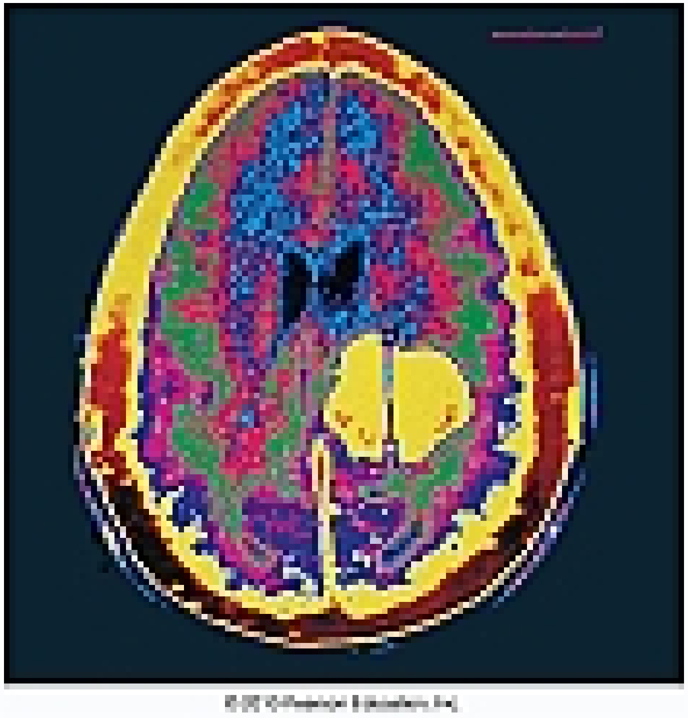


A CT scan (computed tomography) of the brain using X-ray beams

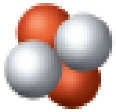
A **radioactive isotope** has an unstable nucleus;
it emits radiation to become more stable and
can be one or more of the isotopes of an element

TABLE 4.1 Stable and Radioactive Isotopes of Some Elements

Magnesium	Iodine	Uranium
Stable Isotopes		
${}^{24}_{12}Mg$	${}^{127}_{53}I$	None
Magnesium-24	Iodine-127	
Radioactive Isotopes		
${}^{23}_{12}Mg$	${}^{125}_{53}I$	${}^{235}_{92}U$
Magnesium-23	Iodine-125	Uranium-235
${}^{27}_{12}Mg$	${}^{131}_{53}I$	${}^{238}_{92}U$
Magnesium-27	Iodine-131	Uranium-238

Alpha (α) particle

is two protons and two neutrons, a helium nucleus



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

Beta (β) particle

is a high-energy electron

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

Positron (β+)

is a positive electron (an extract from a proton)

$^{0}_{+1}e$ (or β^{+})

Gamma (γ) ray

is high-energy released from a nucleus in the form of electromagnetic radiation

TABLE 4.3 Properties of Radiation and Shielding Required

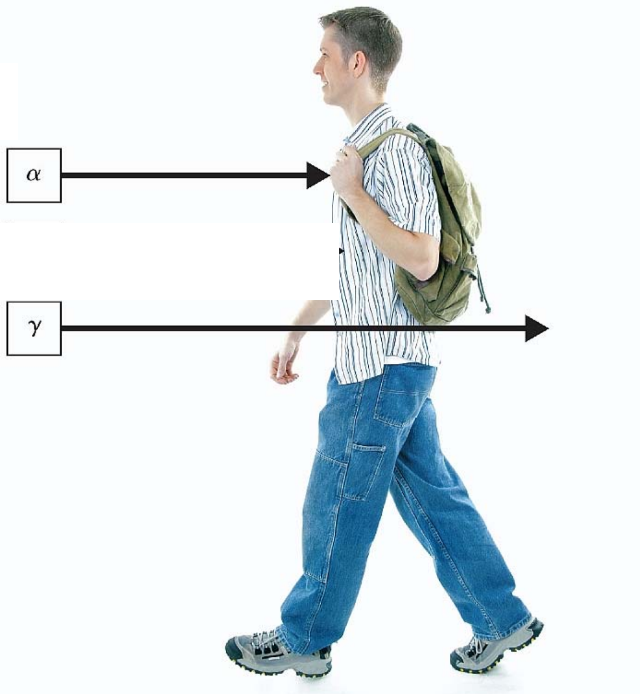
Property	Alpha (α) particle	Beta (β) particle	Gamma (γ) ray
Travel distance in air	2–4 cm	200–300 cm	500 m
Tissue depth	0.05 mm	4–5 mm	50 cm or more
Shielding	Paper, clothing	Heavy clothing, lab coats, gloves	Lead, thick concrete
Typical source	Radium-226	Carbon-14	Technetium-99m

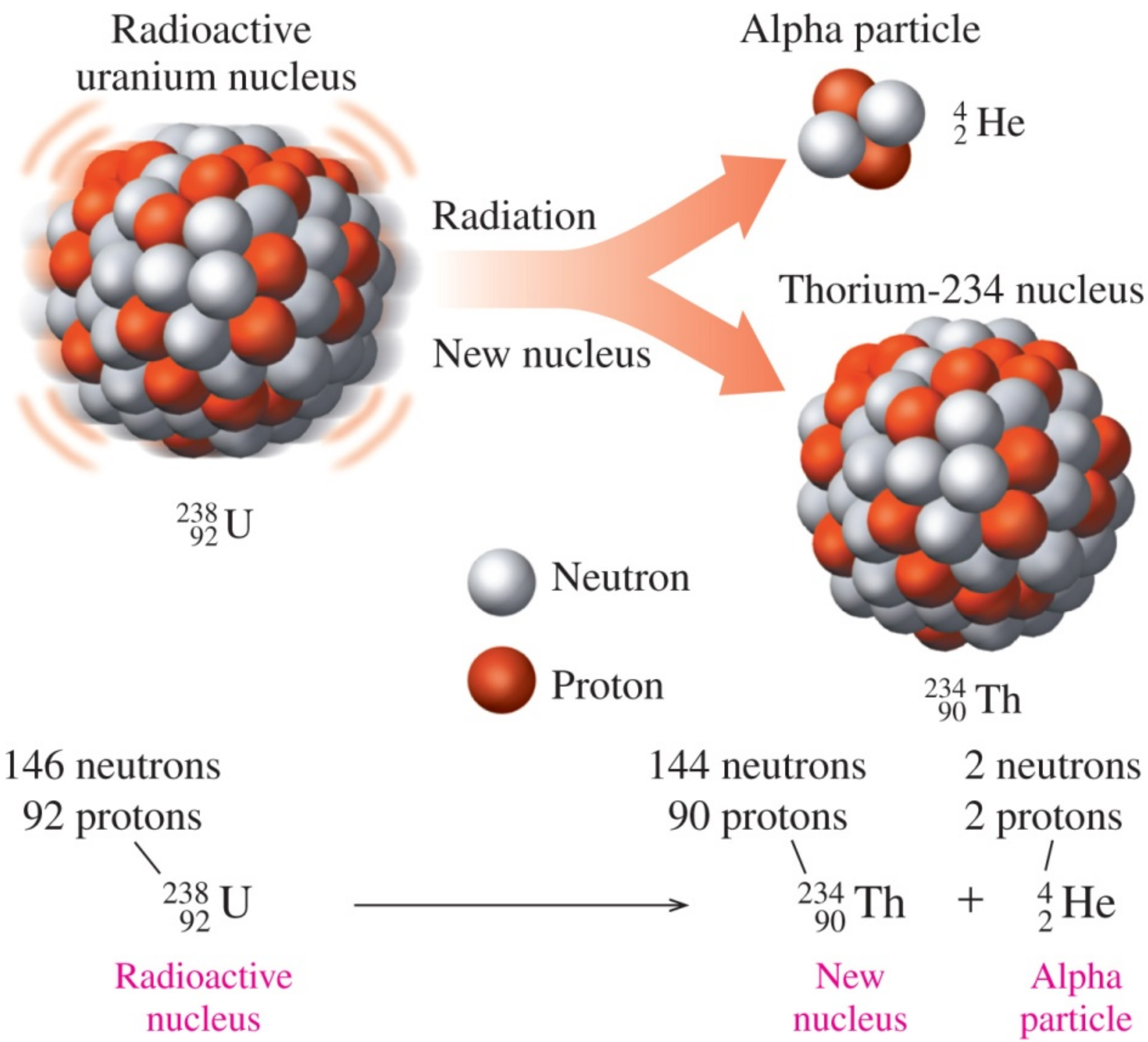
Radiation protection requires

paper and clothing for alpha particles

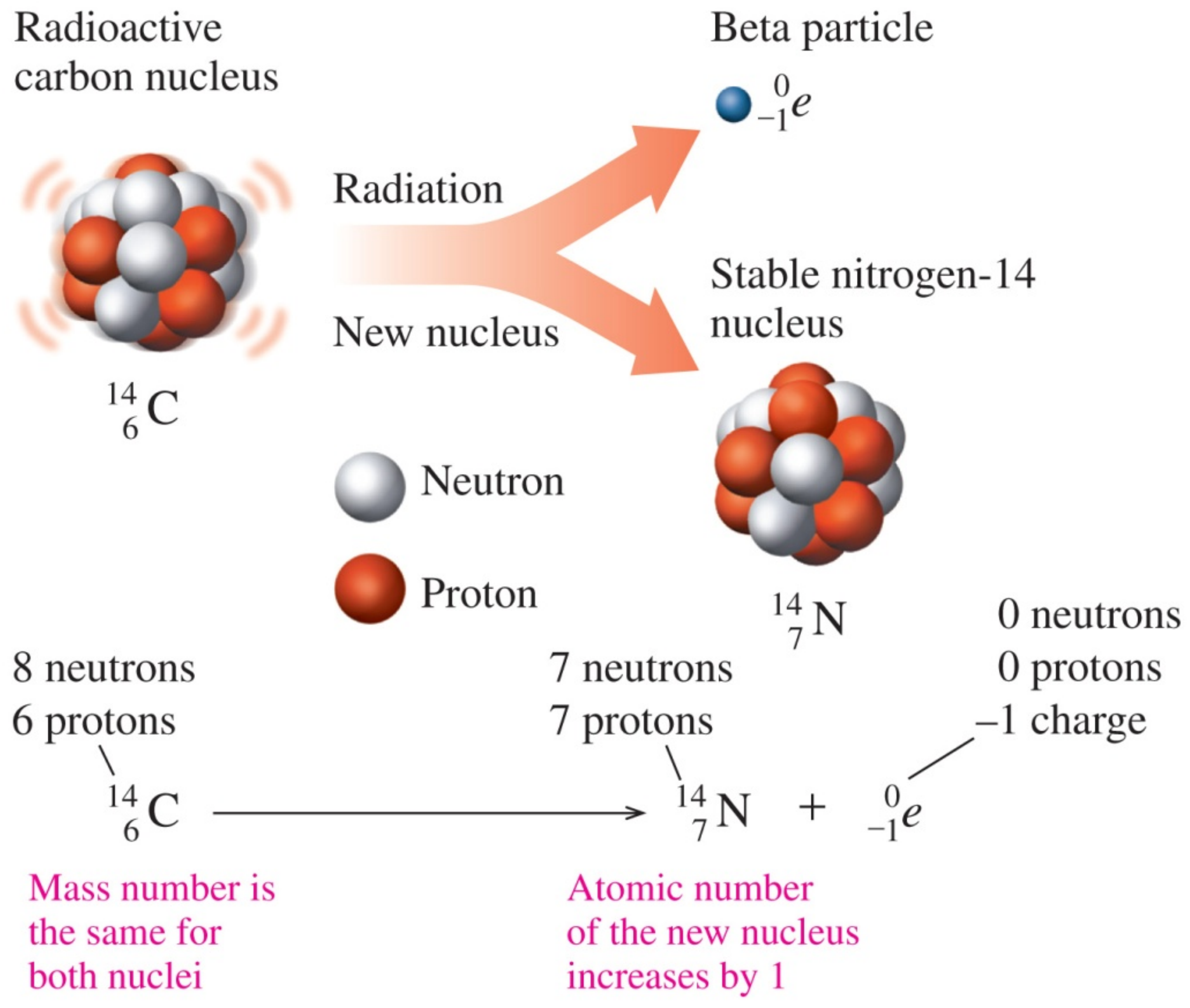
limiting the amount of time spent near a radioactive source

increasing your distance from the source





Note that the atomic mass and atomic number are reversed in the equation but that the sum of the atomic masses and numbers in the reactant (U) equals the sum in the products (Th and He)



Remember that the mass of an electron is very small compared to neutrons and protons and that a neutron can be thought of as a proton and electron combined

Write an equation for the decay of $^{19}K_{42}$ (potassium-42), a beta (electron) emitter.

$$^{19}K_{42} \longrightarrow {}^{-1}e_o + ?$$

Mass number of ?

same (42)

Atomic number of ?

This electron is emitted from the nucleus, not from one of the outer electrons

A neutron must have been split to give an electron and a proton

$$^{0}n_1 = {}^{+}p_1 + {}^{-1}e_0$$

$$^{20}?_{42}$$

$$^{20}Ca_{42}$$

In positron emission, a proton is converted to a neutron and positron, $^{+1}e_0$

$$^{49}Mn_{25} \longrightarrow {}^{+1}e_0 + ?$$

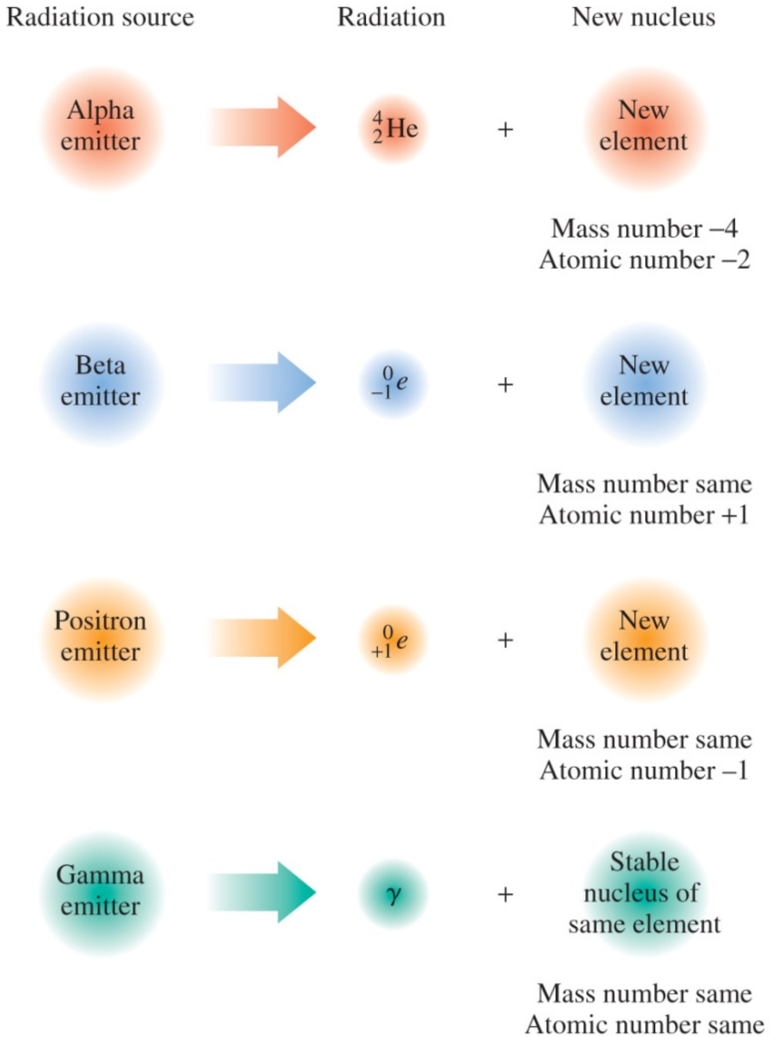
In this case the nucleus loses a positive charge but the mass remains the same

$$^{49}_{25}Mn \rightarrow {}^{49}_{24}? + {}^{0}_{+1}e$$

In **gamma radiation**, energy is emitted from an unstable nucleus, indicated by m following the mass number;

the mass number and the atomic number of the new nucleus are for the same element

$$^{99m}_{43}\mathrm{Tc} \rightarrow {}^{99}_{43}\mathrm{Tc} + {}^{0}_{0}\gamma$$



A summary of the different types of radioactivity

When an alpha particle collides and cools down, it becomes helium atom by extracting 2 electrons from its collision partner

The emitted electron gets captured by its collision partner

A positron eventually collides with an electron and gamma radiation is given off

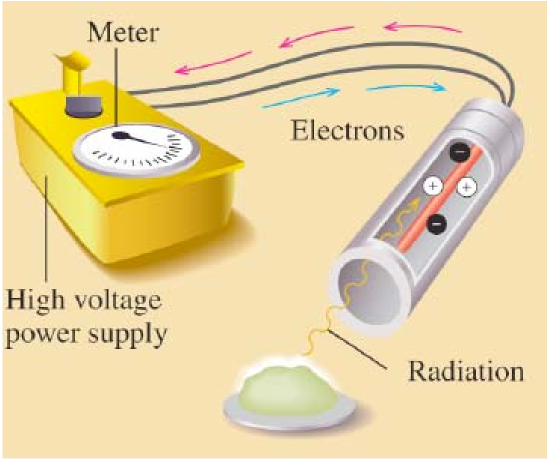
When a gamma ray is absorbed it usually causes the loss of electrons from the absorber and subsequent chaos (bonds breaks)

TABLE 4.4 Mass Number and Atomic Number Changes due to Radiation

Decay Process	Radiation Symbol	Change in Mass Number	Change in Atomic Number	Change in Neutron Number
Alpha emission	^4_2He	−4	−2	−2
Beta emission	$^{0}_{-1}e$	0	+1	−1
Positron emission	$^{0}_{+1}e$	0	−1	+1
Gamma emission	$^{0}_{0}\gamma$	0	0	0

Radiation Measurement

A Geiger counter detects beta and gamma radiation;
uses ions produced by radiation to create an electrical current



Units of radiation include:

curie (Ci)- measures activity as the number of atoms that decay in one second

rad (radiation absorbed dose) **-** measures the radiation absorbed by the tissues of the body

rem (radiation equivalent) - measures the biological damage caused by different types of radiation

Exposure to radiation occurs from:

naturally occurring radioisotopes
medical and dental procedures
air travel, radon, smoking
cigarettes, and eating

TABLE 4.11 Radiation Doses Used for Diagnostic and Therapeutic Procedures

Organ/Condition	Dose (rem)
Diagnostic	
Liver	0.3
Thyroid	50.0
Lung	2.0
Therapeutic	
Lymphoma	4500
Skin cancer	5000–6000
Lung cancer	6000
Brain tumor	6000–7000

TABLE 4.6 Average Annual Radiation Received by a Person in the United States

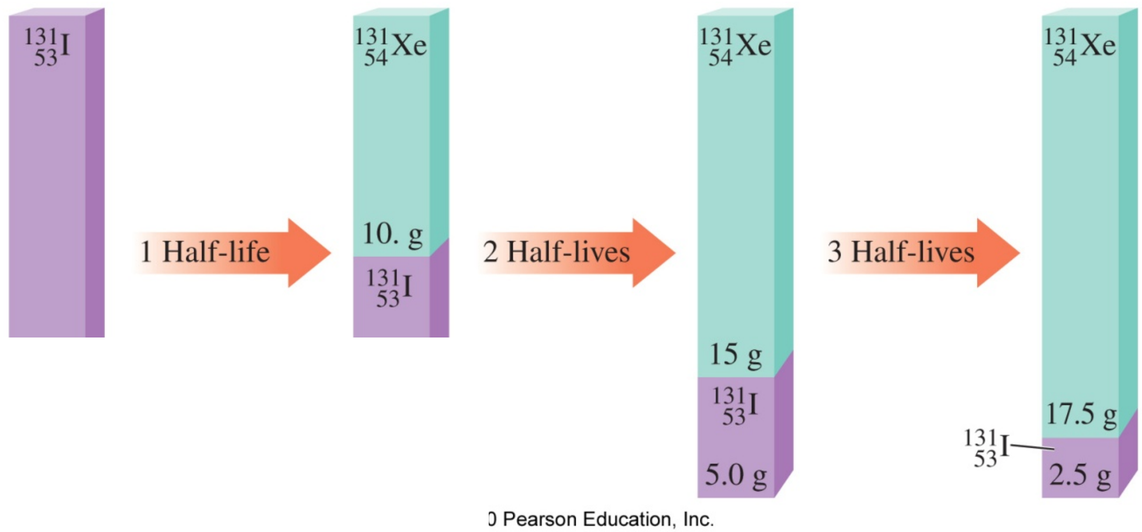
Source	Dose (mrem)
Natural	
The ground	20
Air, water, food	30
Cosmic rays	40
Wood, concrete, brick	50
Medical	
Chest X-ray	20
Dental X-ray	20
Hip X-ray	60
Lumbar spine X-ray	70
Mammogram	40
Upper gastrointestinal tract X-ray	200
Other	
Television	20
Air travel	10
Radon	200[a]

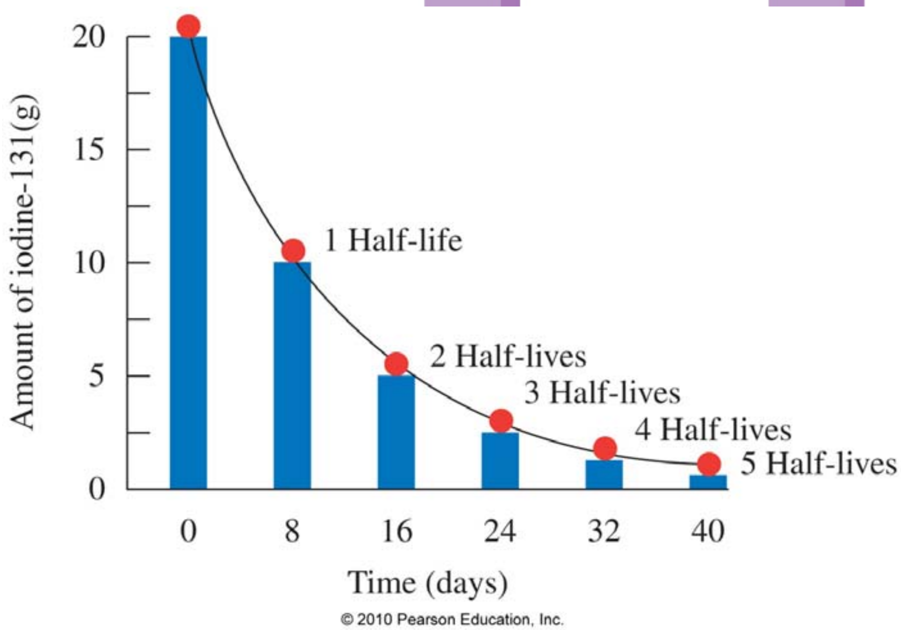
[a]Varies widely.

Half-Life of a Radioisotope

The **half-life** of a radioisotope is the time for the radiation level to decrease (decay) to one-half of the original value.

$t_{1/2}$ (I_2) = 8 days





Radioisotopes that are naturally occurring tend to have long half-lives; those used in nuclear medicine have short half-lives

TABLE 4.9 Half-Lives of Some Radioisotopes

Element	Radioisotope	Half-Life
Naturally Occurring Radioisotopes		
Carbon	$^{14}_{6}C$	5730 y
Potassium	$^{40}_{19}K$	1.3×10^9 y
Radium	$^{226}_{88}Ra$	1600 y
Uranium	$^{238}_{92}U$	4.5×10^9 y
Some Medical Radioisotopes		
Chromium	$^{51}_{24}Cr$	28 d
Iodine	$^{131}_{53}I$	8 d
Iron	$^{59}_{26}Fe$	44 d
Technetium	$^{99m}_{43}Tc$	6.0 h
Iridium	$^{192}_{77}Ir$	74 d

Radioisotopes with short half-lives are used in nuclear medicine because they have the same

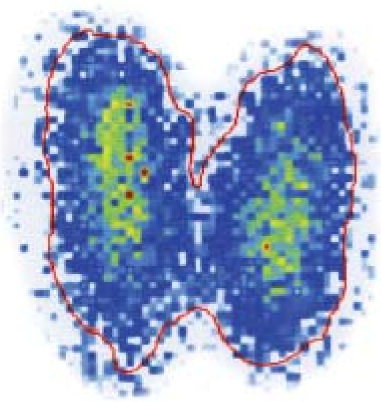
body chemistry as the non-radioactive atoms;

give off radiation that exposes a photographic plate (scan), giving an image of an organ;

obviously some of the radiation should be absorbed by the organ to provide contrast

Can you guess which element in the thyroid is probably responsible for a good fraction of the contast?

$^{53}I_{126.9}$

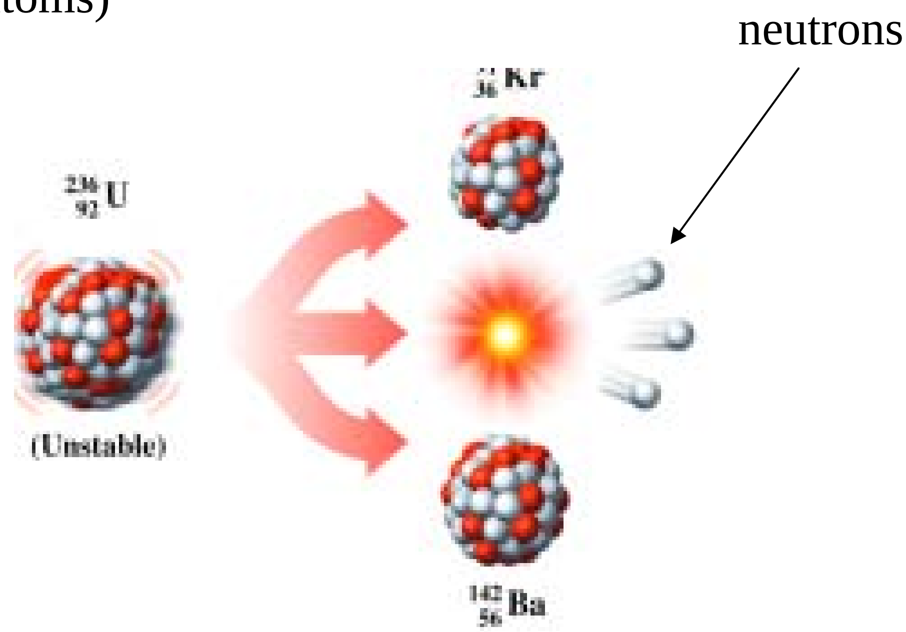


Thyroid scan

TABLE 4.10 Medical Applications of Radioisotopes

Isotope	Half-Life	Medical Application
Ce-141	32.5 days	Gastrointestinal tract diagnosis; measuring blood flow to the heart
Ga-67	78 h	Abdominal imaging; tumor detection
Ga-68	68 min	Detection of pancreatic cancer
P-32	4.3 days	Treatment of leukemia, excess red blood cells, pancreatic cancer
I-125	60 days	Treatment of brain cancer
I-131	8 days	Imaging of thyroid; treatment of Graves' disease, goiter, and hyperthyroidism; treatment of thyroid and prostate cancer
Sr-85	65 days	Detection of bone lesions; brain scans
Tc-99m	6 h	Imaging of skeleton, heart muscle, brain, liver, heart, lungs, bone, spleen, kidney, and thyroid; most widely used radioisotope in nuclear medicine

Nuclear Fission (natural splitting of atoms)



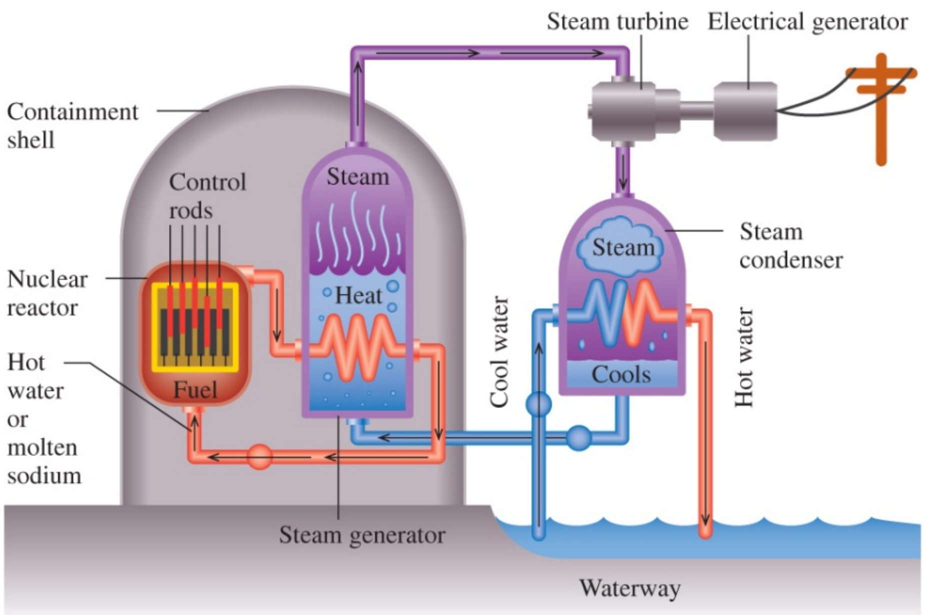
In **nuclear fission**,

a large nucleus is bombarded with a small particle

the nucleus splits into smaller nuclei and several neutrons

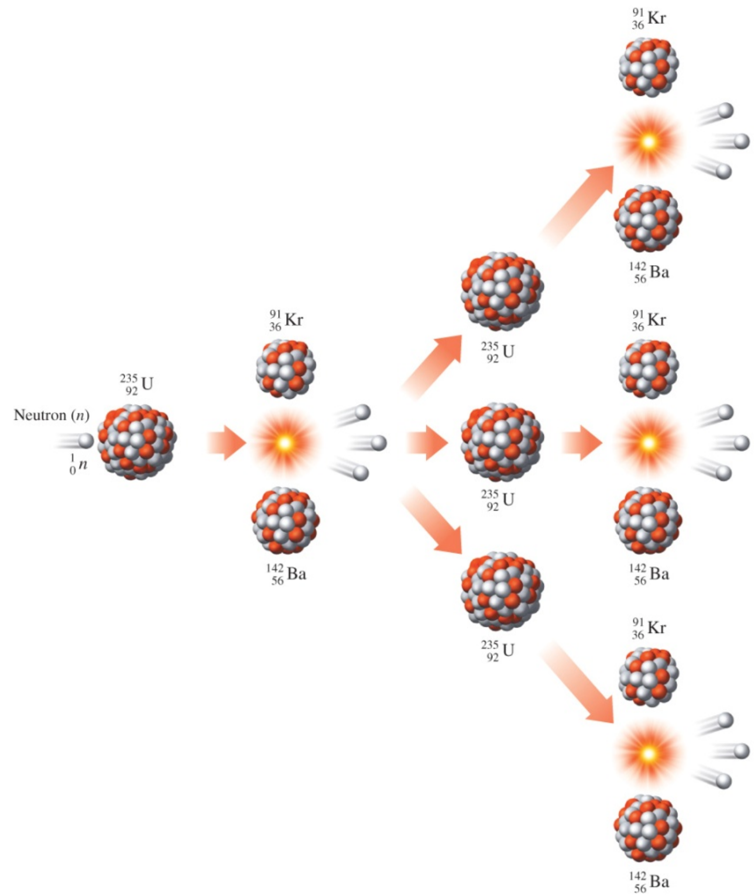
large amounts of energy are released

$$ {}^{1}_{0}n + {}^{235}_{92}\mathrm{U} \rightarrow {}^{236}_{92}\mathrm{U} \rightarrow {}^{91}_{36}\mathrm{Kr} + {}^{142}_{56}\mathrm{Ba} + 3\,{}^{1}_{0}n + \text{energy} $$



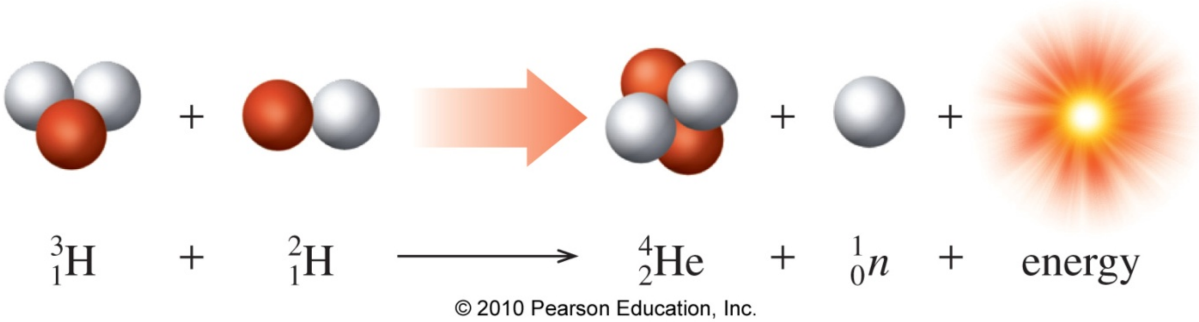
In **nuclear power plants**,
fission is used to produce energy
control rods in the reactor absorb neutrons to slow and control the chain reactions of fission

Chain Reaction



Nuclear fusion

occurs at extremely high temperatures (100 000 000 °C)
combines small nuclei into larger nuclei
releases large amounts of energy
occurs continuously in the sun and stars



Conservation of mass-energy

$E = mc^2$