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NARPM Presents...Radiation Safety for Environmental Professionals

Sponsored by: EPA Office of Superfund Remediation and Technology Innovation

Delivered: March 3, 2011, 1:00 PM - 3:00 PM, EST (18:00-20:00 GMT)

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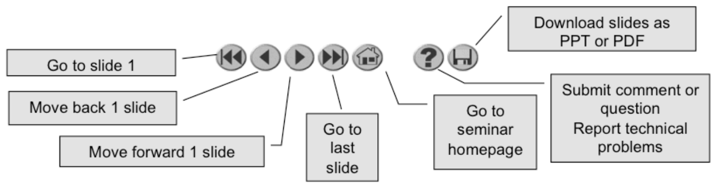

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Although I'm sure that some of you have these rules memorized from previous CLU-IN events, let's run through them quickly for our new participants.

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With that, please move to slide 3.

NARPM PRESENTS

RADIATION SAFETY FOR ENVIRONMENTAL PROFESSIONALS

Presented by
Guy Cooley
Tetra Tech NUS, Inc.

COURSE OBJECTIVES

Understand basic terminology and fundamental principles of radiation

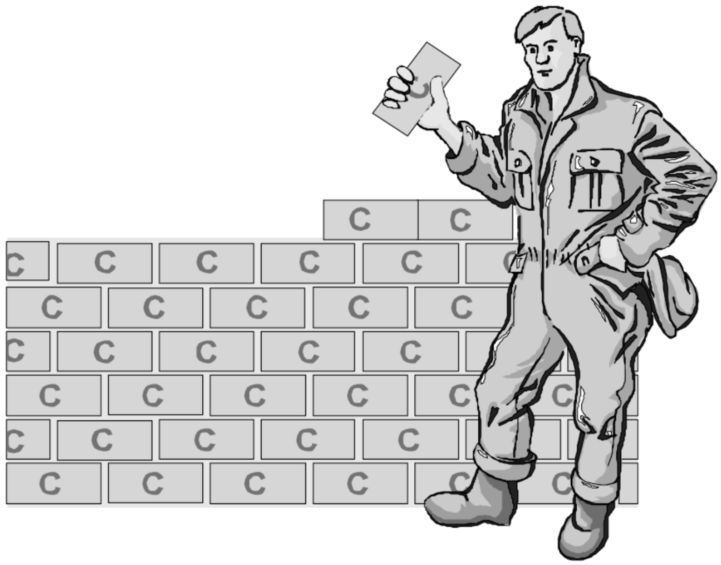
Identify the three primary types of ionizing radiation and their characteristics

Identify radiation dose limits and explain basic methods to control exposures

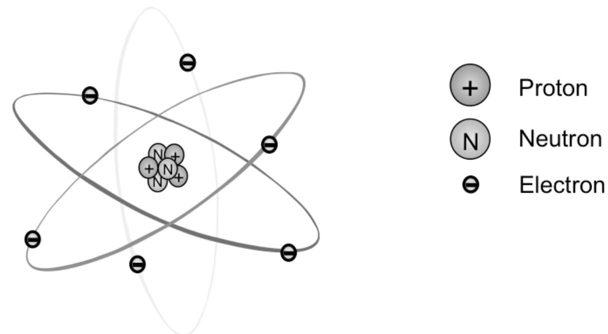
Understand the biological effects of radiation

ATOMIC STRUCTURE
AND
FUNDAMENTAL
PRINCIPLES
OF RADIATION

Atoms are the Fundamental Building Blocks of All Matter

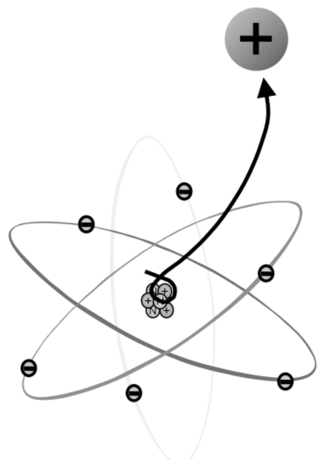


The Atom
The smallest building block of matter



Components of an Atom:		Weight	Charge
	Neutron	1 amu	none
	Proton	1 amu	+1
	Electron	.0005 amu	-1

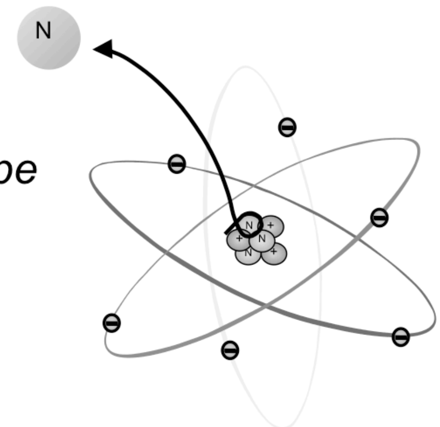
Proton



Positively charged
Number of protons determines the element
Mass = 1 atomic mass unit (AMU) = (1.673 x 10^{-24} gram)

Neutron

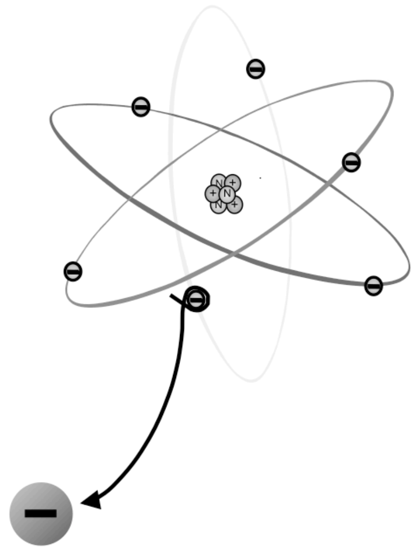
No charge
Mass of 1 AMU
Number of neutrons determines the *isotope*



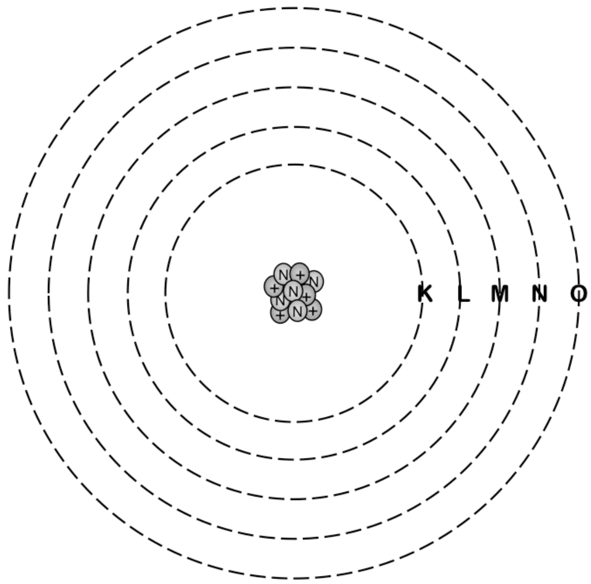
$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

Electrons

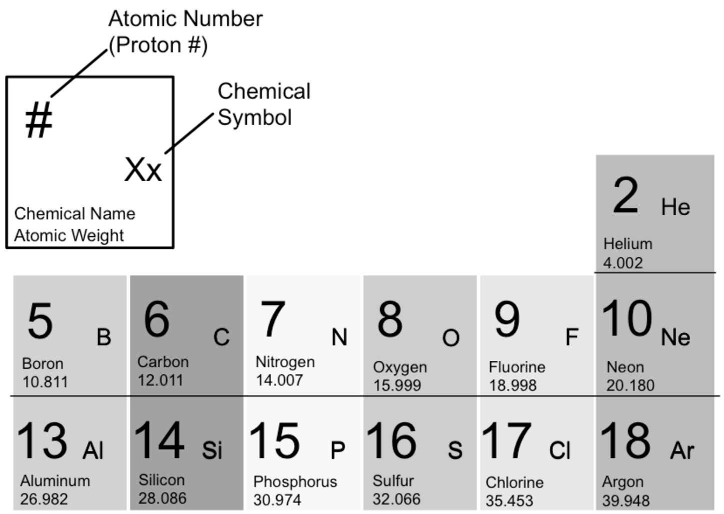
- Negati[redacted] charged parti[redacted] that orbit the nucleus
- Mass of .0005 AMU
- Orbit in structured shells
- Shells are lettered K - Q



Electron Shells



Chemical Notation



Convention

$$^{A}_{Z}X$$

A = Mass Number = Z + N

(Note: N = neutron number)

Z = Atomic number (number of protons)

X = Element symbol (indicates element)

Notation Example

$$^{12}_{6}C \;=\; ^{12}C \;=\; C\text{-}12$$

Nuclide

A species of an atom characterized by the constitution of its nucleus, which is specified by its number of protons and neutrons, and its energy content.

Radionuclide

A radioactive (unstable) nuclide.

Isotopes

Atoms of the same element with a different number of neutrons (same Z, but different A).

Isotope Examples

$^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$

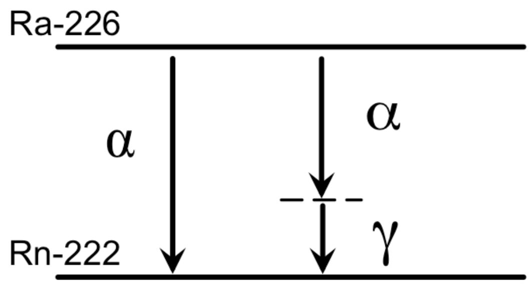
(C-12 and C-13 are stable)

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

(H-1 and H-2 are stable)

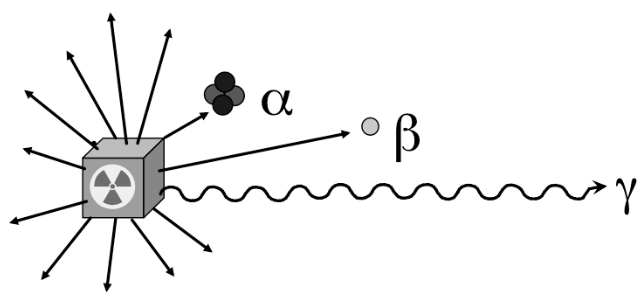
Radioactivity

The process by which unstable atoms try to become stable, and as a result, emit radiation



Radiation

Energy emitted as electromagnetic waves or energetic particles



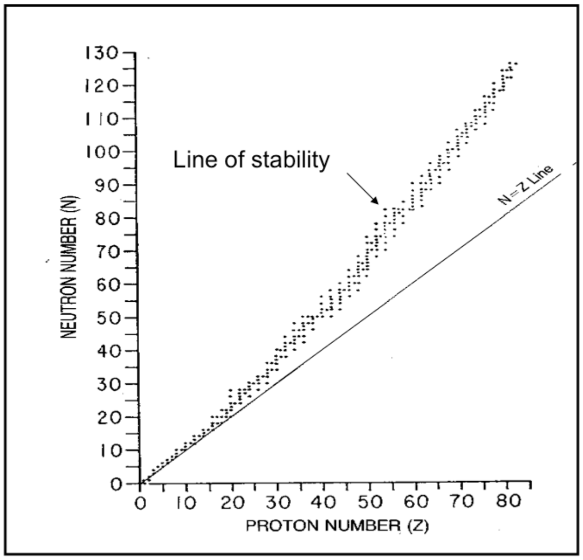
Radioactive Decay

Process by which atoms change (decay) to atoms of a different element or to a lower energy state of the same element by the spontaneous emission of charged particles or electromagnetic waves

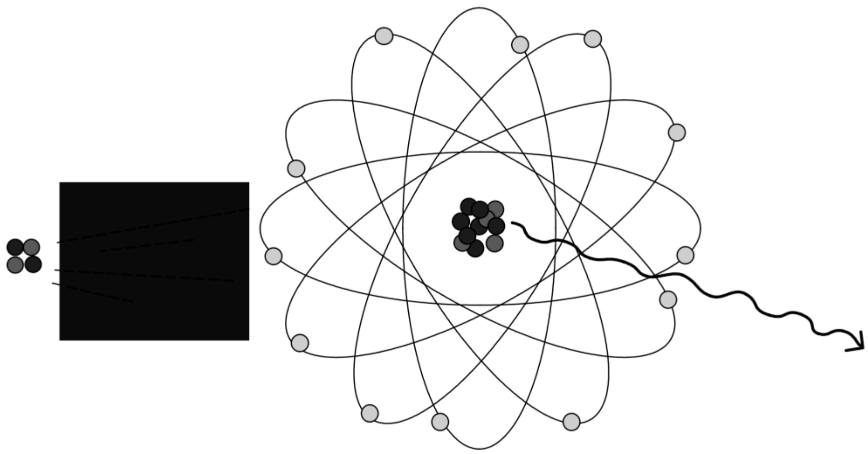
Causes - Radioactive Decay

Unstable proton-to-neutron ratio
Excess binding energy

Line of Stability

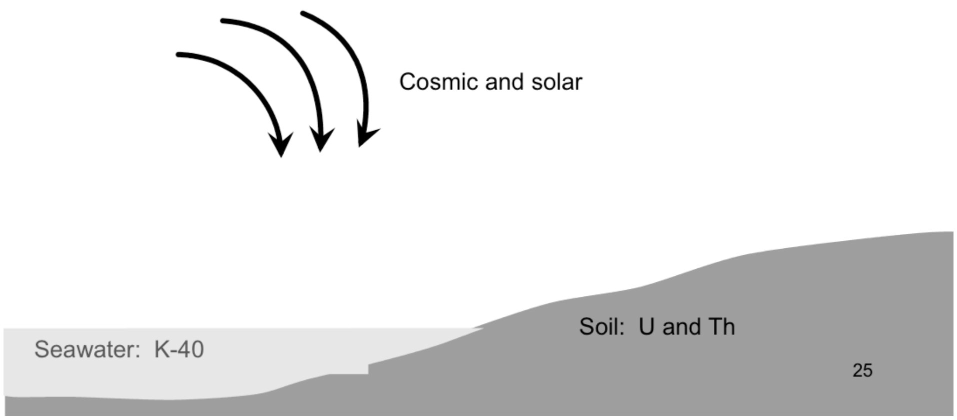


Radioactive Decay



Natural Radioactivity

naturally-occurring radionuclides



Artificial or Induced Radioactivity

Radioactivity produced in a stable substance by particle bombardment or electromagnetic irradiation of elements

Also called *activation*

Co-59 ⇨ Co-60 neutron bombardment

Activity

The measurement of radioactive material

Measured by counting the number of disintegrations per unit time

- Disintegrations per second (dps)
- Disintegrations per minute (dpm)

Traditional Activity Units

Note: International System (SI)
1 Becquerel (Bq) = 1 dps

Activity Subunits

1 microcurie (μCi) $= 1 \times 10^{-6}$ Ci

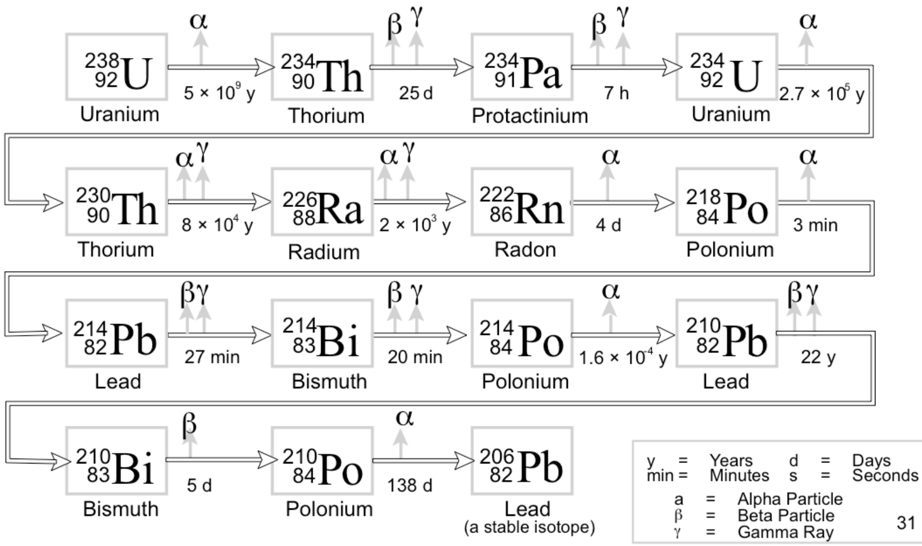
1 picocurie (ρCi) $= 1 \times 10^{-12}$ Ci

Half-Life

The time required for a radioactive substance to lose one-half of its activity due to radioactive decay. Each radionuclide has a specific half-life.

Decay Schemes

Radioactive Disintegration Series for Uranium 238



Calculate the Activity

$A = A_o e^{-\lambda t}$

where: A = activity after time t

A_o = original activity
e = base of natural logarithm (2.718)
λ = decay constant (ln 2/half-life)
t = elapsed time

Example

A 10.5 Ci Co-60 radiography source was prepared three years ago, having a half-life of 5.271 years. What is the activity today?

A_o = 10.5 Ci
t = 3 years
$T_{½}$ = 5.271 years

$$A = A_0 e^{\left(\frac{-\ln 2}{T_{1/2}}\right)t}$$

Equation

$$A = A_o e^{\left(\frac{-\ln 2}{T_{1/2}}\right) t}$$

$$A = 10.5e^{\left(\frac{-.693}{5.271}\right) 3}$$

$$A = 10.5e^{-0.39}$$

$$A = 10.5(0.677)$$

A = 7.1 Ci Co-60

Conclusion

Three basic particles of the atom
Chemical notation
Radionuclide
Radioactive decay
Decay scheme
Activity and half-lives

QUESTIONS

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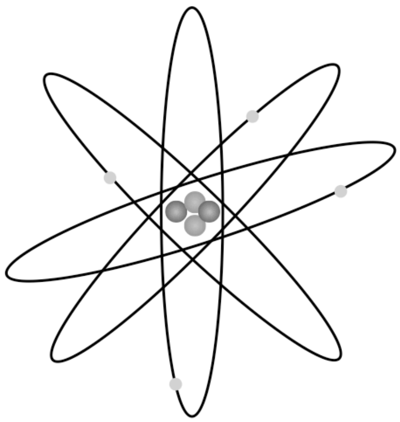
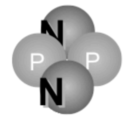
TYPES AND CHARACTERISTICS OF IONIZING RADIATION

Four Basic Types of Ionizing Radiation

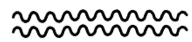


Alpha particles



Beta particles

Gamma rays

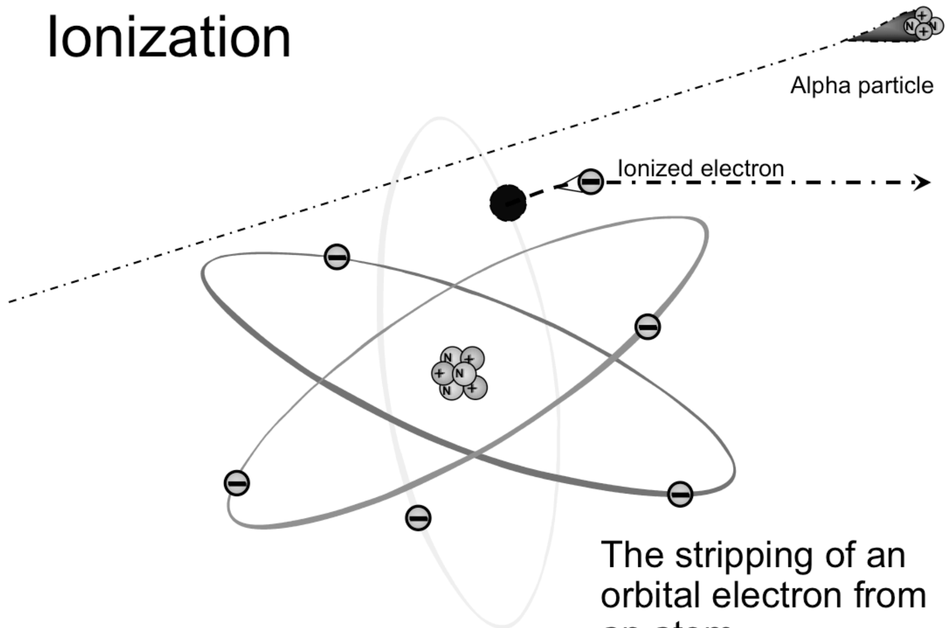


Neutrons

Common Interactions of Radiation With Matter

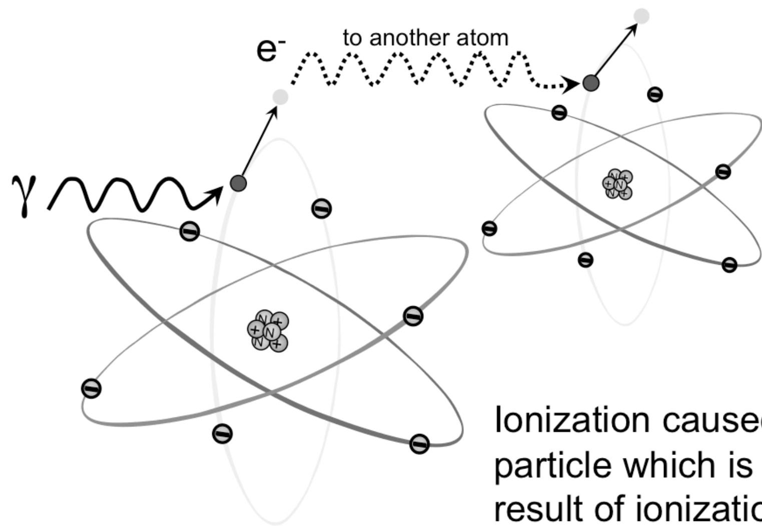
- Ionization
- Excitation

Ionization



The stripping of an orbital electron from an atom

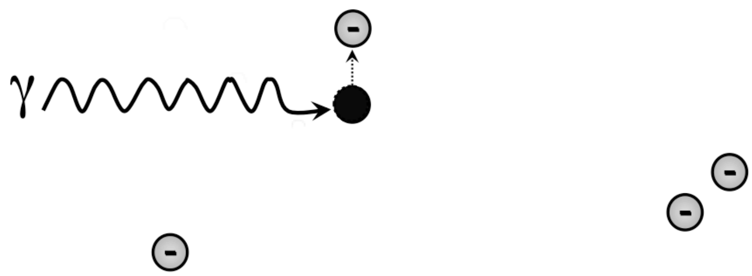
Secondary Ionization



Ionization caused by a particle which is *itself* a result of ionization

Excitation

The forced movement of an electron from an inner shell to some outer shell



Linear Energy Transfer (LET)

The amount of energy deposited by a specific radiation over a specific distance (ionizations per unit path length)

α	10,000s of ionizations/cm air
β	100s of ionizations/cm air
γ	1 ionization/cm air

Characteristics of Alpha Particles

- Emitted from nucleus
- Composition: 2 neutrons, 2 protons (same as ^{4}He nucleus)
- High mass: 4 amu
- High charge: + 2
- High energy: 4 - 8 MeV

Sources of Alpha Particles

- Radioactive decay of heavier radionuclides (predominantly Z > 82)
- Examples:

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}\alpha + 4.2\ MeV$$

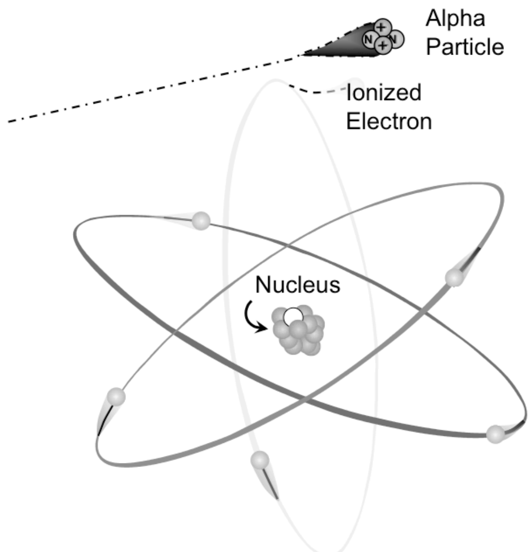
$$^{239}_{94}Pu \longrightarrow ^{235}_{92}U + ^{4}_{2}\alpha + 5.2\ MeV$$

$$^{226}_{88}Ra \longrightarrow ^{222}_{86}Rn + ^{4}_{2}\alpha + 5.5\ MeV$$

Alpha Particle Interactions

- Path length ≈ 1 inch in air
- High ionization per unit path length (LET)
- Becomes helium atom by attracting two electrons

Alpha Particle Interactions



Characteristics of Beta Particles

- Emitted from nucleus
- Composition: identical to electron
- Two types: negatron with -1 charge (β^-)
  positron with +1 charge (β^+)
- Low mass: about .0005 amu
- Energies: most commonly 0.1 to 4 MeV
- Share decay energy with neutrino

Sources of Beta Particles

- β^- emitted from nucleus with too many neutrons
- β^+ emitted from nucleus with too few neutrons
- Examples:

$$^{3}_{1}H \longrightarrow \, ^{3}_{2}He + \, ^{0}_{-1}\beta + \bar{\nu} + 0.019\ \text{MeV}$$

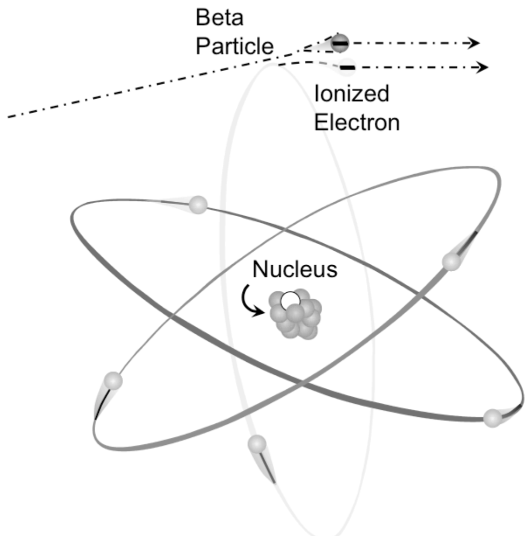
$$^{40}_{19}K \longrightarrow \, ^{40}_{20}Ca + \, ^{0}_{-1}\beta + \bar{\nu} + 0.17\ \text{MeV}\ (89\%)$$

$$^{40}_{19}K \longrightarrow \, ^{40}_{18}Ar + \, ^{0}_{+1}\beta + \nu + 0.49\ \text{MeV}\ (11\%)$$

Beta Particle Interactions

- Possible bremsstrahlung
- Medium ionization per unit path length (LET)
- Path length a few feet in air
- Positrons produce annihilation photons

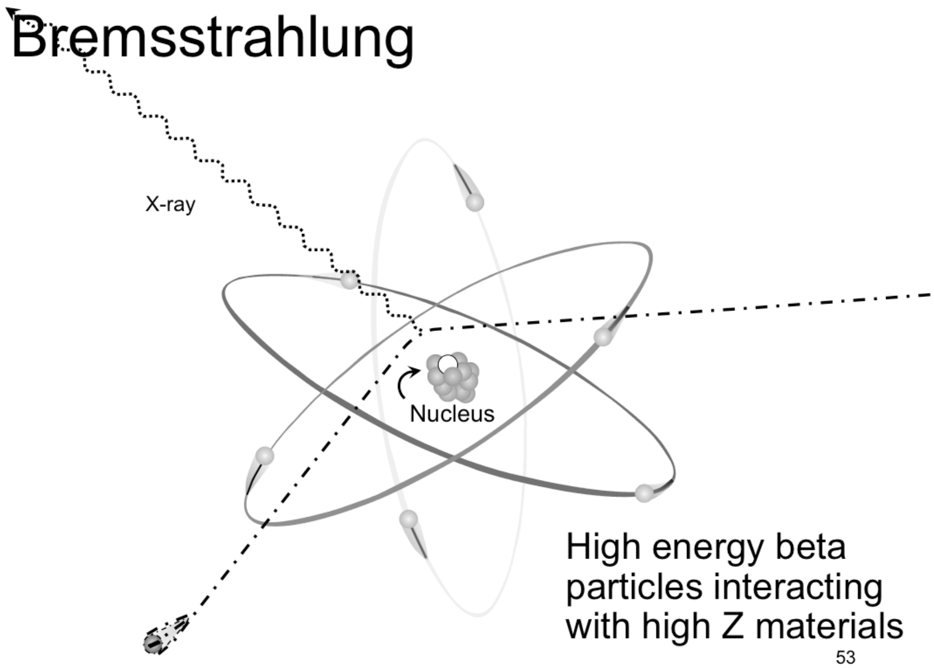
Beta Particle Interactions



Bremsstrahlung

Braking Radiation is produced by the deceleration of a beta particle around the (+) charged nucleus of an atom, causing x-rays to be emitted.

Bremsstrahlung



High energy beta particles interacting with high Z materials

Characteristics of Gamma Rays

- Electromagnetic energy
- Gamma rays from nucleus
- Zero mass, zero charge
- Energies: most commonly 0.5 to 2 MeV

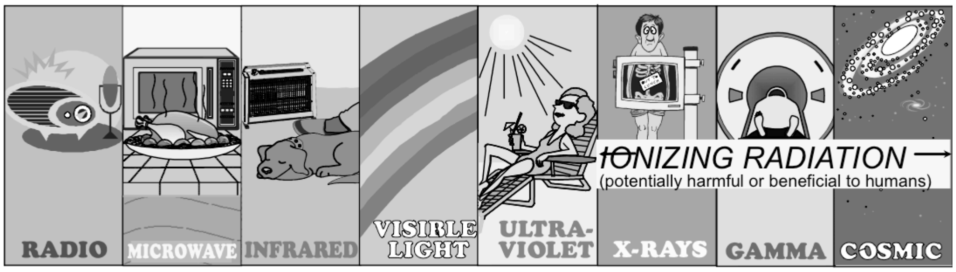
Sources of Gamma Rays

- Nucleus rearrangements following alpha or beta decay
- Nucleus moves from excited state to lower energy state
- Examples:

$$^{137}_{55}\text{Cs} \longrightarrow\ ^{137}_{56}\text{Ba}^{*} +\ ^{0}_{-1}\beta$$

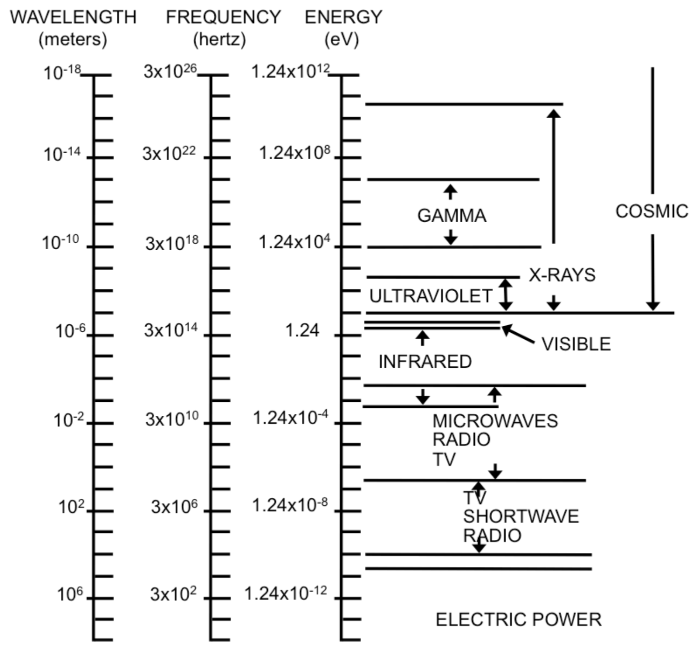
$$^{137}_{56}\text{Ba}^{*} \longrightarrow\ ^{137}_{56}\text{Ba} + \text{0.662 MeV gamma ray}$$

The Electromagnetic Energy Spectrum



Low frequency/Energy High frequency/Energy

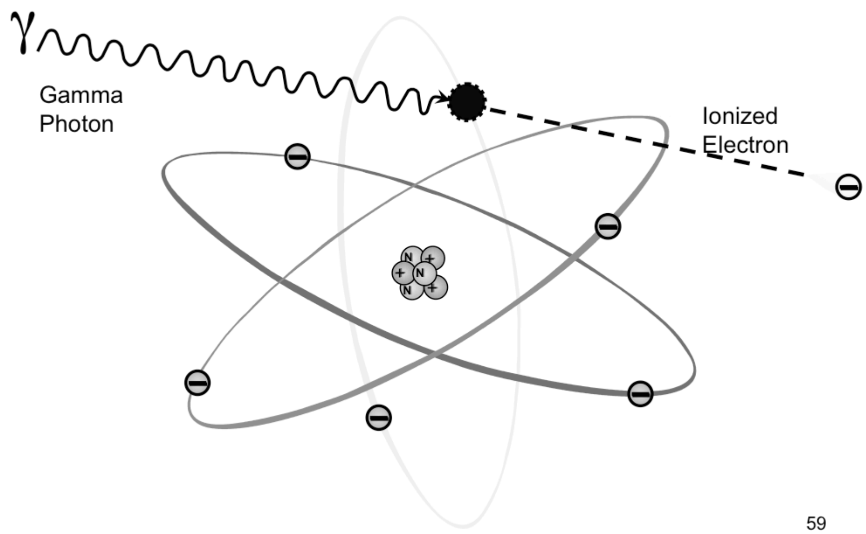
The Electromagnetic Energy Spectrum



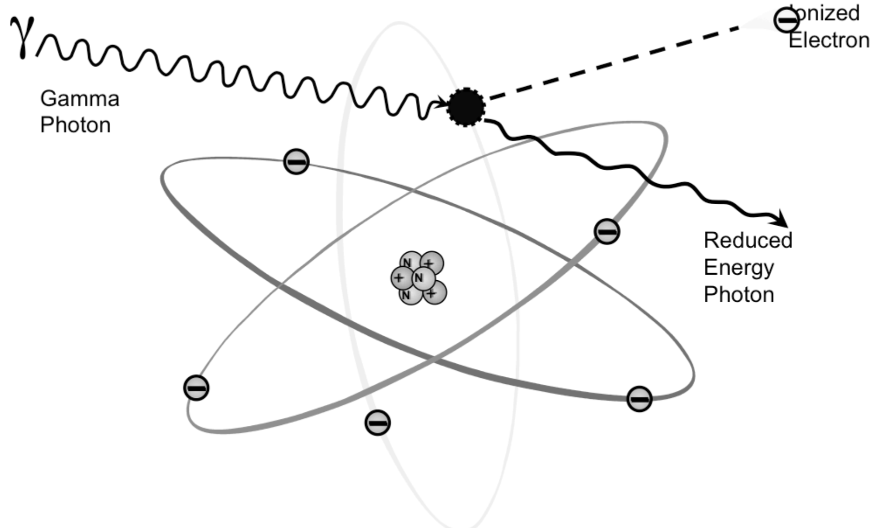
Gamma Ray Interactions

- Very long path length ≈ 100s of meters in air
- Low ionization per unit path length (LET)
- Three principle interactions
  - Photoelectric effect
  - Compton scattering
  - Pair production

Photoelectric Effect

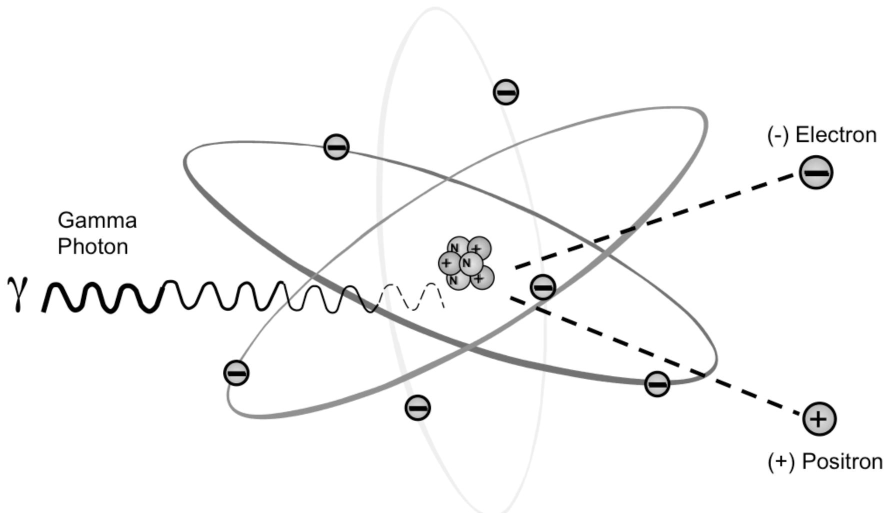


Compton Scattering



Pair Production

(all photon energy converted to mass)



Characteristics of Neutrons

- Emitted from nucleus
- Mass: 1 amu
- Charge: 0
- Energies
  - Thermal neutrons ≈ 0.025 eV
  - Fast neutrons ≈ 0.1 to 10 MeV

Sources of Neutrons

- Spontaneous fission of uranium and transuranics
- Neutron-induced fission in
  - Operating nuclear reactors
  - Nuclear weapons explosions
- Neutron sources – alpha bombardment – alpha sources mixed with beryllium (americium, polonium, plutonium)

$$^{9}_{4}Be + ^{4}_{2}\alpha \longrightarrow ^{13}_{6}C^{*} \longrightarrow ^{12}_{6}C + ^{1}_{0}n$$

Neutron Interactions

- Almost exclusively nuclei interactions
- Activation and excitation of nuclei
- Long path lengths in air ≈ hundreds of feet, but much shorter path lengths in hydrogenous materials

Shielding Alpha Radiation

- Most alpha particles are stopped by a few centimeters of air, a sheet of paper, or the dead layer of skin
- Alpha particles are considered an internal hazard only. If ingested or inhaled, they can cause great damage

Shielding Beta Radiation

- Shielded by plastic, aluminum, rubber, glass, or safety glasses
- Can penetrate skin and eyes
- Most dangerous if inhaled or ingested

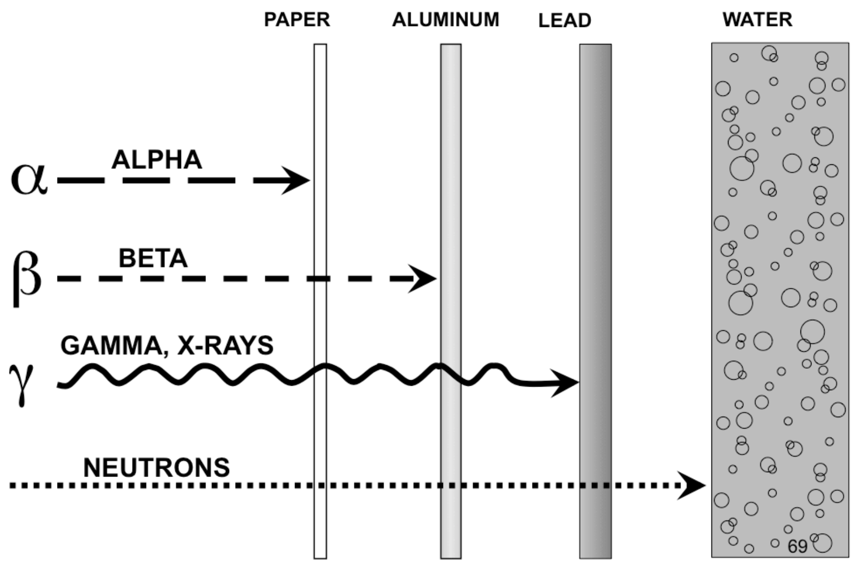
Shielding Gamma Radiation

- Shielded by very dense materials (high Z) such as iron, lead, or steel
- Very penetrating, thus whole-body hazard

Shielding Neutron Radiation

- Has ability to penetrate the whole body
- Primarily an external hazard, but not normally found in the environment
- Shielded by hydrogenous materials such as water or paraffin

Shielding Materials



QUESTIONS

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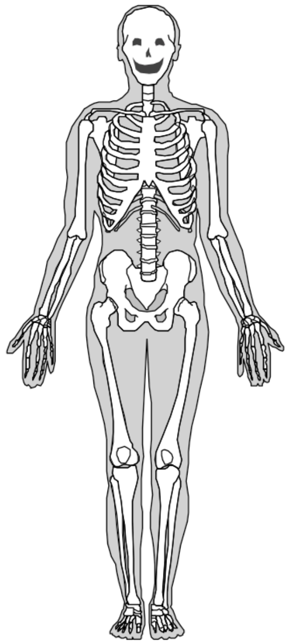


RADIATION DOSE LIMITS AND BIOLOGICAL EFFECTS

Radiation Dose Limits

Dose Limits: Radiation Protection Recommendations

- International Commission on Radiological Protection (ICRP)
- National Council on Radiation Protection and Measurements (NCRP)
- Radiation exposure safe guiding principle: **A**s **L**ow **A**s **R**easonably **A**chievable (ALARA) adopted by ICRP and NCRP

Units of Dose Measurement

- Roentgen (R): *A measure of charge produced by "X" and "Gamma" rays.* That amount of X or gamma radiation that will produce 1 electrostatic unit of charge per cubic centimeter of air (cm^3).
  - Most radiation exposure instruments measure in R/hr, mR/hr, μR/hr (dose rate)

Units of Dose Measurement

- RAD: *Radiation Absorbed Dose.* The amount of energy absorbed in material (tissue).
  - 1 RAD = 100 ergs/g of energy
  - 1 RAD = .01 Gray (SI)

Units of Dose Measurement

- REM: *Roentgen Equivalent Man.* The measure of biological risk from a dose regardless of the type of radiation. A unit of Dose Equivalent for any type of radiation that represents the equivalent damage caused by depositing 1 RAD of X or gamma radiation.
  - Based on the Quality Factor (QF)
  - 1 REM = .01 Sievert (SI)

Quality Factor

A numerical value multiplied by the absorbed dose to determine the "dose equivalent."

(RAD x QF = REM)

GAMMA 1 RAD x 1 = 1 REM

BETA 1 RAD x 1 = 1 REM

NEUTRON 1 RAD x 10 = 10 REM
(Unknown Energy)

ALPHA 1 RAD x 20 = 20 REM

Radiation Subunits

- 1 rem = 1,000 mrem (millirem)
- 1 mrem = 1,000 μrem (microrem)

U.S. EPA Exposure Guidelines

- U.S. EPA Safety, Health and Environmental Management Program (SHEMP) Guide 38

- Guide 38 – “Radiation Safety and Health Protection Program”

Administrative Control Level (ACL) for U.S. EPA Employees

- Enrolled in program
- ACL of 500 mrem/year
  - Any 12 consecutive months
  - At 500 mrem – restrict radiation exposure (do not exceed 500 mrem for any 12-month period)

Administrative Control Level (ACL) for U.S. EPA Employees

- Waivers/Exceptions to ACL:
  - Critical work: 5 rem
  - Single planned event: 10 rem
  - Life-saving activities: 25 rem

Reference: U.S. EPA 400-R-92-001

Action Reference Level (ARL) for U.S. EPA Employees

- ARL of 50 mrem/quarter
- Monitor the employee dose every quarter year
- Measured over three months (one quarter)

Monitoring and Dosimetry of U.S. EPA Employees

- Dosimeter required for U.S. EPA work activities where radiation exposure is above background
- Thermoluminescent dosimeter (TLD):
  - Monitors external exposure
  - Wear for one calendar quarter, then read for dose
  - Exchanged more frequently under special circumstances

Monitoring and Dosimetry of U.S. EPA Employees

- Additional dosimeters:
  - Extremities: finger ring, ankle
  - Neutron
  - Dose/dose rate level alarms

Emergency Exposure Guidance "Turnback Levels"

Time Period	Stop-and-Check	Condition
Early Phase	**10 R/h**	Voluntary, with supervisor review, for lifesaving or critical actions ONLY – evaluate anticipated doses against dose limits above
Intermediate Phase	**1.5 R/hr**	Dose management imperative
Late or Recovery Phase	Site-specific according to site health and safety plan	EPA Action Reference Level: 50 mrem/quarter *and* Administrative Control Level: 500 mrem/year

Source: U.S. EPA SHEMP 38

Protective Action Guides (PAGs)

During a radiological emergency, public health officials must act quickly to protect public health. EPA has developed a system (PAGs) to help officials make critical decisions.

Source: U.S. EPA 400-R-92-001

U.S. EPA Protective Action Guides (PAG's)

10 REM – To save equipment

25 REM – To save personnel

>25 REM – Use volunteers only

Source: U.S. EPA 400-R-92-001

Protective Action Guides (PAGs)

- PAGs identify three phases of an emergency:
  - Early
  - Intermediate
  - Late

Protective Action Guides (PAGs)

- Early phase
  - Several hours to several days, evacuation and sheltering are the principal actions to protect the public from exposure to direct radiation and inhalation of airborne radioactive material

Protective Action Guides (PAGs)

- Intermediate phase
  - From weeks to months, protective actions may include limiting food and water consumption to decrease ingestion of radioactive material and relocating people to protect them from radiation exposure

Protective Action Guides (PAGs)

- Late phase
  - From months to years, the PAGs address the decontamination of property

OSHA Dose Limits

- 29 CFR 1910.1096
- Quarterly
  - Whole-body: head and trunk, active blood-forming organs, lens of eyes, or gonads: 1.25 rem per quarter (5 rem/year)
  - Hands and forearms, feet and ankles: 18.75 rem per quarter (75 rem/year)
  - Skin of whole body: 7.5 rem/quarter (30 rem/year)

NRC Dose Equivalent Limits

- NRC standard 10 CFR 20
  - 5 rem/year
- NRC standard 10 CFR 20, Appendix B
  - Provides annual limits on intake (ALI)
  - Limits on intake of given radionuclide by a "reference man"

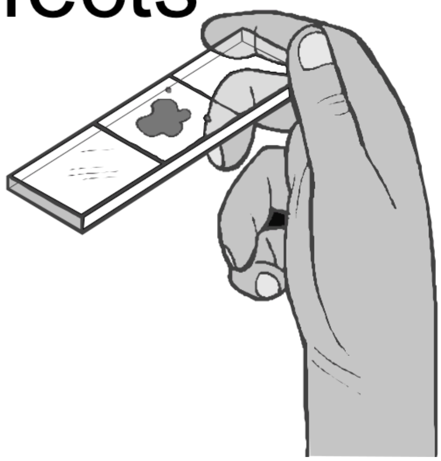
Declared Pregnant Worker

- Instructions – NRC Regulatory Guide 8.13, and SHEMP Guide 38
- Declared pregnant worker (voluntary)
  - Worker may notify employer in writing that she is pregnant
  - The declaration may be revoked in writing at any time by the declared worker
  - 500 mrem limit/gestation period

ALARA

- ALARA (As Low As Reasonably Achievable)
  - Principle for minimizing radiation doses and release of radioactive materials by all *reasonable methods*
- Time – Minimize the time of exposure
- Distance – Maximize the distance to reduce exposure rate
- Shielding – Use appropriate absorber materials to reduce exposure

Biological Effects



Biological Effects of Radiation

- More is known about the biological effects of radiation now than ever before
- Four major groups of people who have been exposed to radiation:
  - Radiological workers
  - Atomic bomb survivors (250,000)
  - People involved in radiation accidents
  - Radiation therapy patients

Effects of Acute Radiation Dose

- Dose received in a short time period, usually less than one day

700 RAD = LD_{100}	Within days
600 RAD = LD_{99}	Within days
450 RAD = LD_{50}	Within 30 days
200 RAD = LD_{LO}	Within several weeks
100 RAD = TD_{LO}	Immunosuppressive reaction
25 RAD = ED_{LO}	Blood serum changes

Effects of Chronic Radiation Dose

- Small amount of radiation over a long time period
- Body has time to repair damage

Effects of Chronic Radiation Dose

- Any member of the U.S. population has about a 33% chance of contracting cancer and about a 25% chance of dying of cancer
- Cancer risk is approximately .02%/rem
  - 50 rem = 1% increased risk of cancer

Damage Mechanisms

- Living tissue damage can result when ionizing radiation causes atoms and molecules to become ionized or excited
- Ionizations and excitations can:
  - Produce free radicals
  - Break chemical bonds
  - Damage molecules that control essential cell functions (e.g., DNA)

Possible Effects of Radiation On Cells

- Cells may not be damaged
- Cells may be damaged, but can fully repair at lower levels and operate normally
- Cells may be damaged and operate abnormally
- Cell death may result at higher doses

Cell Sensitivity

Most Radiosensitive

- Actively dividing and non-specialized cells
  - Blood-forming cells
  - Cells that line the intestinal tract
  - Hair follicles
  - Cells that form sperm
- These cells are more susceptible to damage from ionizing radiation

Cell Sensitivity

Least Radiosensitive

- Less actively dividing and more specialized cells
  - Cells that divide more slowly
  - Specialized cells
    - ✓ Brain cells
    - ✓ Muscle cells
- These cells are not as susceptible to damage from ionizing radiation

Somatic Effects

- Damage to cells other than reproductive cells
- Seen in the exposed individual
- Not passed on to offspring

Delayed Somatic Effects

- Delayed effects may result from acute or chronic exposure
  - Cancer
  - Cataracts
  - Shorter life expectancy

Genetic Effects of Radiation Exposure

- Mutations due to radiation damage to the DNA of a cell
- Genetic damage passed on to offspring
- Atomic bomb survivors:
  - No heritable effects found in children born to the survivors; 77,000 children

Sources of Radiation Exposure

- Naturally occurring in the environment
- Man-made radionuclides in the environment

See: www.epa.gov/radiation
and
www.epa.gov/oar

Average Annual Dose

- The average annual dose to the general population is about 625 mrem. This estimate is for non-smokers.

SOURCE: 2009 NCRP Report No. 160 Ionizing Radiation Exposure of the Population of the United States

Sources of Radiation Exposure of the U.S. Population

SOURCE	SOURCE (mrem/year)	% of TOTAL
NATURAL (ubiquitous background)		
Internal, inhalation (radon and thoron) ……………	228	37%
External, space ………………	33	5%
Internal, ingestion …………….	29	5%
External, terrestrial ……………	21	3%
TOTAL NATURAL	**311**	**50%**

SOURCE: 2009 NCRP Report No. 160 Ionizing Radiation Exposure of the Population of the United States

Sources of Radiation Exposure of the U.S. Population

SOURCE	SOURCE (mrem/year)	% of TOTAL
MANMADE		
Medical …………………………………	300	48%
CT 147, 24%		
Nuclear Medicine 77, 12%		
Interventional Fluoroscopy 43, 7%		
Conventional Radiography and Fluoroscopy 33, 5%		
Consumer ………………………………	13	2%
Industrial ..………………………………	.3	<0.1%
Occupational ………………………….	.5	<0.1%
TOTAL MANMADE (Non-smokers)	**313. 8**	**50%**

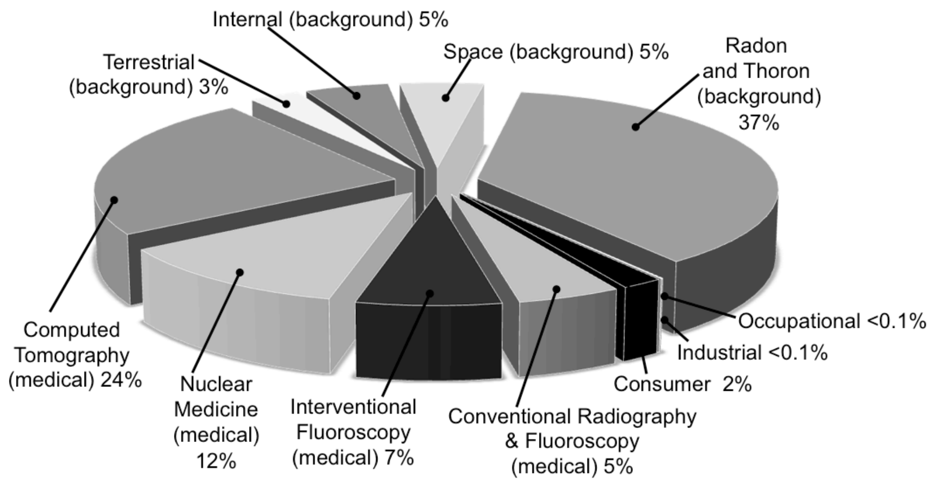
SOURCE: 2009 NCRP Report No. 160 Ionizing Radiation Exposure of the Population of the United States

Sources of Radiation Exposure of the U.S. Population

SOURCE	SOURCE (mrem/year)	% of TOTAL
TOTAL NATURAL	**311.0**	**50%**
TOTAL MANMADE (Non-smokers)	**313.8**	**50%**
TOTAL OF MANMADE AND NATURAL (Non-smokers)	**624.8**	**100%**

SOURCE: 2009 NCRP Report No. 160 Ionizing Radiation Exposure of the Population of the United States

Sources of Radiation Exposure of the U.S. Population



SOURCE: 2009 NCRP Report No. 160 Ionizing Radiation Exposure of the Population of the United States

HEALTH RISK	ESTIMATED LIFE EXPECTENCY LOST
Smoking 20 cigarettes a day	6 years
Overweight by 15%	2 years
Alcohol (U.S. average)	1 year
All accidents	207 days
Occupational dose of 1 rem/year from age 18-65 (47 yrs total)	**51 days**
Occupational dose of 300 mrem/year from age 18-65 (47 yrs total)	**15 days**
All natural hazards	7 days
Medical radiation	6 days

SOURCE: these estimates are taken from NRC Draft Guide DG-8012 and were adapted from B.L. Cohen and L.S. Lee, "Catalogue of Risks Extended and Updates," Health Physics, Vol. 61, September 1991.

QUESTIONS

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Resources & Feedback

- To view a complete list of resources for this seminar, please visit the **Additional Resources**
- Please complete the **Feedback Form** to help ensure events like this are offered in the future

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