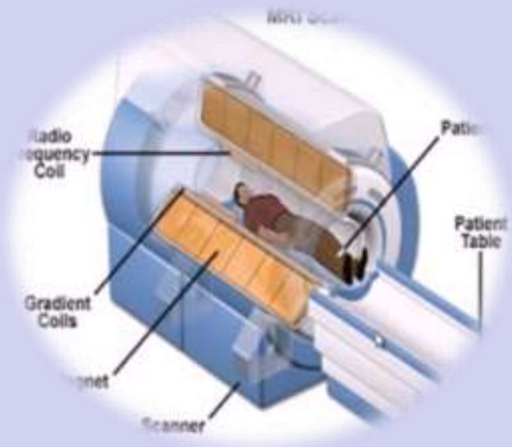
Physics for Medical Science SCPY 164

BSC Program Degree in Biomedical Science (International program)

Nuclear physics and radioactivity: Biological &Medical Applications



By
Assoc. Prof. Wannapong Triampo, Ph.D.

May 7, 2018 (0:30-3:30 pm) @ Room SC1-159

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09-88240430

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Let Us Thank God

Complete War History, Maps, Pictures: Pages 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 26

The Philadelphia Inquirer

PUBLIC LEDGER

An Independent Newspaper for All the People

CITY

PEACE

Truman Announces Japan Surrender, Ends Fighting; MacArthur Named Chief; Draft Calls Are Slashed

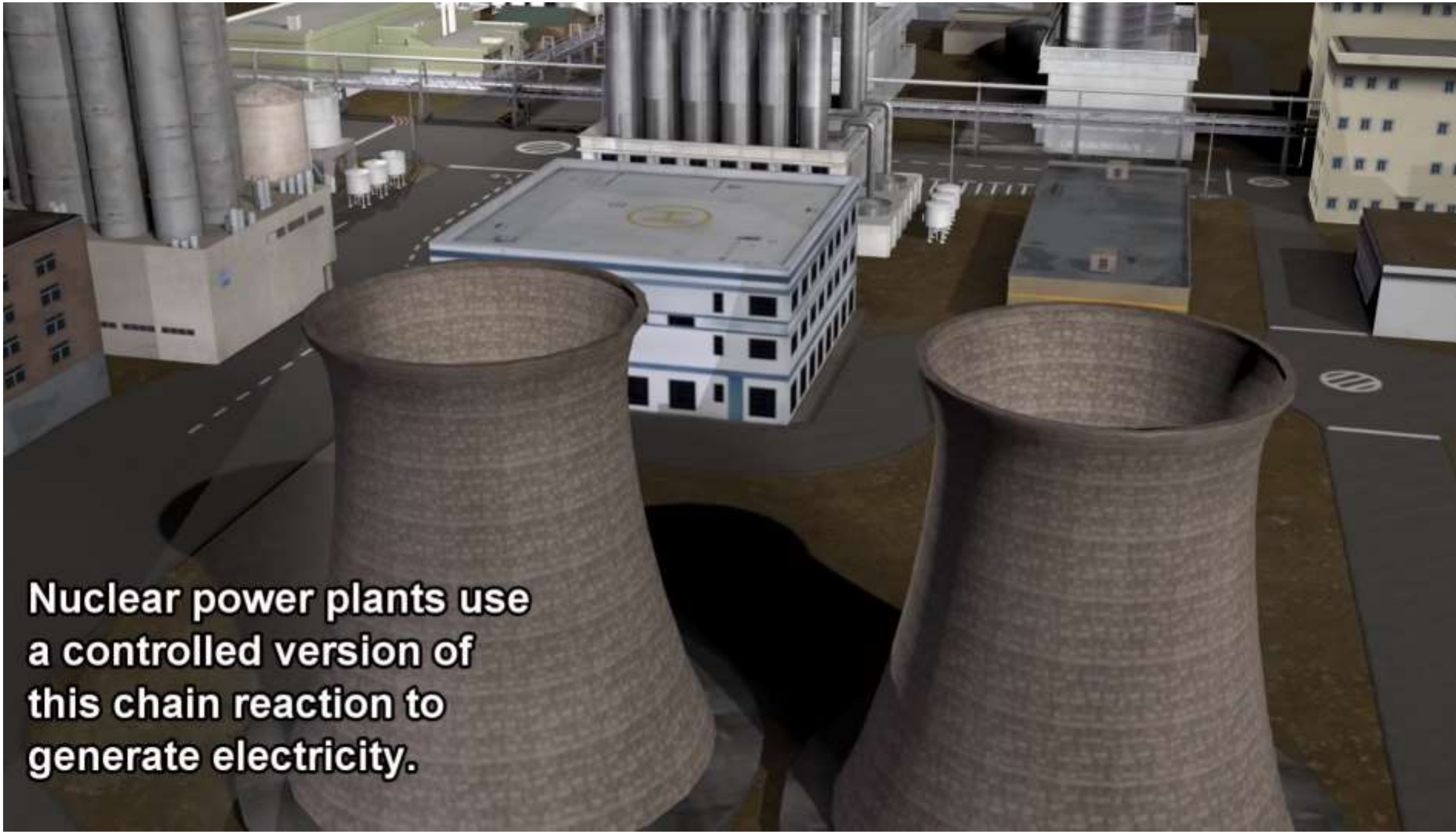
By ALEXANDER KENDRICK

WASHINGTON, Aug. 14—The war is over. Japan has surrendered unconditionally, and Allied forces on land and sea and in the air have been ordered to cease firing. President Truman broke the news to a tensely waiting Nation at 7 P.M. today, just one hour after the Japanese acceptance of the final Allied terms had been delivered to the State Department by the

Learning outcomes

After completing this lecture, you should be able to

- ✓ Explain about medical applications in nuclear physics and radioactivity
- ✓ Demonstrate your understanding of medical applications in nuclear physics and radioactivity

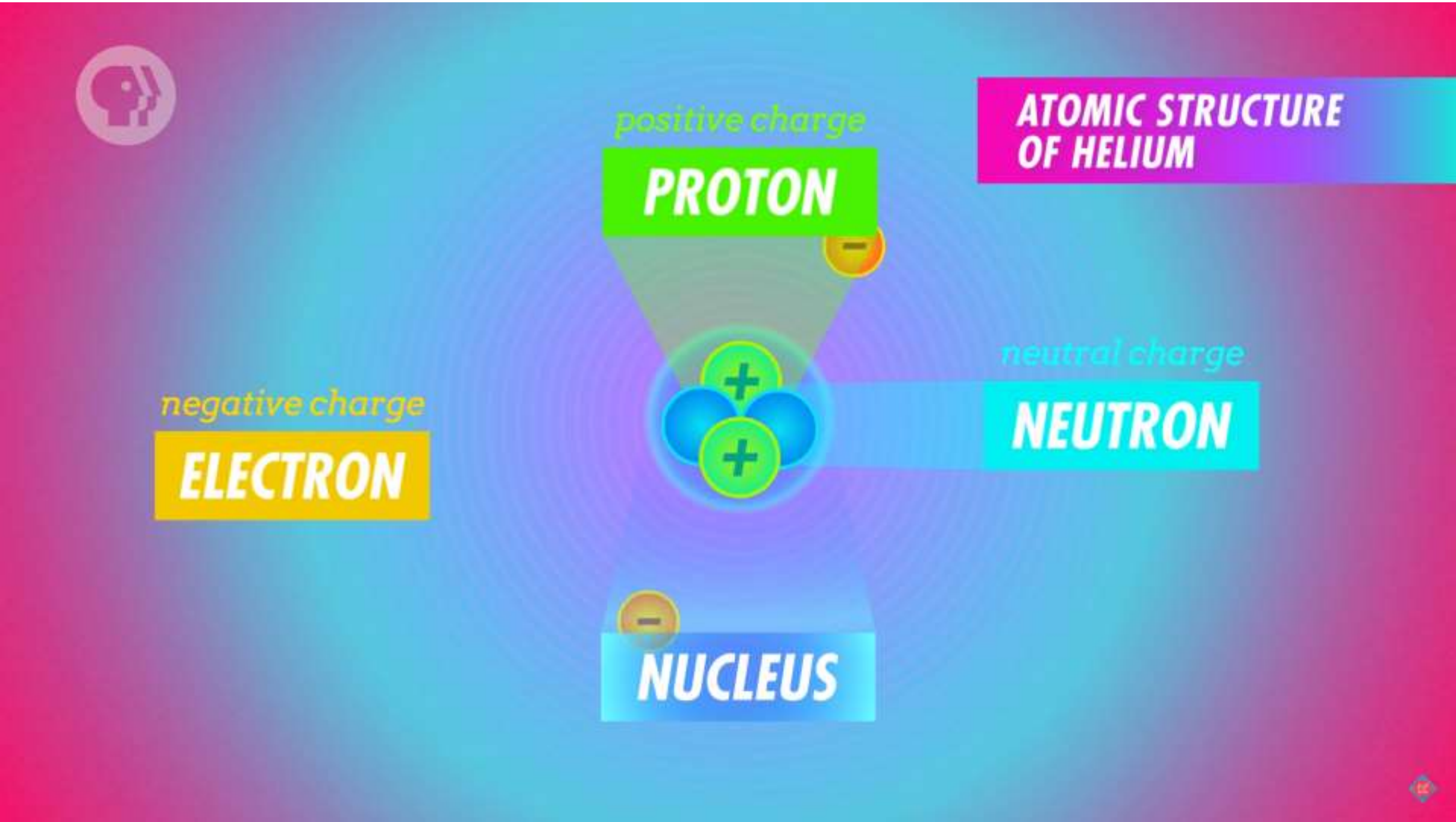

Nuclear power plants use
a controlled version of
this chain reaction to
generate electricity.

Outline

- ✓ Brief summary of Nuclear physics & Radioactivity
- ✓ Medical Applications for Nuclear physics and radioactivity

Brief summary of Nuclear physics & Radioactivity

Atomic Structure and Subatomic Particles: The Nuclear Atom



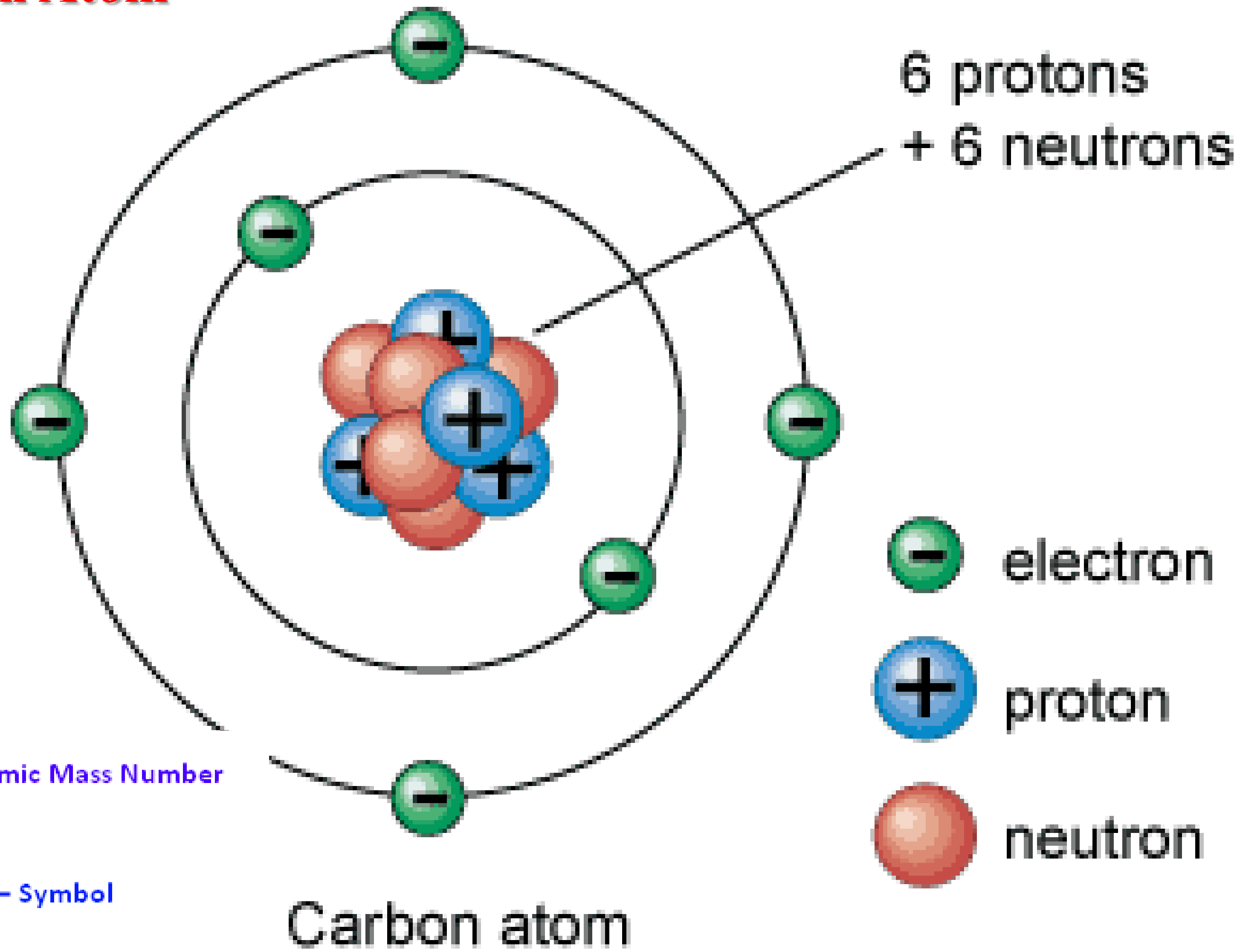
Atoms and Their Components

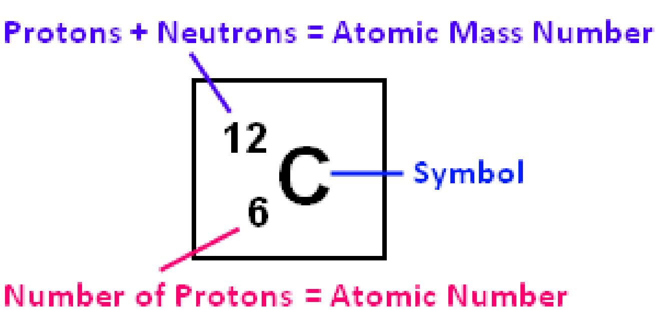
- **Structure of an Atom**
  - 1 and 2 are clustered together in the **nucleus**.
  - 3 are dispersed throughout the area around the nucleus.
  - The space occupied by the electrons is called 4 since the electrons are constantly moving and are difficult to pinpoint
  - Most of an atom consists of 5

Atoms and Their Components

- **<u>Subatomic particles</u>** organize to form all atoms.
  - **The three basic subatomic particles are the , and**
  - **and are charged particles.**
  - **are neutral or uncharged.**
  - **have a positive (+) charge, and have a negative (-) charge.**
  - **Overall, atoms have *no charge* because the number of protons is equal to the number of electrons.**

Structure of an Atom





Atomic Number and Mass Number

Symbolic Notation for Isotopes

$^{A}_{Z}X$

A = Mass Number

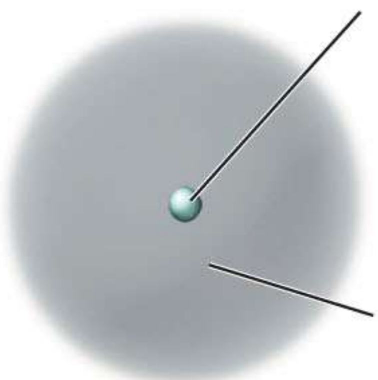
Z = Atomic Number

X = Atomic symbol

Isotopes of Calcium and the Number of Particles in Each

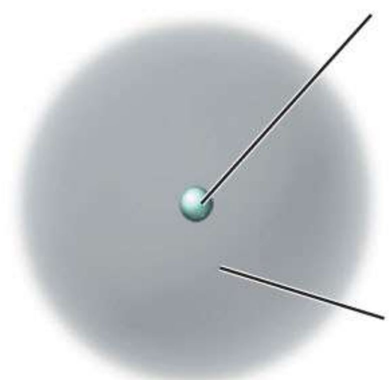
Calcium-40

$^{40}_{20}Ca$



Calcium-42

$^{42}_{20}Ca$



Atoms and Their Components

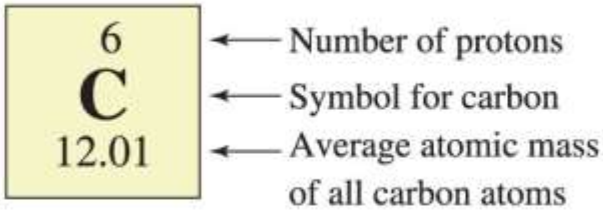
- **Structure of an Atom**
  - A unit called the **a**tomic **m**ass **u**nit, or **amu**, is used when discussing atoms.
  - An **amu** is one-twelfth the mass of a carbon atom.
  - A proton and neutron each weigh 1 amu.
  - The mass of an electron is about 2000 times less than that of a proton or neutron.

TABLE 2.1 Properties of Particles in an Atom

Subatomic Particle	Symbol	Electrical Charge	Relative Mass	Location in Atom
Electron	e^-	1–	0.0005 (1/2000)	Outside nucleus
Proton	p or p^-	1+	1	Nucleus
Neutron	n or n^0	0	1	Nucleus

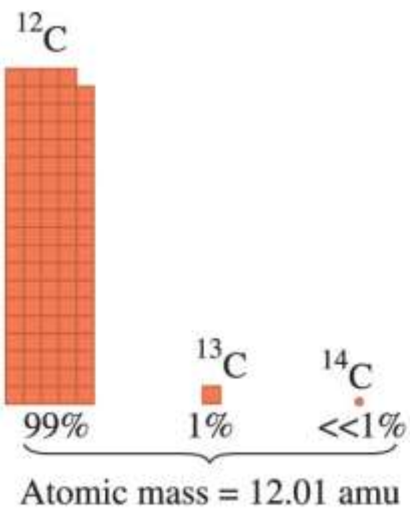
Isotopes and Atomic Mass

(a)



Isotope	^{12}C	^{13}C	^{14}C
Atomic number	6	6	6
Protons	6	6	6
Neutrons	6	7	8
Abundance	Most	1/100	1/1,000,000,000,000

(b)



Not all atoms of the same element have the same mass number.

Atoms of the same element with different mass numbers are called **isotopes**

Atomic Structure and Subatomic Particles: The Nuclear Atom

Fill in the blanks.

Element	Protons	Neutrons	Electrons	Mass number	Complete symbol
Cu				65	
Kr				86	
	78	117			
		46	35		

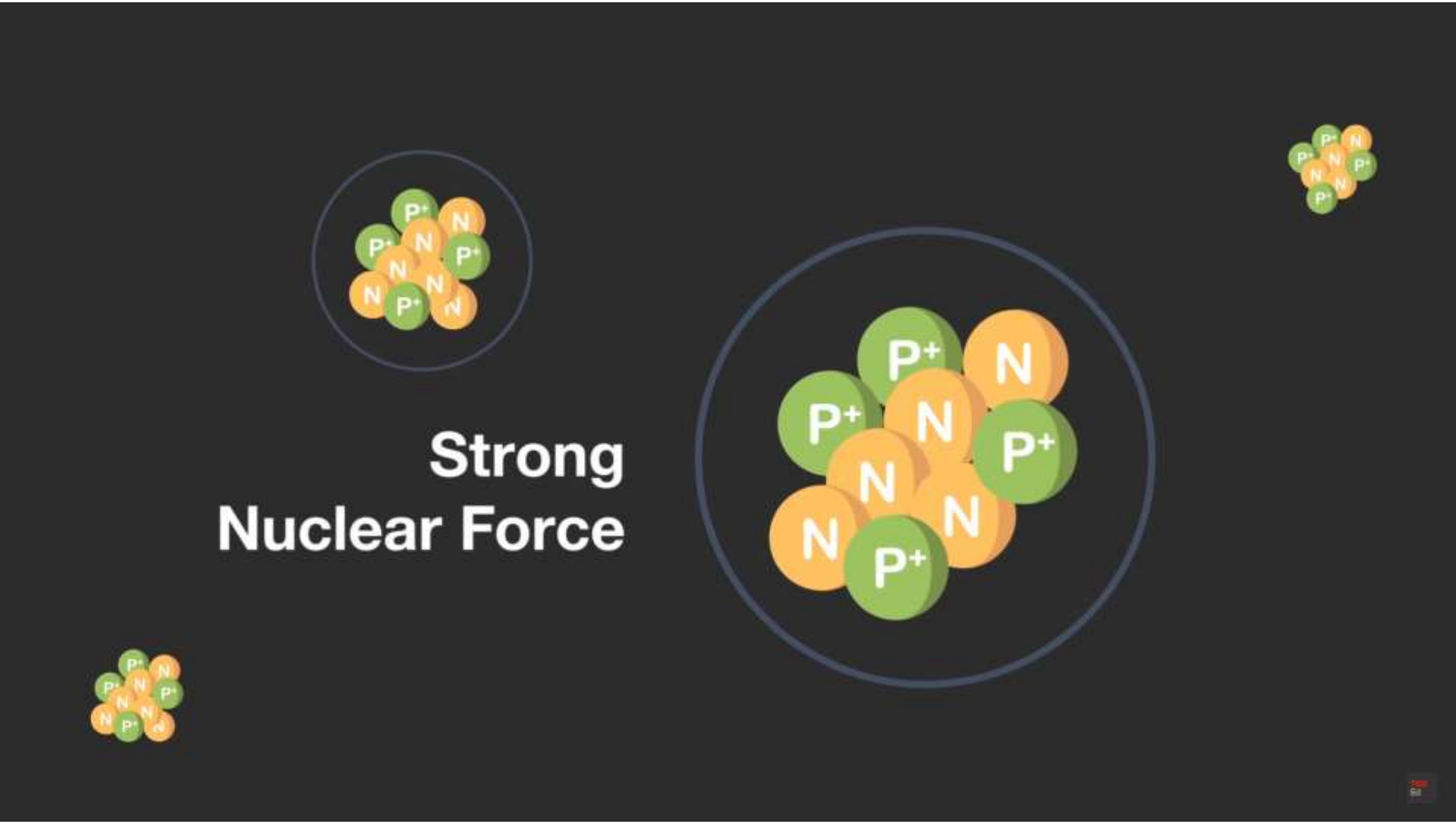
Atomic Structure and Subatomic Particles: The Nuclear Atom

Fill in the blanks.

Element	Protons	Neutrons	Electrons	Mass number	Complete symbol
Cu	29	36	29	65	$^{65}_{29}Cu$
Kr	36	50	36	86	$^{86}_{36}Kr$
Pt	78	117	78	195	$^{195}_{78}Pt$
Br	35	46	35	81	$^{81}_{35}Br$

STRONG NUCLEAR FORCE

AN ATTRACTIVE FORCE THAT ACTS BETWEEN PROTONS AND NEUTRONS IN A NUCLEUS.

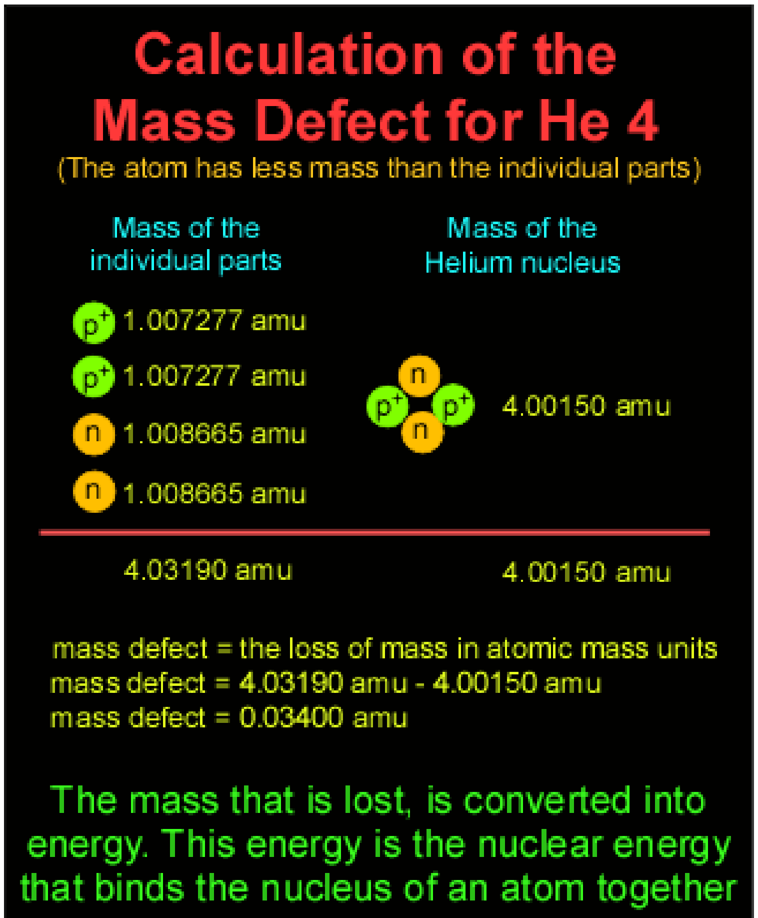

Strong
Nuclear Force

Einstein – Energy/Mass Equivalence

Mass Defect – Example

$1\,u = 1.660559 x 10^{-27}\,kg$

Particle	Mass(kg)	u
Proton	$1.6726 x 10^{-27}$	1.007276
Neutron	$1.6750 x 10^{-27}$	1.008665
Electron	$9.109 x 10^{-31}$	$5.486 x 10^{-4}$



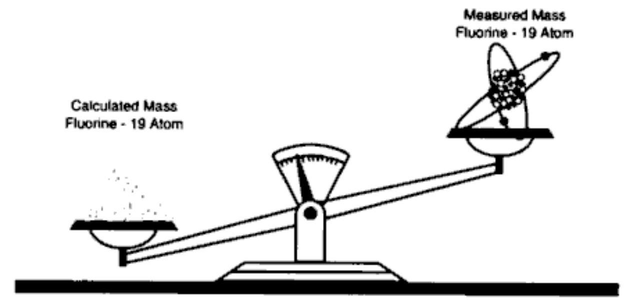
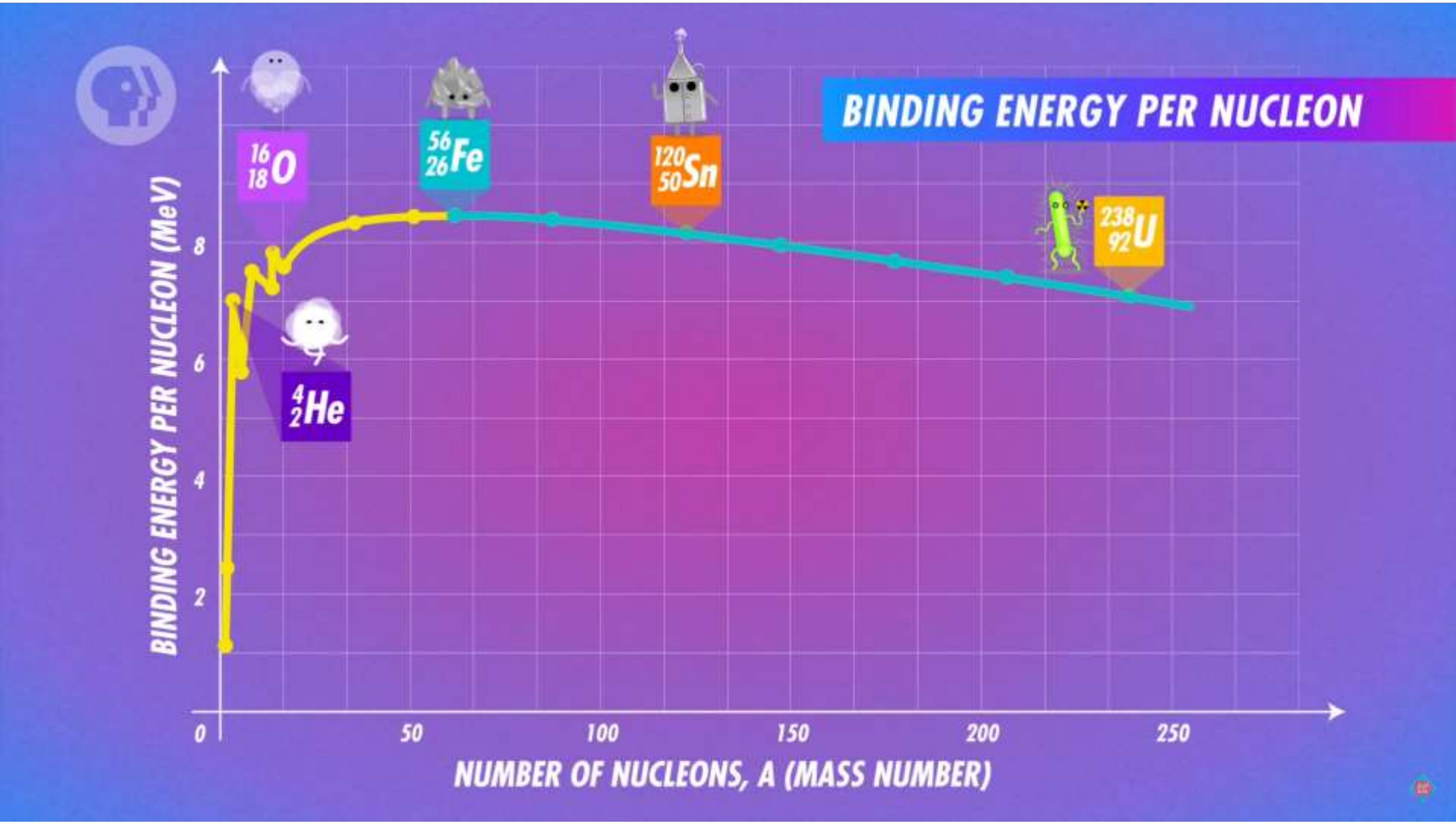


Figure 2-V. Illustration of a Mass Defect

$$E_B = \Delta m c^2$$

$$E_B = \text{Binding energy}$$

$$\Delta m = \text{mass defect}$$



BINDING ENERGY PER NUCLEON
BINDING ENERGY PER NUCLEON (MeV)
NUMBER OF NUCLEONS, A (MASS NUMBER)
0
2
4
6
8
50
100
150
200
250
$^{16}_{18}O$
$^{56}_{26}Fe$
$^{120}_{50}Sn$
$^{238}_{92}U$
$^{4}_{2}He$

Radioactivity and Radioisotopes

- **Energy given off spontaneously from the nucleus of an atom** is called

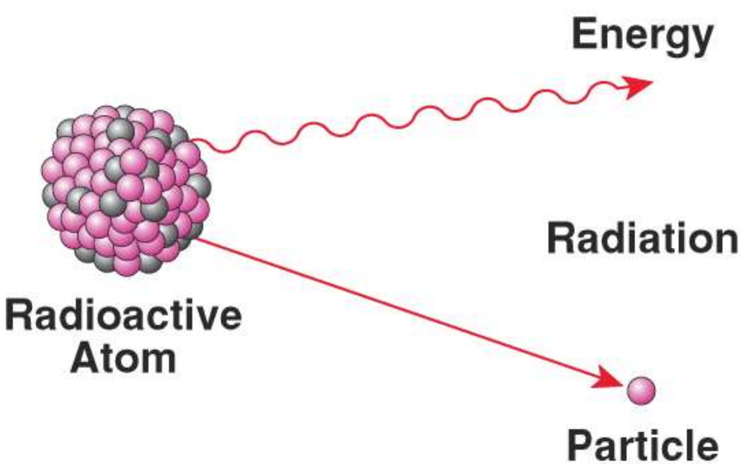
- Elements that emit radiation are said to be ***radioactive***.
- **Radiation is a form of energy** that we get from natural and human-made sources.
-

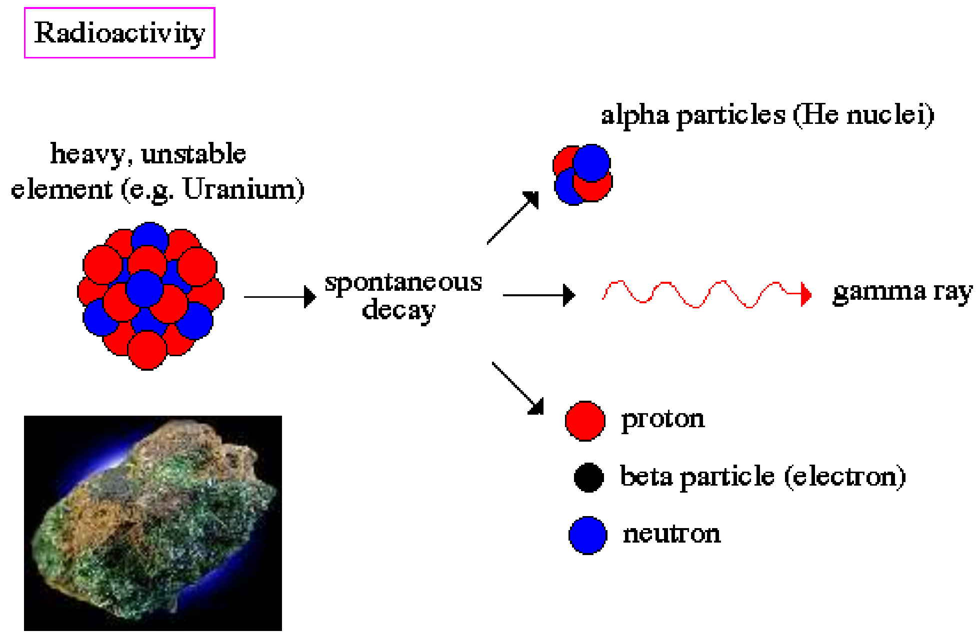
Radioactivity and Radioisotopes

- Most naturally occurring isotopes have a stable nucleus and are not radioactive.
- **Isotopes that are <u>not stable</u> become stable *<u>by spontaneously emitting radiation</u>* from their nuclei**.
- This is radioactive decay.
- Isotopes that emit radiation are also called
- All the isotopes of elements with atomic number 83 and higher are radioactive.
- Some smaller elements also have radioisotopes.

Radioactivity

When an unstable nucleus releases energy and/or particles.





Radioactive Decay

There are 4 basic types of radioactive decay

- **Alpha – Ejected Helium**
- **Beta – Ejected Electron**
- Positron – Ejected Anti-Beta particle
- **Gamma – Ejected Energy**

You may encounter protons and neutrons being emitted as well

$${}^{4}_{2}He$$

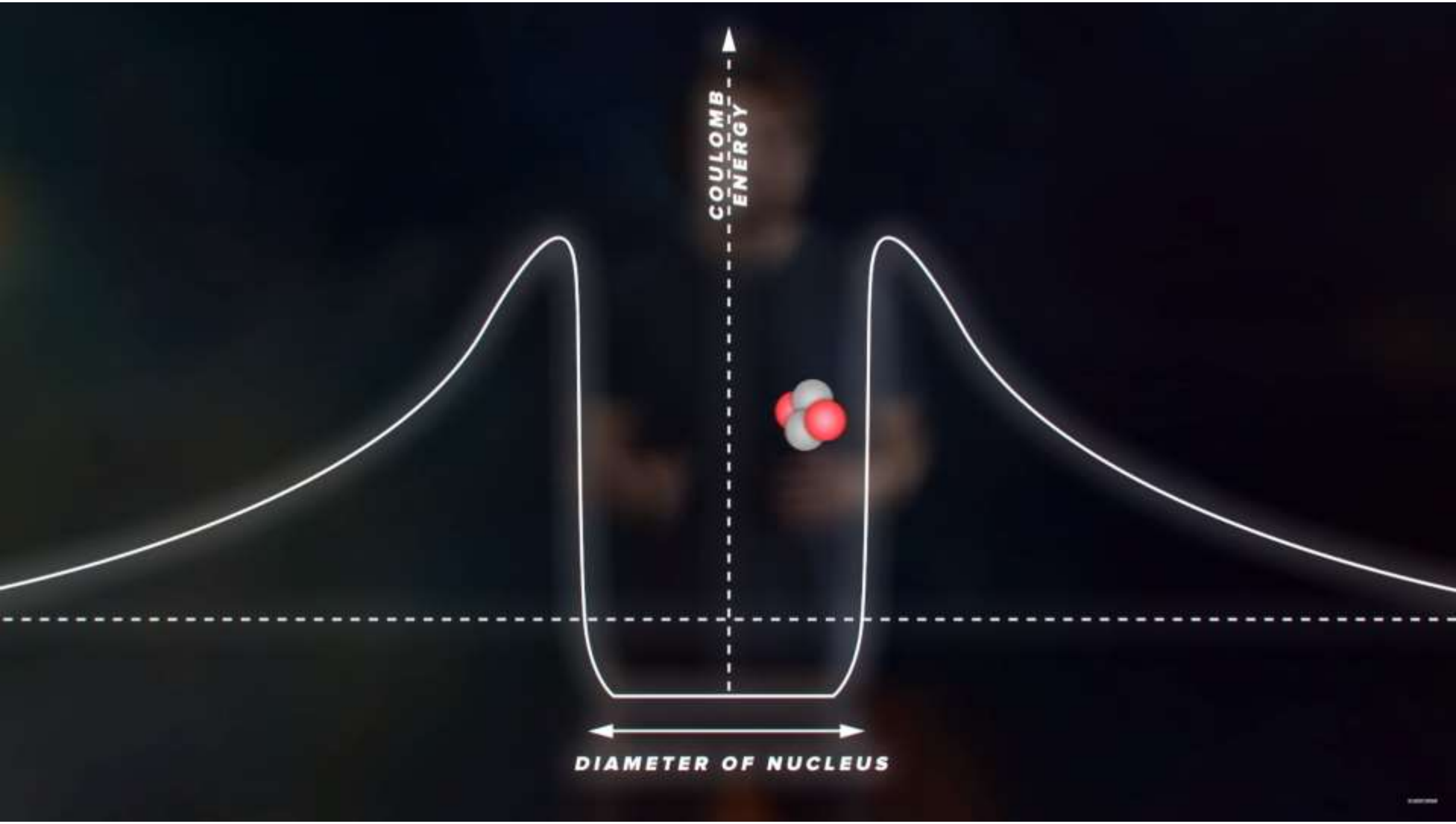
$${}^{0}_{-1}e$$

$${}^{0}_{1}e$$

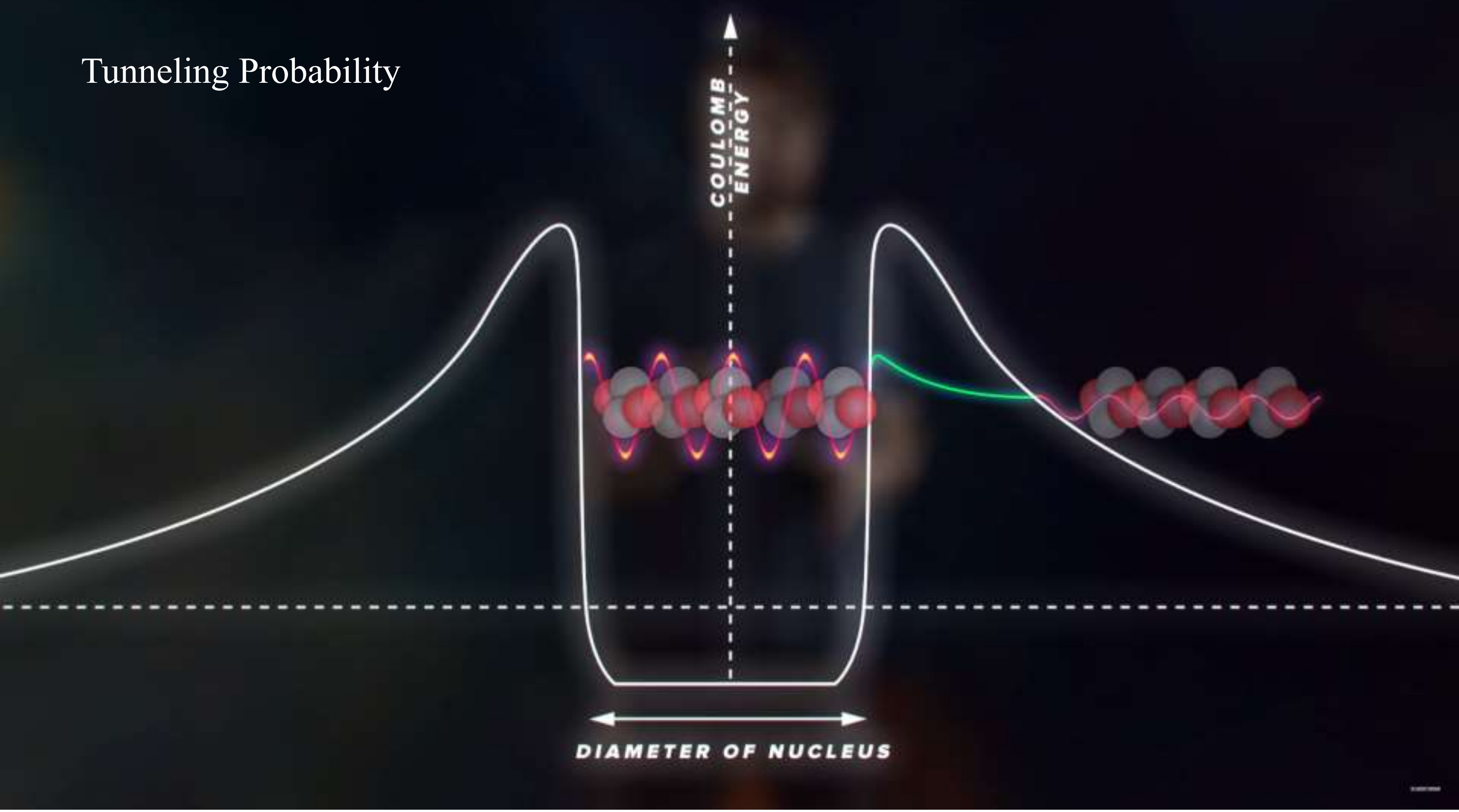
$${}^{0}_{0}\gamma$$

$${}^{1}_{1}p$$

$${}^{1}_{0}n$$


COULOMB
ENERGY
DIAMETER OF NUCLEUS

Tunneling Probability



Radiation

For the following nuclear reactions, fill in the missing information.

$$^{42}_{19}\mathrm{K} \rightarrow {}^{0}_{-1}\mathrm{e} + \boxed{}$$

$$^{210}_{84}\mathrm{Po} \rightarrow \boxed{} + {}^{206}_{82}\mathrm{Pb}$$

$$^{9}_{4}\mathrm{Be} \rightarrow {}^{9}_{4}\mathrm{Be} + \boxed{}$$

$$\boxed{} \rightarrow {}^{0}_{1}\mathrm{e} + {}^{13}_{6}\mathrm{C}$$

$$^{26}_{13}\mathrm{Al} + {}^{0}_{-1}\mathrm{e} \rightarrow \boxed{}$$

Radiation

For the following nuclear reactions, fill in the missing information.

$$^{42}_{19}K \rightarrow {}^{0}_{-1}e + \boxed{^{42}_{20}Ca}$$

$$^{210}_{84}Po \rightarrow \boxed{^{4}_{2}He} + {}^{206}_{82}Pb$$

$$^{9}_{4}Be \rightarrow {}^{9}_{4}Be + \boxed{^{0}_{0}\gamma}$$

$$\boxed{^{13}_{7}N} \rightarrow {}^{0}_{1}e + {}^{13}_{6}C$$

$$^{26}_{13}Al + {}^{0}_{-1}e \rightarrow \boxed{^{26}_{12}Mg}$$

Radiation Units and Half-Lives

- **Radioactivity Units**

TABLE 2.6 Units for Radiation Activity

Common Unit	Relationship to Other Units
becquerel (Bq)	1 Bq = 1 disintegration per second
curie (Ci)	1 Ci = 3.7×10^{10} disintegrations per second
millicurie (mCi)	1 Ci = 1000 mCi
microcurie (μCi)	1 Ci = 1,000,000 μCi

Radiation Units and Half-Lives

Every radioactive isotope emits radiation, at a different rate.

Unstable isotopes emit radiation more rapidly.

The rate of decay is measured as half-life, *the time it takes for one-half (50%)* of the atoms in a sample to decay.

Decay is measured on a Geiger counter.

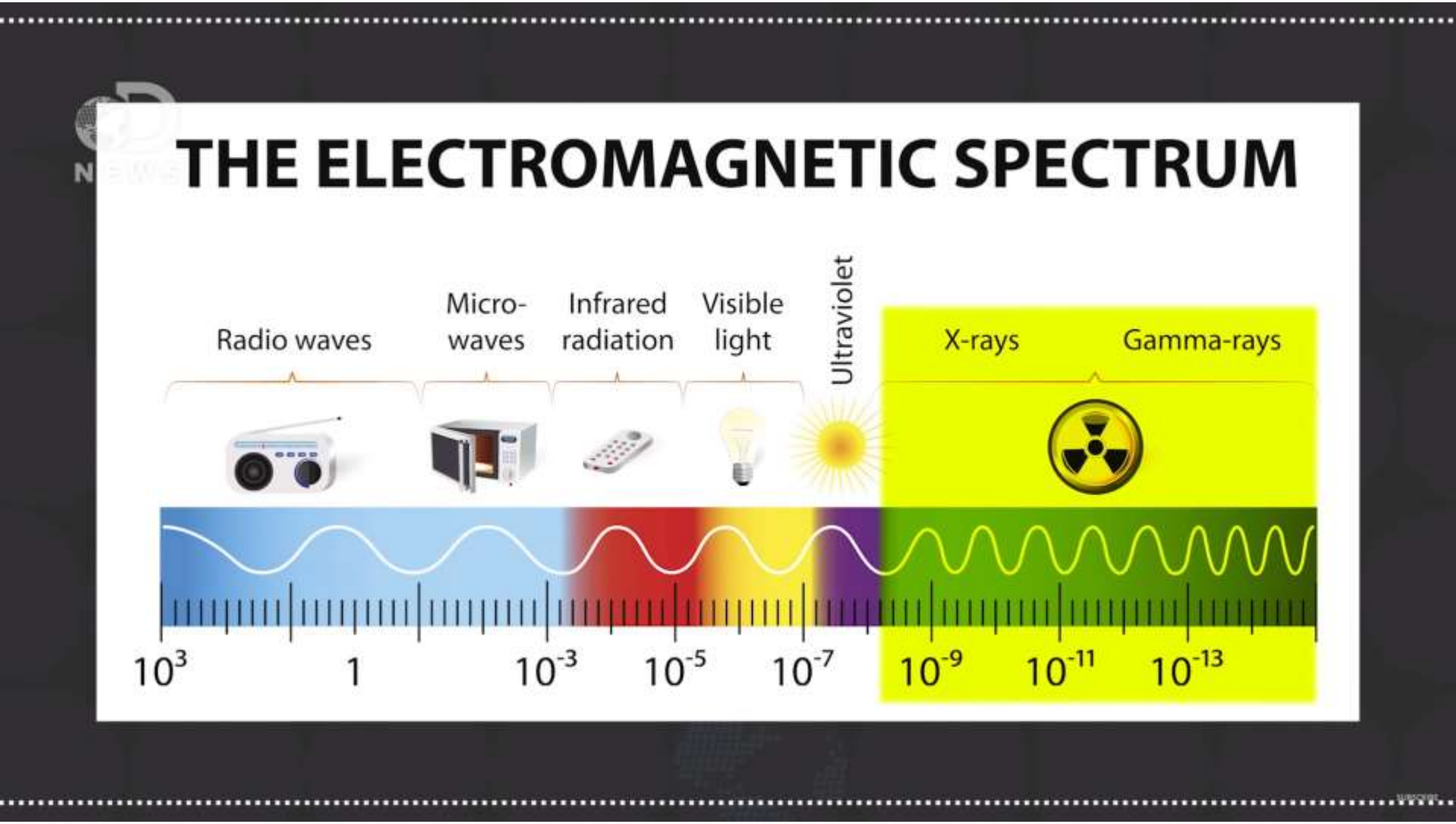
Half-Lives

Natural radioisotopes have long half-lives.

Radioisotopes used in medicine have short half-lives; radioactivity is eliminated quickly.

Radioisotope	Symbol	Half-Life	Radioisotope	Symbol	Half-Life
Naturally occurring radioisotopes			***Radioisotopes used in medicine***		
Hydrogen-3 (tritium)	^{3}H	12.3 years	Chromium-51	^{51}Cr	28 days
Carbon-14	^{14}C	5730 years	Fluorine-18	^{18}F	110 minutes
Radium-226	^{226}Ra	1600 years	Iron-59	^{59}Fe	45 days
Uranium-238	^{238}U	4.5 billion years	Phosphorus-32	^{32}P	14.3 days
			Technetium-99m	^{99m}Tc	6.0 hours
			Iodine-123	^{123}I	13.2 hours
			Iodine-131	^{131}I	8 days

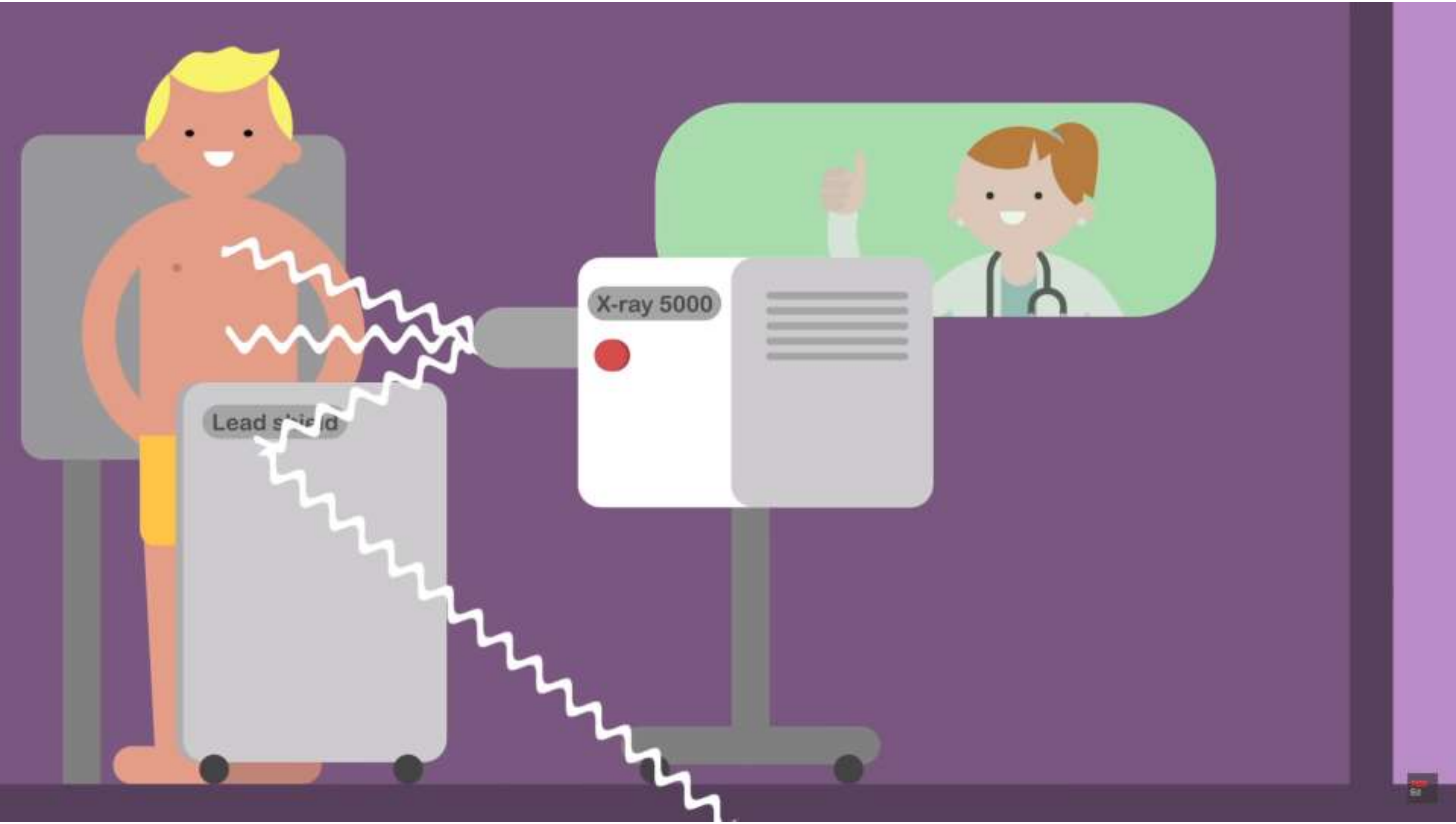
Biological & Medical Effects of Radiation

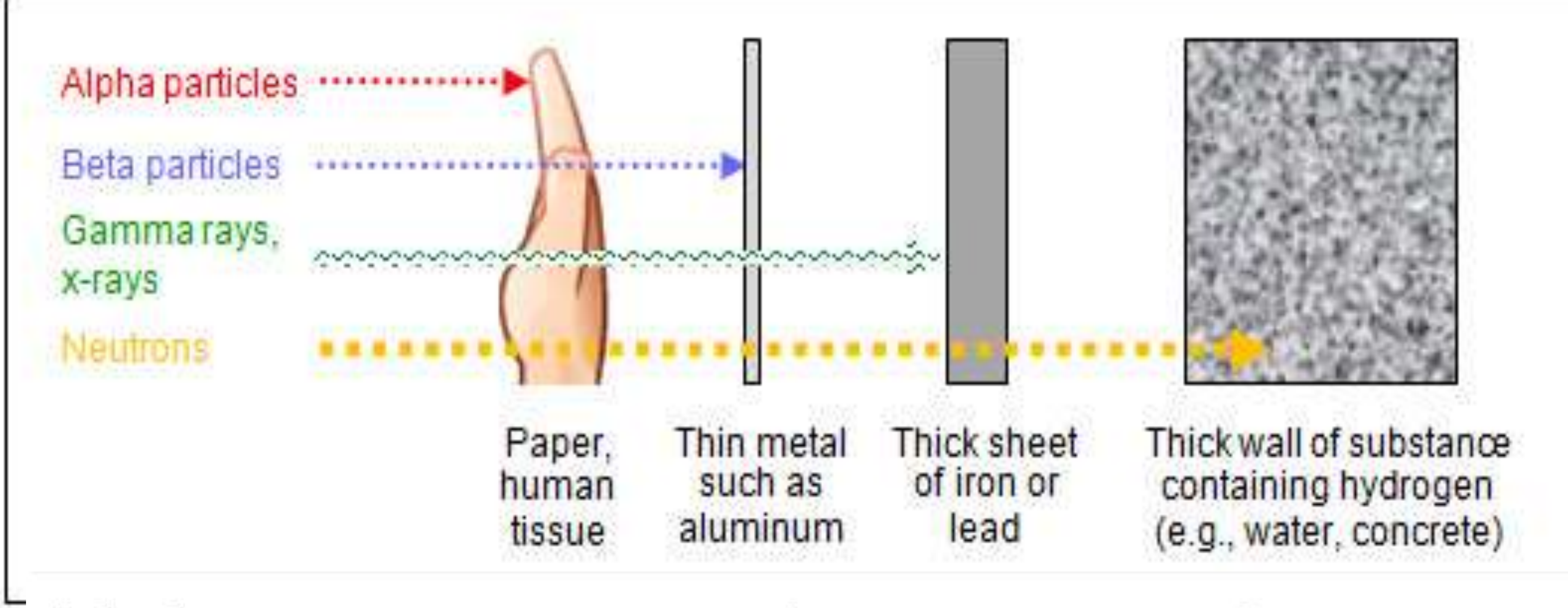


IONIZING RADIATIO

Electromagnetic radiation

Nuclear radiation


X-ray 5000
Lead



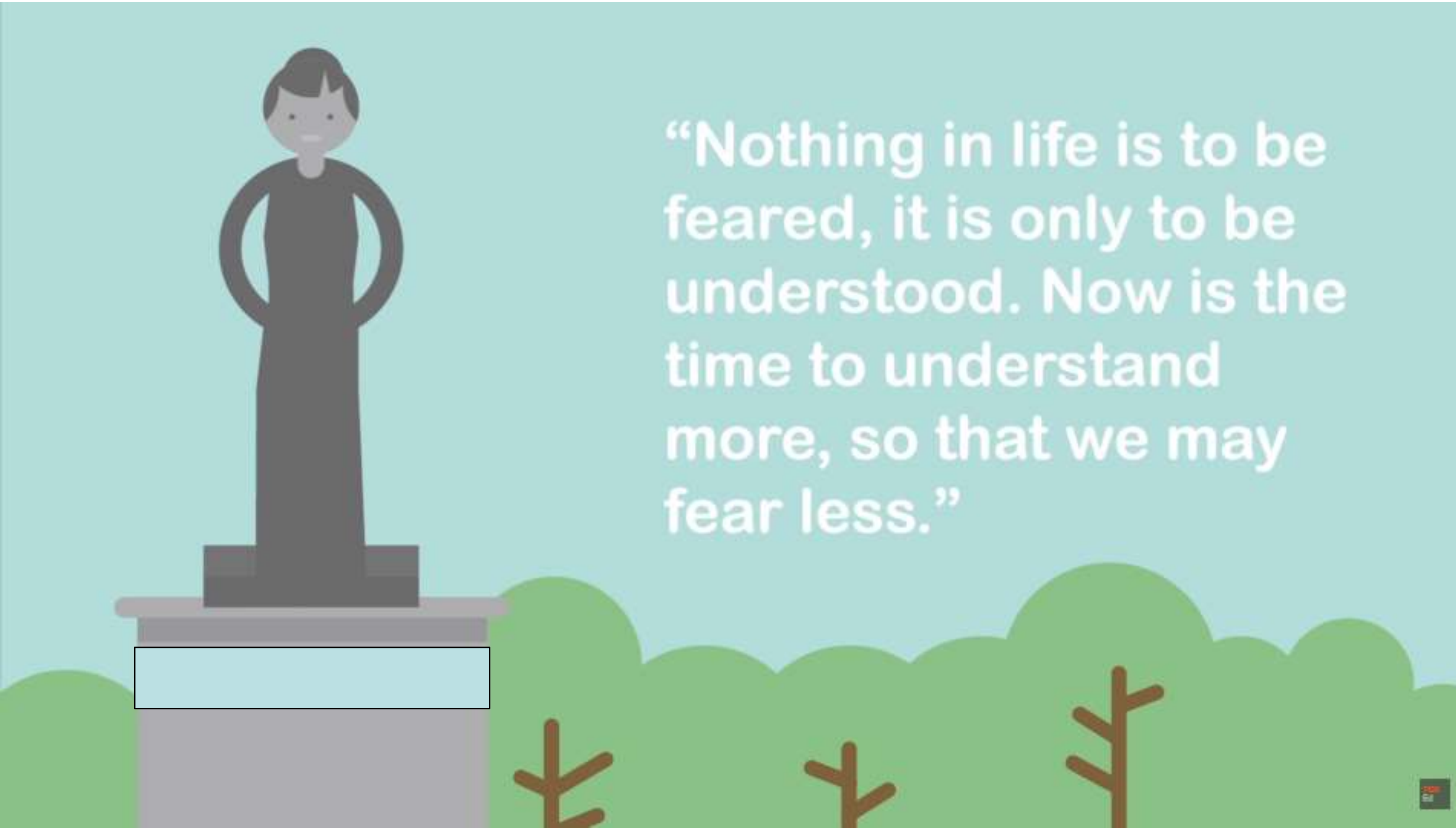
Alpha	α or ${}^{4}_{2}\mathrm{He}$	2+
Beta	β or ${}^{\ 0}_{-1}\mathrm{e}$	1−
Gamma	${}^{0}_{0}\gamma$	0
Positron	${}^{0}_{1}\mathrm{e}$	1+
Neutron	${}^{1}_{0}\mathrm{n}$	0

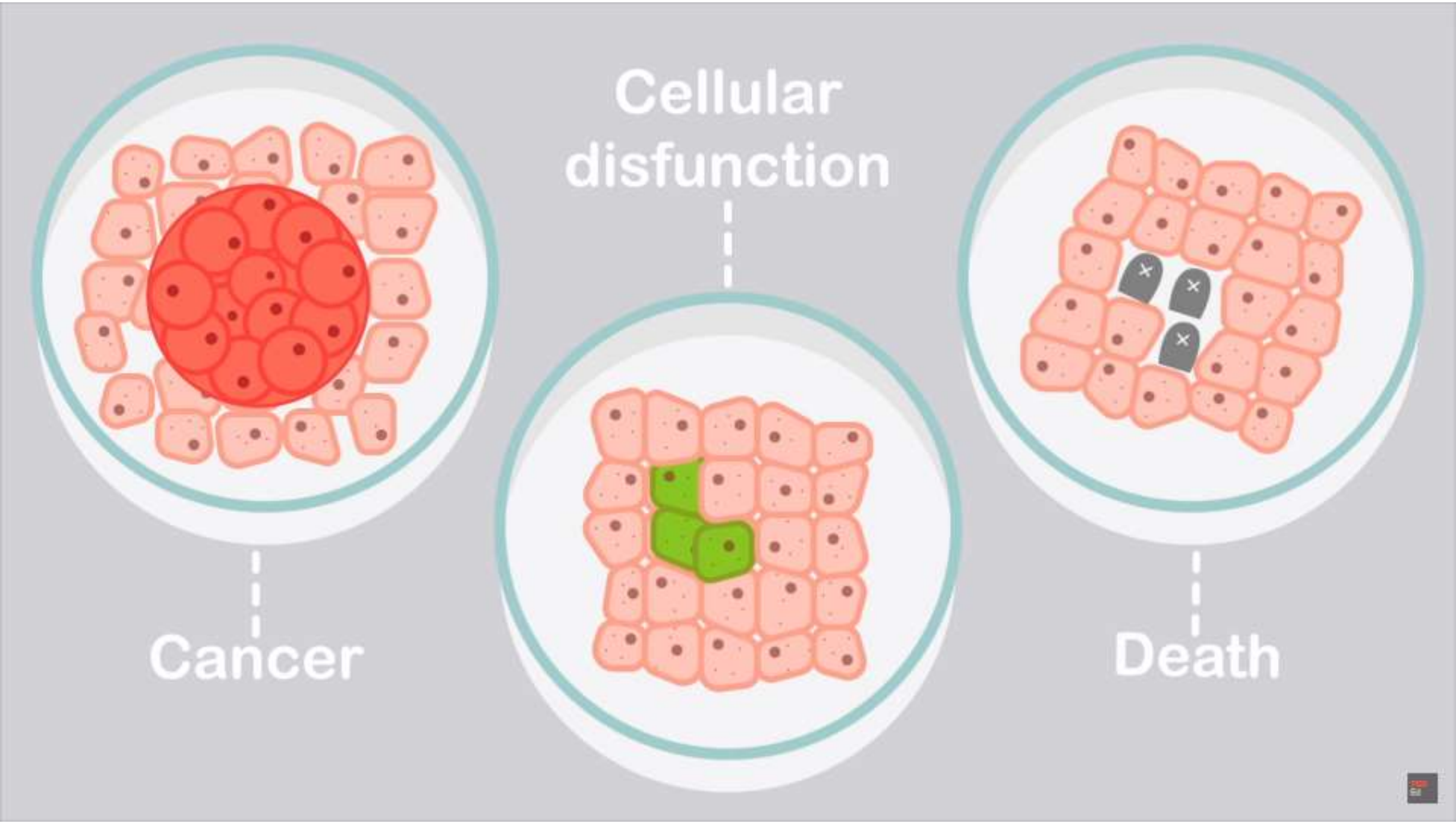
Radioactivity and Radioisotopes

- **Biological Effects of Radiation**

TABLE 2.5 Properties of Common Ionizing Radiation

	Travel Distance through Air	Tissue Penetration	Protective Shielding
Alpha (α)	A few centimeters	Stops at the skin surface; only dangerous if inhaled or eaten	Paper, clothing
Beta (β)	A few meters	Will not penetrate past skin layer	Heavy clothing, plastic, aluminum foil, gloves
X-ray	Several meters	Penetrates tissues, but not bone	Lead apron, concrete barrier
Gamma (γ)	Several hundred meters	Fully penetrates body	Thick lead, concrete, layer of water

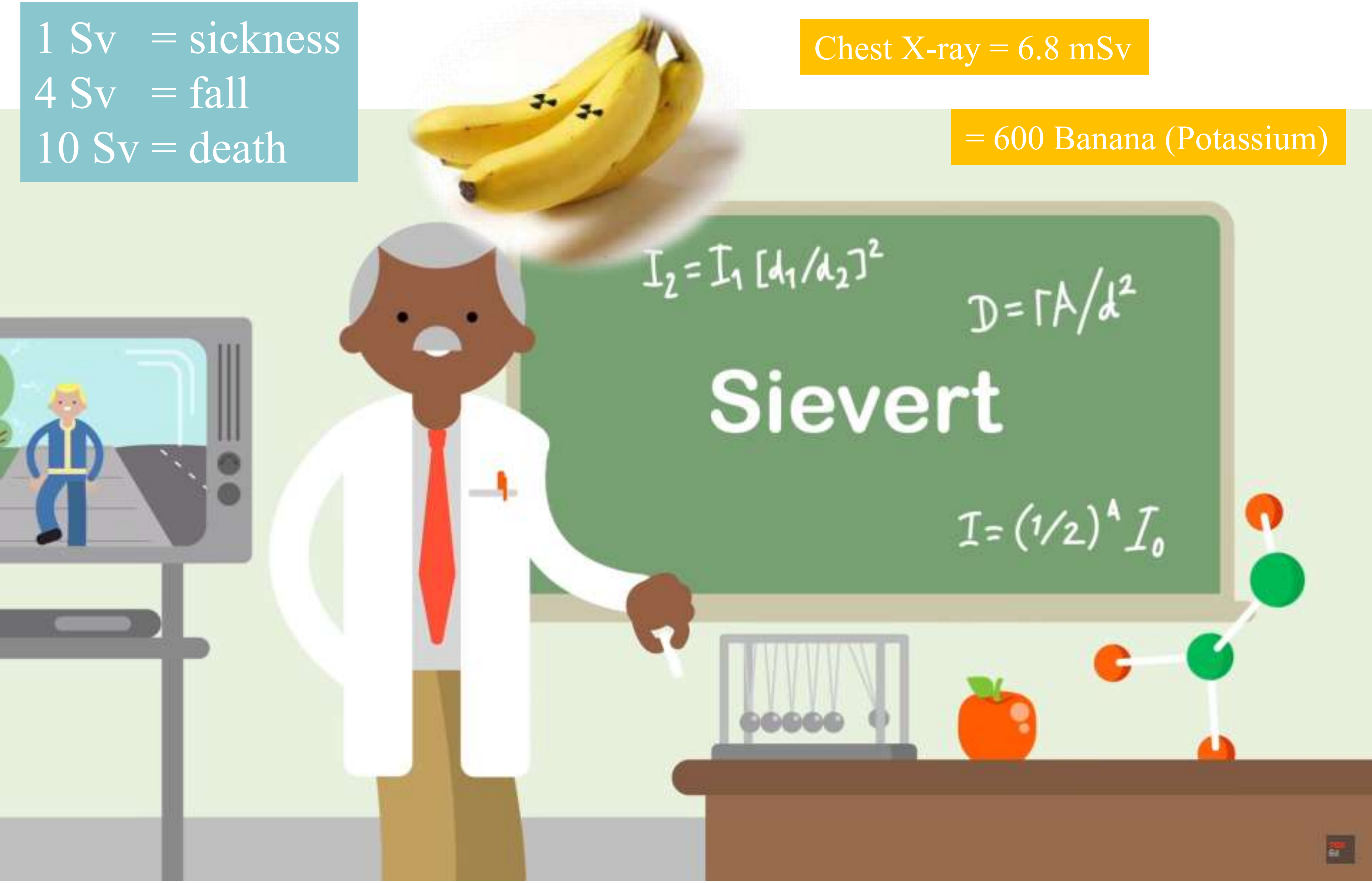

“Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less.”


Cellular
disfunction
Cancer
Death

1 Sv = sickness
4 Sv = fall
10 Sv = death

Chest X-ray = 6.8 mSv

= 600 Banana (Potassium)



Biological Effects of Radiation

Radioactive emissions contain a lot of energy and will interact with any atoms.

Alpha and beta particles, neutrons, gamma rays, and X-rays are <u>ionizing radiation</u>.

When they interact with another atom, they can eject one of that atom's electrons, making the atom more reactive and less stable.

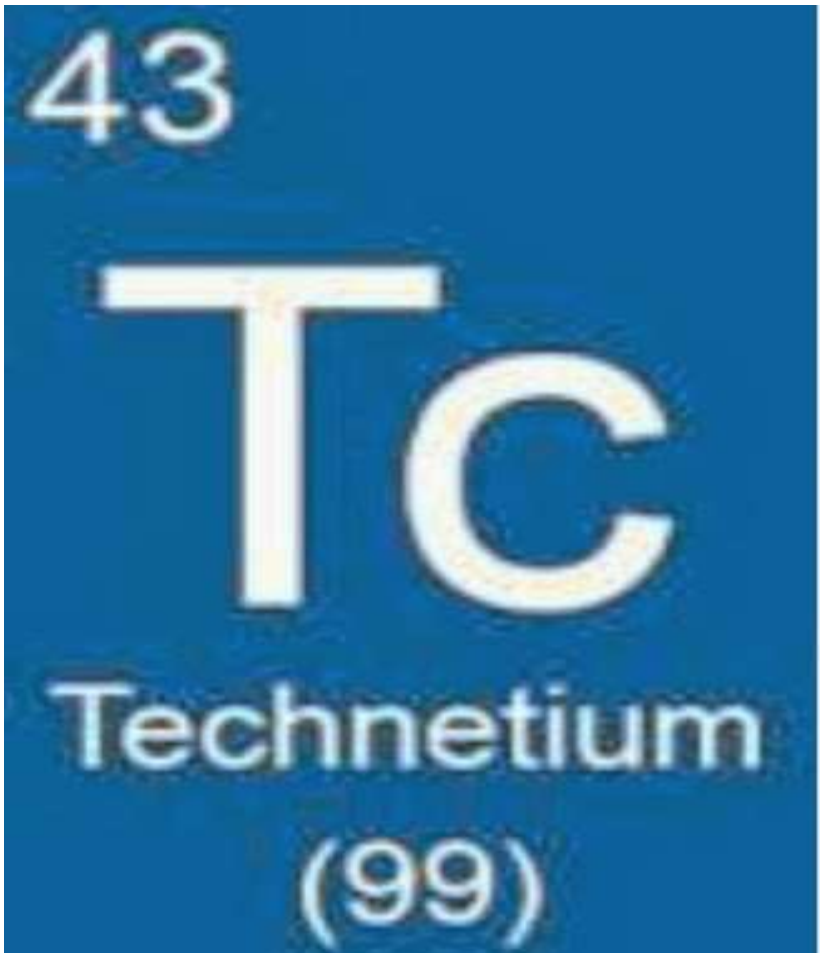
The loss of electrons in living cells can affect a cell's chemistry and genetic material. In humans, this can cause problems, the most common of which is cancer.

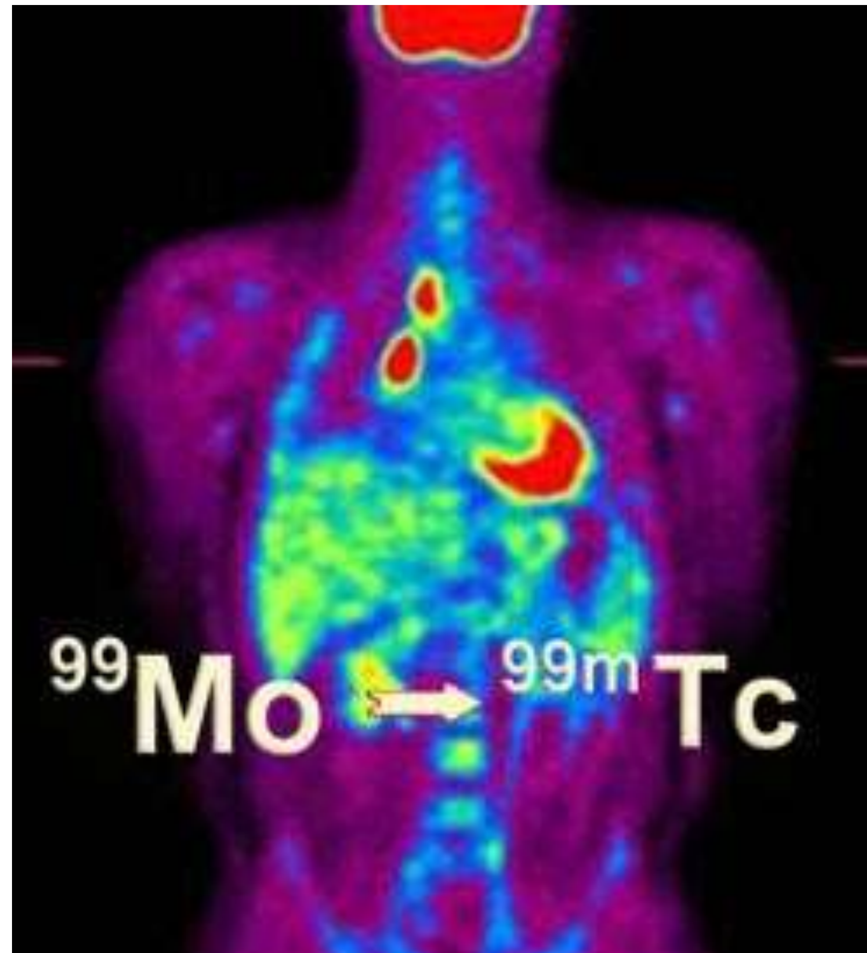
Nuclear Equations and Radioactive Decay

- ***Producing Radioactive Isotopes***
  - **Although some radioisotopes occur in nature, many more are prepared in chemical laboratories.**
  - **Radioisotopes can be prepared by bombarding stable isotopes with fast-moving alpha particles, protons, or neutrons.**

$$^{98}_{42}\text{Mo} + ^{1}_{0}\text{n} \rightarrow ^{99}_{42}\text{Mo}$$

Nuclear Medicine:
using radioscopes for diagnosis and imaging



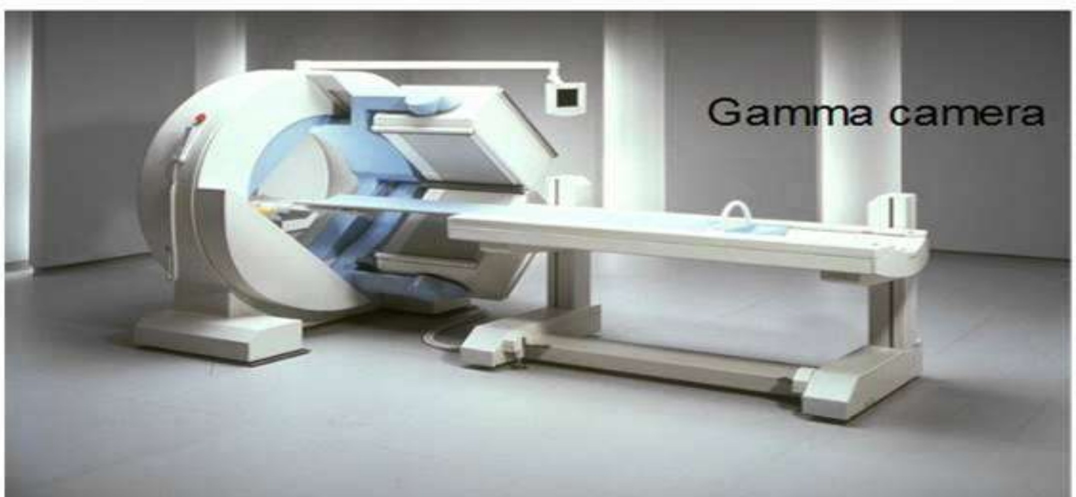


We can use radioisotopes inside the body and detect the emitted gamma photons externally to give us an image.

Benefits of Using Technetium-99m

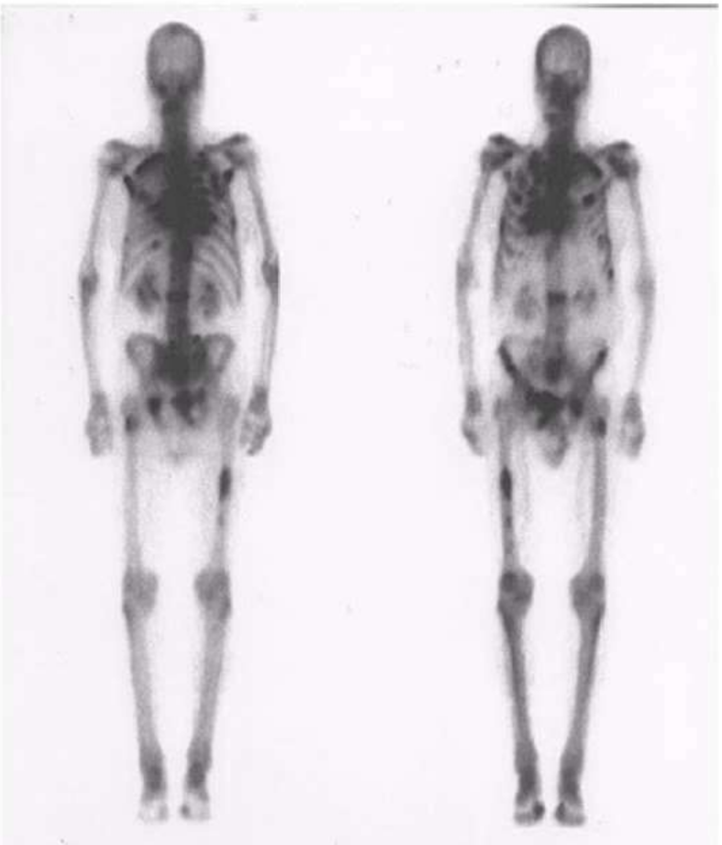
- Safer
- Environmental friendly
- Less damage
- Efficient
- Precise
- Minimises radiation does

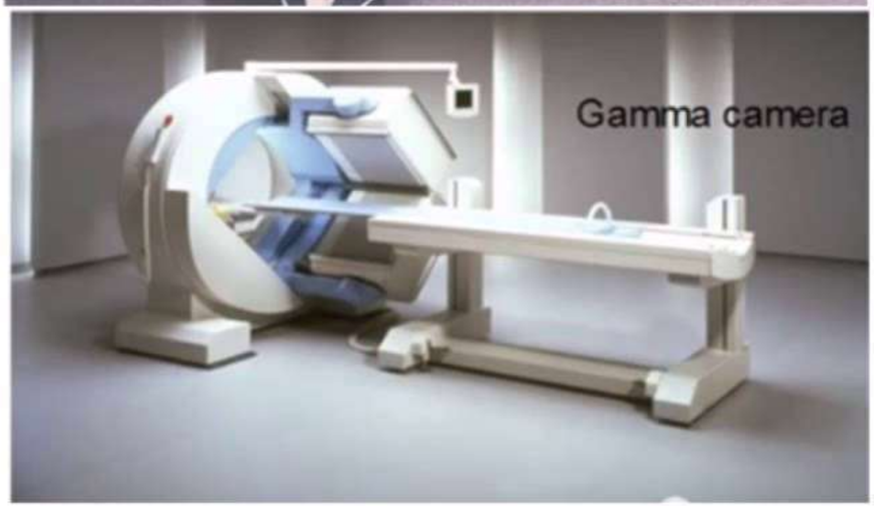
X-Ray



Gamma camera

Gamma rays detected by Gamma camera

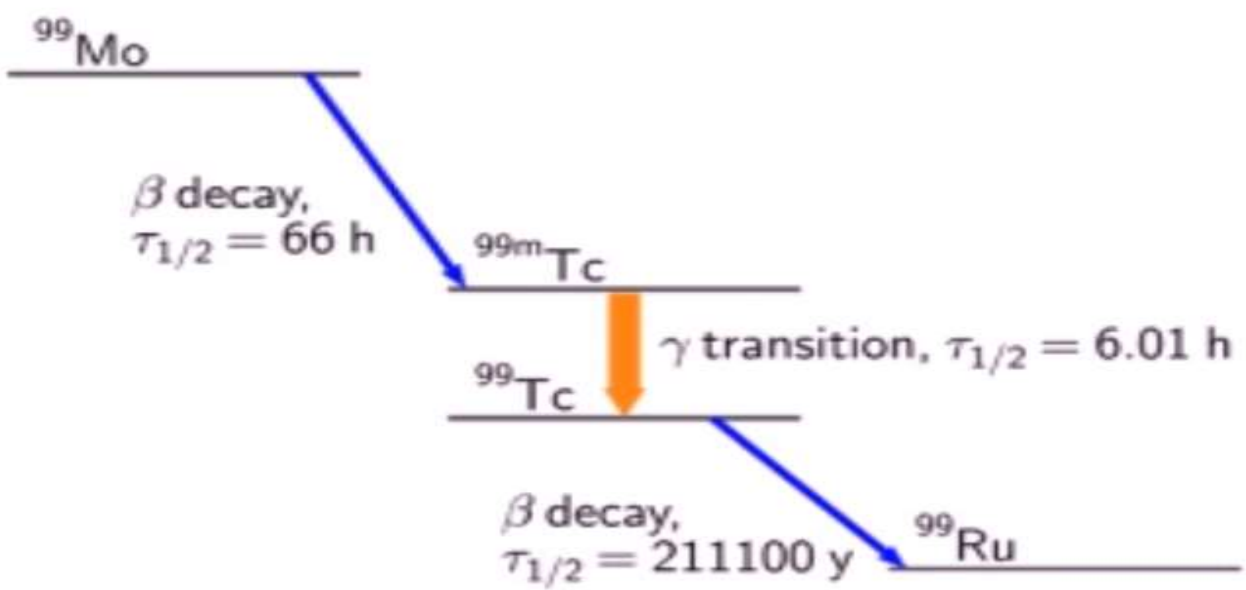


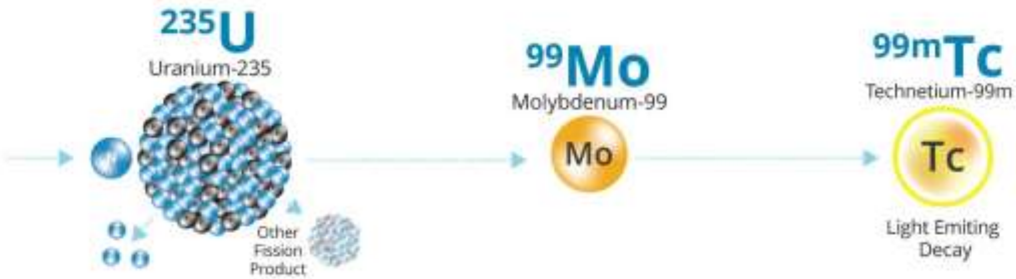


A useful gamma emitter is Technetium-99m. It is a product of the decay of molybdenum-99.

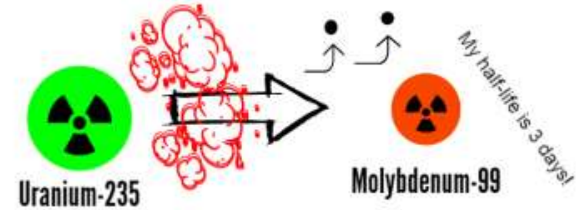
The following decay chain shows how Tc-99m is produced.

${}^{99}_{42}\mathrm{Mo} \longrightarrow {}^{99}_{43}\mathrm{Tc}^{\mathrm{m}} + {}^{0}_{-1}\mathrm{e} + \bar{\nu}$	half-life 67 h
${}^{99}_{43}\mathrm{Tc}^{\mathrm{m}} \longrightarrow {}^{99}_{43}\mathrm{Tc} + \gamma$	half-life 6 h
${}^{99}_{43}\mathrm{Tc}$ decays by β emission	half-life 2.1×10^{5} years

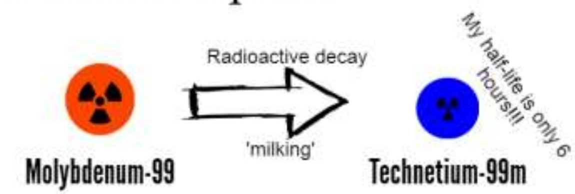




In the Nuclear Reactor:

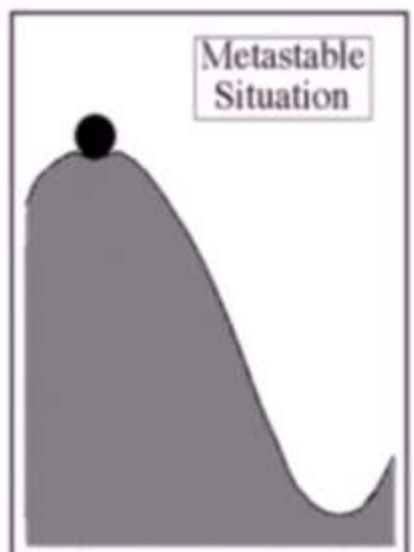


At the Hospital

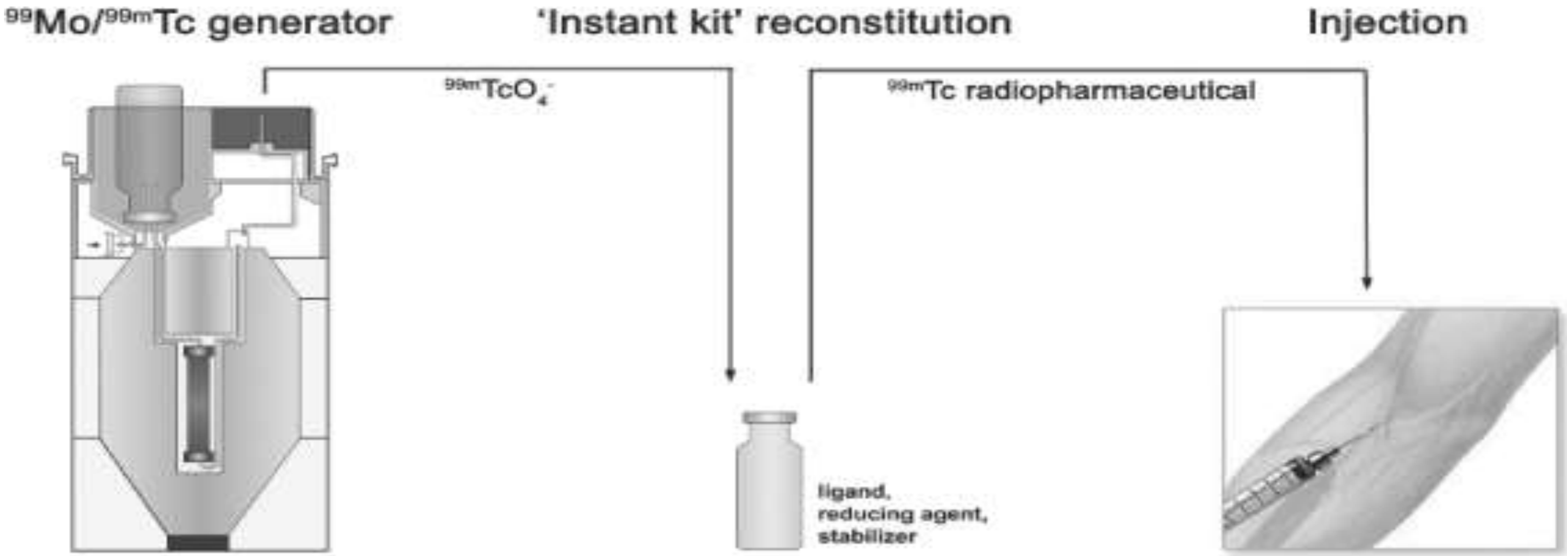


$^{99}_{43}\mathrm{Tc}^{m}$

The m indicates that the technetium produced is **metastable** - ie after the decay from molybdenum it will remain in an excited state for far longer than usual (i.e. a half life of a few hours) before releasing the gamma photon.



The gamma ray has an energy of 140 keV.



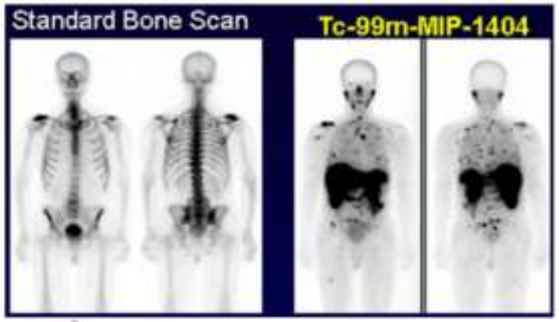
The molybdenum-99 is adsorbed onto alumina (Al_2O_3) in a **technetium generator,** in the form of molybdate, MoO_4^{2-}.

As it decays it forms **pertechnetate, TcO_4^-**.

As the pertechnetate is only singly ionised it is less tightly bound to the alumina, pulling saline solution through the alumina under pressure is enough to release the pertechnetate.

It dissolves in the saline solution, running out into an elution vial (or collection vessel) as **sodium pertechnetate**.

Radiopharmaceutical tracers



The radioisotope is chemically bonded to other molecules that are taken up by the tissue type that the medic wants to image.

For a bone scan, Tc-99m is bonded to a phosphor containing chemical.

Because they are designed to target particular body organs, these chemicals are known as **tracers**.

Imaging the body with the gamma camera

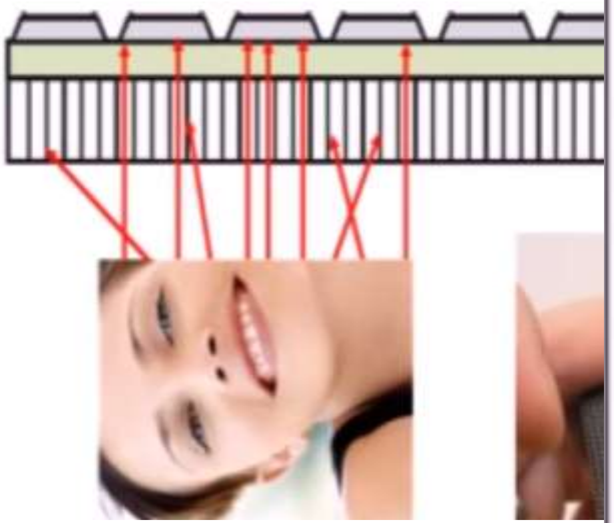
The gamma camera is a device that detects the gamma rays emerging from the body of the patient.

It's main parts are

- the collimator
- the scintillator
- an array of photomultiplier tubes
- a computer

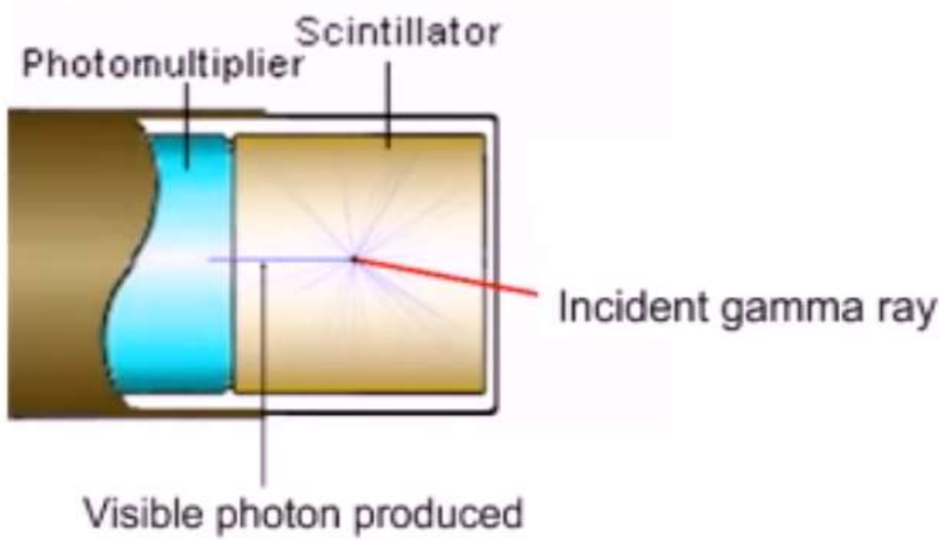
The collimator

The collimator is a honeycomb of cylindrical tubes in lead shielding. It prevents gamma rays entering the camera at large angles and lets in only those gamma rays that are normally incident on the camera.

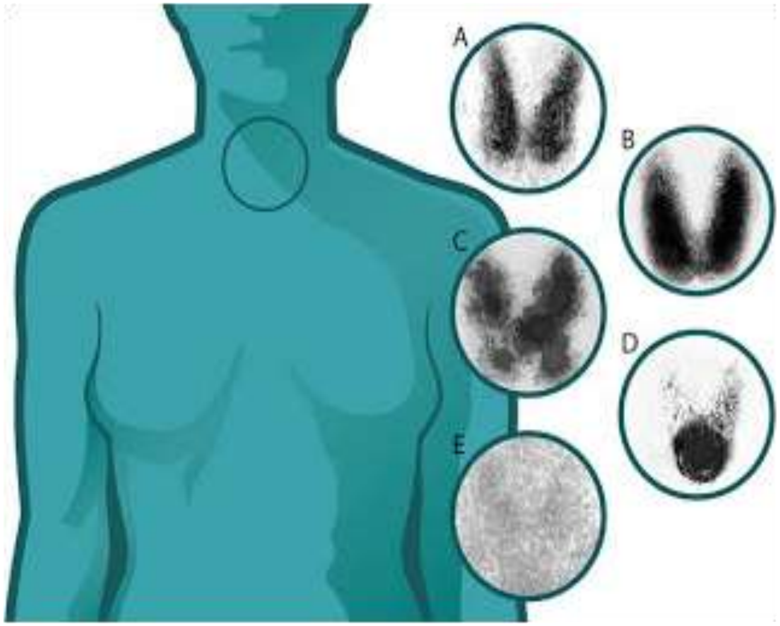


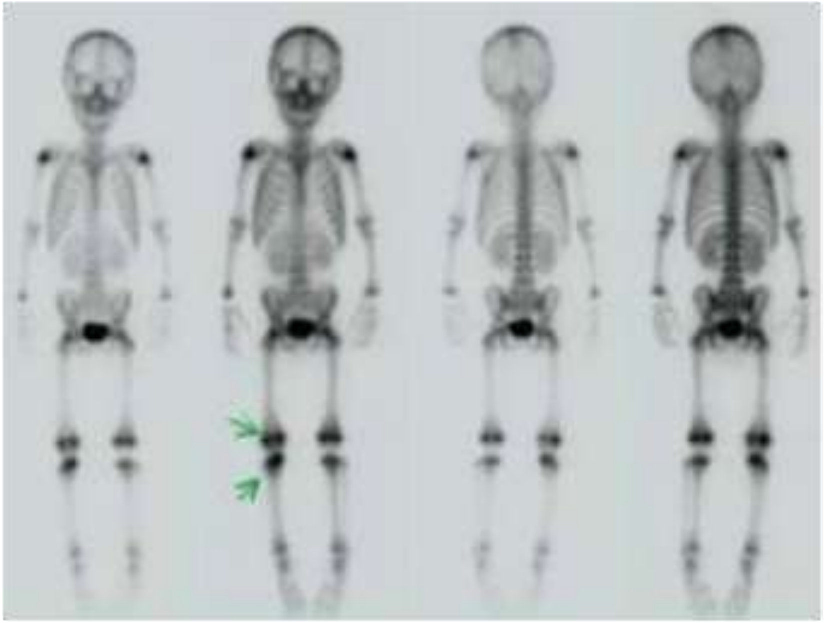
The scintillator

The scintillator is a very large single crystal (50cm diameter and 1cm thick) of sodium iodide, with about 0.5% thallium iodide. When a gamma ray strikes the crystal it can give off a flash of light (scintillate) with an efficiency of about 1 in 10.



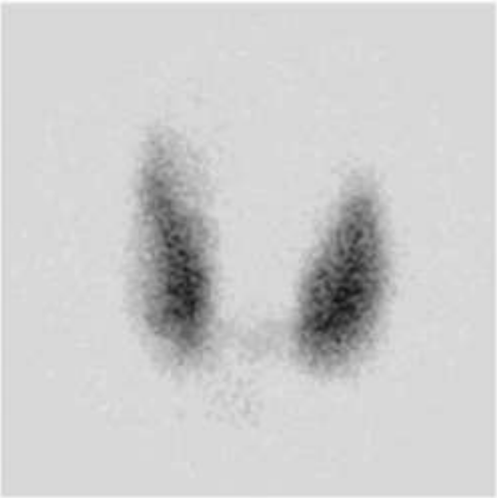
Medical Applications for Radioisotopes



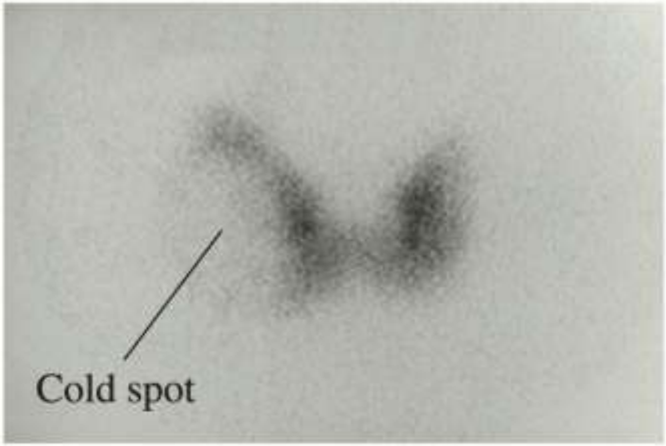


Medical Applications for Radioisotopes

- It is important to expose patients to the smallest possible dose of radiation for the shortest time period.
- Radioisotopes with short half-lives are selected for use in nuclear medicine.
- Iodine is used only by the thyroid gland:



(a)



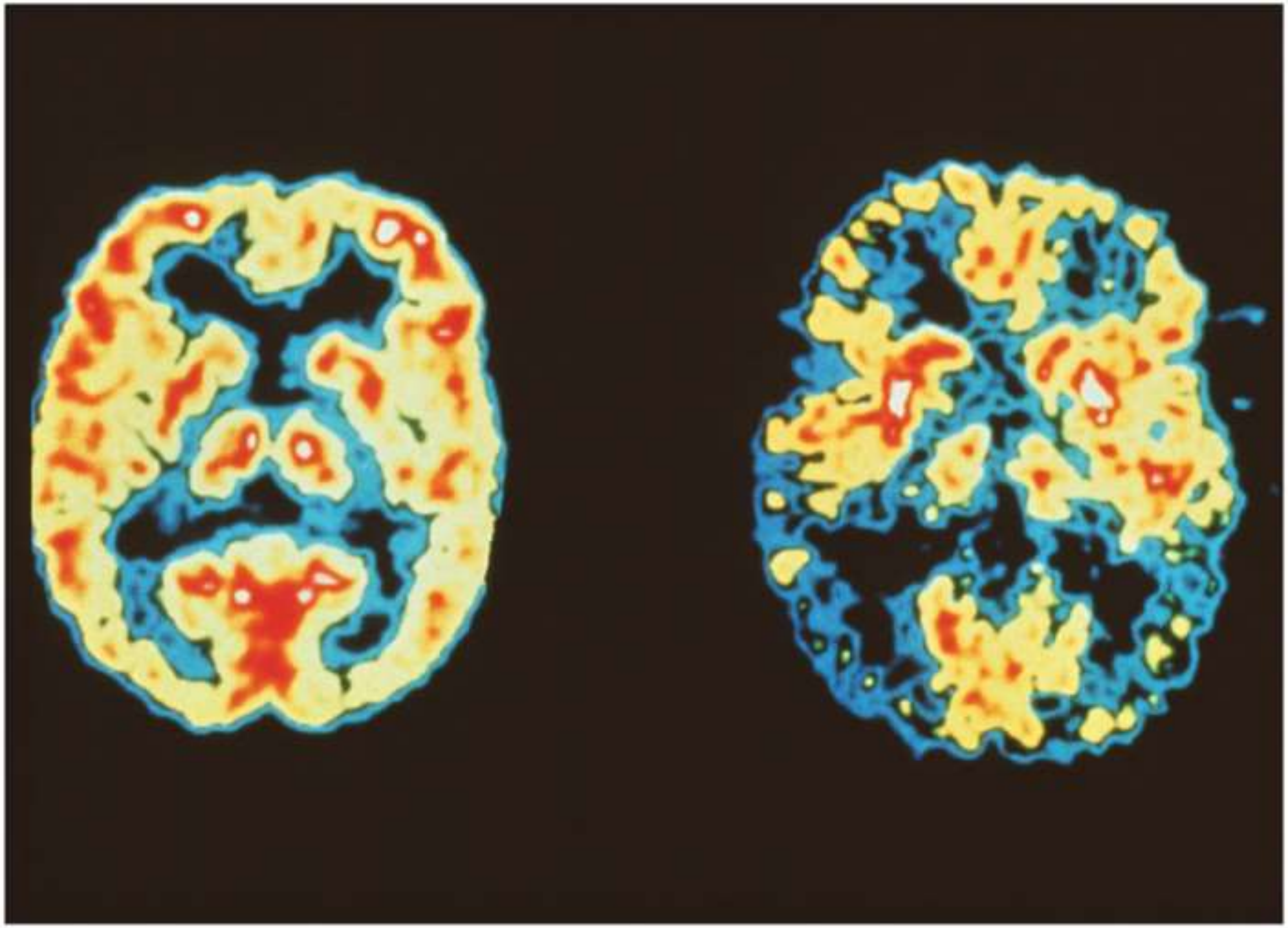
(b)

Radioisotope tracers used in medecine.

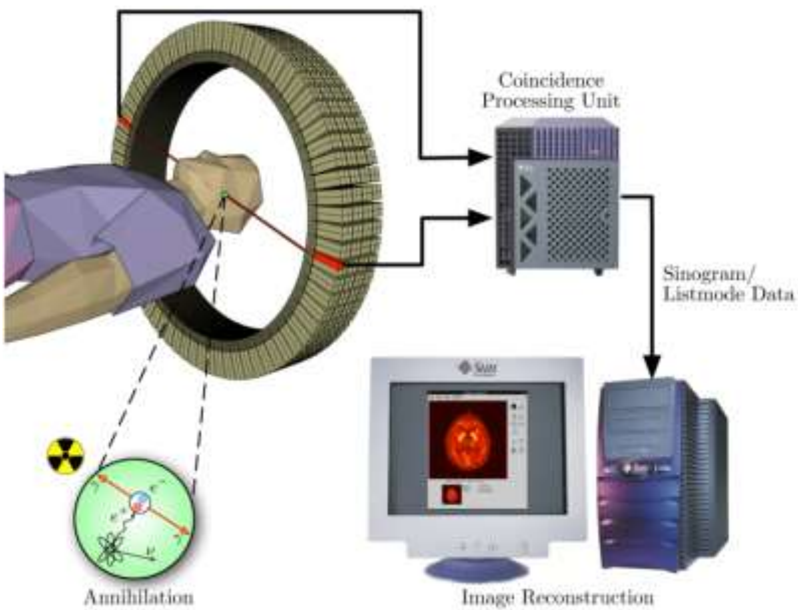
Radioisotope	Uses
fluorine-18 ($^{18}_{9}F$)	bone imaging
technetium-99m ($^{99}_{43}Tc^{m}$)	bone growth blood circulation in lung, brain and liver function of heart and liver
iodine-123 ($^{123}_{53}I$)	function of thyroid function of kidney
xenon-133 ($^{133}_{54}Xe$)	function of lung

Medical Applications for Radioisotopes

- **Positron Emission Tomography**



Beta Plus Decay Application – Positron emission tomography (PET)



Positron emission tomography (**PET**) is a nuclear medicine imaging technique which produces a three-dimensional image or picture of functional processes in the body. The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologically active molecule. Images of tracer concentration in 3-dimensional space within the body are then reconstructed by computer analysis.

SUMMARY

- ✓ **Brief summary of Nuclear physics & Radioactivity**
  - ✓ **Structure**
  - ✓ **Radioactivity**
- ✓ **Medical Applications for Nuclear physics and radioactivity**
  - ✓ **Gamma ray based imaging**
  - ✓ **PET scan**

References

Fundamentals of Physics 8-10th Edition by David Halliday, Robert Resnick (Author), Jearl Walker (Author) and Online textbook

Bushong S.C., (2004) Radiological science for technologists: Physics, Biology and Protection, 8th Ed. Mosby, St Louis

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