

Introduction to Radiation: Effects and Uses

Presented by:

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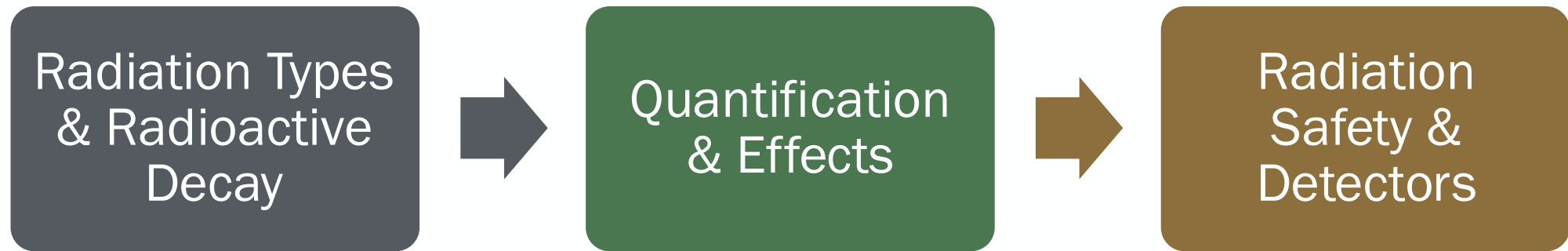
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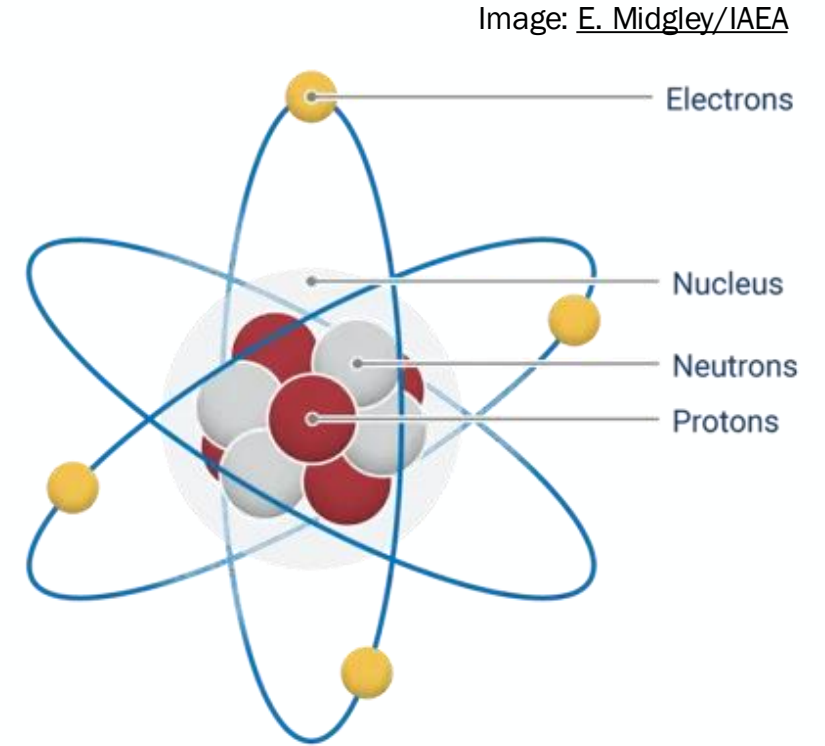
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Outline



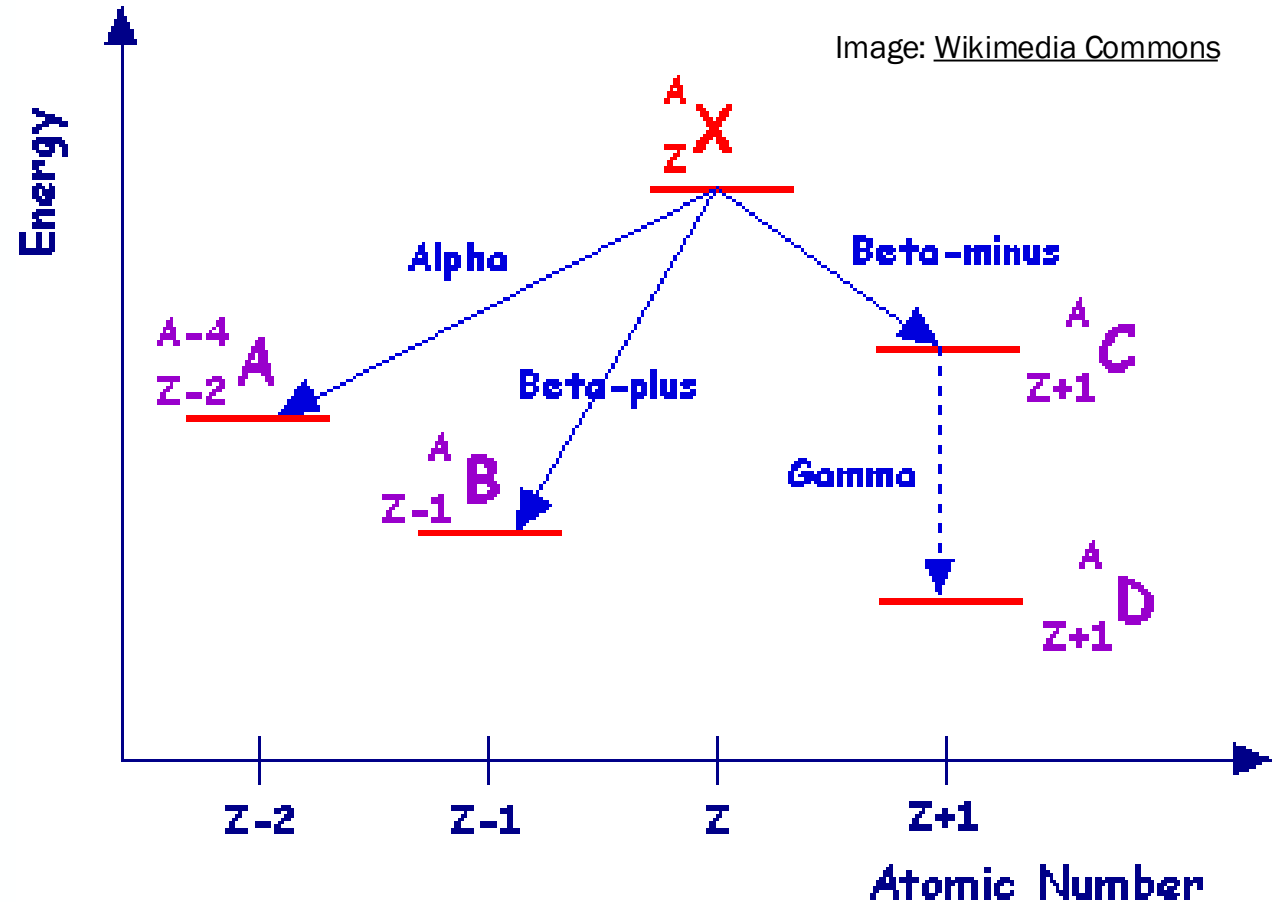
What is an atom?

- Building blocks of all matter
 - Extremely small, made up of subatomic particles
 - **Protons:** Positively charged subatomic particles in the nucleus
 - **Neutrons:** Not charged subatomic particles in the nucleus
 - **Electrons:** Negatively charged subatomic particles surrounding the nucleus
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- Isotopes: Same Z, different A
 - Too many/too few neutrons: unstable
 - **What happens if unstable?**



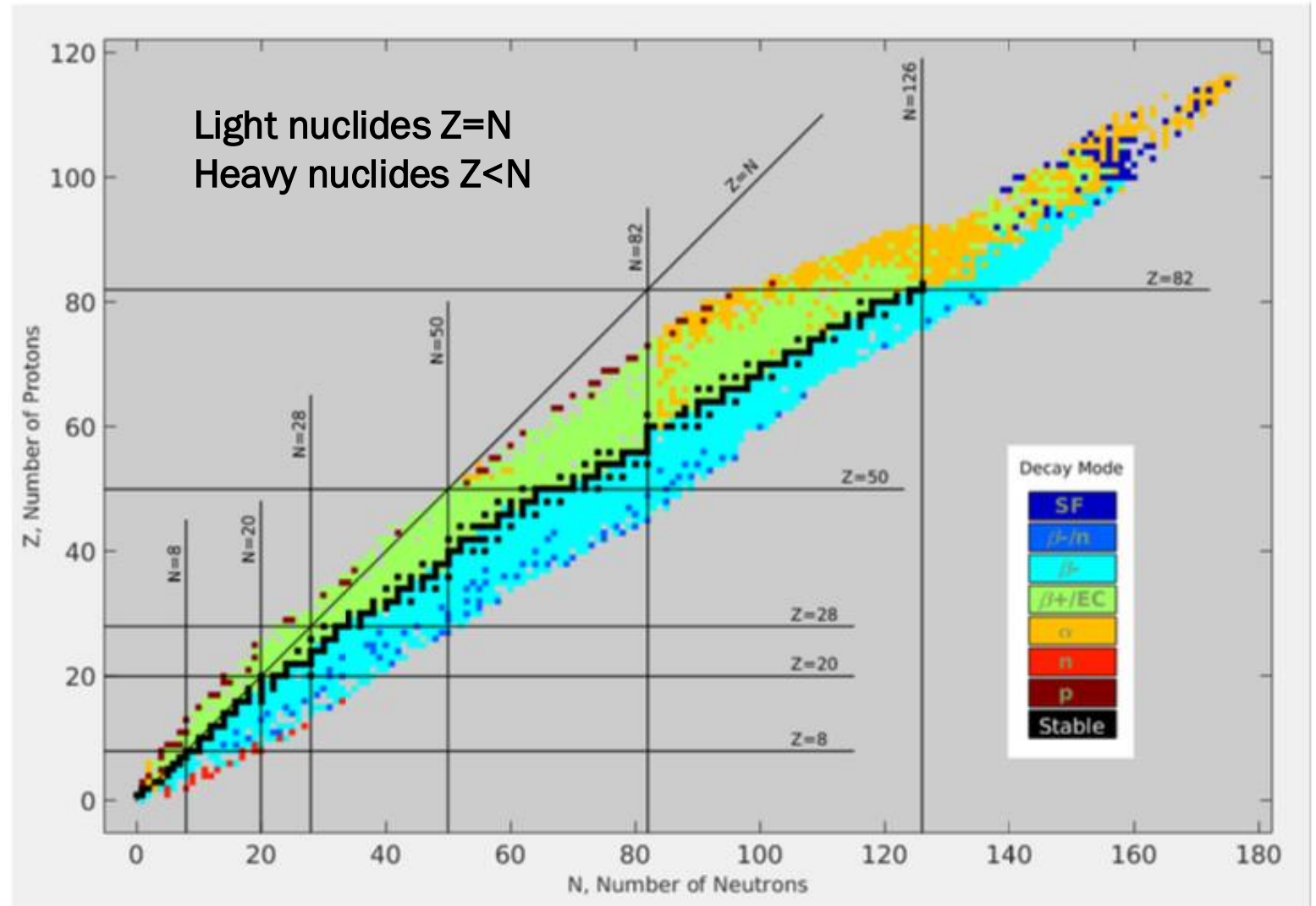
Radioactive decay

- Unstable nucleus loses energy by radiation
- **Undergoes radioactive decay**
- Material is considered radioactive
- Example:
 - Oxygen, O ($Z=8$)
 - Stable isotopes for $N=8,9,10$
 - Unstable/Radioactive: $N=5, 6, 7, 11, 12$ etc.

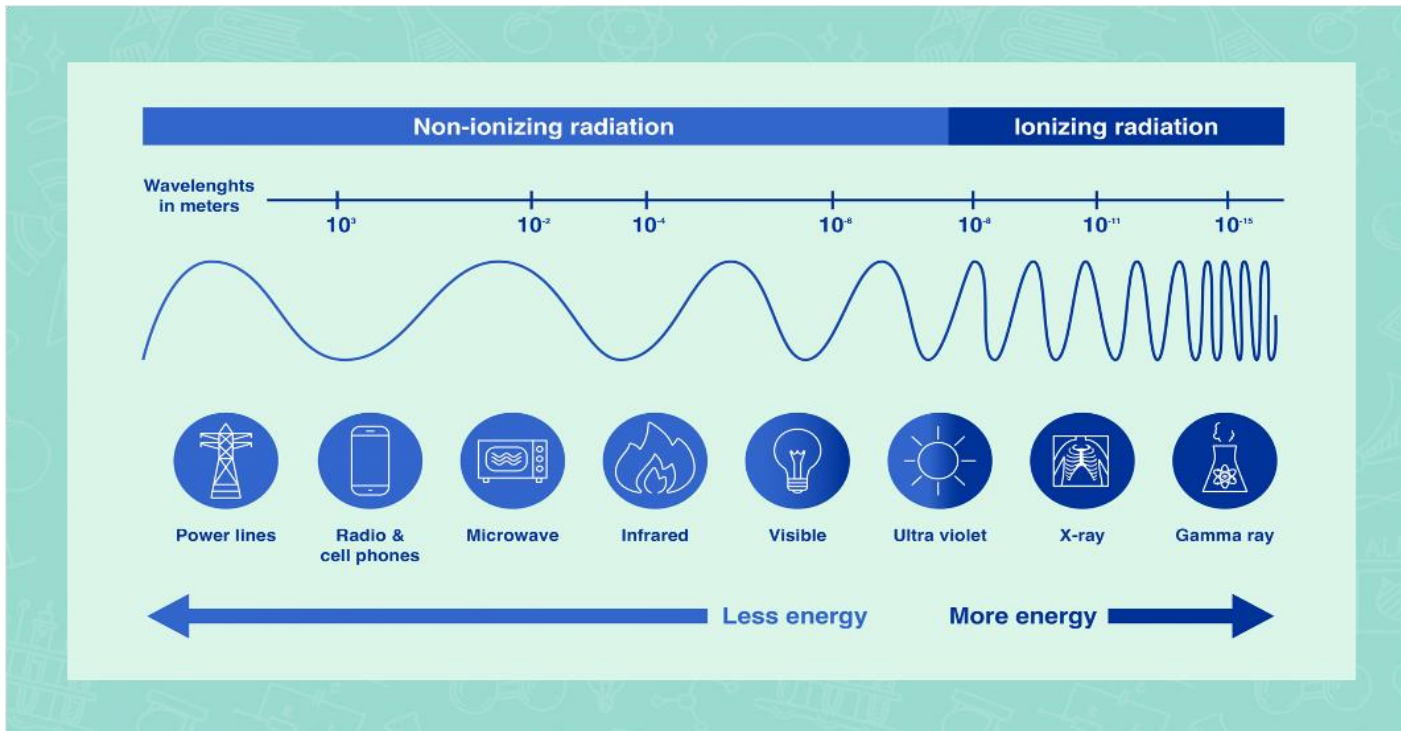


Why are some nuclei radioactive?

- Nucleus: electromagnetic battle for position
- Strong force: holding particles together
- However, repulsion between protons!
- Neutrons: fill the space between protons to minimize repulsion
- **If too many/too few neutrons: radiation is emitted**



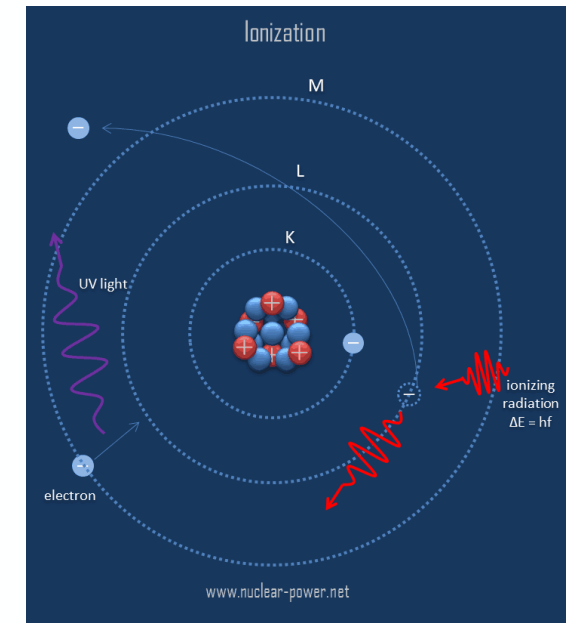
What is radiation?



- Electromagnetic waves or subatomic particles emitted from an atom as it moves from a higher energy state to a lower energy state
- Radiation associated with wavelength
- **Ionization:** Radiation removes electrons from an atom

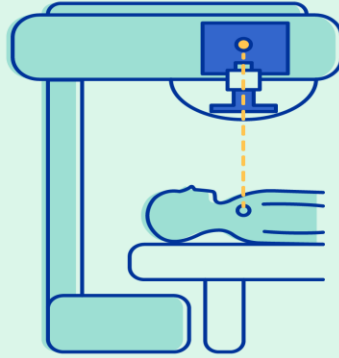
$$E = \frac{hc}{\lambda}$$

Image: [A.Vargas/IAEA](#)

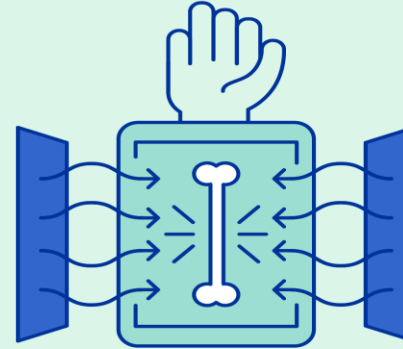


- Ionizing (shorter λ)
 - High energy per photon/particle
 - Can ionize an atom or molecule
 - X-rays, Gamma Rays, neutrons, alpha, beta

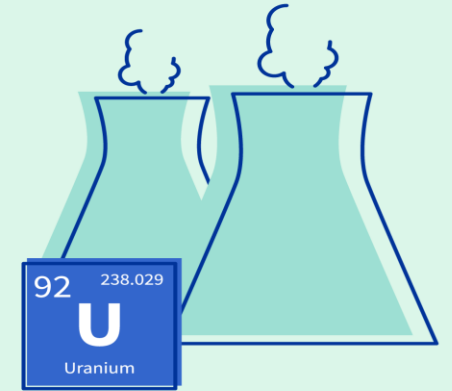
Ionizing Radiation



Certain cancer treatments using gamma rays



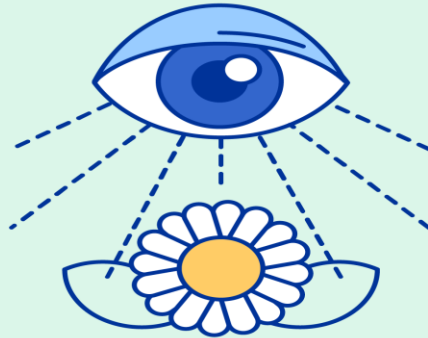
X-rays



Some of the materials used in nuclear power plants

- Non-ionizing (longer λ):
 - Can cause physical damage, burns etc. but cannot ionize atoms/molecules

Non-ionizing Radiation



Visible light



Radio waves



Microwaves

Ionizing radiation

- Radiation safety is focused on ionizing radiation
- Common types:
 - Gamma: high energy EM radiation
 - Alpha: heavy, positively charged particles
 - Beta: smaller particles (electrons)
 - Neutron: neutrons emitted from nucleus
- Direct ionization (e.g., beta, alpha):
 - Charged particles directly strip atoms of their electrons
- Indirect ionization:
 - Particles impart energy into atoms/electrons
 - Electrons are ejected

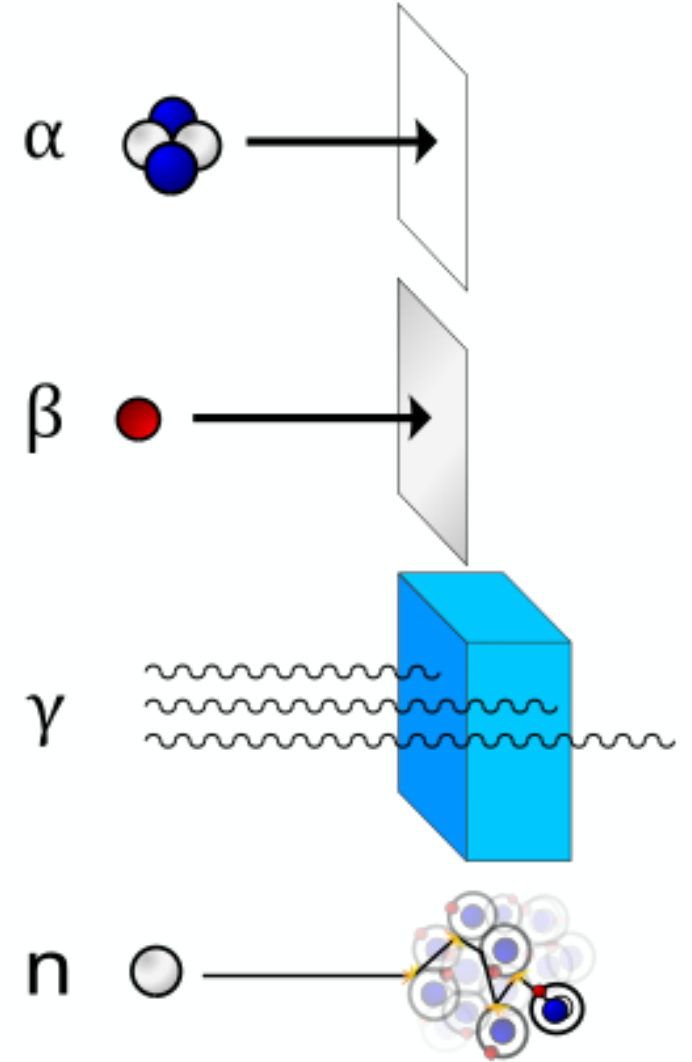
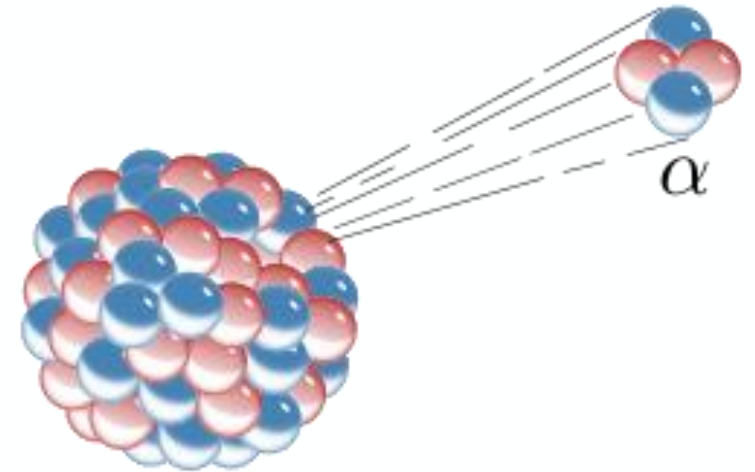


Image: [Wikimedia Commons](#)

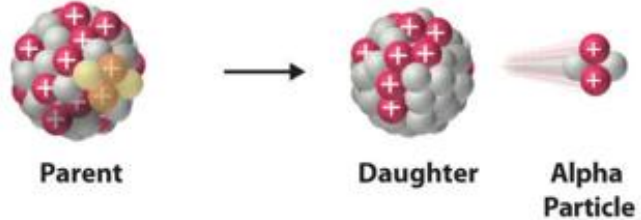
Alpha Radiation

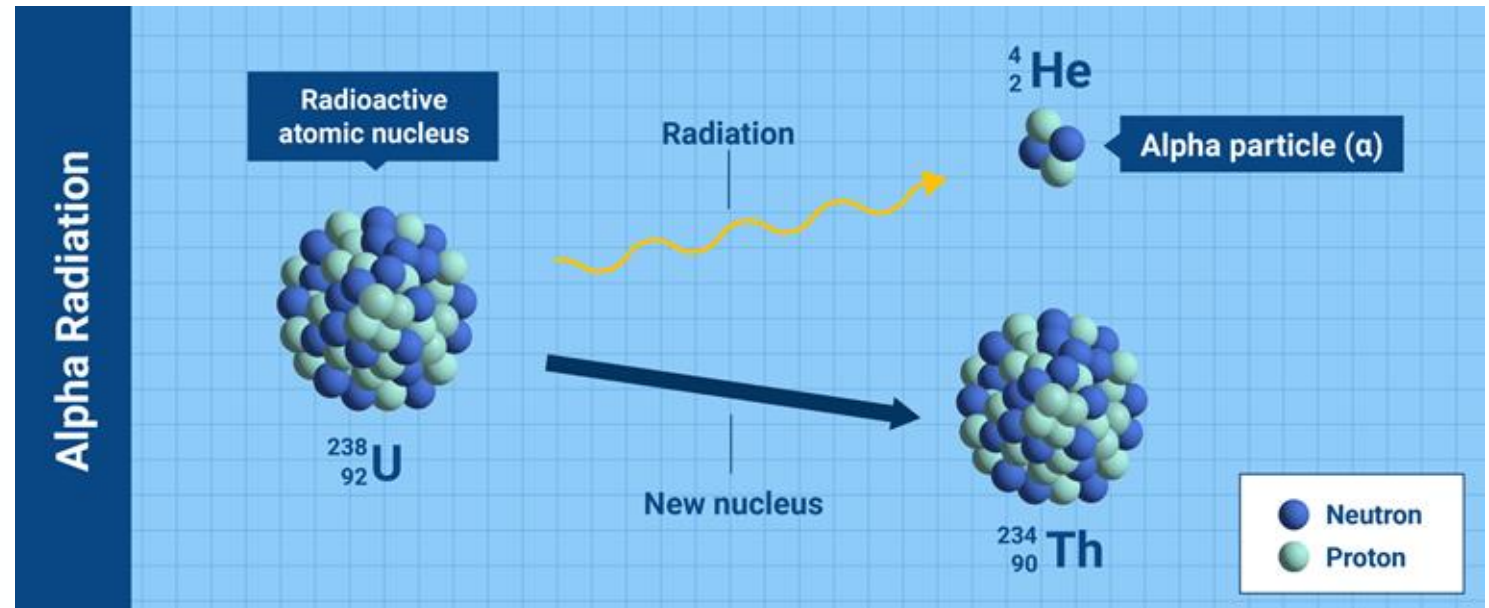
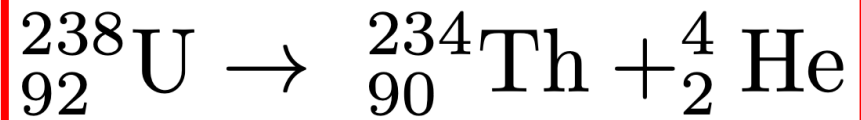
- **Alpha particles:** helium nuclei consisting of two protons and two neutrons
- Commonly emitted in radioactive decay of **highly unstable isotopes**
- Large size and charge: not very penetrating
- Often stopped easily by clothes, skin, paper, etc.
- If an alpha emitter is ingested, it can be particularly dangerous due to alpha's high mass and charge
- Common Sources:
 - Radium
 - Americium-241



Alpha decay

Image: nuclear-power.com

Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	${}^4_2\alpha$	${}^A_ZX \longrightarrow {}^{A-4}_{Z-2}X' + {}^4_2\alpha$	 The model shows a 'Parent' nucleus (a cluster of red '+' protons and grey '-' neutrons) decaying into a 'Daughter' nucleus (a smaller cluster of red '+' protons and grey '-' neutrons) and an 'Alpha Particle' (a cluster of two red '+' protons and two grey '-' neutrons).



Beta Radiation

- **Beta particles:** electrons and positrons
- Commonly produced through **beta decay**
- Lower mass and charge than alphas: slightly more penetrating
- Stopped by skin, plastic, aluminum, etc.
- Similarly to alpha particles, the real danger is upon ingestion of a beta emitter
- Common Sources:
 - Strontium-90
 - Caesium-137
 - Carbon-14

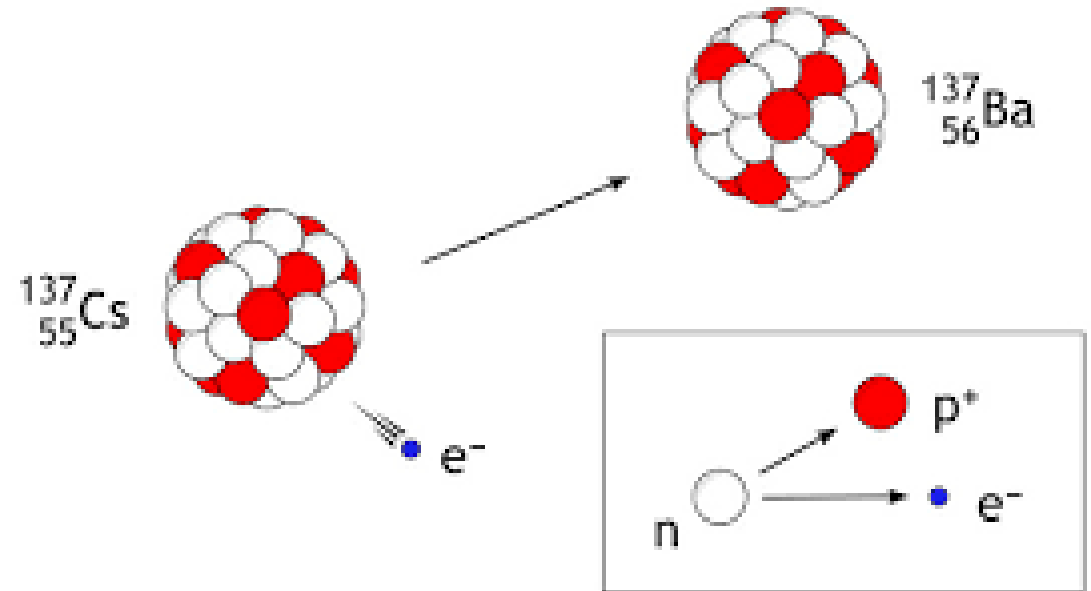


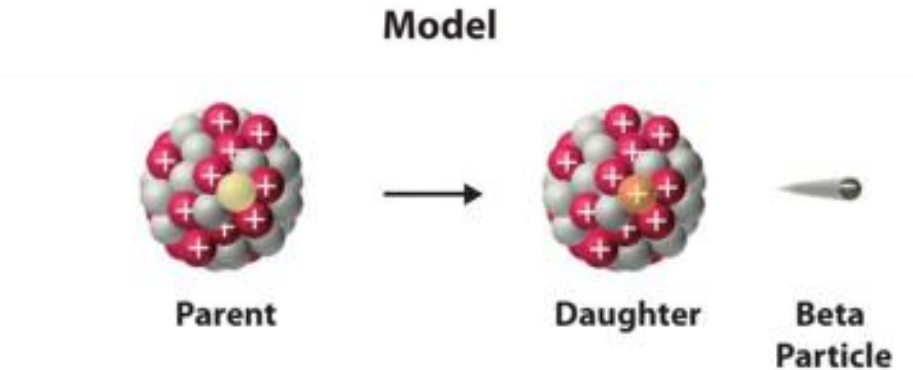
Image: [MikeRun, Wikimedia Commons, CC BY-SA 4.0](#)

Beta decay

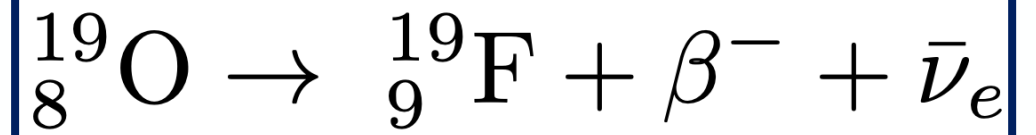
Mass number A stays the same !

Image: nuclear-power.com

Decay Type	Radiation Emitted	Generic Equation
Beta decay	${}_{-1}^0\beta$	${}_Z^AX \longrightarrow {}_{Z+1}^AX' + {}_{-1}^0\beta$



Too many neutrons, β -decay:



Too few neutrons, β^{+} -decay:

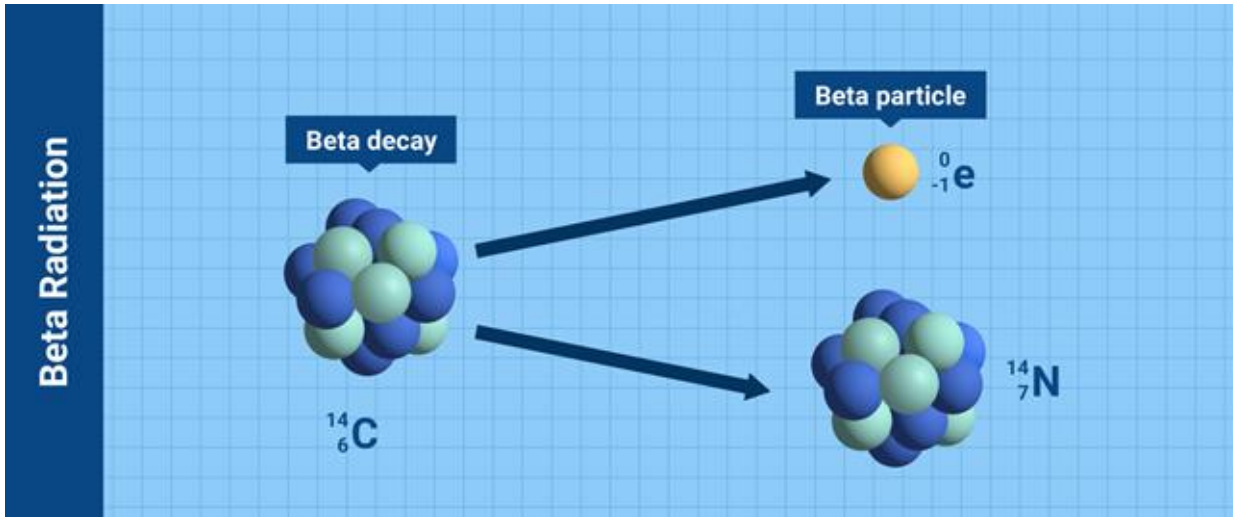


Image: A.Vargas/IAEA

Gamma Radiation

Gamma Decay

ScienceFacts.net

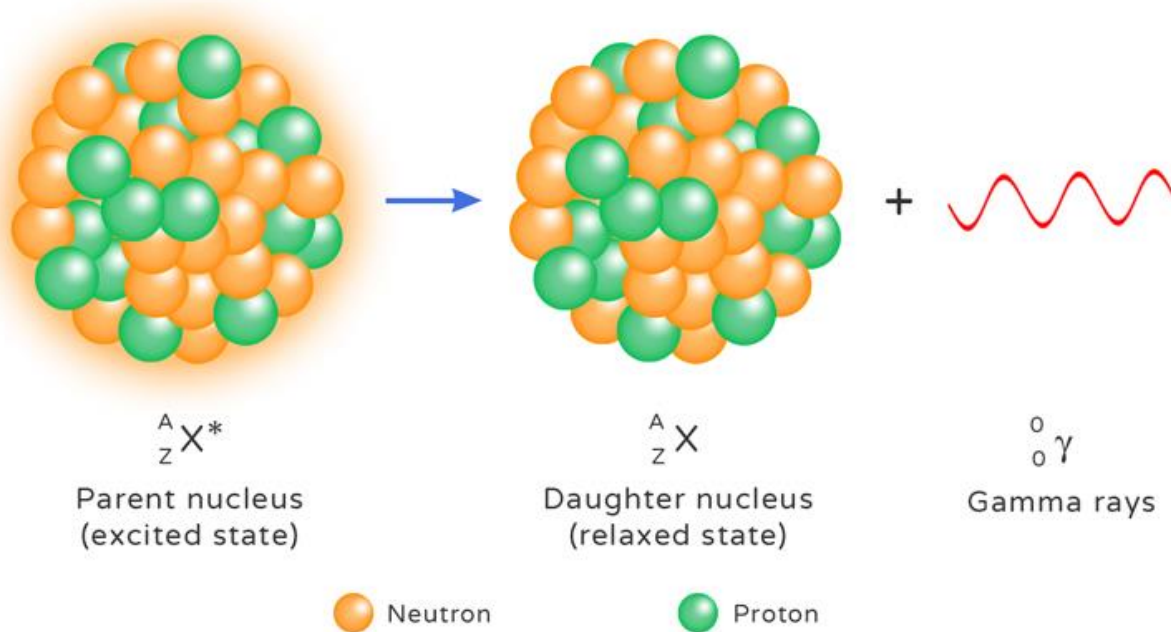
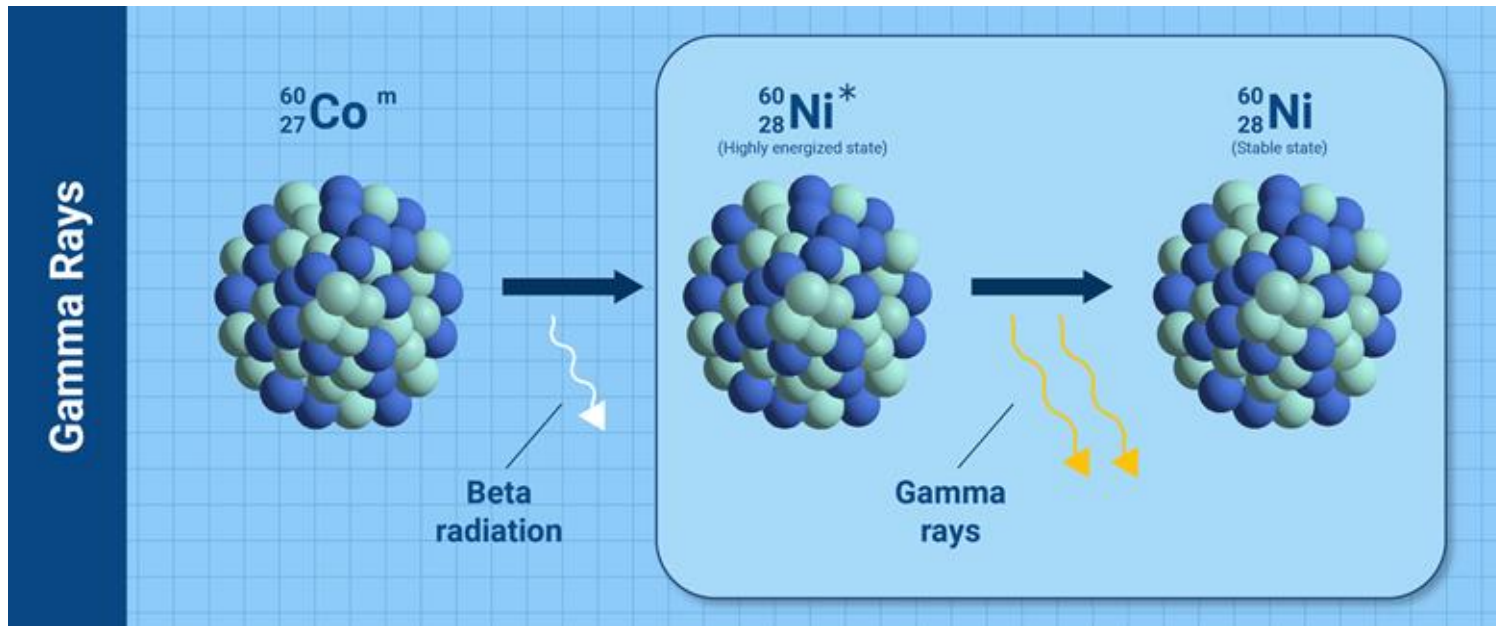


Image: sciencefacts.net

- **Photons:** massless particles that make up the electromagnetic spectrum
- Gamma rays : high energy photons
- **Indirect ionization**
- Frequently accompany alpha and beta decay
- Extremely penetrating (neutral charge)
- Best shielded using a high Z material (e.g., lead)
- Common Sources:
 - Cobalt-60,
 - Potassium-40

$$E = \frac{hc}{\lambda}$$

Gamma Emission



Atomic number does not change,
chemical element remains the same!

Image: [A. Vargas/IAEA](#)

$$\gamma_1 = 1.17 \text{ MeV}$$

$$\gamma_2 = 1.33 \text{ MeV}$$



Neutron radiation

- Two general energy groups:
 - **Fast (high energy)** neutrons may scatter when colliding with atoms, imparting enough energy for ionization or decay
 - **Thermal (low energy)** neutrons may be captured into the target nucleus causing gamma emission and later possible radioactive decay
- Uncharged particles:
 - Extremely penetrating,
 - No interaction with charged particles
- Common sources:
 - Plutonium-Beryllium Source
 - Americium-Beryllium Source
 - Californium Source
 - Fission

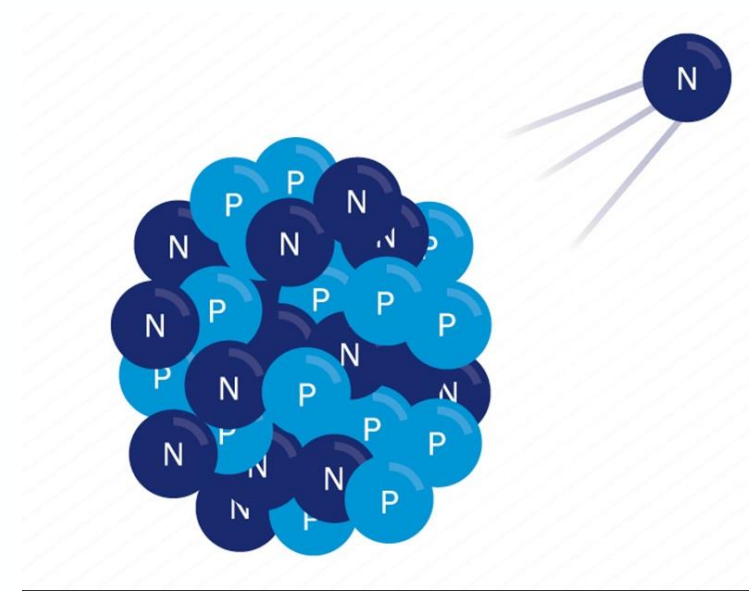
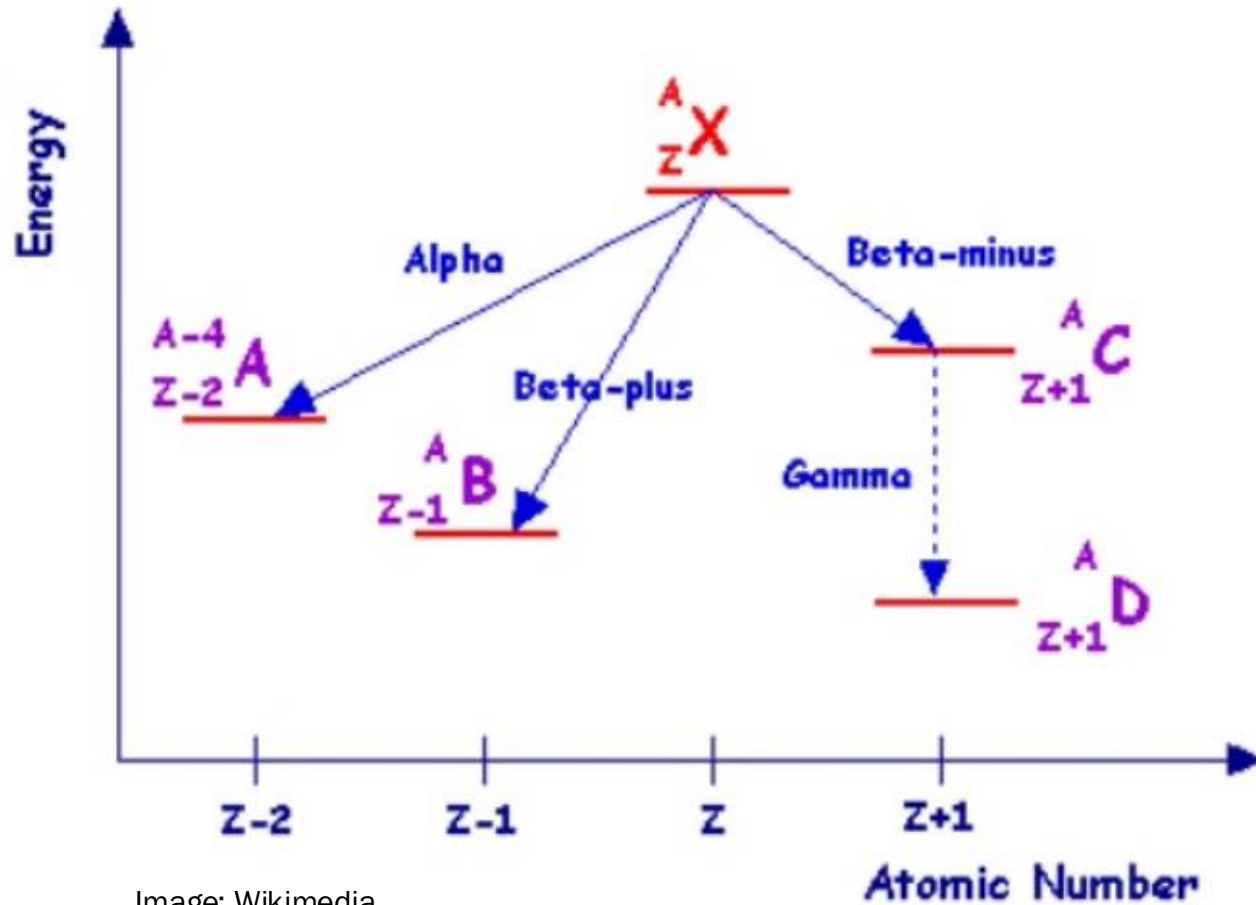


Image: IAEA

Decay schemes

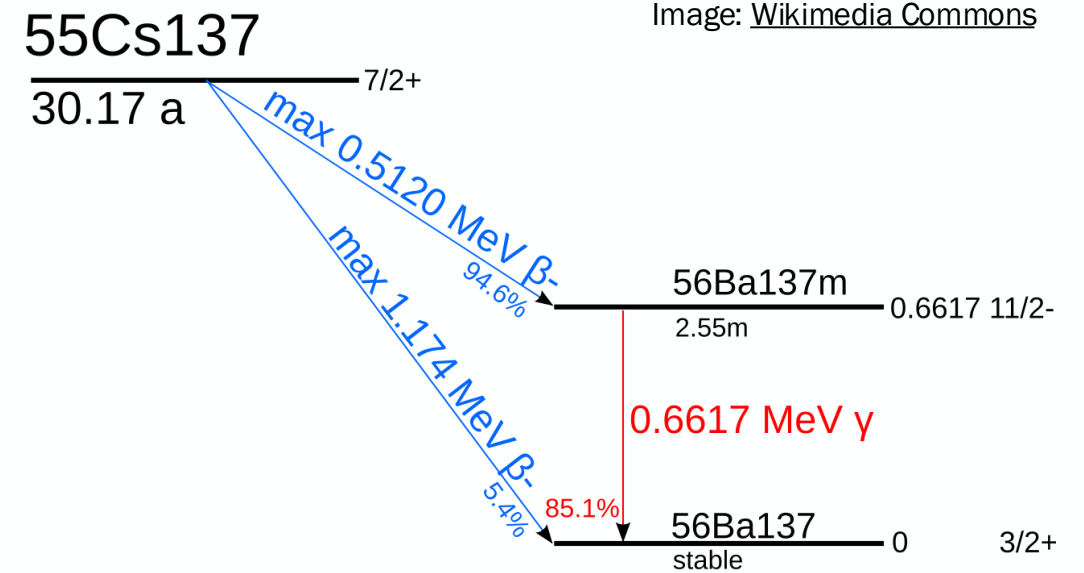


${}^{55}\text{Cs}137$

30.17 a

$7/2^+$

Image: [Wikimedia Commons](#)



$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

Radiation Quantification & Effects



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How to quantify radiation?

Activity of a radioactive source (A, Curie)

- 1 Ci: 3.7×10^{10} decays per second (Ra-226)
- No information on energy of radiation (not useful for safety)

Exposure (X, Roentgen)

- 1 Roentgen: Radiation required to ionize 1 kg of dry air to the charge $q = 2.58 \times 10^{-4}$ Coulombs
- However: No info about radiation damage and absorbed dose

Absorbed dose (D, Rad)

- 1 Rad = 0.01 Joules deposited per kg of any medium
- More useful, but what about biological effects?

Absorbed dose equivalent (H, Rem)

- Dosage in rads that will result in biological effects as 1 rad of gamma rays
- Roentgen equivalent man
- 1 Sievert = 100 Rem

$$H = DQ$$

Quality factor

- Unitless factor indicating relative biological damage caused by different radiation types
- $Q=1$ is set as 250 keV X-rays

Type of radiation	Q
X-rays, γ -rays	1
β ($E > 0.03$ MeV)	1
Natural α	10
Heavy recoil nuclei	20
Neutrons (thermal to 1 keV)	2
Neutrons (1 MeV)	11

Table 2.2 Quality Factors for Different Radiations

L in Water (keV/ μm)	Q
< 10	1
10–100	$0.32L - 2.2$
> 100	$300/\sqrt{L}$

From ICRP.³⁰

L : linear energy transfer,
radiation type-dependent

Radiation doses

- Typical nuclear power plant dose equivalent is very low

Radiation Source	H (mRem/year)
Cosmic (at sea level)	27
Cosmogenic (^{14}C , T)	1
Terrestrial	28
Body Burden (^{40}K)	39
Inhaled (Radon)	200
Medical/Dental X-rays	72
Radiopharmaceuticals	2
Fallout	4
Nuclear Power	0.003
TOTAL	~380

Effects of ionizing radiation

- Large Acute Dose:
 - **LD 50/30:** Lethal dose to **50% of exposed** population **within 30 days**
 - No medical attention LD 50/30 = **500 Rem**
 - Medical Attention LD 50/30 = **700 Rem**
- Latent Effects of Acute Dose
 - No measurable effects < 100 Rem < Cancer (Leukemia) risk increase linearly with dose
 - Cataracts after long exposure, threshold at 200 Rem
- Chronic Low Doses
 - Relevant for radiation workers in the nuclear industry who receive constant low occupational doses
 - Despite being studied extensively, it is difficult to quantify the effect of low-level doses
 - **Can we predict the risk of health effects of chronic low doses?**

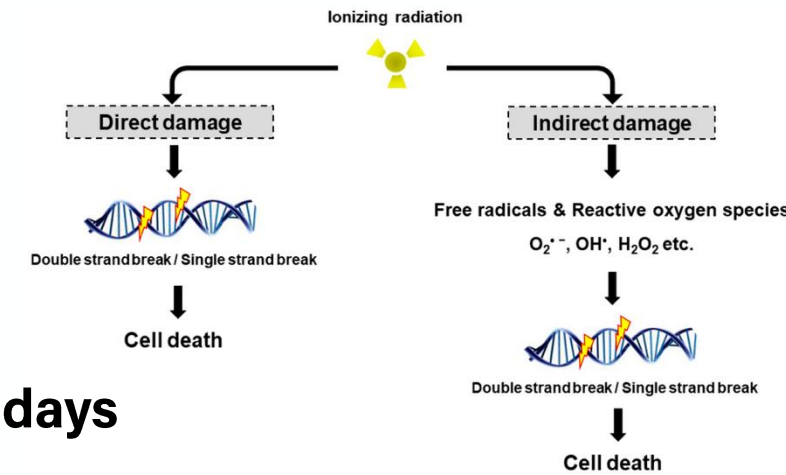
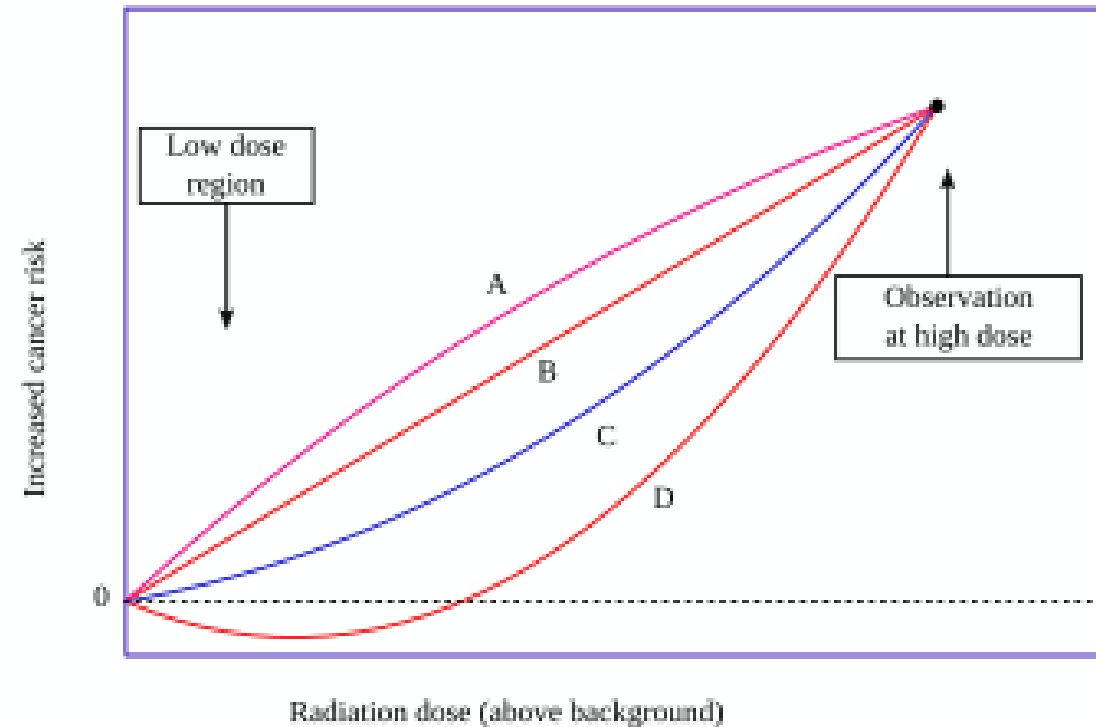


Image: [W. Hur & S.K. Yoon](#), [Wikimedia Commons](#), CC BY-SA 4.0

Can we estimate risk of health effects?

- Linear Non-Threshold Model (LNT):
 - Estimate probability of radiation-induced cancer
 - Any radiation amount can increase the risk
 - No minimum dose threshold
 - Current model used for regulation (U.S. NRC)
 - **However, controversial because of data extrapolation**
 - **Potentially over-conservative**
- Non-linear models:
 - Radiation could be harmless/useful in low doses
 - Levels twice the background radiation rate
 - Threshold model: small exposures are harmless
 - Hormesis model: **low doses can be beneficial**

Image: [Wikimedia Commons](#)



(A) supra-linearity, (B) linear
(C) linear-quadratic, (D) hormesis

Radiation Safety & Shielding



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Dosimetry

- Use: **monitor dose limits in radiation-present facilities**
- Required for employees/guests in radiation-present facilities
- Dosimeter:
 - Measures radiation dose
 - Typically absorbed dose equivalent
- Passive Dosimetry:
 - Records radiation exposure over a period of time
 - Analyzed later
- Real-Time Dosimetry
 - Actively measures the radiation dose in real time
 - Immediate feedback

Image: mirion.com



Image: inteccon.com

Radiation shielding

- Anything which can be placed between yourself and a radiation source to block the radiation
- Alpha
 - Paper
 - First layer of skin
- Beta
 - Subdermal skin and clothes
 - Thin sheets of plastic or aluminum
- Gamma
 - Lead
 - Dense, heavy metals
- Neutron
 - Water, Concrete
 - Cadmium, Boron, Graphite

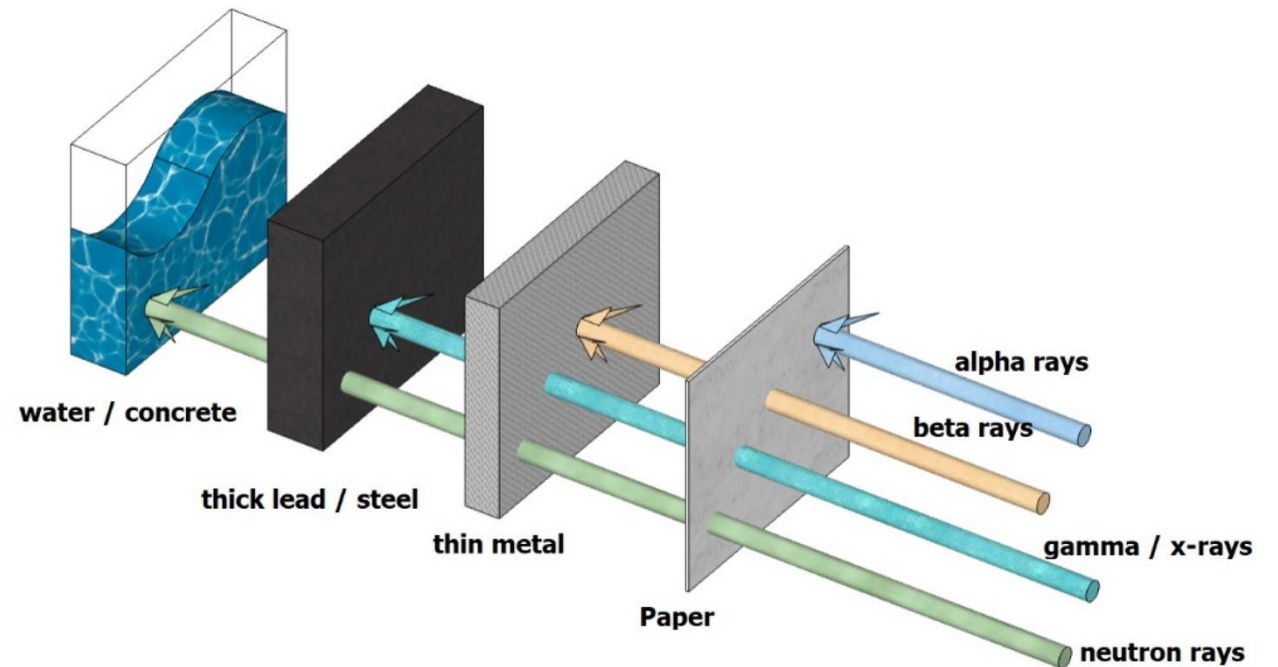
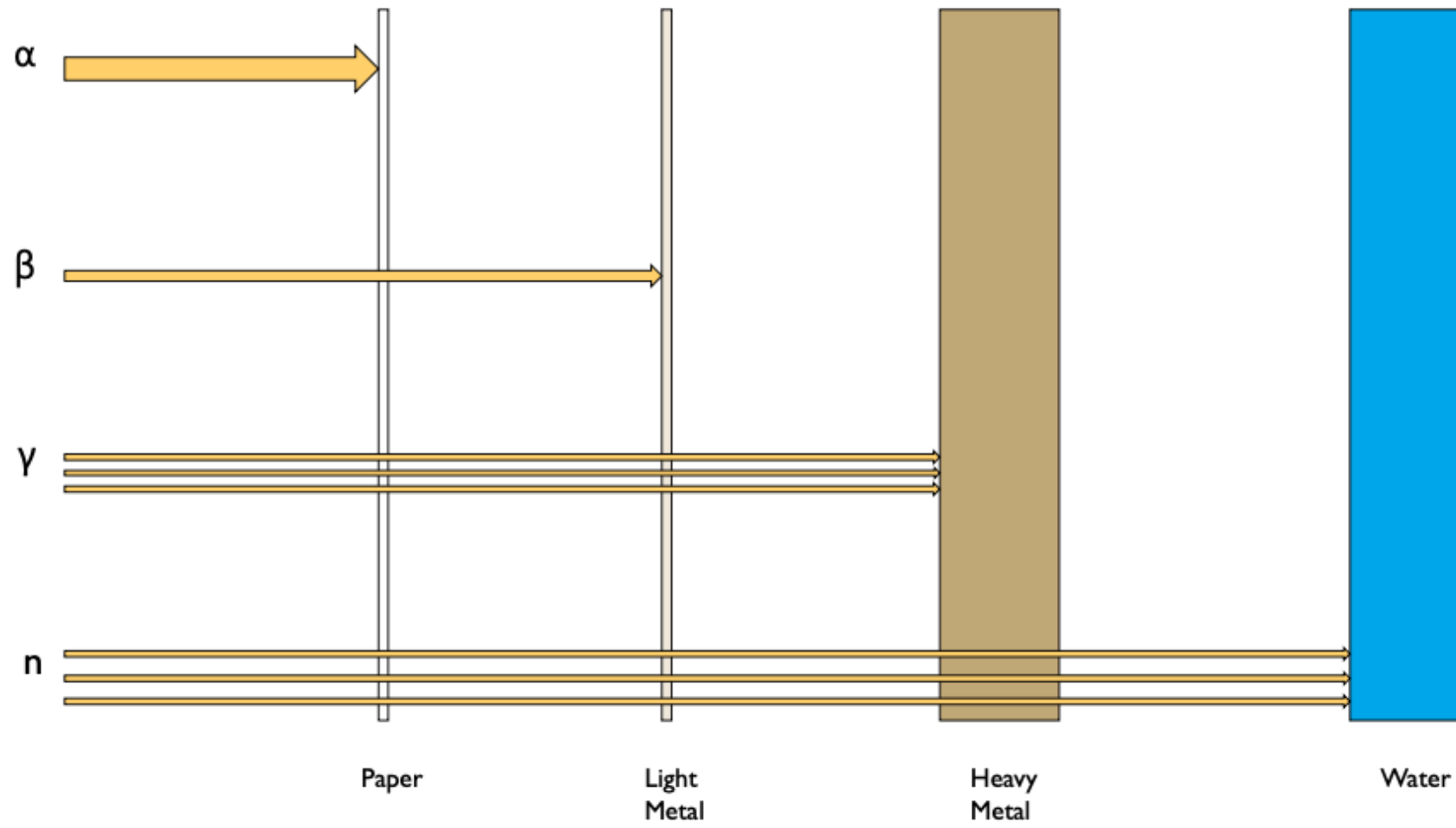


Image: Abdullah, M.A.H.; Rashid, R.S.M.; Amran, M.; Hejazii, F.; Azreen, N.M.; Fediuk, R.; Voo, Y.L.; Vatin, N.I.; Idris, M.I. *Polymers* 2022, 14, 2830. <https://doi.org/10.3390/polym14142830>

Radiation shielding



ALARA

- Gold standard in radiation safety
- ALARA – **As Low As Reasonably Achievable**
 1. Time: Limit exposure time
 2. Distance: Increase distance between yourself and the source
 3. Shielding: Use shielding to reduce the exposure when working with radioactive sources
 4. Amount: Use the weakest source activity that will perform the necessary function

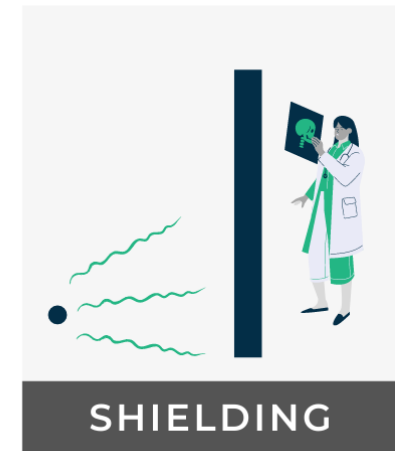
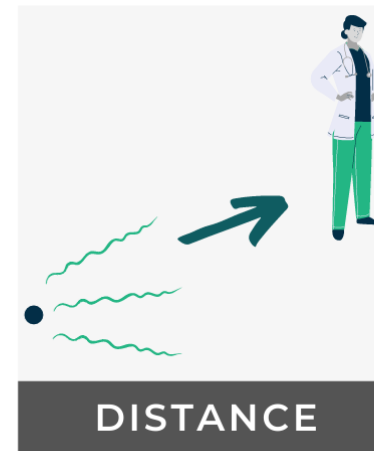
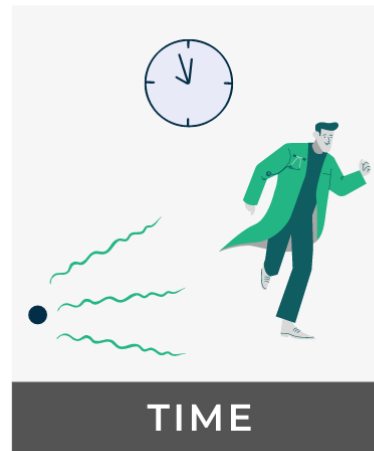


Image: [versantphysics.com](https://www.versantphysics.com)

Radiation areas

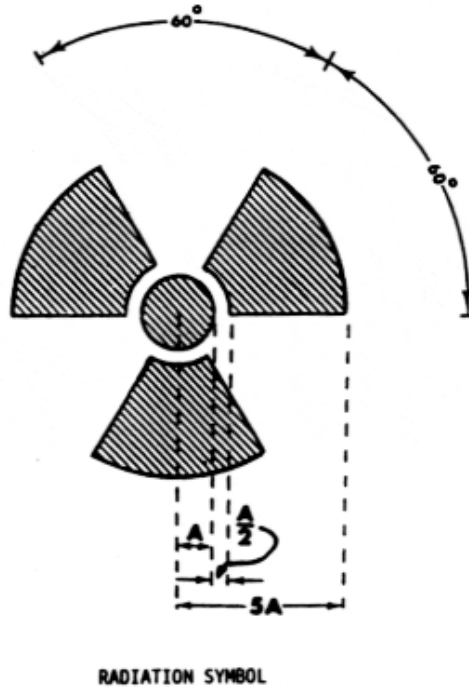
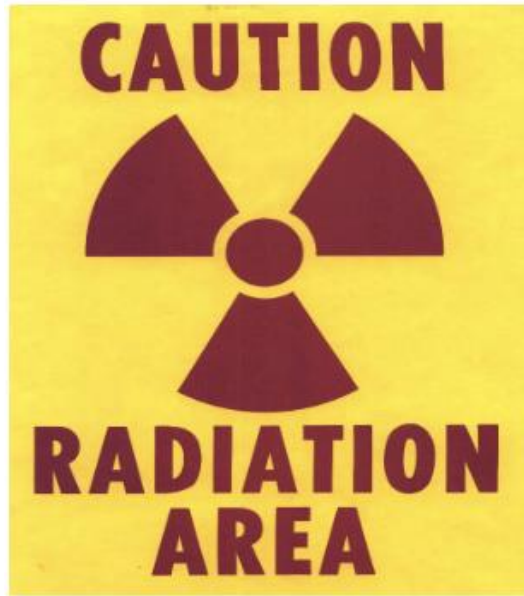


Image: U.S. NRC

- **Radiation Area:** radiation levels could result in an individual receiving a
 - dose equivalent > 0.005 Rem
 - in **1 hour**
 - at **30 cm** from source or any surface the radiation penetrates
- **High Radiation Area:**
 - Dose equivalent > 0.1 Rem
- **Very High Radiation Area:**
 - Same definition but the dose is **500 rads at 1 meter**

Summary

Radiation comes in many different forms including alpha, beta, gamma, and neutron

Radiation may be nonionizing or ionizing

Different forms of radiation affect biological systems differently

The gold standard in radiation safety is ALARA (As Low As Reasonably Achievable)

Practice ALARA by remembering time, distance, shielding, and amount

Every facility that handles radioactive materials has emergency procedures

Thank you for your attention

Questions?



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