PHYS12 CH:22.5 When Radiation Heals

Medical Applications of Radioactivity

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Outline

The Paradox of Radiation

How can radiation both
cause and cure cancer?

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Understanding this paradox requires understanding cells, DNA, and targeted destruction.

Learning Objectives

By the end of this lesson, you will be able to:

- **22.5:** Describe how nuclear imaging works (radioisotope imaging, PET)

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- **22.5:** Describe the ionizing effects of radiation and how they can be used for medical treatment

22.5 Seeing the Invisible

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2. **Radiation depends on the nucleus, not the molecule** - we can tag compounds with radioactive isotopes

The Universal Tool

Put a radioactive isotope in a drug. Track where the drug goes. See what's happening inside the body.

22.5 The Tagged Compound

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A compound tagged with a radioactive isotope and used for medical purposes.

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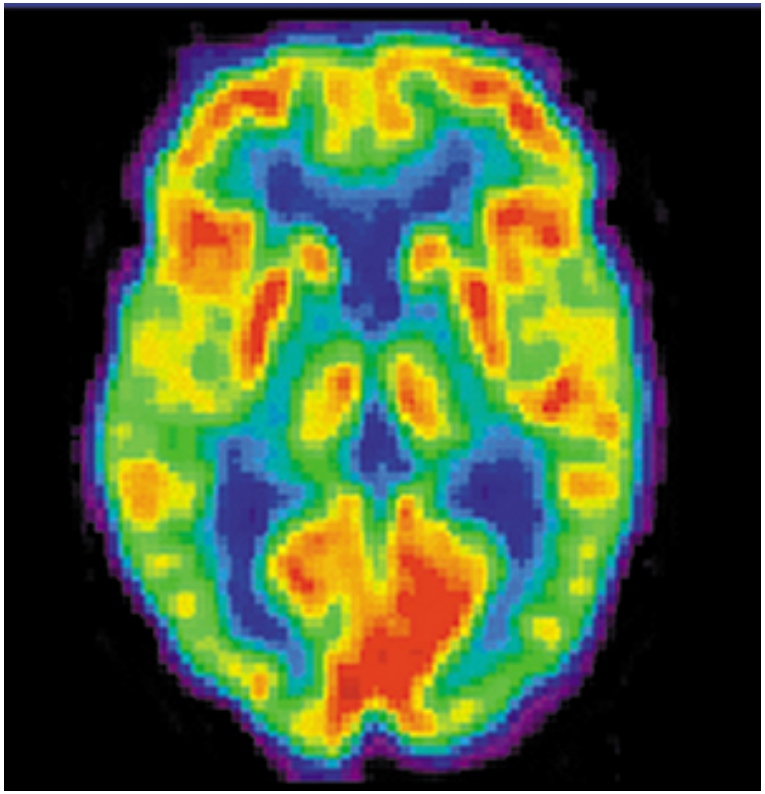
The Mental Model

Each isotope is like a specialized spy, reporting from specific locations in the body.

22.5 Brain Imaging with Radiopharmaceuticals



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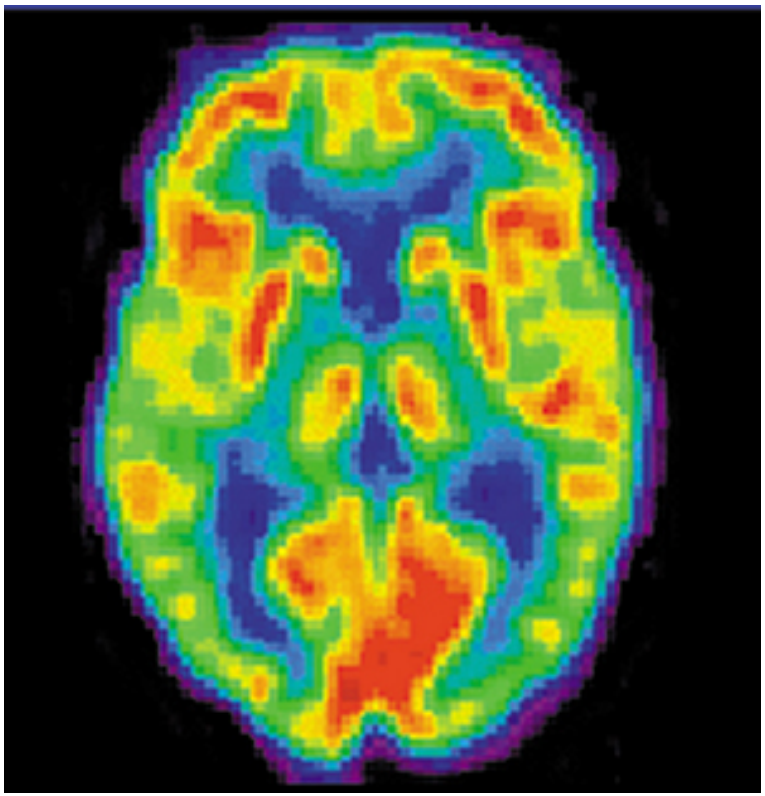

Brain scan of patient with Alzheimer's disease using a radiopharmaceutical.

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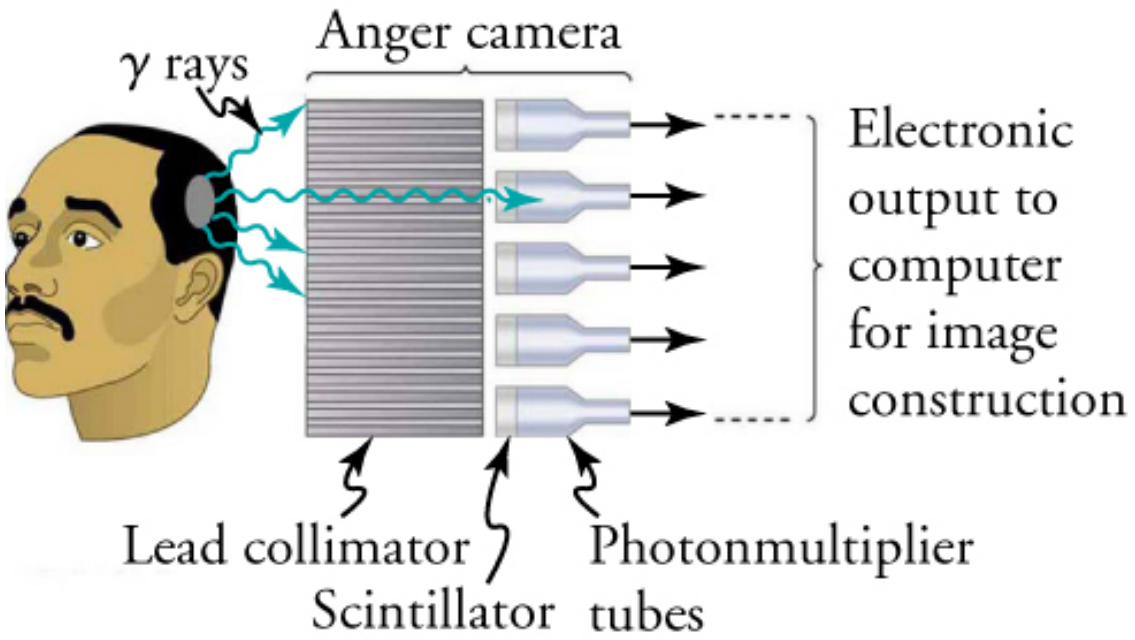

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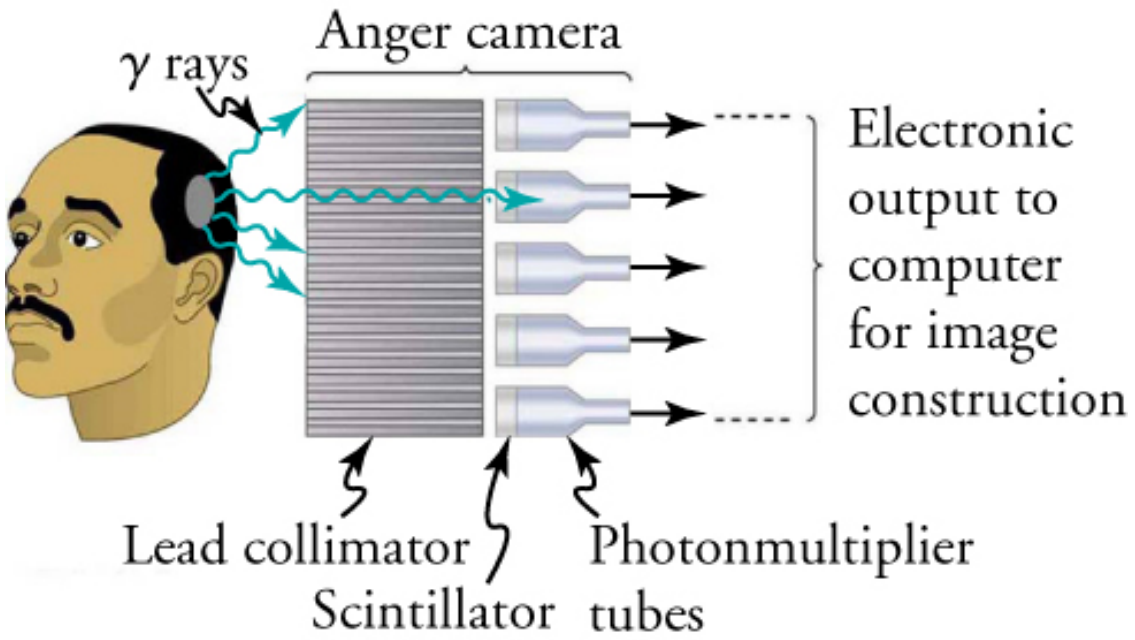

Components:

- Lead collimator narrows gamma ray beams
- Scintillator converts gamma rays to visible light
- Photomultipliers convert light to electrical signals
- Computer creates image from detector array

22.5 SPECT: Adding the Third Dimension

Single-Photon-Emission Computer Tomography

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- Trade-off: Better 3D detail, but lower spatial resolution

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Positron Emission Tomography (PET):
Uses isotopes that emit positrons (β^+ particles).

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The Universal Law

$$E = mc^2$$

Mass converts to energy: electron mass = 0.511 MeV per gamma ray.

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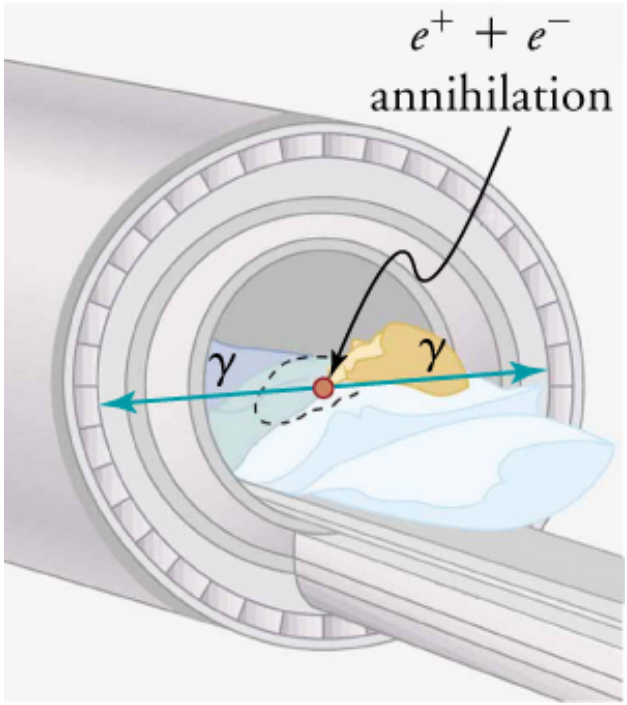

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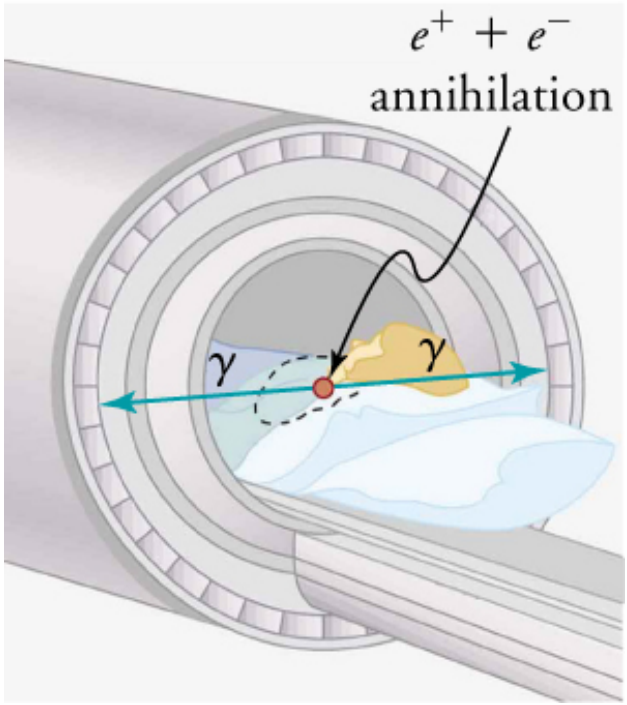

Detectors on opposite sides detect simultaneous 0.511 MeV photons, pinpointing annihilation location.

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Real-World: Mapping Thought

PET can show which parts of brain activate when you speak, close your eyes, or solve math problems.

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How do we understand this?

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The Universal Truth

All effects of ionizing radiation come from one source:
Damage to DNA molecules inside cells.

22.5 DNA: The Code of Life

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The Mental Model

DNA is like the source code for your body. Radiation introduces bugs. The cell tries to debug.

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Civilian View vs. Reality

Civilian: "Radiation always causes cancer."
Physicist: "Radiation damages DNA. Outcome depends on dose, cell type, and repair ability."

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The Vulnerability

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This is why radiation can both cause and cure cancer.

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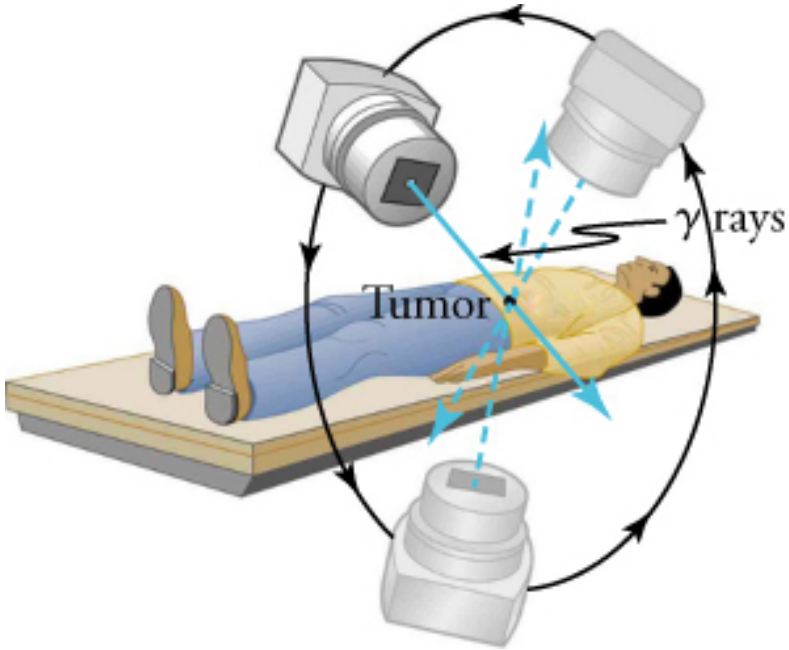
The Trade-off

Radiation doesn't distinguish cancer from normal cells - only rapidly dividing from slowly dividing.

22.5 Geometric Targeting



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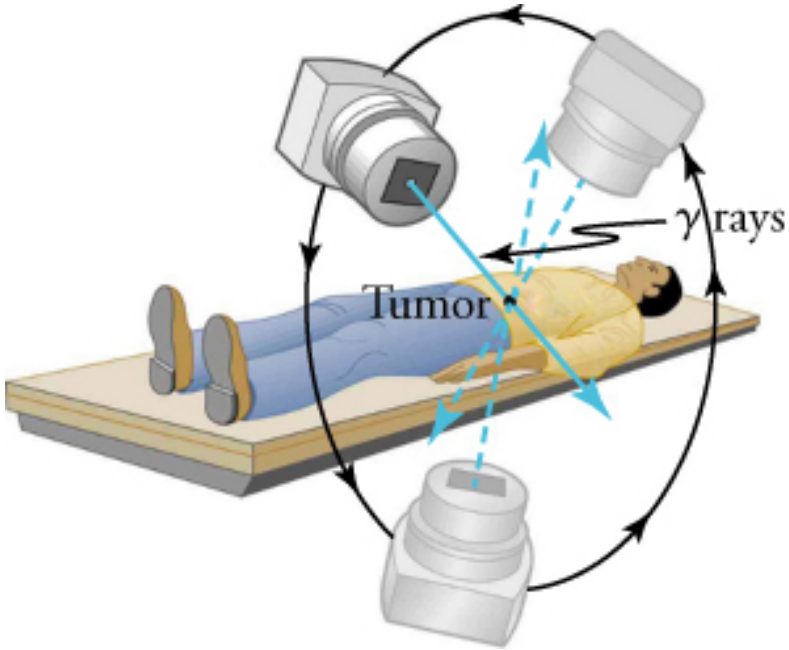

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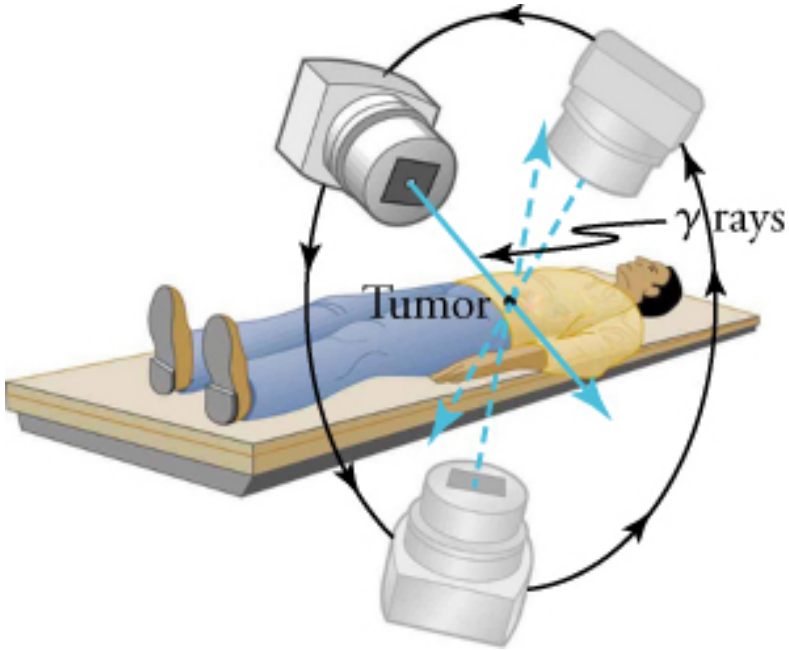

Strategy: Rotate ^{60}Co gamma source around patient. All beams intersect at tumor.

- Tumor receives high dose from all directions
- Surrounding tissue receives low dose from each beam

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6. Radiation destroys cancer cells locally

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The Limit

Technique is limited by tolerable damage to organs that process and eliminate the radiopharmaceutical.

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Key point: Must specify which tissue received the dose.

- Whole-body dose
- Localized dose (e.g., forearm)

Attempt: Radiation Dose Calculation

The Challenge (3 min, silent)

A 60.0-kg person is exposed to ionizing radiation over their entire body and absorbs 1.80 J of energy.

Given:

- Mass = 60.0 kg
- Energy absorbed = 1.80 J

Find: Whole-body radiation dose in rads

Can you calculate the dose? Work silently.

Compare: Dose Calculation

Turn and talk (2 min):

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2. How do you convert J/kg to rads?
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Name wheel: One pair share your approach (not your answer).

Reveal: The Dose

Self-correct in a different color:

Step 1: Energy per mass

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Check: 1.80 J over 60 kg is small energy per mass, so low rad dose. Reasonable!

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Number expressing relative damage from a given type of radiation.

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- X-rays, γ rays: RBE $\approx$ 1
- Beta particles: RBE $\approx$ 1-2
- Alpha particles: RBE $\approx$ 10-20
- Neutrons: RBE $\approx$ 3-10

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Civilian View vs. Reality

Civilian: "Alpha is safe - can't penetrate skin."
Physicist: "Alpha is safe OUTSIDE. Deadly INSIDE."

22.5 The Rem: Dose Equivalent

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The Mental Model

Rads measure energy deposited. Rems measure biological damage.

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Dose Levels

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- **Moderate dose:** 10-100 rem
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Key Point

Dose spread over time allows repair. Same total dose over weeks causes less damage than in one day.

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Context

Average background radiation: $\sim$0.3 rem/year
Chest X-ray: $\sim$0.01 rem
CT scan: $\sim$1 rem

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The Revelations

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2. Gamma cameras, SPECT, and PET create images from radiation outside body

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2. Gamma cameras, SPECT, and PET create images from radiation outside body
3. PET uses antimatter annihilation to pinpoint isotope location

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7. Dose units: rad (energy), RBE (effectiveness), rem (biological damage)

Key Equations

$$1 \text{ rad} = 0.01 \text{ J/kg} \tag{1}$$

$$\text{rem} = \text{rad} \times \text{RBE} \tag{2}$$

$$\text{Therapeutic Ratio} = \frac{\text{Abnormal cells killed}}{\text{Normal cells killed}} \tag{3}$$

The Cosmic Connection

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now heal human bodies.

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Physics doesn't just explain the universe - it saves lives.

Homework

Complete the assigned problems

posted on the LMS