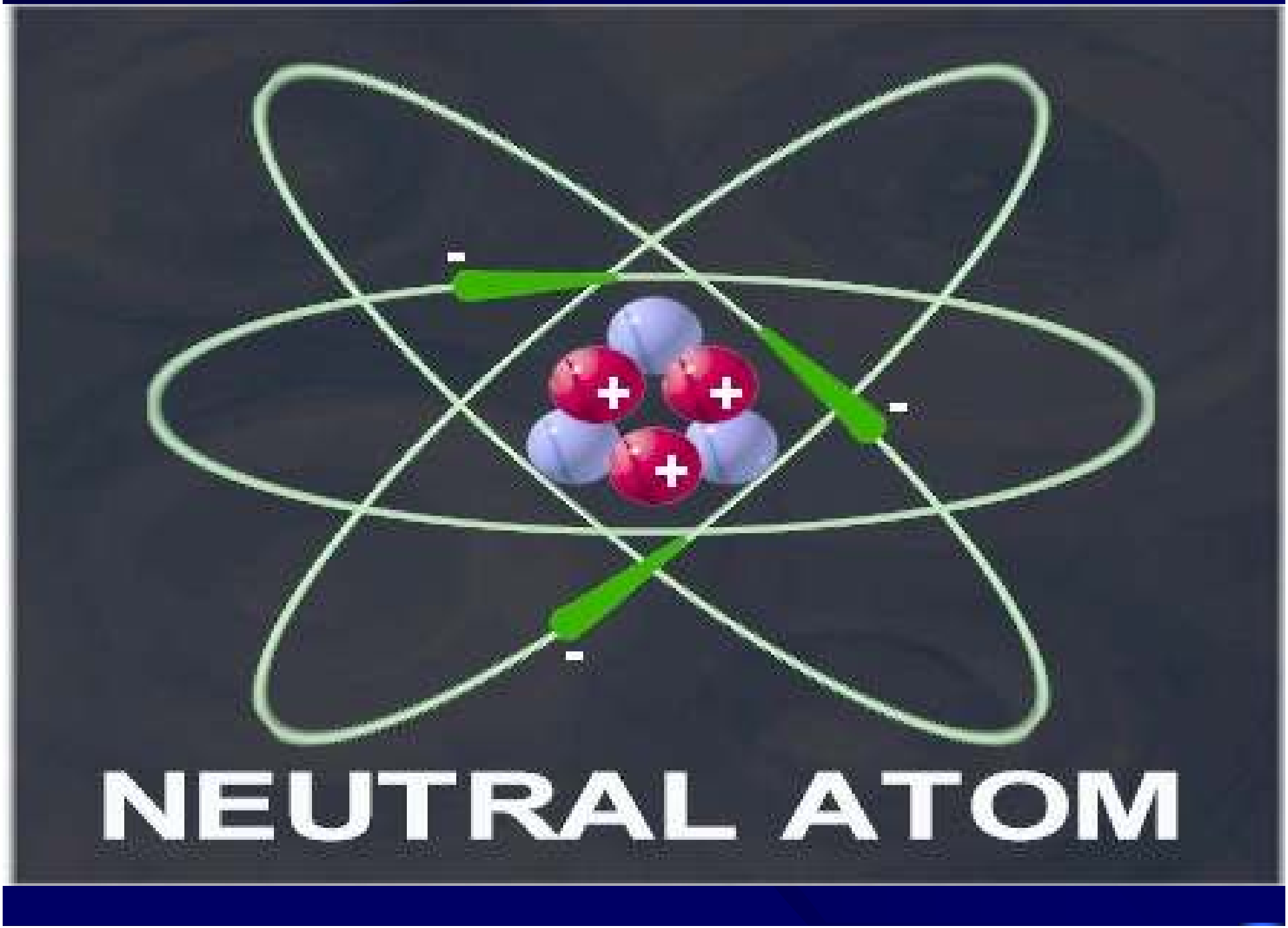
# Introduction to Ionizing Radiation

Bob Curtis

OSHA Salt Lake Technical Center

Supplement to Lecture Outline
V. 10.02


-
+
+
+
-
-
NEUTRAL ATOM

# Basic Model of a Neutral Atom

- Electrons(-) orbiting nucleus of protons(+) and neutrons.
- Same number of electrons as protons; net charge = 0.
- Atomic number (number of protons) determines element.
- Mass number (protons + neutrons) gives mass in terms of 1/12th mass of Carbon atom.

# Ionization vs. Excitation

- Excitation transfers enough energy to an orbital electron to displace it further away from the nucleus.
- In ionization the electron is removed, resulting in an ion pair.
  - the newly freed electron(-) and the rest of the atom(+).

# Ionizing Radiation

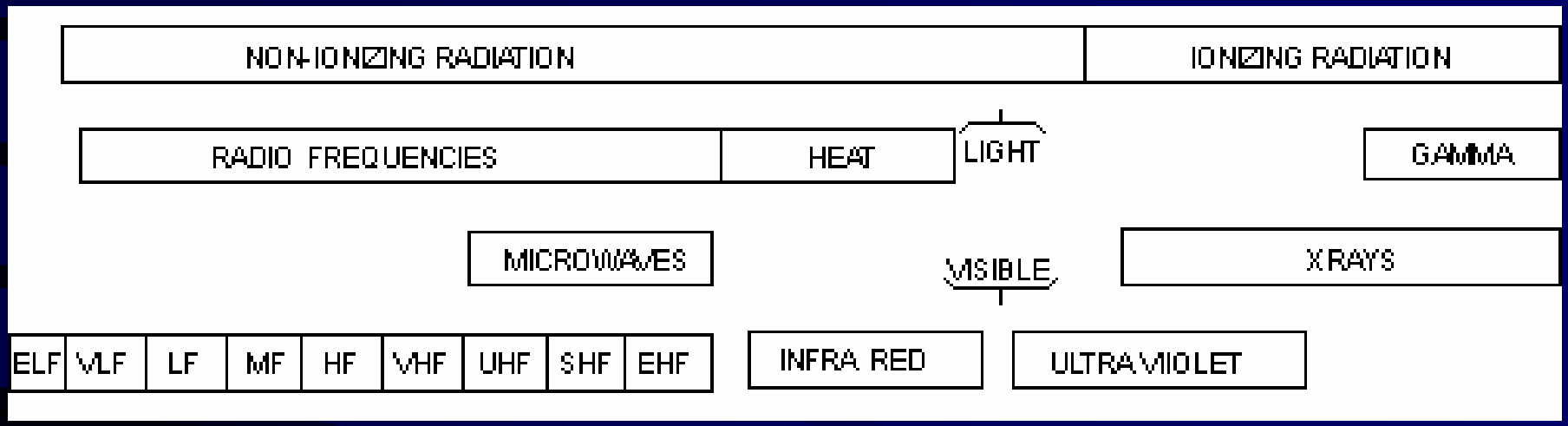
- Any electromagnetic or particulate radiation capable of producing ion pairs by interaction with matter.
- Scope limited to X and gamma rays, alpha particles, beta particles (electrons), neutrons, and charged nuclei.
- Important biologically since media can be altered (e.g., ionized atom in DNA molecule may be altered, thereby causing cell death, or mutation).

# Particulate vs. Electromagnetic Radiations

- Particulate Radiations are sub-atomic particles with mass (e.g., alpha and Beta particles, electrons, neutrons).

- EM Radiations (X-rays and gamma rays) have no mass and no charge.

# Electromagnetic Spectrum

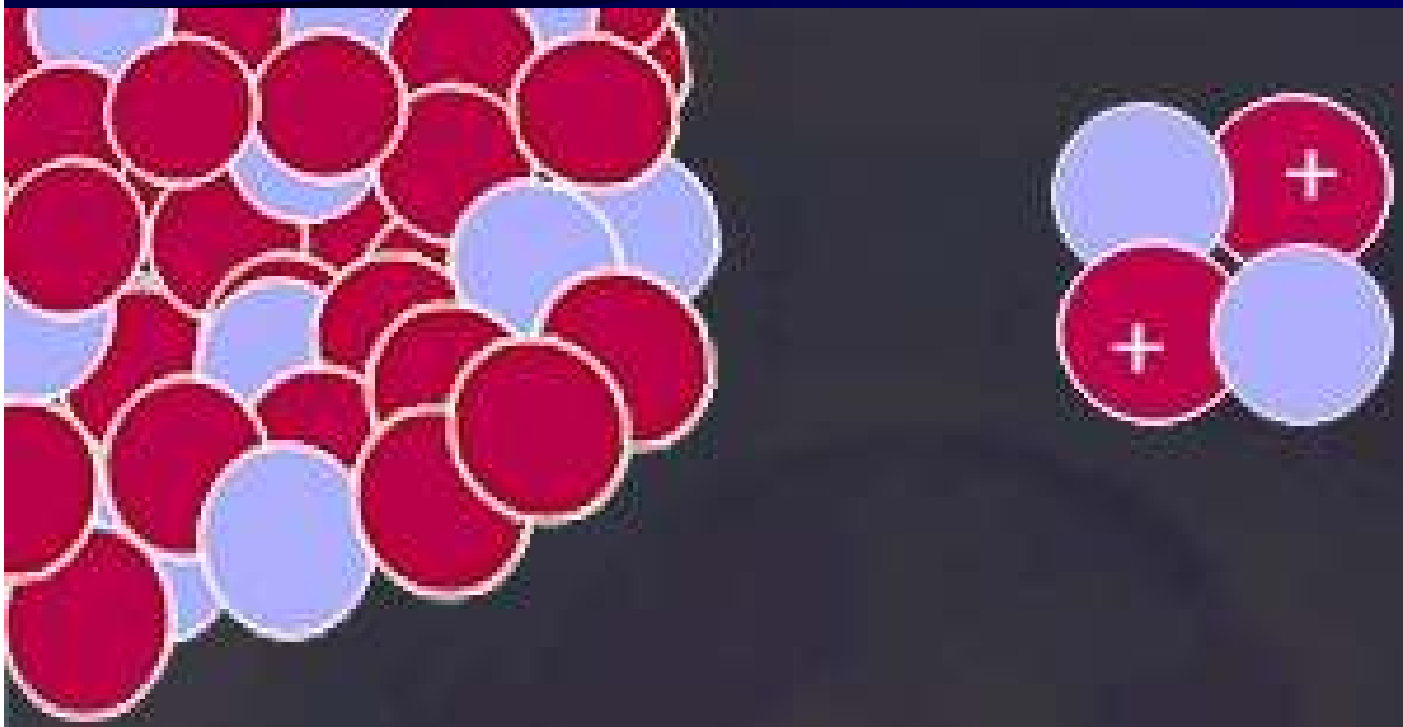


# High vs. Low Energy Radiation

- Absorption of radiation is the process of transferring the energy of the radiation to the atoms of the media through which it is passing.
- Higher energy radiation of the same type will penetrate further.
- Usually expressed in KeV or MeV
- 1 eV = $1.6 \times 10^{-19}$ Joules = $1.6 \times 10^{-12}$ ergs

# High vs. Low Linear Energy Transfer (LET)

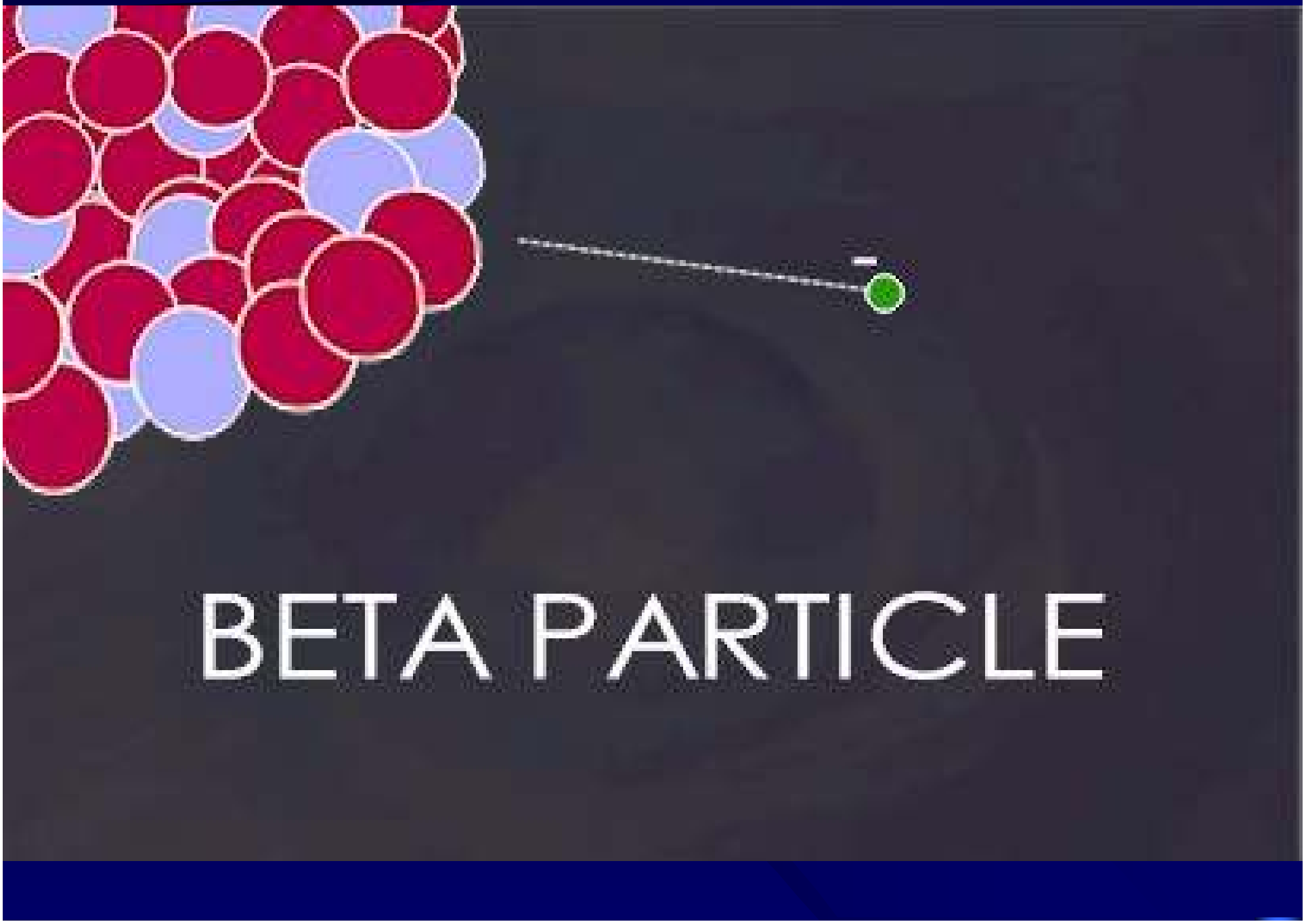
- LET is measured by the ionization density (e.g., ion pairs/cm of tissue) along the path of the radiation.
- Higher LET causes greater biological impact and is assigned a higher Quality Factor(QF).
  - Example QF values: X, gamma, and beta have QF = 1; alpha QF=20; thermal neutrons QF=3; "fast" neutrons (>10 KeV) QF = 10; fission fragments QF>20.




# ALPHA PARTICLE

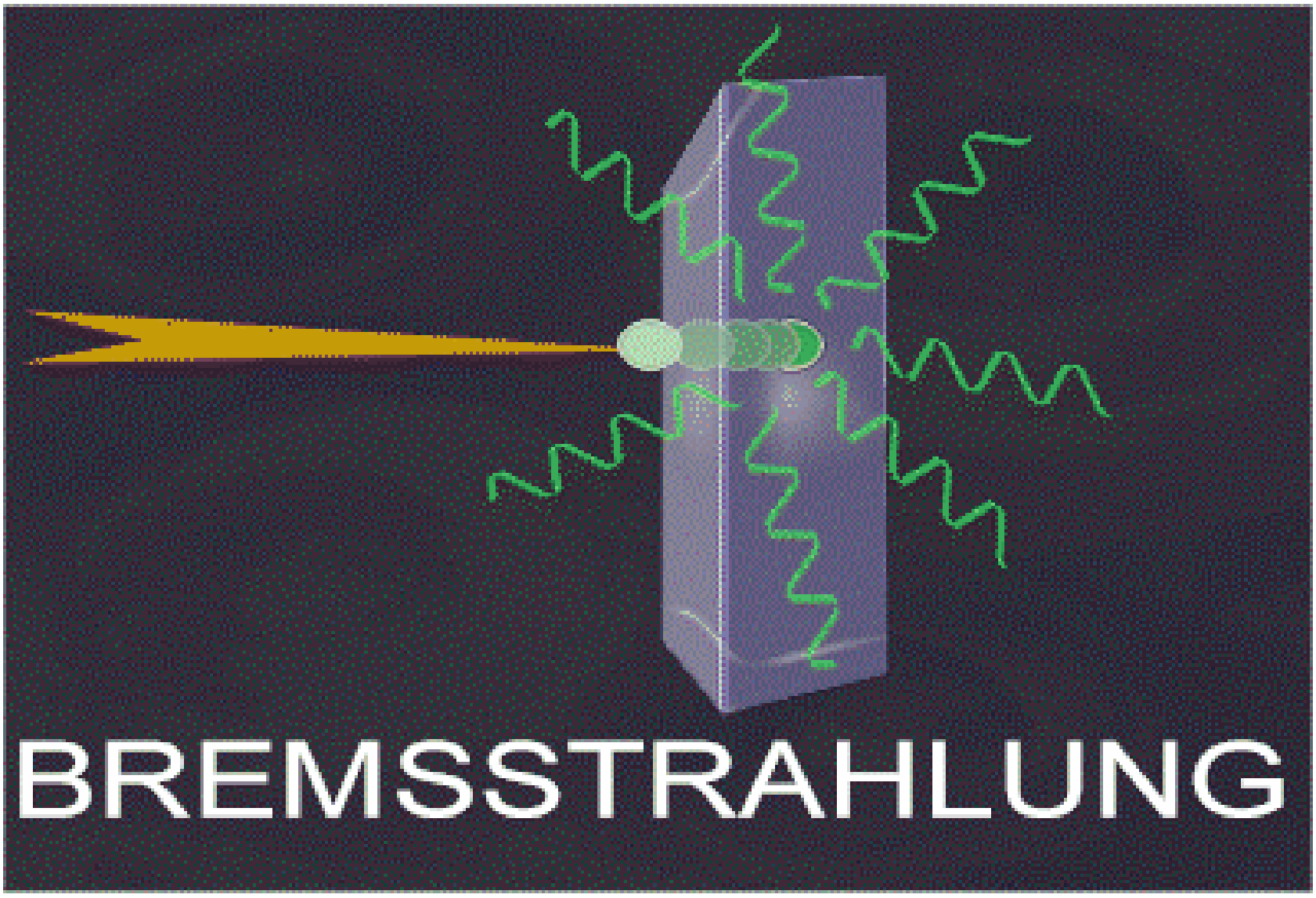
# Alpha Particles (or Alpha Radiation)

- Helium nucleus (2 neutrons and 2 protons); +2 charge; heavy (4 AMU). Typical Energy = 4-8 MeV;
- Limited range (<10cm in air; 60μm in tissue);
- High LET (QF=20) causing heavy damage (4K-9K ion pairs/μm in tissue);
- Easily shielded (e.g., paper, skin) so an internal radiation hazard.


BETA PARTICLE

# Beta Particles

- High speed electron ejected from nucleus;  -1 charge; light 0.00055 AMU; Typical Energy = several KeV to 5 MeV;
- Range approx. 12'/MeV in air, a few mm in tissue;
- Low LET (QF=1) causing light damage (6-8 ion pairs/μm in tissue);
- Primarily an internal hazard, but high beta can be an external hazard to skin.


BREMSSTRAHLUNG

# Bremsstralung (or Braking) Radiation

- High speed electrons may lose energy in the form of X-rays when they quickly decelerate upon striking a heavy material.
- Aluminum and other light (<14) materials and organo-plastics are used for shielding.

# Positrons

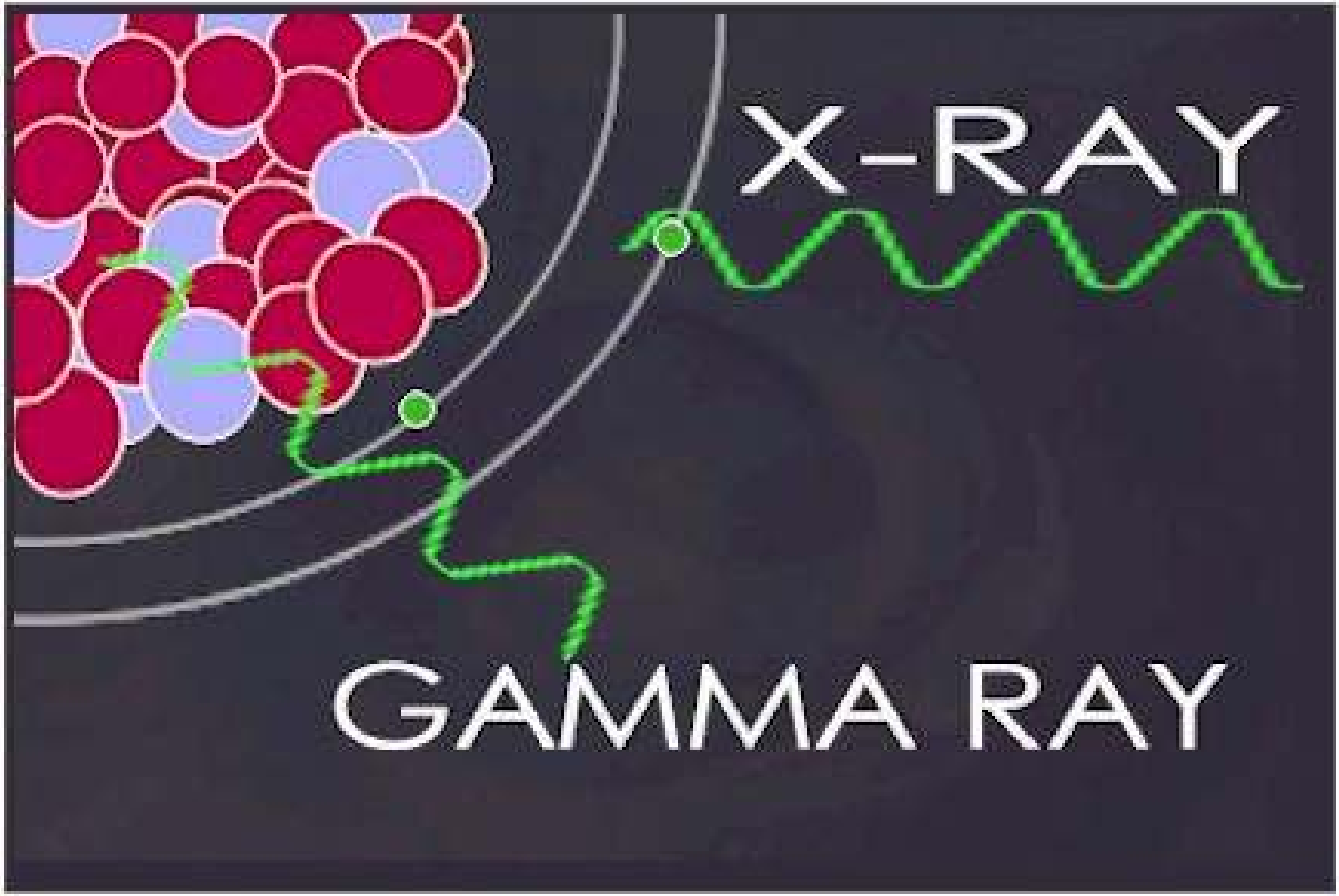
- Beta particles with an opposite (+) charge.
- Quickly annihilated by combination with an electron, resulting in gamma radiation.

# Neutrons

- Neutrons ejected from a nucleus; 1 AMU; 0 Charge;
- Free neutrons are unstable and decay by Beta emission (electron and proton separate) with T½ of approx. 13 min;
- Range and LET are dependant on "speed": Slow (<10 KeV), "Thermal" neutrons, QF=3; and Fast (>10 KeV), QF=10.

# Shielding Neutrons

- Shielded in stages: High speed neutrons are "thermalized" by elastic collisions in hydrogenous materials (e.g., water, paraffin, concrete).
- The “hit” nuclei give off the excess energy as secondary radiation (alpha, beta, or gamma).
- Slow neutrons are captured by secondary shielding materials (e.g., boron or cadmium).


X-RAY
GAMMA RAY

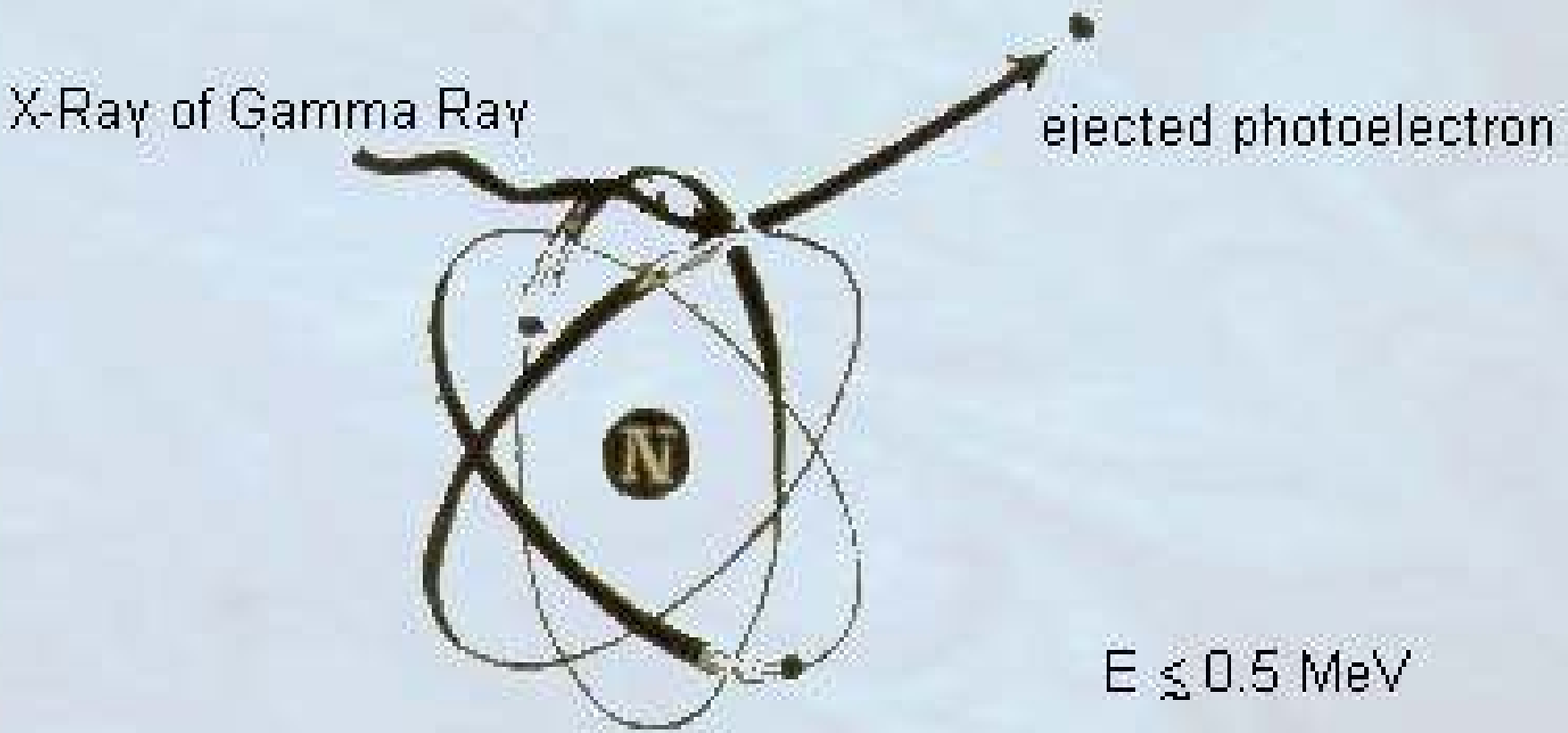
# X-Rays and Gamma Rays

- X-rays are photons (electromagnetic radiations) emitted from electron orbits, such as when an excited orbital electron "falls" back to a lower energy orbit.

- Gamma rays are photons emitted from the nucleus, often as part of radioactive decay.

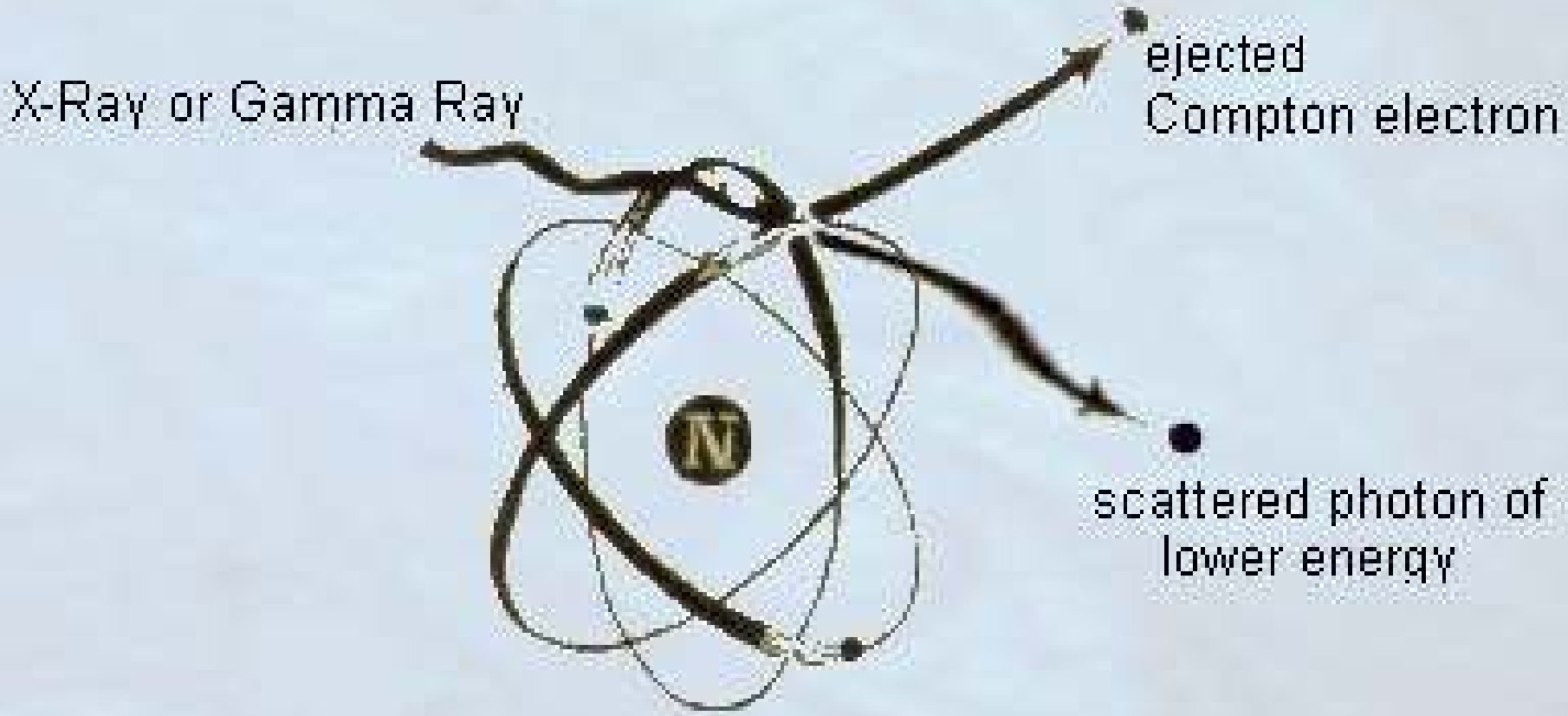
# X-rays and Gamma Radiation

- Gamma rays typically have higher energy (Mev's) than X-rays (KeV's), but both are unlimited.
- No mass; Charge=0; Speed = C; Long range (km in air, m in body); Light damage (QF=1);
- An external hazard (>70 KeV penetrates tissue); Usually shielded with lead or concrete.



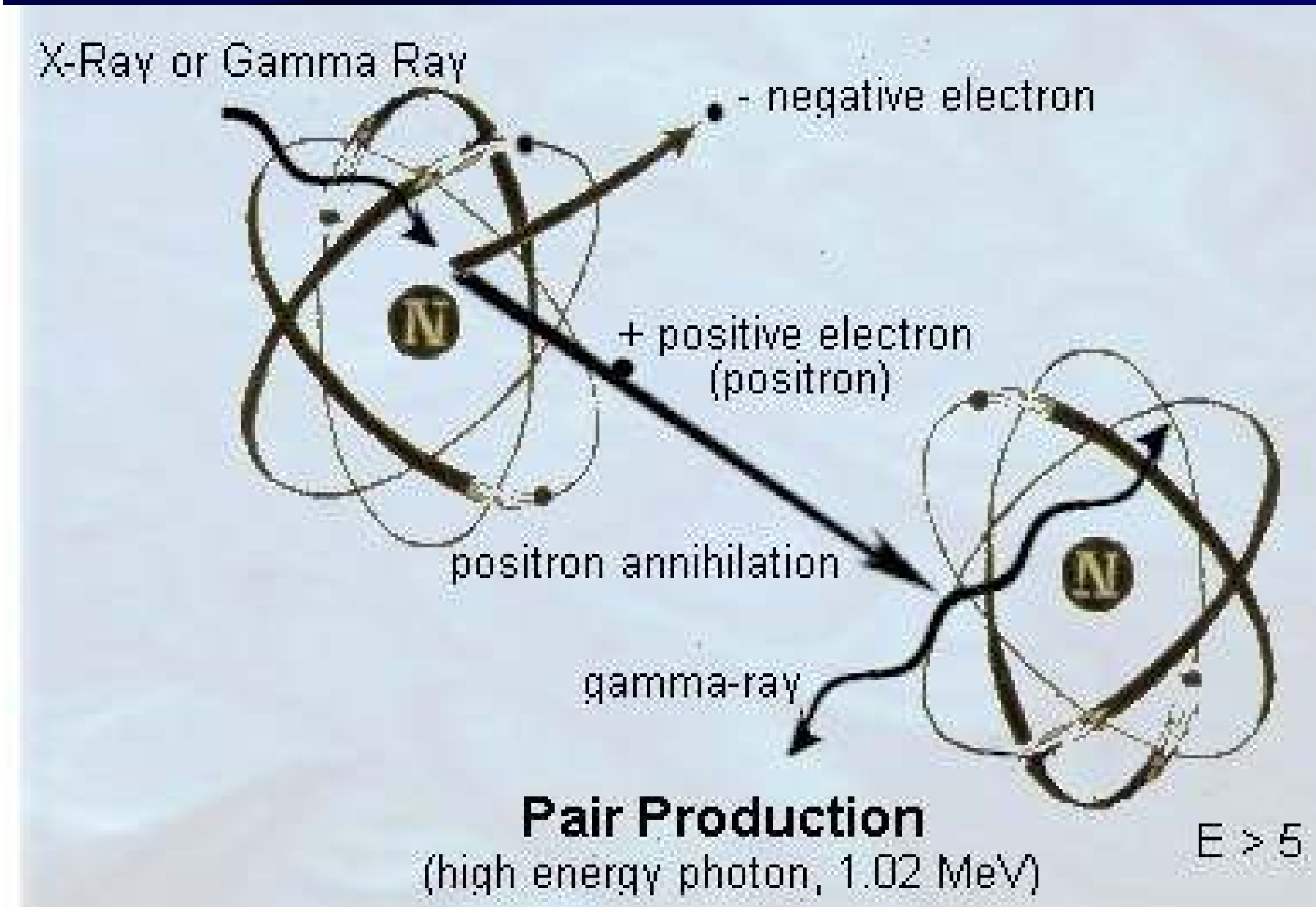

**Photoelectric Effect**

(primarily low-energy photon)




**Compton Effect**

(primarily medium energy photon)




**Pair Production**

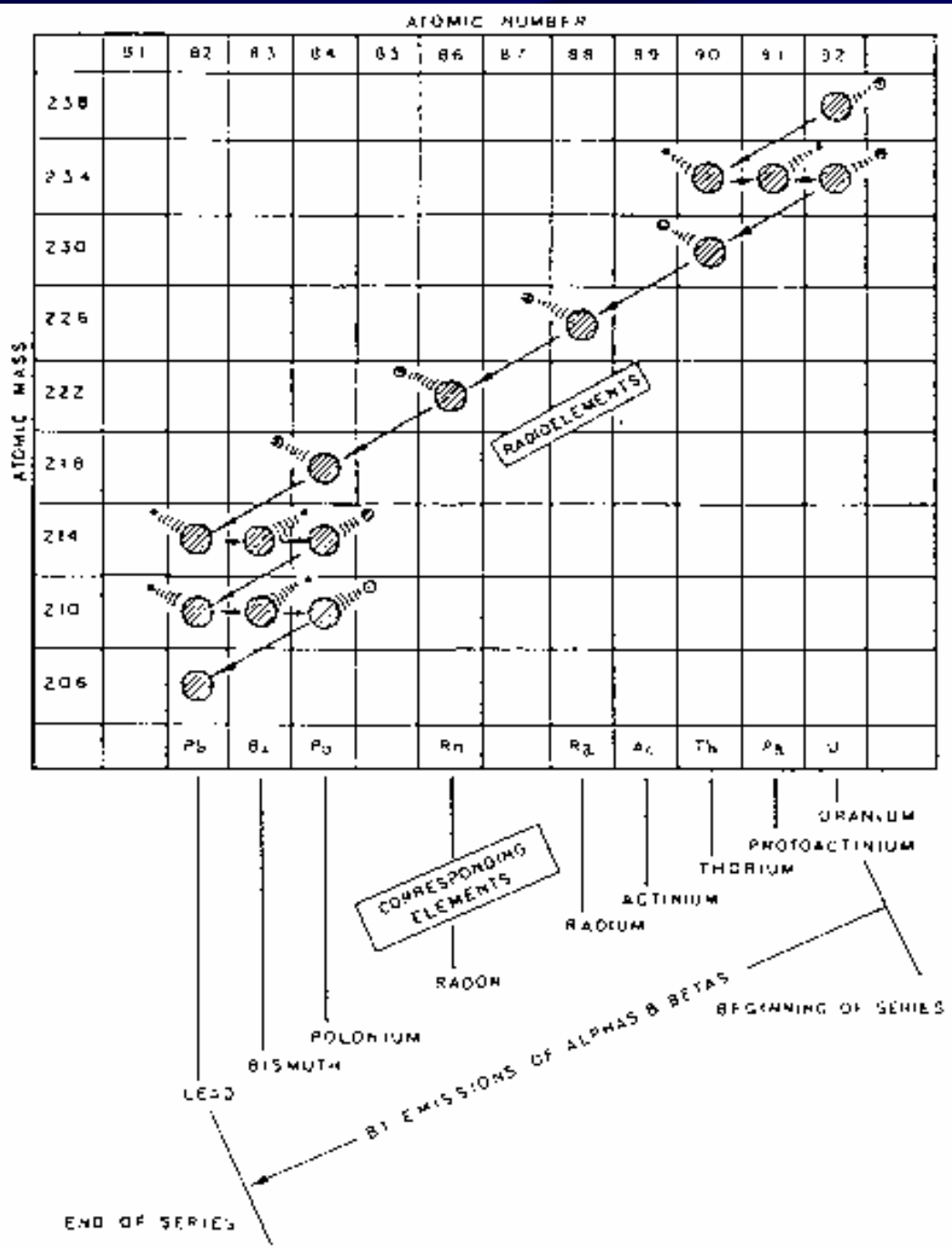
(high energy photon, 1.02 MeV)

E > 5

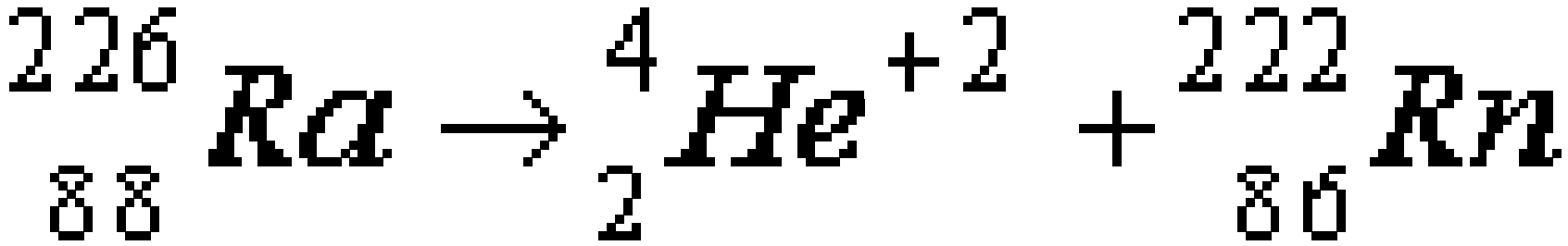
# Radioactive Decay

- Matter transforms from unstable to stable energy states.
- Radioactive materials are substances which spontaneously emit various combinations of ionizing particles (alpha and beta) and gamma rays of ionizing radiation to become more stable.
- Radioisotopes are isotopes (same number of protons but different numbers of neutrons) which are radioactive.

# Decay Series

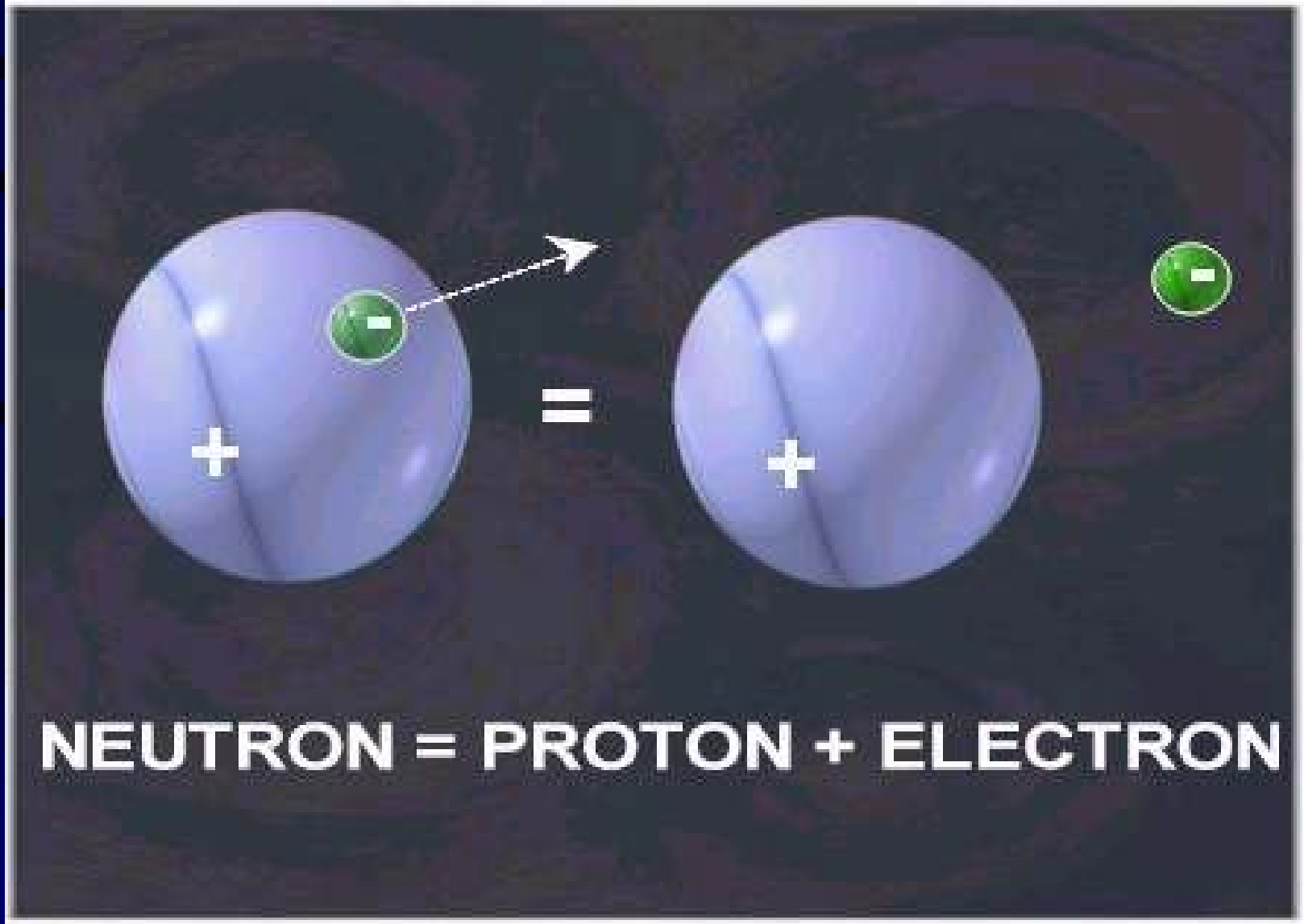


$$\text{Radium} \rightarrow \text{ alpha particle} + \text{ Radon}$$


226 88 Ra → 4 2 He +2 + 222 86 Rn

$$^{90}_{38}\mathrm{Sr} \rightarrow \text{Beta electron} + {}^{90}_{39}\mathrm{Y}$$

# Proton "Gain" during Beta Decay



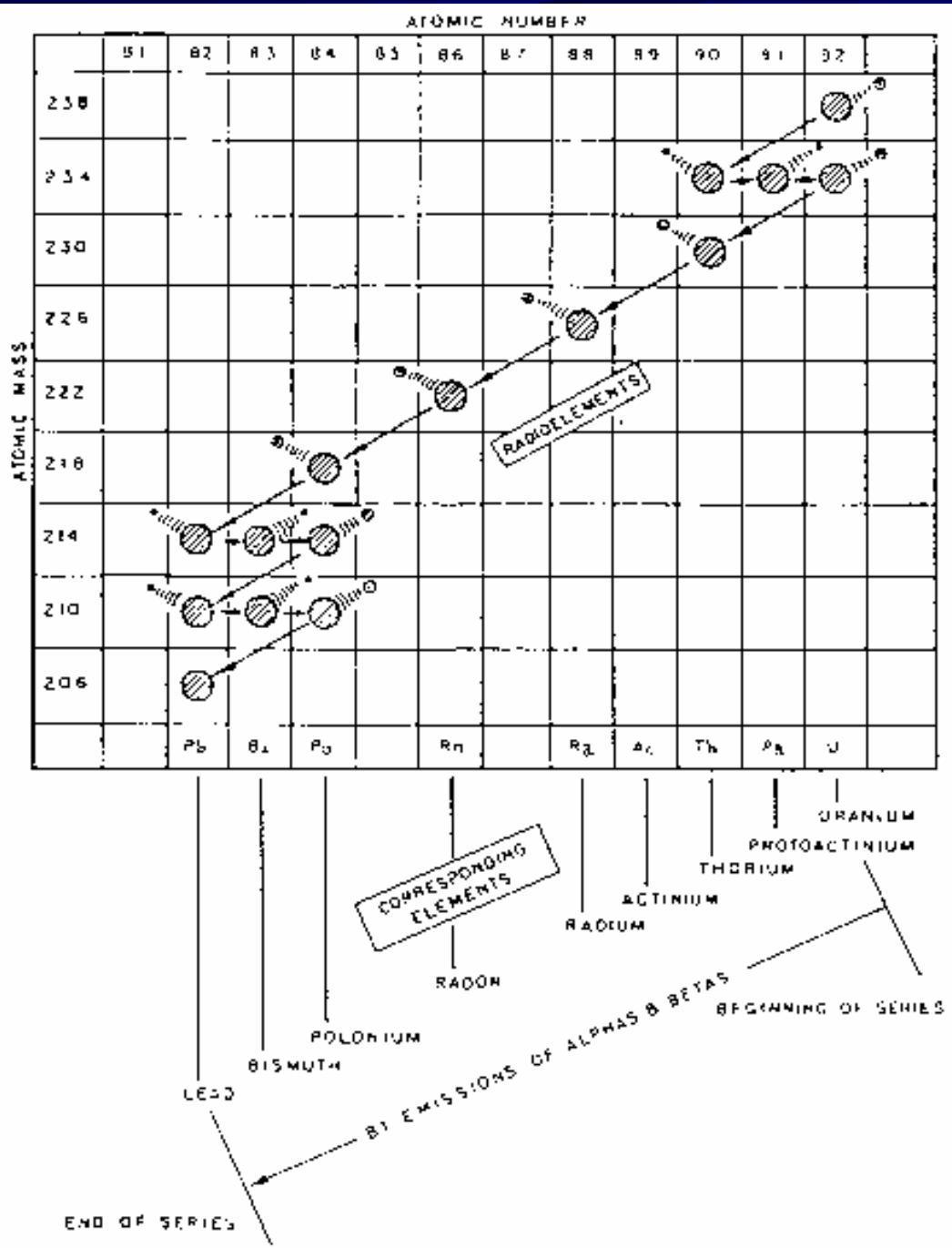
# Beta Decay

- No change in atomic mass; protons increase by 1.
- Consider a neutron as a proton embedded with an electron; net charge = 0. When the electron is ejected, a proton is "created", thus increasing the atomic number.

# Decay Series

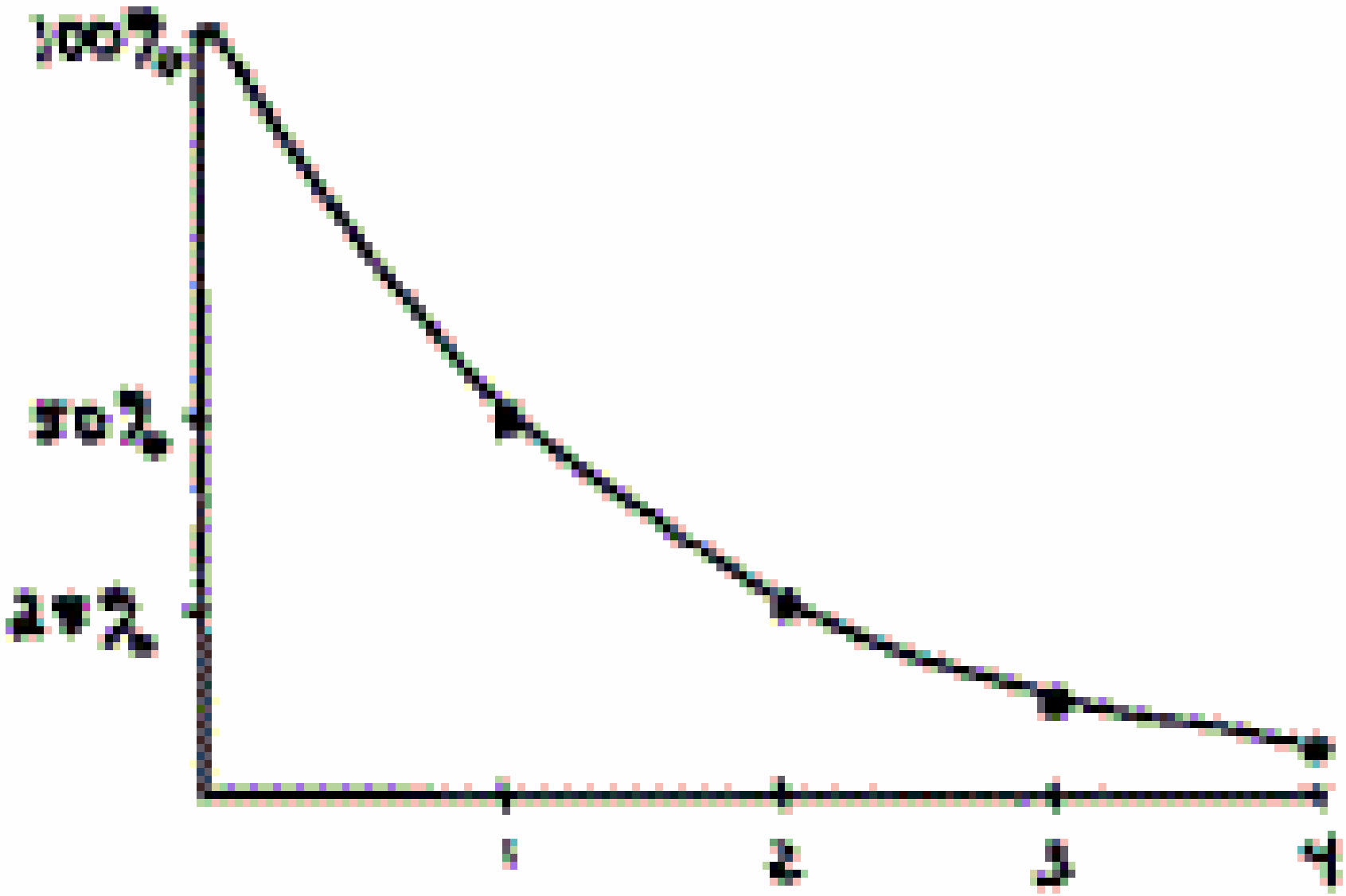
- Radioactive parent decays to a **"daughter"** which may also be radioactive, therefore, is also simultaneously decaying.
- Resulting exposure is to the combination of both decays (and possibly additional daughters).
- Radon daughters are an important example of series decay exposure in uranium mines and basements.

# Series Decay



With alpha = $^{9}_{4}\mathrm{Be} + ^{4}_{2}\mathrm{He}^{+2} \rightarrow ^{1}_{0}\mathrm{neutron} + ^{12}_{6}\mathrm{C}$

x100
x10
x1
bat.
off
483
VICTOREEN
phone


100%
50%
25%
1
2
3
4

# Note common formula structure.

$$A_t = A_o e^{(-\lambda t)}$$

$$N_t = N_o e^{(-\lambda t)}$$

$$I_x = I_o e^{(-\mu x)}$$

$$\lambda = \frac{.693}{\text{Half - Life}} = \text{Decay Constant}$$

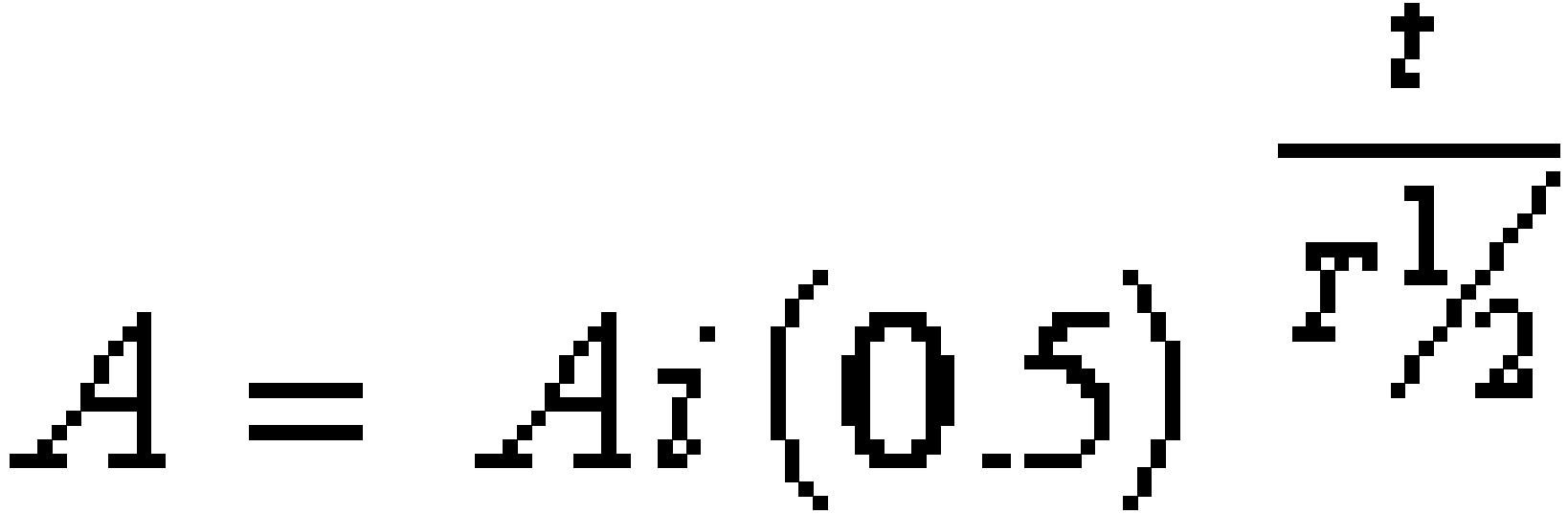
$$\mu = \frac{.693}{\text{Half - VL}} = \text{Linear Coeff. of ABS}$$

$$3\ \text{yr} = 3(365) = 1095\,\text{days}$$

$$A_t = A_0 e^{-\frac{0.693}{T_{\frac{1}{2}}}t} = A_0 e^{-\frac{0.693}{T_{\frac{1}{2}}}t}$$

$$A_t = (300)e^{\frac{-0.693 * 1095}{138.4}} = (300)e^{-5.48}$$

$$= (300)(0.00416) = 1.25\mu Ci$$



$$n = \frac{1095\,\text{days}}{138.4\,\text{days/half-life}} = 7.91\,\text{half lives}$$

$$A_n = 300\left(\tfrac{1}{2}\right)^{7.91} = 300\,(0.00416) = 1.25\,\mu Ci$$

$$I = I_0 e^{\frac{-0.693 * x}{HVL}} = (100) e^{\frac{-0.693(3")(25.4\,mm/inch)}{5\,mm}}$$

$$= (100) e^{-7.04} = 100\,(0.000876) = 0.088\ R/hr$$

# Calibration Source

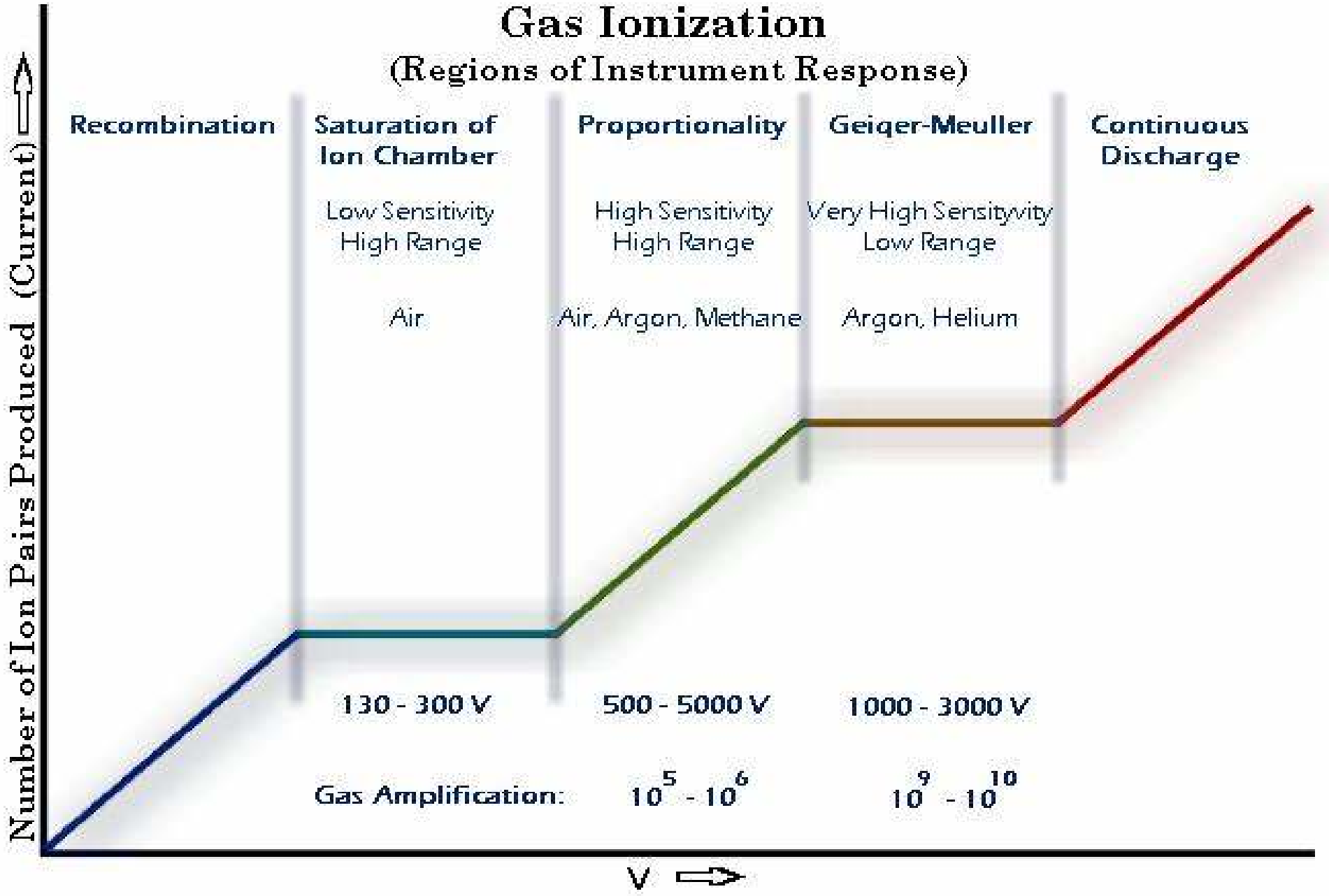
$$\frac{I_1}{I_2} = \left(\frac{d_1}{d_2}\right)^2 \quad I_1 = 500 \quad d_1 = 6 \quad d_2 = 50$$

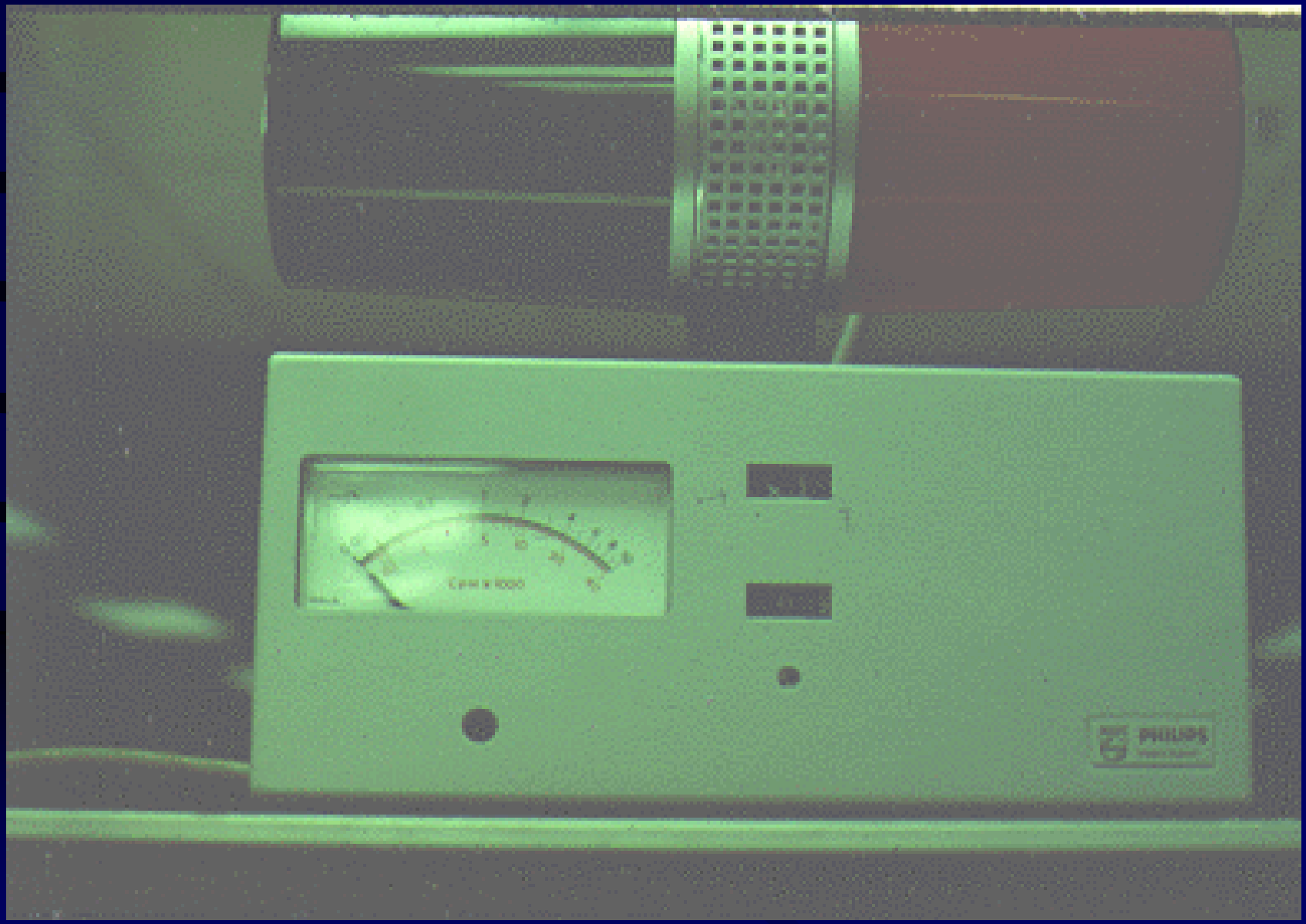
$$I_2 = \frac{I_1}{\left(\frac{d_2}{d_1}\right)^2} = \frac{500}{\left(50/6\right)^2} = \frac{500}{(8.33)^2} = \frac{500}{69.4} = 7.2 \, mR/hr$$

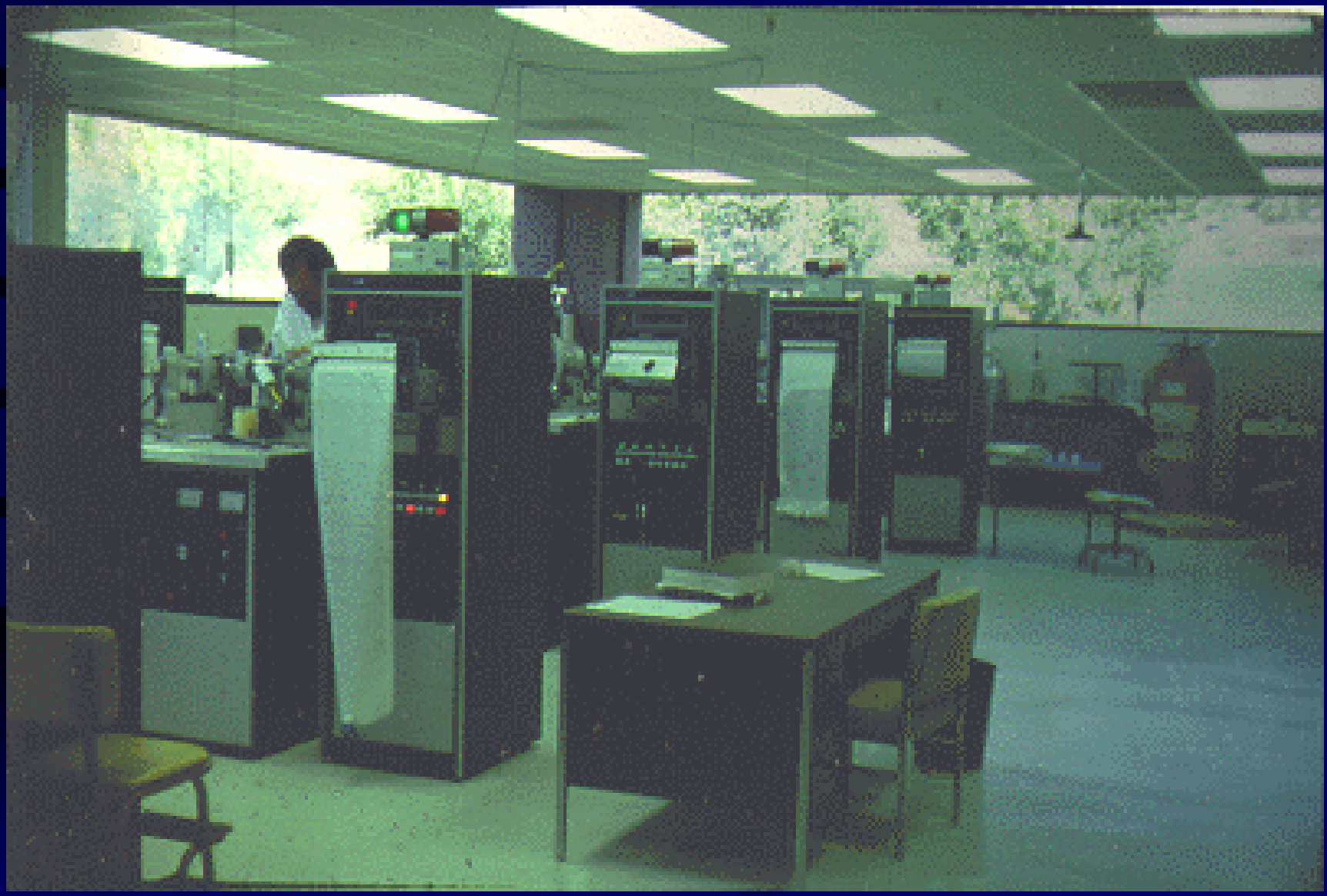
$$D = 0.869 \int X(R) \, rads$$

$$D = (0.869)(0.965)(0.5 \times 10^{-3}\ {}^{R}/_{hr}$$

$$= 0.419\ {}^{m\,rad}/_{hr}$$


Gas Ionization
(Regions of Instrument Response)
Number of Ion Pairs Produced (Current)
Recombination
Saturation of Ion Chamber
Proportionality
Geiqer-Meuller
Continuous Discharge
Low Sensitivity
High Range
High Sensitivity
High Range
Very High Sensityvity
Low Range
Air
Air, Argon, Methane
Argon, Helium
130 - 300 V
500 - 5000 V
1000 - 3000 V
Gas Amplification:
10^5 - 10^6
10^9 - 10^10
V


PHILIPS



DANGER

# RADIOACTIVE SYMBOLS

NFPA 704M LABEL

D.O.T. LABEL