Nuclear Science – It's Not Rocket Science, But It's Still Pretty Cool

Rebecca Steinman, Ph.D., P.E.

Michigan Section of the American Nuclear Society

Who we are…

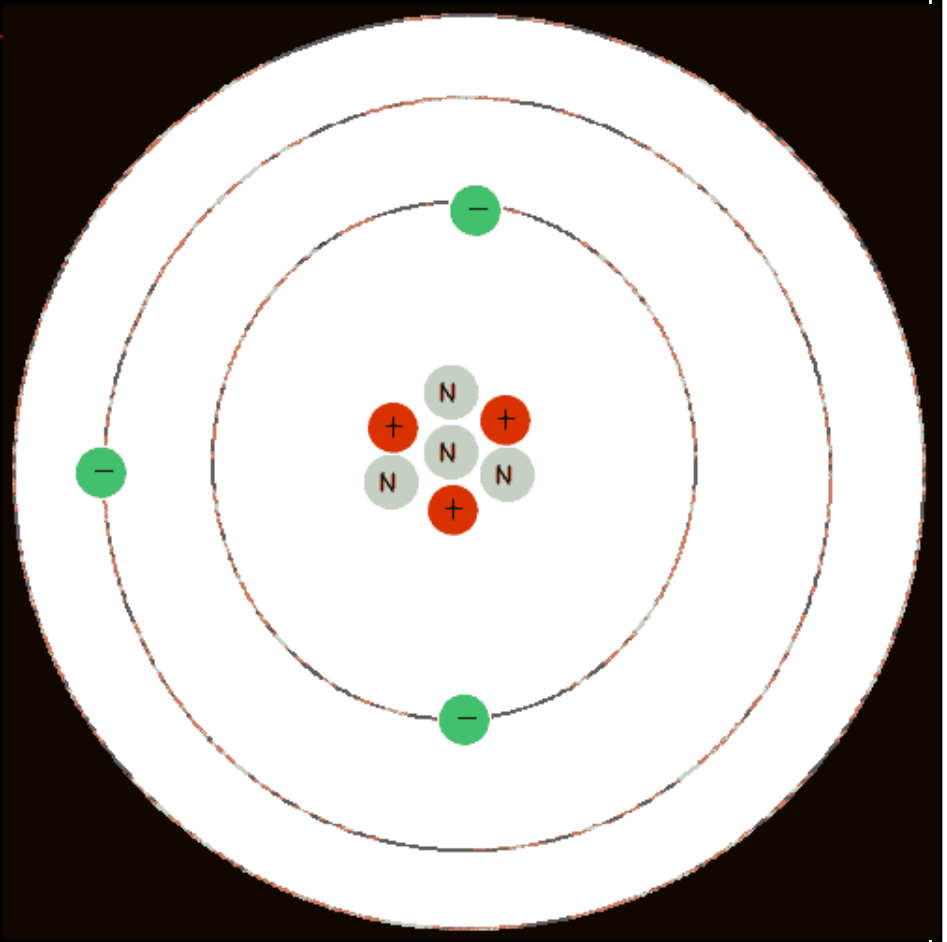
- The American Nuclear Society is a non-profit professional organization dedicated to the development, application, & dissemination of information about the benefits of nuclear science & technology.
- Contact Us:
  - http://local.ans.org/mi
  - MI-ANS@adventengineering.com

Nuclear Science

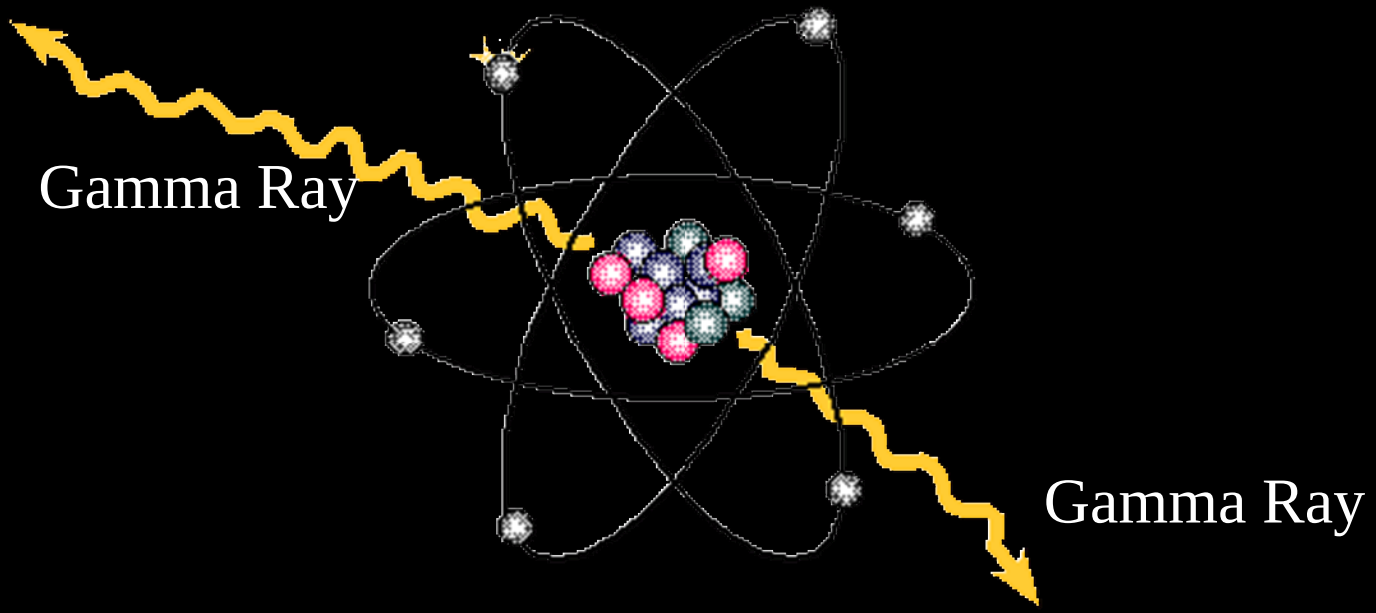
An Overview of Basic Fundamentals

Parts of the Atom

- Proton
  - Positive charge found in the nucleus
  - Number of protons is unique to an element
- Neutron
  - No charge also found in the nucleus
- Electron
  - Negative charge
  - Much smaller than protons or neutrons
  - Orbit the nucleus

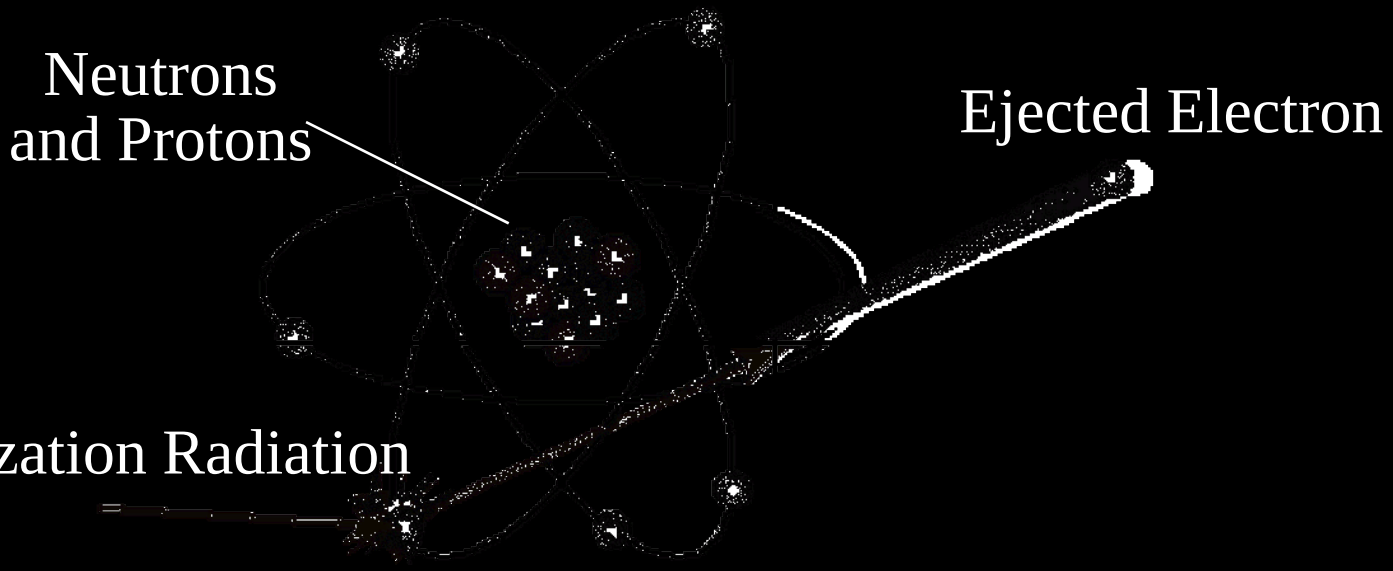


Radioactive Material



Radioactive Material - any material containing atoms that emit radiation.

Ionizing Radiation

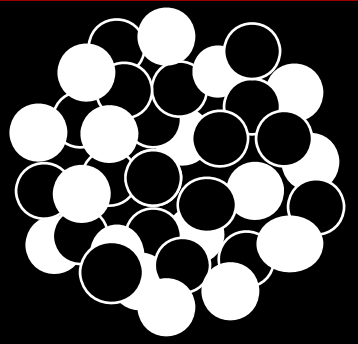


Ionizing Radiation - radiation with enough energy to remove an electron from its atom.

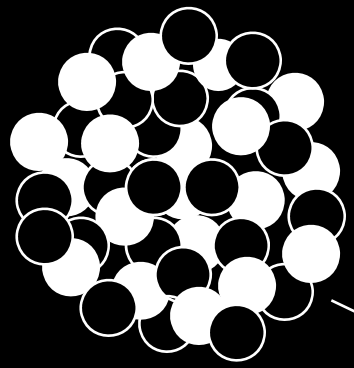
Types of Ionizing Radiation

1) Alpha (α) - positively charged helium nucleus (2 protons and 2 neutrons).

Alpha Particle Radiation



Daughter
Nucleus
Th-231



Parent Nucleus
U-235

$^{4}_{2}\alpha^{++}$

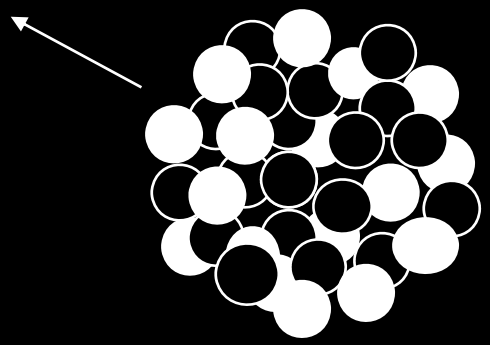
Alpha Particle
(Helium Nucleus)

Types of Ionizing Radiation

1) Alpha (α) - positively charged helium nucleus (2 protons and 2 neutrons).
2) Beta (β) - negatively charged electron.

Beta Particle Radiation

Daughter Nucleus
Calcium-40



Parent Nucleus
Potassium-40

$^{0}_{0}\nu$

Antineutrino

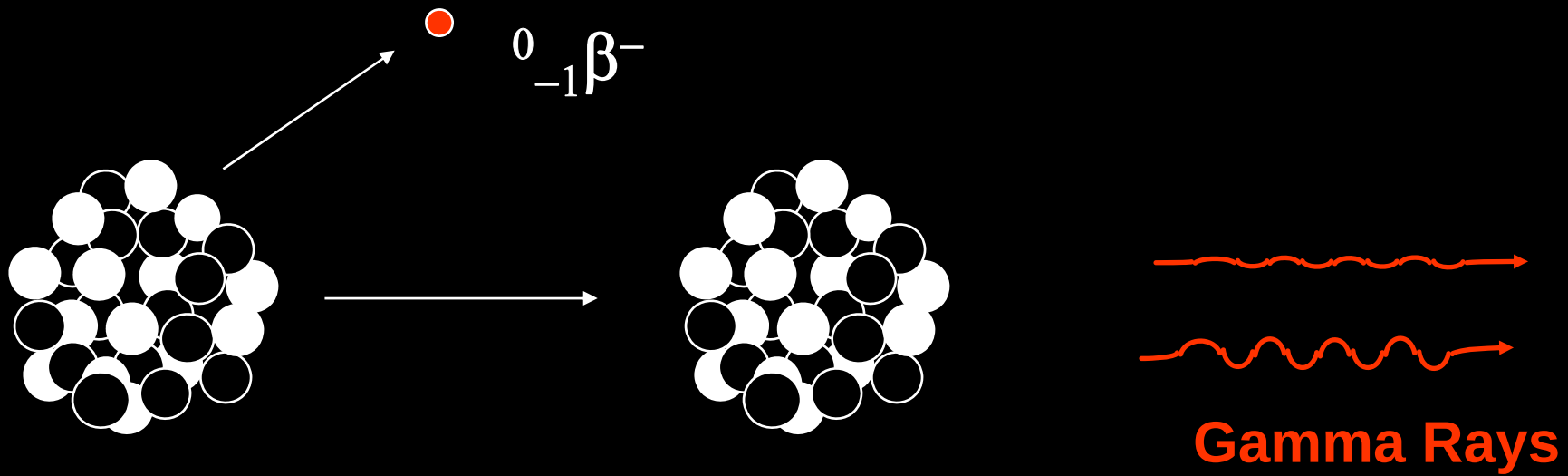
$^{0}_{-1}\beta^{-}$

Beta Particle

Types of Ionizing Radiation

1) Alpha (α) - positively charged helium nucleus (2 protons and 2 neutrons).
2) Beta (β) - negatively charged electron.
3) Gamma (γ) - a packet of energy with zero rest mass. (Similar to an x-ray with a different origin – x-rays come from electron shell, gamma rays come from the nucleus)

Gamma-Ray Radiation



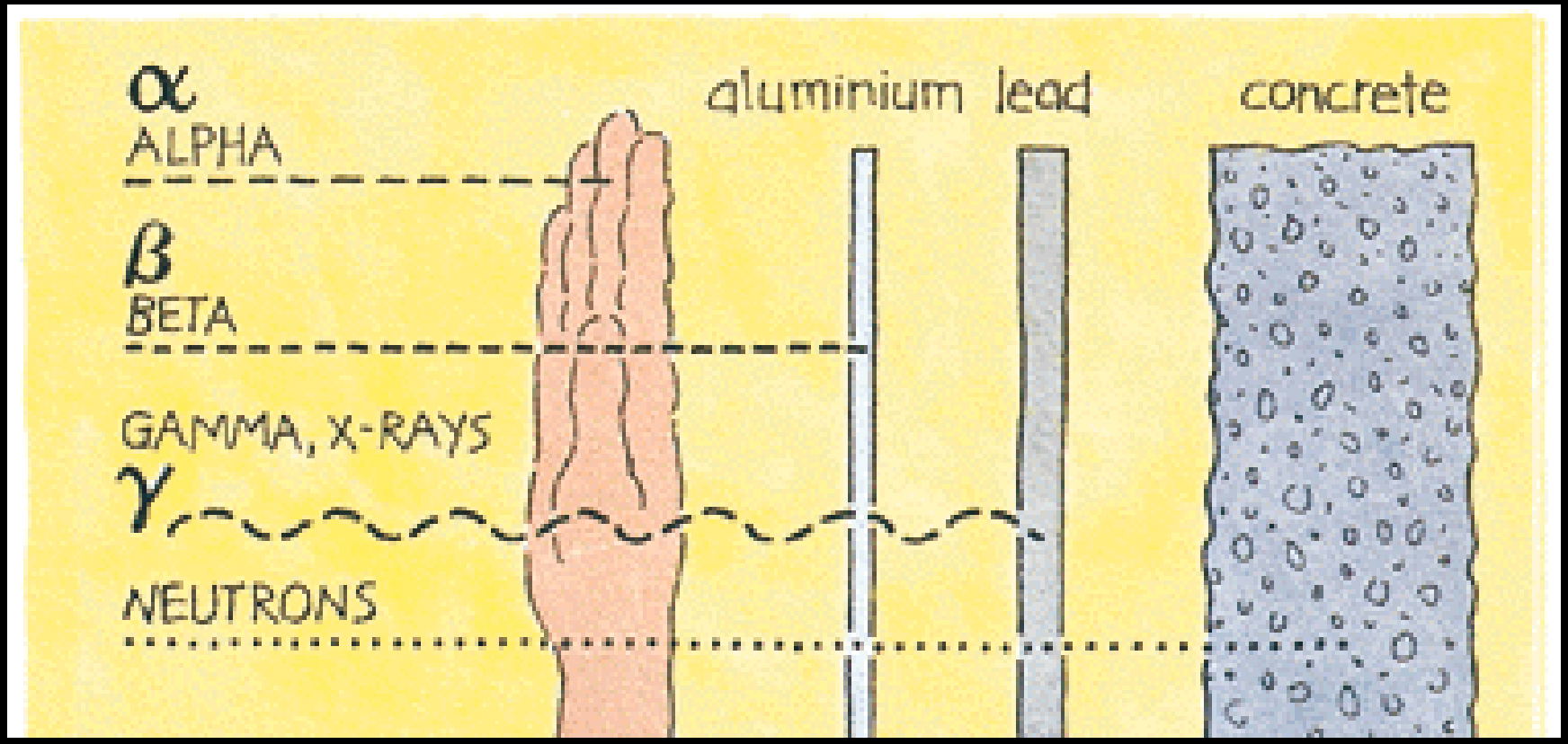
Parent Nucleus
Cobalt-60

Daughter Nucleus
Ni-60

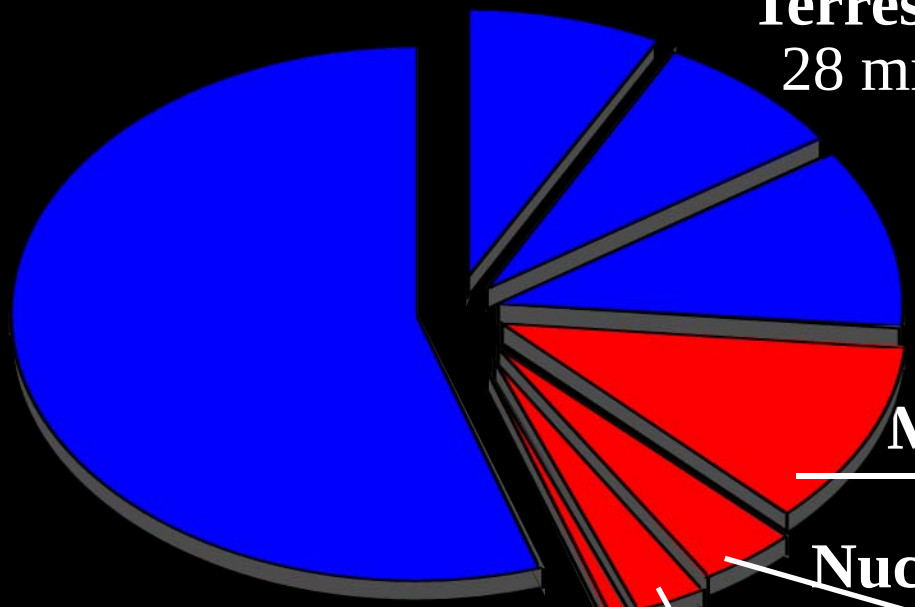
Types of Ionizing Radiation

1) Alpha (α) - positively charged helium nucleus (2 protons and 2 neutrons).
2) Beta (β) - negatively charged electron.
3) Gamma (γ) - a packet of energy with zero rest mass. (Similar to an x-ray with a different origin – x-rays come from electron shell, gamma rays come from the nucleus)
4) Neutron (n) - mainly a concern during nuclear reactor operation.

Penetration of Ionizing Radiation



Average Annual Dose ~360 mrem



Cosmic
28 mrem

Terrestrial
28 mrem

Radon
200 mrem

Internal
40 mrem

Medical X-Rays
40 mrem

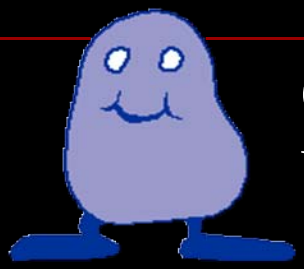
Nuclear Medicine
14 mrem

Consumer Products
10 mrem

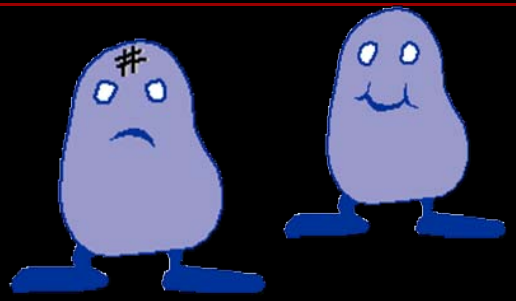
Other
3 mrem

Natural Sources
Man-Made Sources

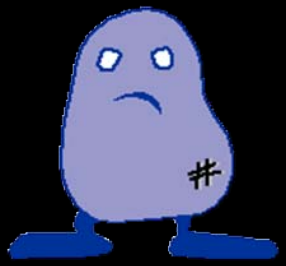
Biological Effects of Radiation



Cells are
undamaged.

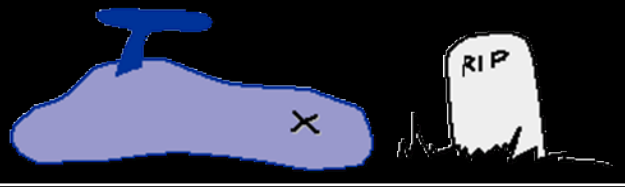


Cells are damaged,
repair damage and operate normally.

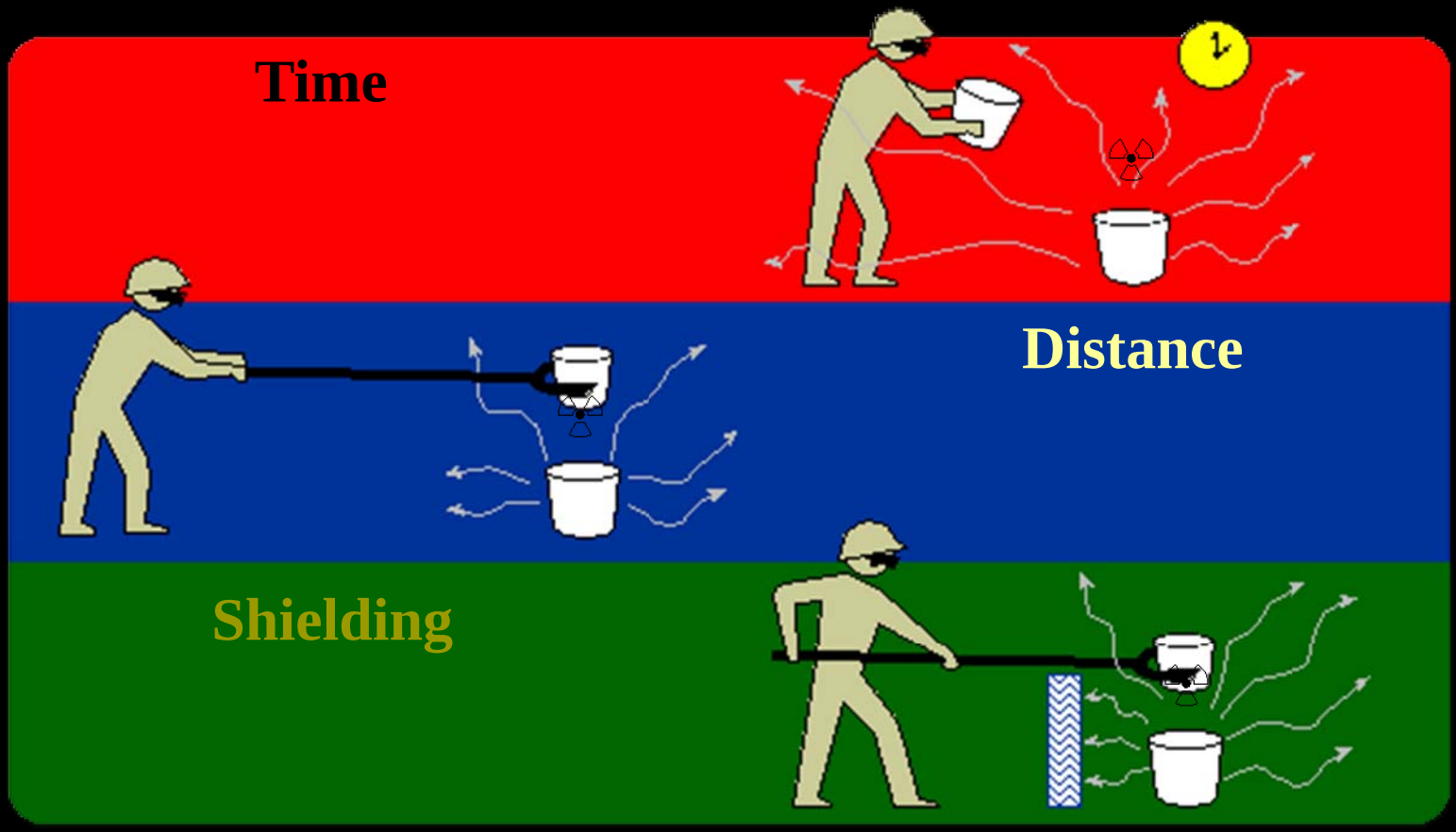


Cells are damaged,
repair damage and operate abnormally.

Cells die as a
result of damage.



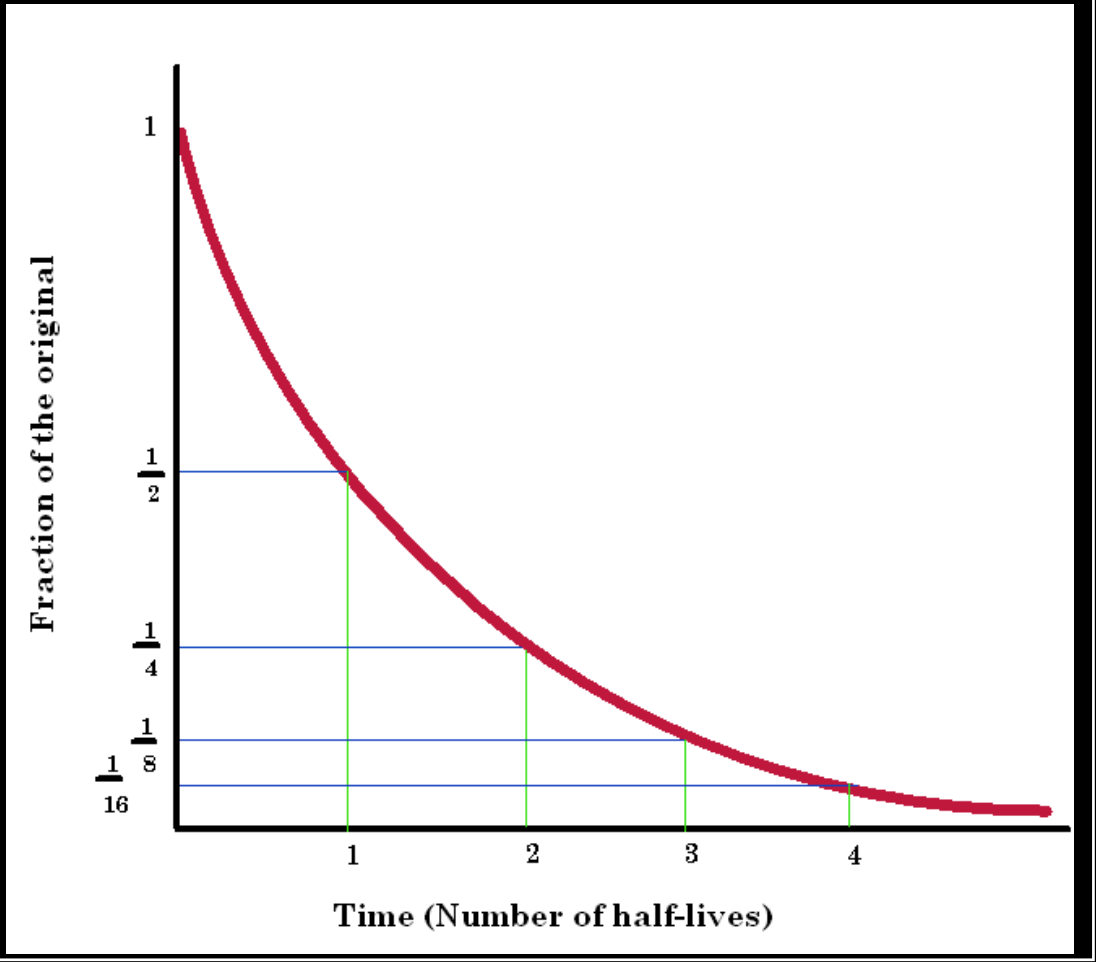
Basic Protective Measures



Half-Life

- Time for half of the sample to decay
- A physical property of the isotope
- Examples:

Carbon-14
    5730 yrs
Potassium-40
    1.3 Billion yrs
Polonium-214
    0.000164 sec



Quantities & Typical Units

- Activity = Decays per time
  - 1 Becquerel = 1 decay per second (dps)
  - 1 Curie = 37 Billion dps
  - 1 microCurie (μCi) = 37,000 dps
  - 1 picoCurie (pCi) = 0.037 dps
- Dose = Energy absorbed per mass
  - Rad
  - Gray (Gy) [1 Gy = 100 rad)
- Dose Equivalent = Dose X QF
  - Rem (1 mrem = 0.001 rem)
  - Sievert (Sv) [1 Sv = 100 rem)]

It’s Not Rocket Science… But It’s Still Pretty Cool

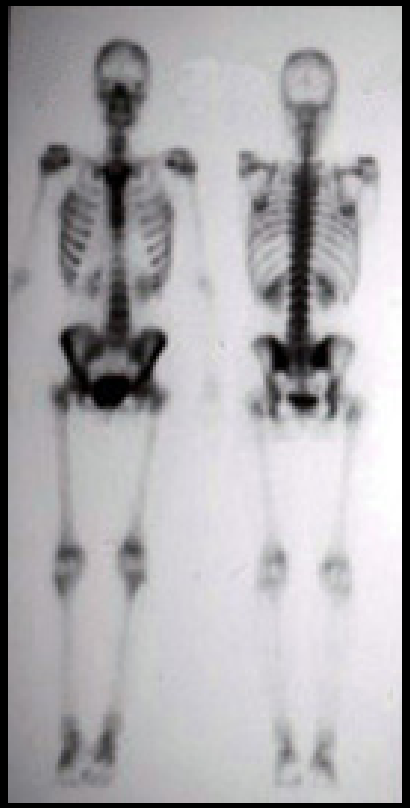
Beneficial Uses of Radiation

- Medical Diagnoses and Treatment

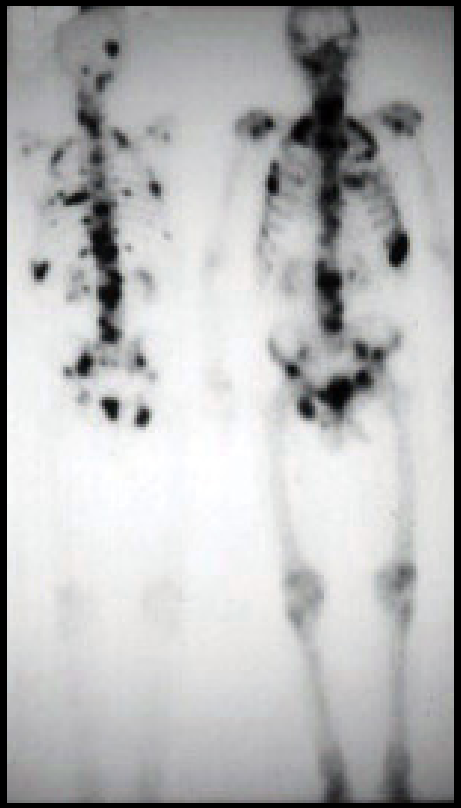
Biomedical Research

Therapy Machine used for Targeting Cancerous Tissue

Tc-99m Bone Scan



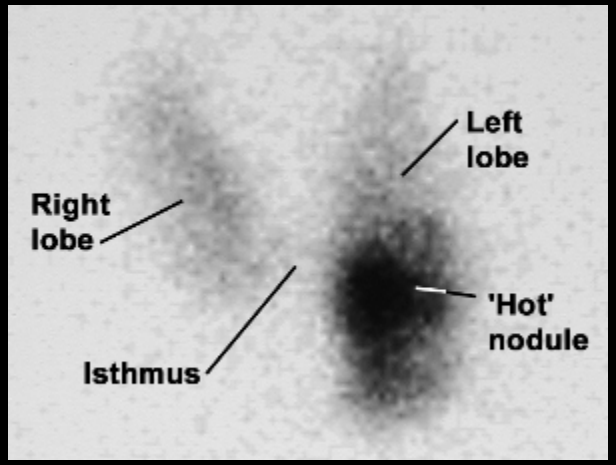
Normal bone scan



Bone metastases

Other Medical Uses

Hyperthyroid conditions in humans and cats can be successfully treated with radioiodine therapy



Brachytherapy (Greek for “short distance”) is used for intracavitary, interstitial and superficial treatment of tumors; small radioactive sources are placed near the tumor

Beneficial Uses of Radiation

- Medical Diagnoses and Treatment
- Industrial / Manufacturing Applications

Industrial / Manufacturing Uses

Automobile industry makes use of isotopes to test the quality of steel in cars

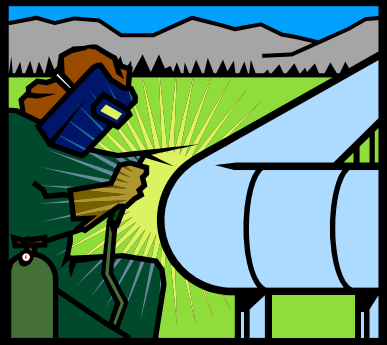
Aircraft manufacturers use radiation to check for flaws in jet engines

Mining & petroleum companies use isotopes to locate and quantify geological mineral deposits

Gamma Radiography

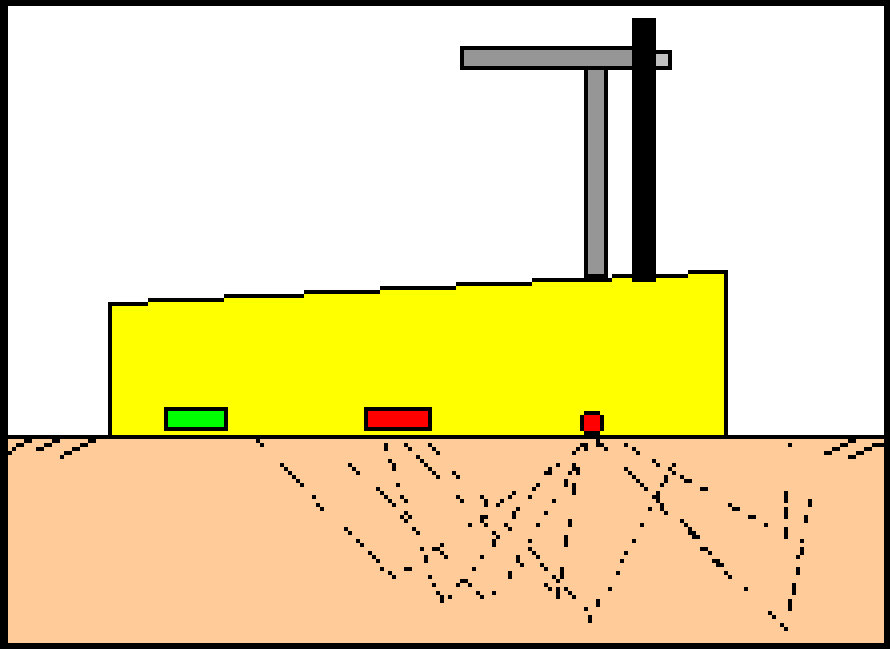
Industrial / Manufacturing Uses

Oil gas & mining companies use isotopes to map geological contours (using test wells) and mine bores and to determine presence of hydrocarbons



Pipeline companies utilize radioactive isotopes to look for defects in welds

Gauge soil moisture content and asphalt density



Nuclear Densometer

Other Industrial Applications

Imaging Applications

- Looking at clogged pipes
- Checking sealed cans for level of contents
- Looking for microcracks in mechanical parts, bridges, and welds

Measurement Applications

- Measuring egg shell thickness
- Maintaining constant thickness for paper, metal, or fabric sheets
- Regulate blast furnaces, liquid metal in molds, and kiln load levels

Beneficial Uses of Radiation

- Medical Diagnoses and Treatment
- Industrial / Manufacturing Applications
- Agricultural Uses

Agricultural Uses

Hardier and more disease resistant crops (peanuts, tomatoes, onions, rice, soybeans, barley) have been developed using radioactive materials in agricultural research

Nutritional value, baking and melting qualities of some crops and cooking times have been improved using isotopes

Radioactive materials pinpoint where illnesses strike animals to breed disease-resistant livestock

Agricultural Uses

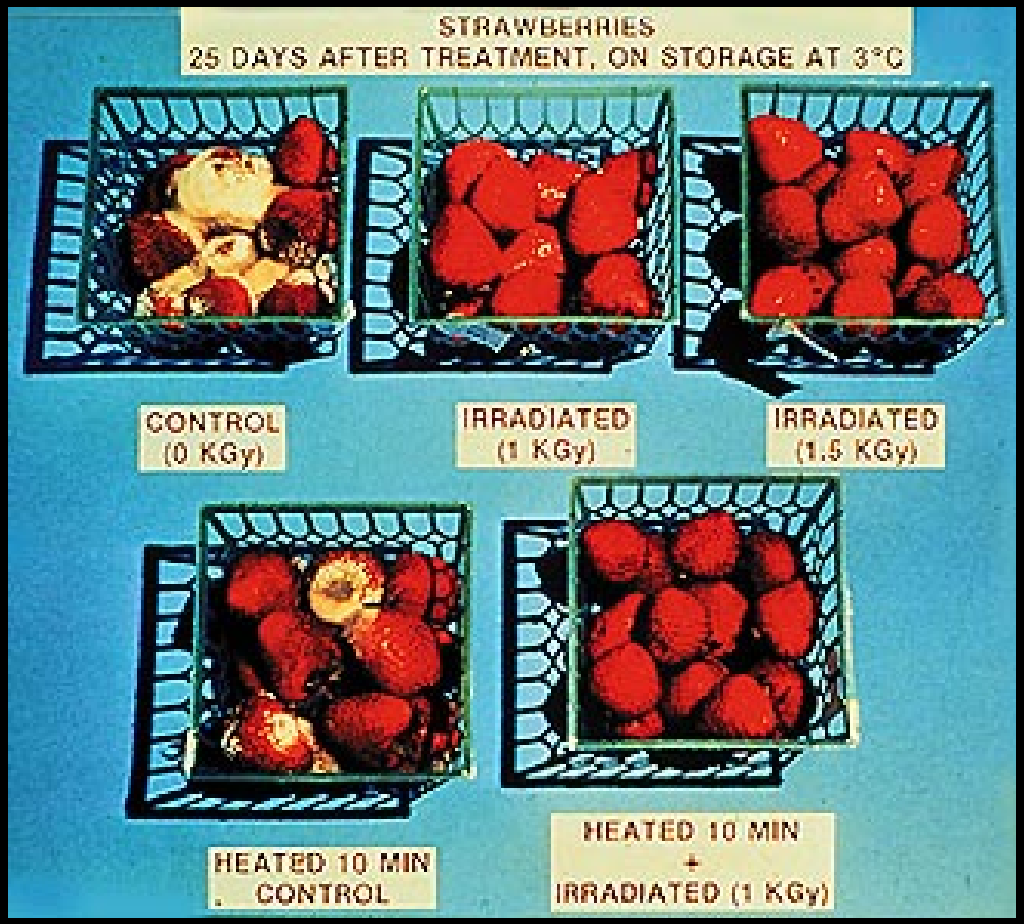
Radioactive materials show how plants absorb fertilizer; this helps researchers figure where and how much to apply to crops for maximum yield

Isotopes help farmers and scientists control pests; e.g., California has used radiation sterilization since the mid-70s to control Mediterranean
fruit fly infestations

Beneficial Uses of Radiation

- Medical Diagnoses and Treatment
- Industrial/Manufacturing Applications
- Agricultural Uses
- Food Irradiation

Example: Irradiated Strawberries



What Foods Can Be Irradiated?

Approval Year	Food	Dose (kGy)	Purpose
1963	Wheat Flour	0.2-0.5	Control of mold
1964	White Potatoes	0.05-0.15	Inhibit sprouting
1986	Pork	0.3-1.0	Kill Trichina parasite
1986	Fruit and Vegetables	1.0	•Insect Control •Increase Shelf Life
1986	Herbs and Spices	30	Sterilization
1990(FDA) 1992(USDA)	Poultry	3(FDA) 1.5-3(USDA)	Bacterial pathogen reduction
1997(FDA) 1999(USDA)	Meat	4.5	

How to tell…

Beneficial Uses of Radiation

- Medical Diagnoses and Treatment
- Industrial/Manufacturing Applications
- Agricultural Uses
- Food Irradiation
- Consumer Products / Safety and Security

Consumer Products

Smoke detectors installed in ~90% of America's homes rely on ^{241}Am to monitor for smoke to signal a fire

Computer disks retain data better when treated with radiation

Consumer Products

Non-stick pans are treated with radiation to retain the coating

Photocopiers and plastic manufacturers use small amounts of radiation to eliminate static and prevent jamming

Cosmetics, hair products and contact lens solutions are sterilized with radiation to remove irritants and allergens

Consumer Products

1930s Fiestaware contains uranium in the ceramic glazes

To maximize light output, some lantern mantles contain radioactive thorium nitrate

Radium dial watches

Vaseline glass

Safety and Security

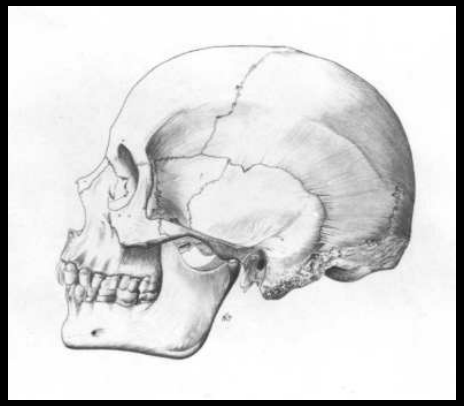
- Sterilize medical bandages and implements
- Self-powered Lighting in Exit Signs
- Lighted Aircraft Instrumentation
- Pharmaceutical Detection
- Bomb / Weapons Detection
- Scanning and Surveillance Equipment
- Theft Deterrent Systems

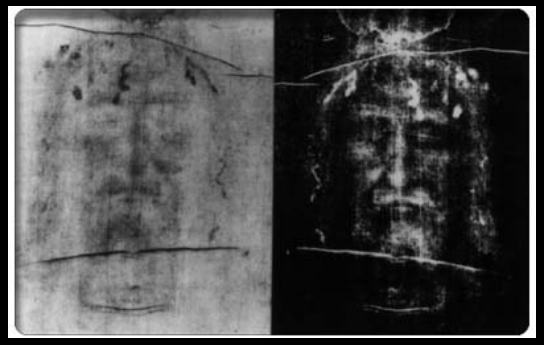
Beneficial Uses of Radiation

- Medical Diagnoses and Treatment
- Research Applications
- Industrial/Manufacturing Applications
- Agricultural Uses
- Food Irradiation
- Consumer Products/Safety and Security
- Identification / Authentication

Identification / Authentication

Archaeologists use ^{14}C to date artifacts containing plant or animal material





Museums rely on radioactive materials to verify authenticity of art objects and paintings

Criminal investigators use radiation to examine evidence

Beneficial Uses of Radiation

- Medical Diagnoses and Treatment
- Research Applications
- Industrial/Manufacturing Applications
- Agricultural Uses
- Food Irradiation
- Consumer Products/Safety and Security
- Identification / Authentication
- Spacecraft Power Supply

Space Applications

- Radioisotope thermonuclear generators (RTGs)
- Nuclear propulsion systems
- Radioisotope heater units (RHUs)

Beneficial Uses of Radiation

- Medical Diagnoses and Treatment
- Industrial/Manufacturing Applications
- Agricultural Uses
- Food Irradiation
- Consumer Products/Safety and Security
- Identification / Authentication
- Spacecraft Power Supply
- Electric Power Generation

103 Operating U.S. Plants
~20% of US Total Electricity

Nuclear Power in Michigan

Radioactive Tracers

- Label molecules to trace them through metabolic processes
- Used to track water flow in areas around landfills and waste sites
- Weapons fallout acts as a global tracer for biogeochemical cycles
- Measure internal combustion engine component wear

New Technologies and Applications

- Ion Implantation
  - Artificial implants
  - Improved wear resistance of mechanical parts
- Plasma Processing
  - Computer chip manufacturing
  - Semiconductor and thin film processing