



## **Welcome to the CLU-IN Internet Seminar**

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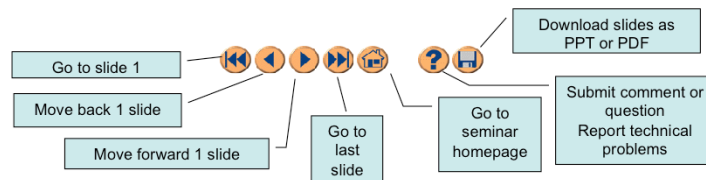
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- Q&A
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Although I'm sure that some of you have these rules memorized from previous CLU-IN events, let's run through them quickly for our new participants.

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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

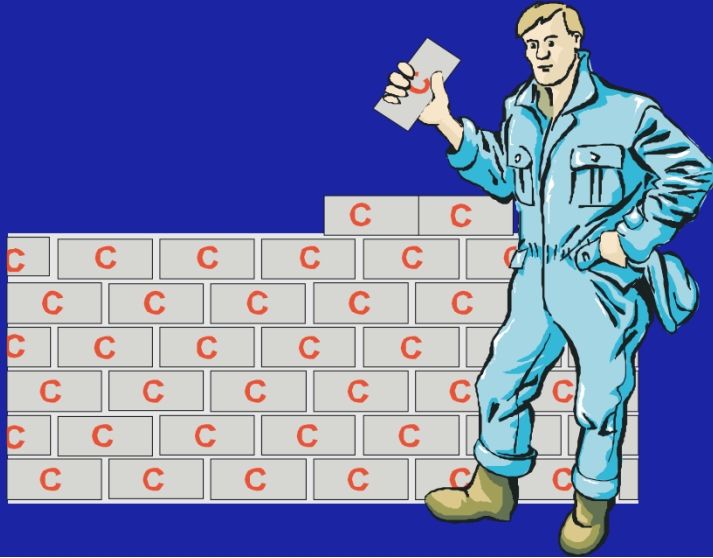
Identify the three primary types of ionizing radiation and their characteristics

Identify radiation dose limits and explain basic methods to control exposures

Understand the biological effects of radiation

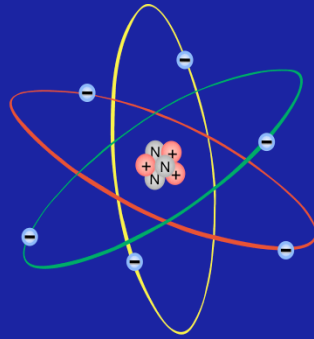
ATOMIC STRUCTURE  
AND  
FUNDAMENTAL  
PRINCIPLES  
OF RADIATION

# Atoms are the Fundamental Building Blocks of All Matter



# The Atom

The smallest building block of matter

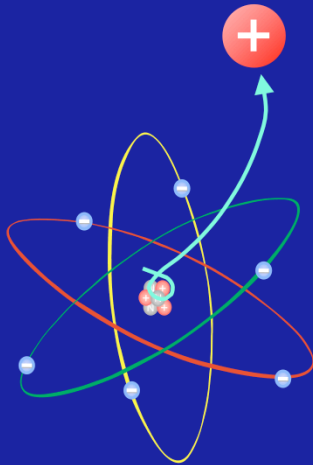


- Proton
- Neutron
- Electron

## Components of an Atom:

	<u>Weight</u>	<u>Charge</u>
Neutron	1 amu	none
Proton	1 amu	+1
Electron	.0005 amu	-1

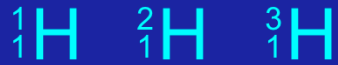
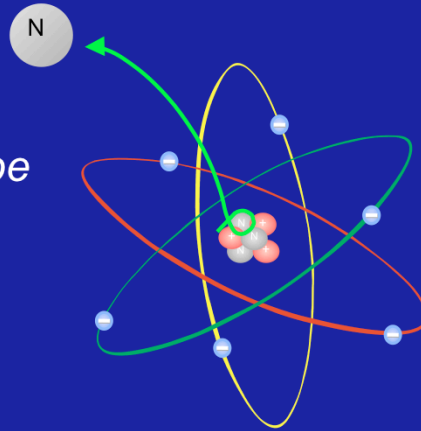
# Proton



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

# Neutron

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



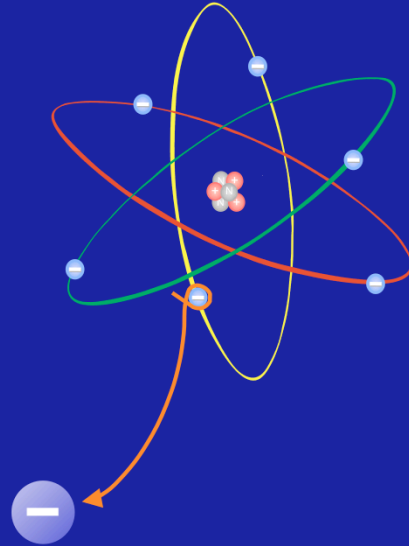
# Electrons

Negatively charged  
particles that orbit the  
nucleus

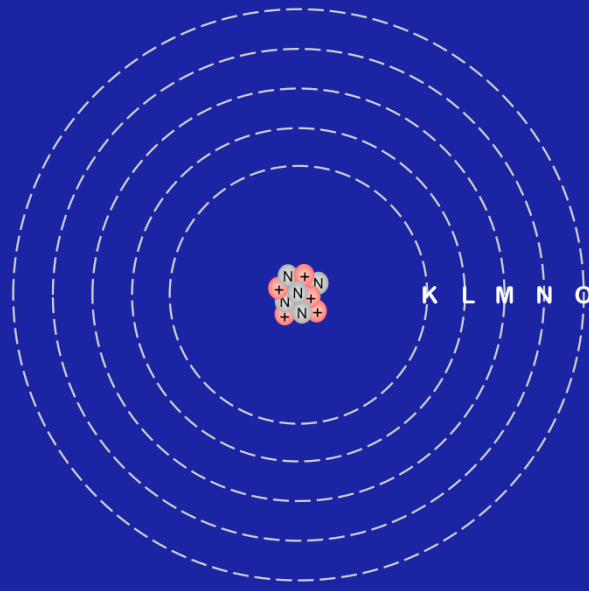
Mass of .0005 AMU

Orbit in structured shells

Shells are lettered K - Q



# Electron Shells



# Chemical Notation

<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid cyan; padding: 5px; text-align: center;"> <p>#</p> <p>Xx</p> <p>Chemical Name Atomic Weight</p> </div> <div style="text-align: center;"> <p>Atomic Number (Proton #)</p> <p>Chemical Symbol</p> </div> </div>					
<div style="border: 1px solid cyan; padding: 5px; text-align: center;"> <p>2 He</p> <p>Helium 4.002</p> </div>					
<p>5 B</p> <p>Boron 10.811</p>	<p>6 C</p> <p>Carbon 12.011</p>	<p>7 N</p> <p>Nitrogen 14.007</p>	<p>8 O</p> <p>Oxygen 15.999</p>	<p>9 F</p> <p>Fluorine 18.998</p>	<p>10 Ne</p> <p>Neon 20.180</p>
<p>13 Al</p> <p>Aluminum 26.982</p>	<p>14 Si</p> <p>Silicon 28.086</p>	<p>15 P</p> <p>Phosphorus 30.974</p>	<p>16 S</p> <p>Sulfur 32.066</p>	<p>17 Cl</p> <p>Chlorine 35.453</p>	<p>18 Ar</p> <p>Argon 39.948</p>

## Convention



A = Mass Number = Z + N

(Note: N = neutron number)

Z = Atomic number (number of protons)

X = Element symbol (indicates element)

## Notation Example



## 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.

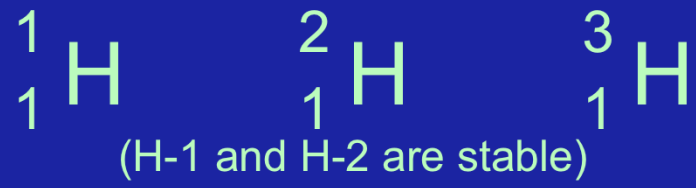
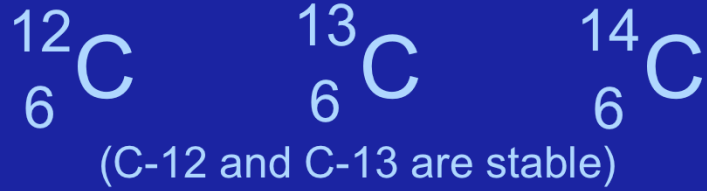
# Radionuclide

A radioactive (unstable) nuclide.

# Isotopes

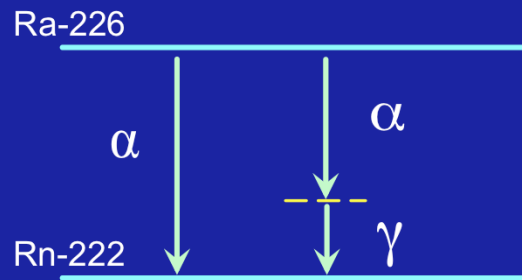
Atoms of the same element with a different number of neutrons (same  $Z$ , but different  $A$ ).

## Isotope Examples



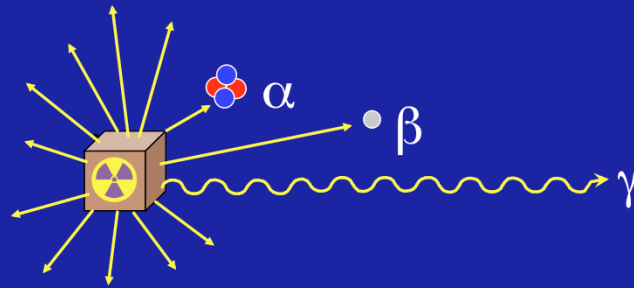
# Radioactivity

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



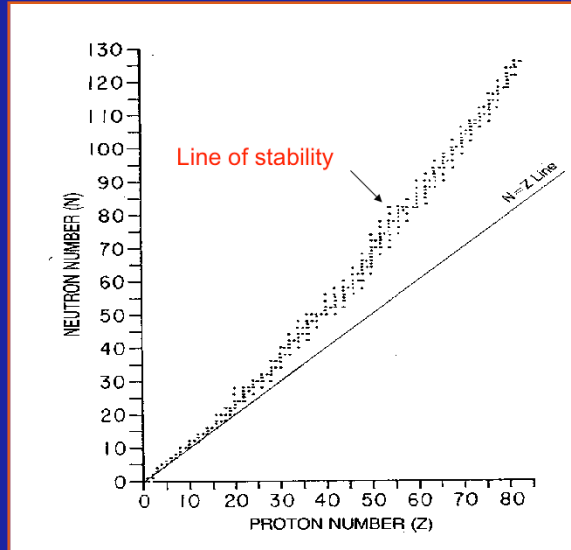
## Radioactive Decay

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

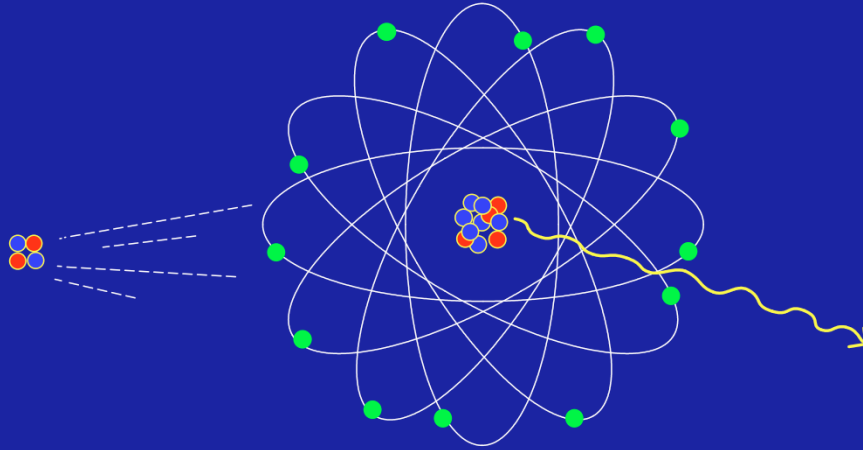
## Causes - Radioactive Decay

Unstable proton-to-neutron ratio  
Excess binding energy

# Line of Stability

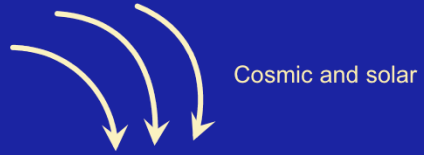


# Radioactive Decay



# Natural Radioactivity

naturally-occurring radionuclides



Seawater: K-40

Soil: U and Th

## Artificial or Induced Radioactivity

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

Also called *activation*

Co-59  $\Rightarrow$  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 ( $\mu\text{Ci}$ ) =  $1 \times 10^{-6}$  Ci

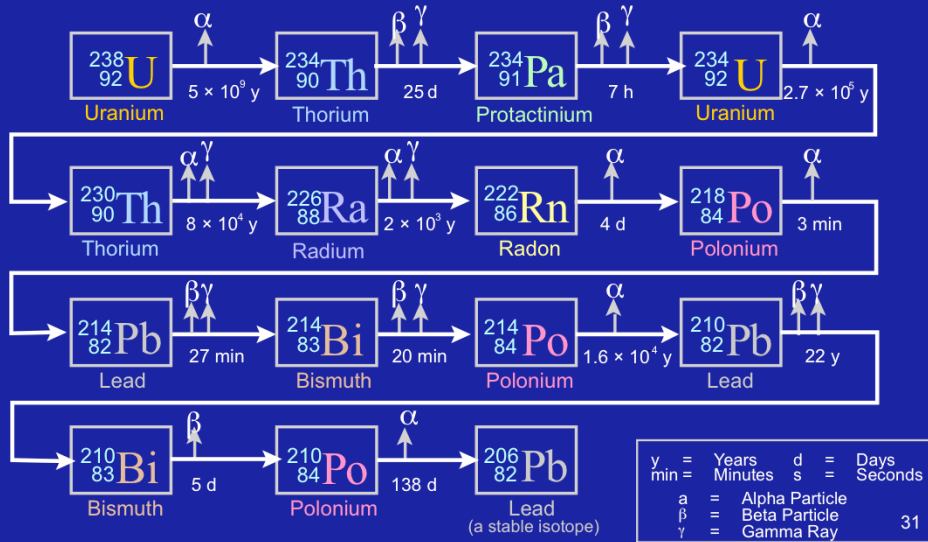
1 picocurie ( $\text{pCi}$ ) =  $1 \times 10^{-12}$  Ci

## 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

$$A = A_0 e^{-\lambda t}$$

where: A = activity after time t

$A_0$  = original activity

e = base of natural logarithm (2.718)

$\lambda$  = 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?

$$A_0 = 10.5 \text{ Ci}$$

$$t = 3 \text{ years}$$

$$T_{1/2} = 5.271 \text{ years}$$

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

## Equation

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

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

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

$$A = 10.5(0.677)$$

$$A = 7.1 \text{ Ci Co-60}$$

## Conclusion

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

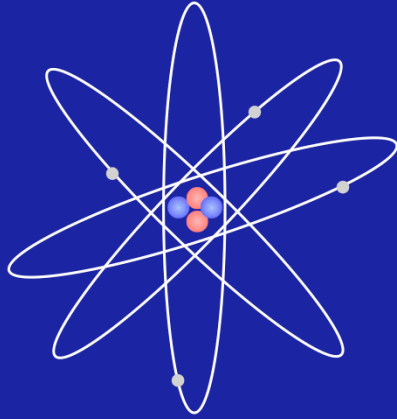
QUESTIONS

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# TYPES AND CHARACTERISTICS OF IONIZING RADIATION

# Four Basic Types of Ionizing Radiation



Alpha particles



Beta particles



Gamma rays



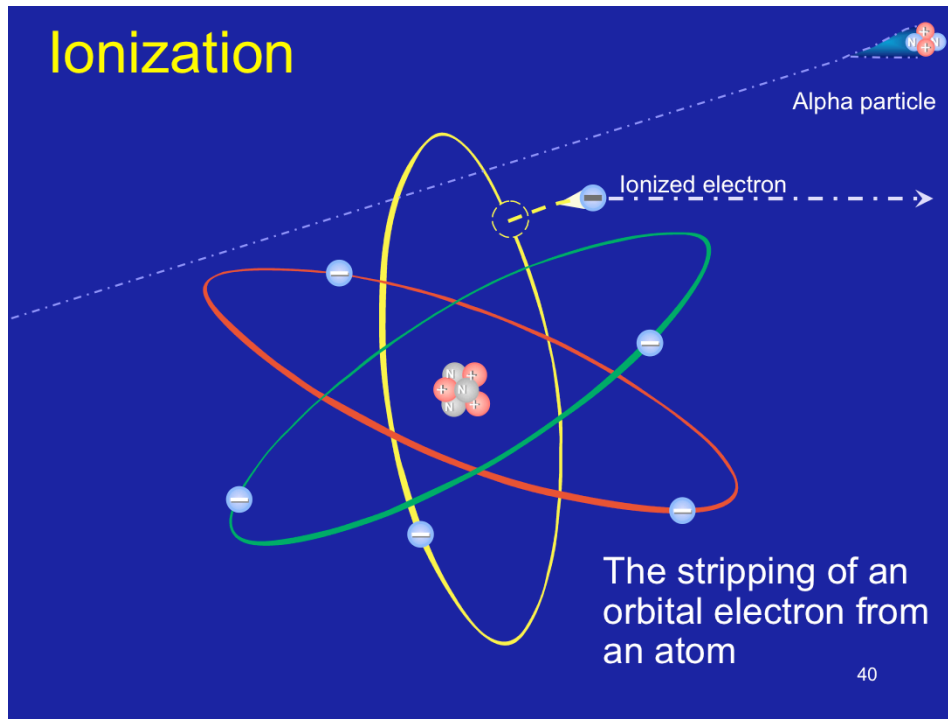
Neutrons



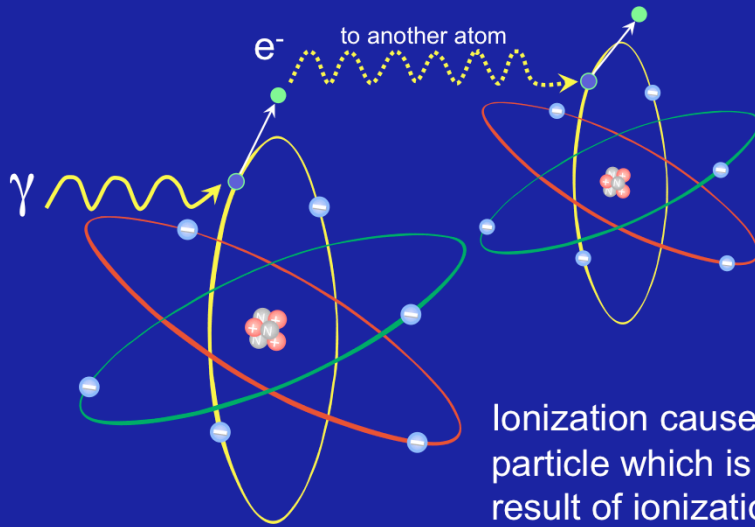
# Common Interactions of Radiation With Matter

- Ionization
- Excitation

# Ionization



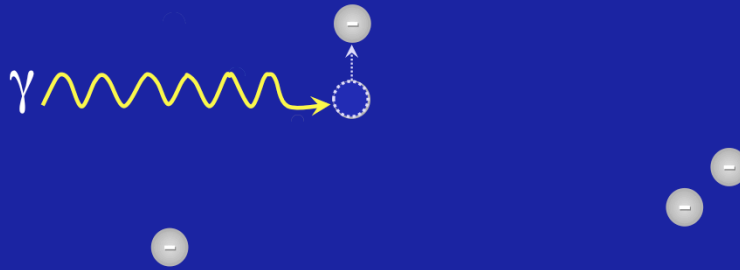
# Secondary Ionization



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)

$\alpha$  10,000s of ionizations/cm air

$\beta$   100s of ionizations/cm air

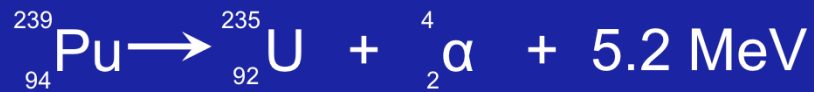
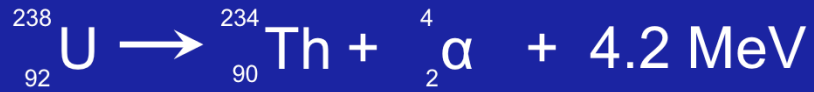
$\gamma$  1 ionization/cm air

## Characteristics of Alpha Particles

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

## Sources of Alpha Particles

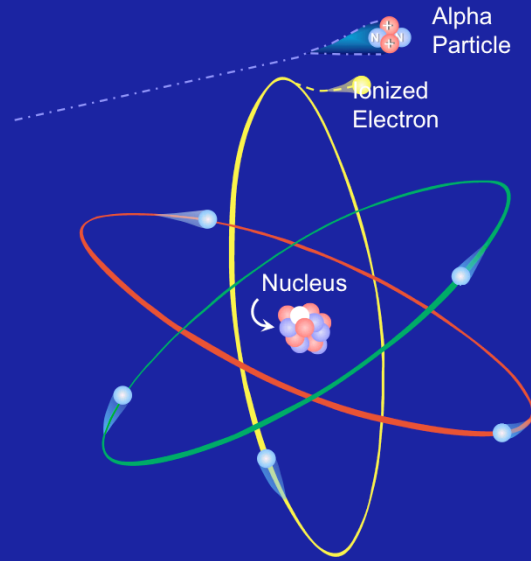
- Radioactive decay of heavier radionuclides (predominantly  $Z > 82$ )
- Examples:



## Alpha Particle Interactions

- Path length  $\approx$  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 ( $\beta^-$ )  
positron with +1 charge ( $\beta^+$ )
- Low mass: about .0005 amu
- Energies: most commonly 0.1 to 4 MeV
- Share decay energy with neutrino

## Sources of Beta Particles

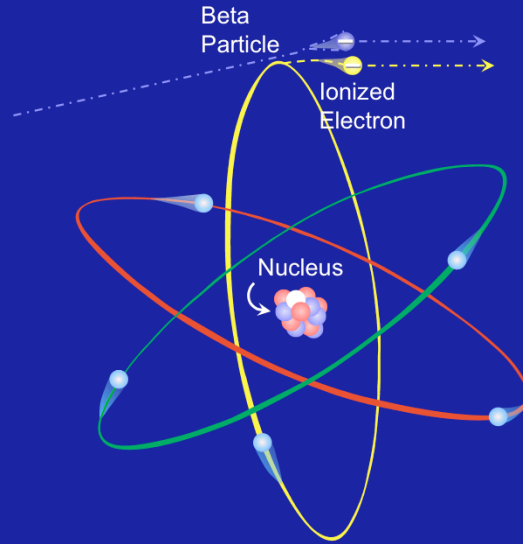
- $\beta^-$  emitted from nucleus with too many neutrons
- $\beta^+$  emitted from nucleus with too few neutrons
- Examples:



## 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.

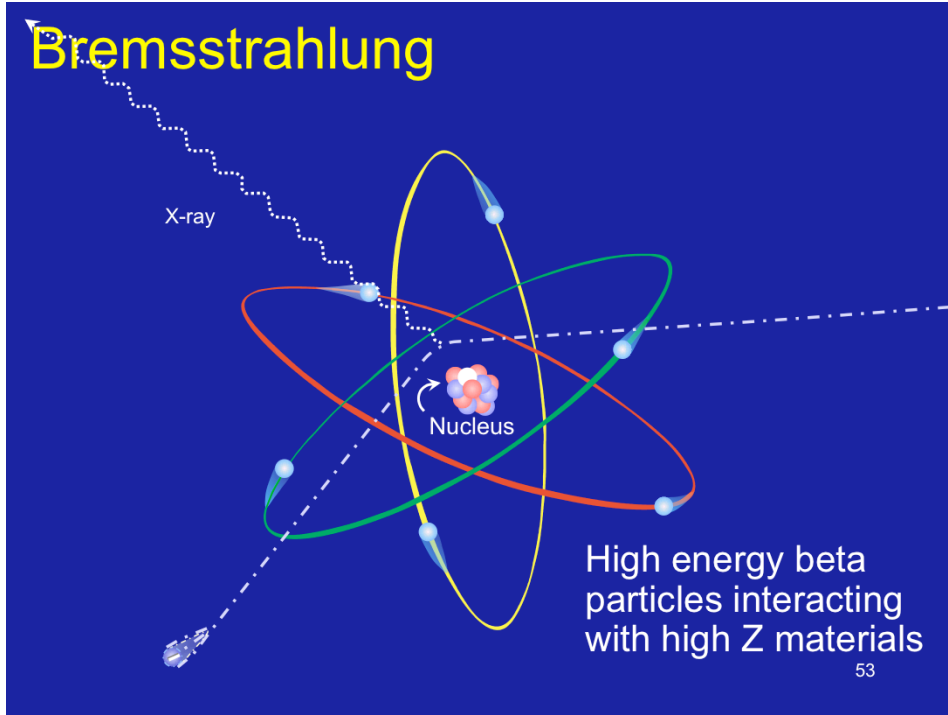
# Bremsstrahlung

X-ray

Nucleus

High energy beta particles interacting with high Z materials

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## Characteristics of Gamma Rays

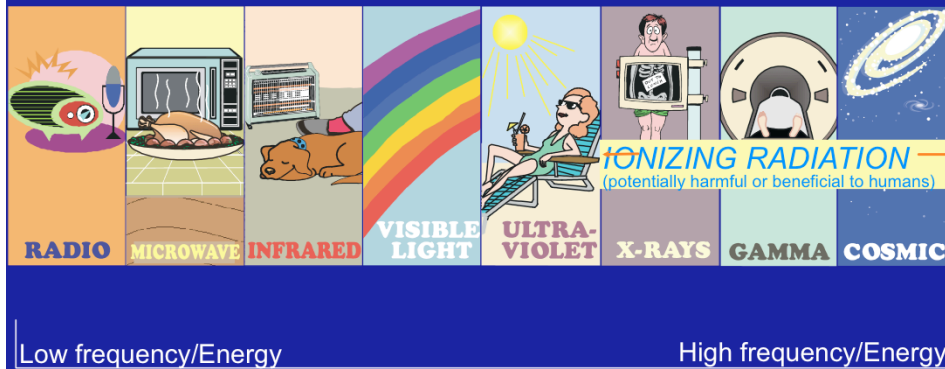
- Electromagnetic energy
- Gamma rays from nucleus
- Zero mass, zero charge
- Energies: most commonly 0.5 to 2 MeV

## Sources of Gamma Rays

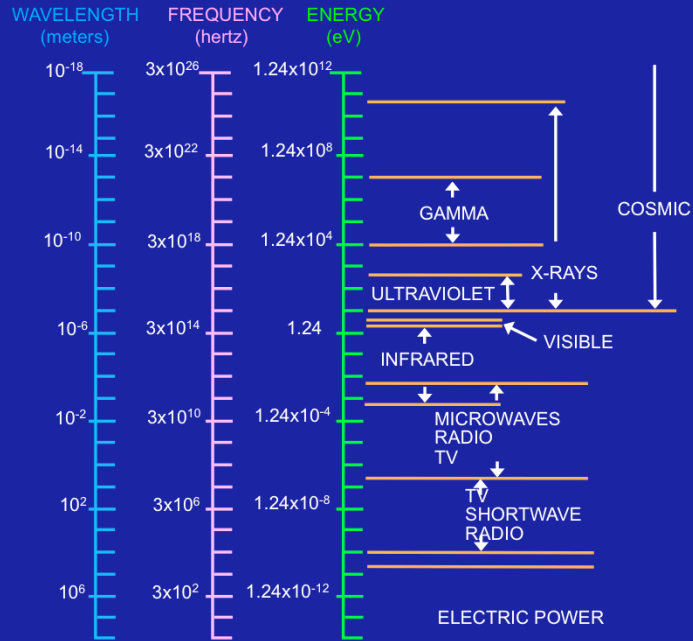
- Nucleus rearrangements following alpha or beta decay
- Nucleus moves from excited state to lower energy state
- Examples:



# The Electromagnetic Energy Spectrum



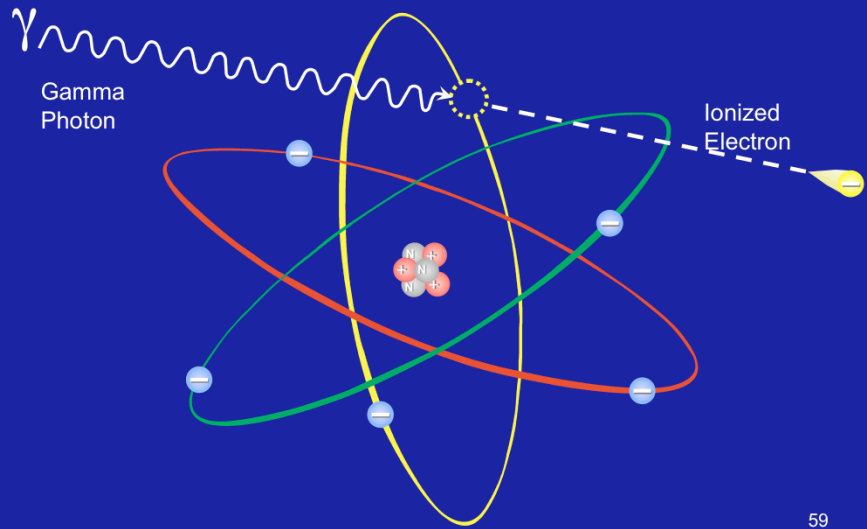
# The Electromagnetic Energy Spectrum



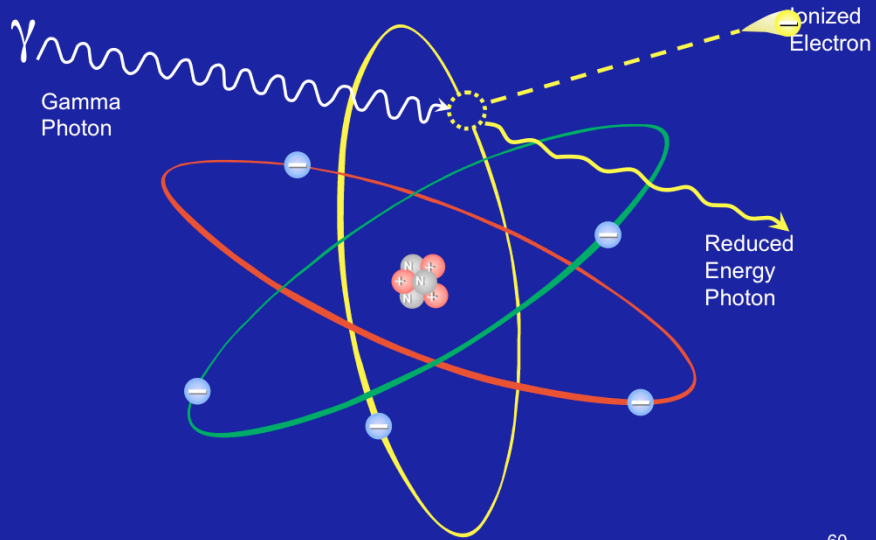
## Gamma Ray Interactions

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

# Photoelectric Effect

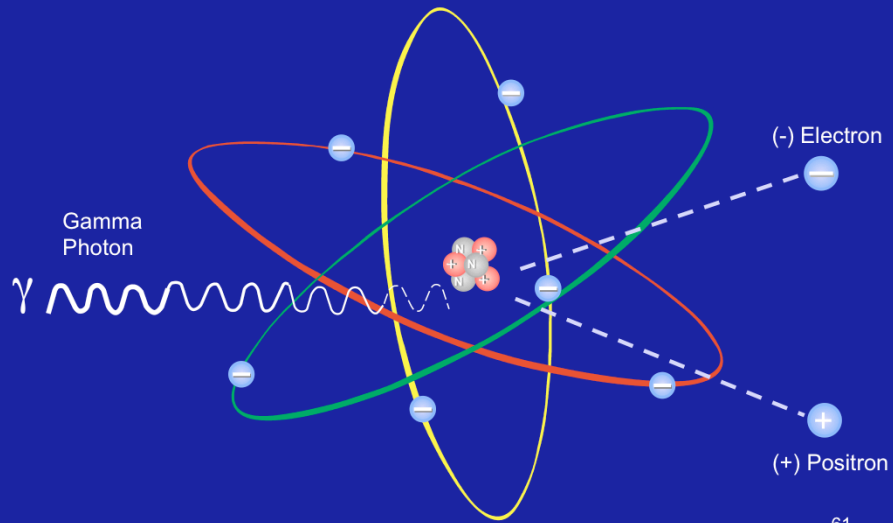


# Compton Scattering



# Pair Production

(all photon energy converted to mass)



## Characteristics of Neutrons

- Emitted from nucleus
- Mass: 1 amu
- Charge: 0
- Energies
  - Thermal neutrons  $\approx 0.025$  eV
  - Fast neutrons  $\approx 0.1$  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)



## Neutron Interactions

- Almost exclusively nuclei interactions
- Activation and excitation of nuclei
- Long path lengths in air  $\approx$  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

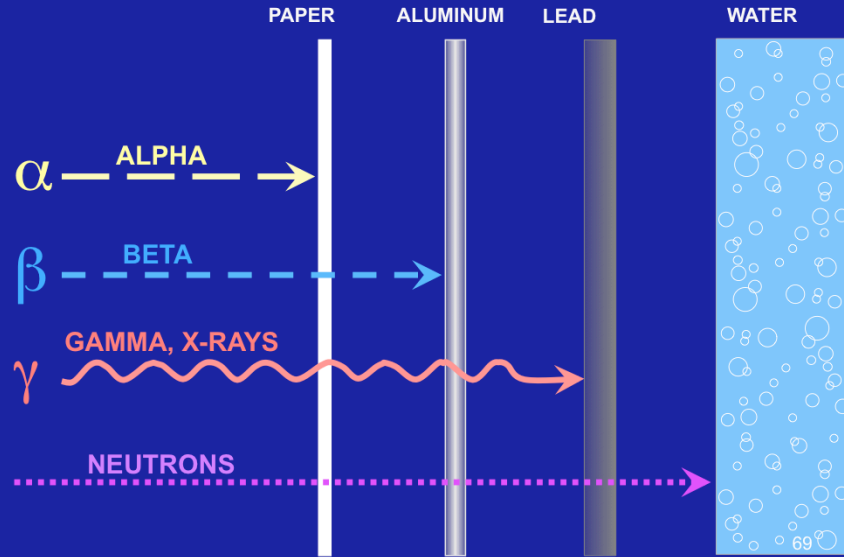
## Shielding Gamma Radiation

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

## Shielding Neutron Radiation

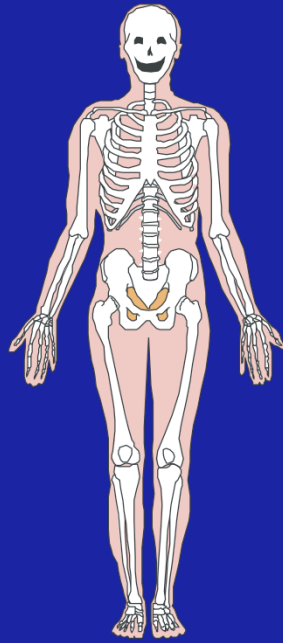
- Has ability to penetrate the whole body
- Primarily an external hazard, but not normally found in the environment
- Shielded by hydrogenous materials such as water or paraffin

# 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:  
**As Low As Reasonably Achievable (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<sup>3</sup>).
  - 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."

$$(\text{RAD} \times \text{QF} = \text{REM})$$

$$\text{GAMMA } 1 \text{ RAD} \times 1 = 1 \text{ REM}$$

$$\text{BETA } 1 \text{ RAD} \times 1 = 1 \text{ REM}$$

$$\text{NEUTRON } 1 \text{ RAD} \times 10 = 10 \text{ REM}$$

(Unknown Energy)

$$\text{ALPHA } 1 \text{ RAD} \times 20 = 20 \text{ REM}$$

## Radiation Subunits

- 1 rem = 1,000 mrem (millirem)
- 1 mrem = 1,000  $\mu$ rem (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

## 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	<b>10 R/h</b>	Voluntary, with supervisor review, for lifesaving or critical actions ONLY – evaluate anticipated doses against dose limits above
Intermediate Phase	<b>1.5 R/hr</b>	Dose management imperative
Late or Recovery Phase	Site-specific according to site health and safety plan	EPA Action Reference Level: 50 mrem/quarter <i>and</i> 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.

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

10 REM – To save equipment

25 REM – To save personnel

>25 REM – Use volunteers only

## 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"

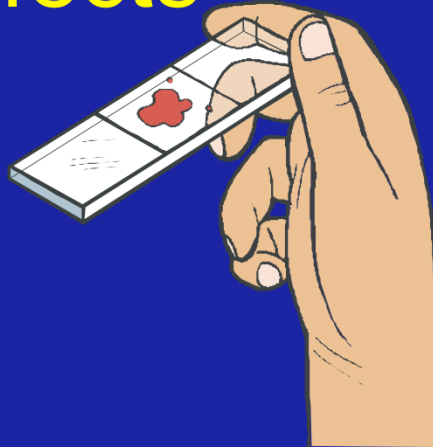
## Declared Pregnant Worker

- 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 <sub>100</sub>	Within days
600 RAD = LD <sub>99</sub>	Within days
450 RAD = LD <sub>50</sub>	Within 30 days
200 RAD = LD <sub>LO</sub>	Within several weeks
100 RAD = TD <sub>LO</sub>	Immunosuppressive reaction
25 RAD = ED <sub>LO</sub>	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](http://www.epa.gov/radiation)  
and  
[www.epa.gov/oar](http://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
<b>NATURAL</b> (ubiquitous background)		
Internal, inhalation (radon and thoron) .....	228	37%
External, space .....	33	5%
Internal, ingestion .....	29	5%
External, terrestrial .....	21	3%
<b>TOTAL NATURAL</b>	<b>311</b>	<b>50%</b>

*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
<b>MANMADE</b>		
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%
<b>TOTAL MANMADE (Non-smokers)</b>	<b>313.8</b>	<b>50%</b>

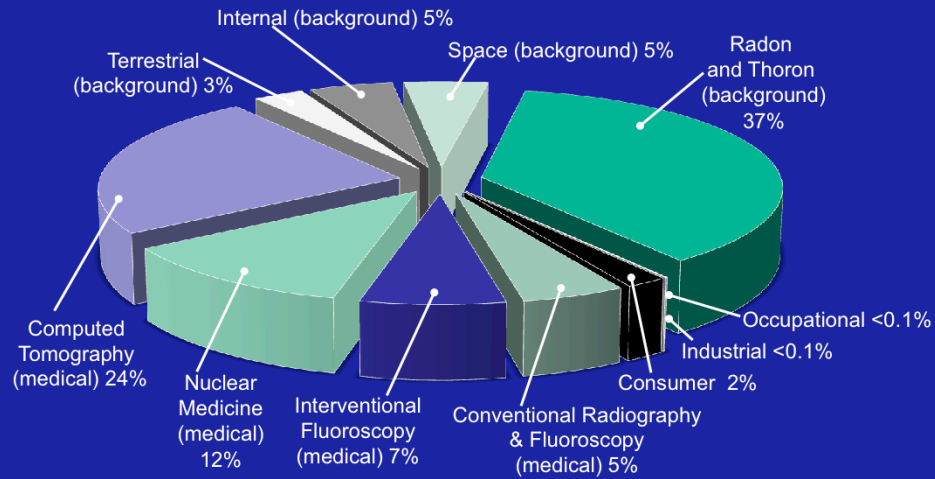
*SOURCE: 2009 NCRP Report No. 160 Ionizing Radiation Exposure of the Population of the United States*

## Sources of Radiation Exposure of the U.S. Population

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

*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
<b>Occupational dose of 1 rem/year from age 18-65 (47 yrs total)</b>	<b>51 days</b>
<b>Occupational dose of 300 mrem/year from age 18-65 (47 yrs total)</b>	<b>15 days</b>
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.*

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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

The screenshot shows a feedback form titled "U.S. EPA Technical Support Project Engineering Forum". The form includes the following fields and elements:

- Header: EPA logo, "United States Environmental Protection Agency", and "Technology Innovation Program".
- Section: "U.S. EPA Technical Support Project Engineering Forum (Open Registration: Opening the Door to Field) for Resource C (Open Registration: Access to Energy)".
- Text: "We would like to receive any feedback you may give us that will improve the course more." and "Please take the time to fill out this form before leaving the site."
- Form Fields: "First Name", "Last Name", "Email", and "Date of Seminar".
- Checkbox: "I would like to receive a copy of my feedback and a confirmation email." (highlighted with a red circle).
- Footer: "Delivery Media".

Need confirmation of your participation today?

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