CEMP TRAINING SESSION 15-17 JULY 2013

ATOMIC STRUCTURE & HISTORY

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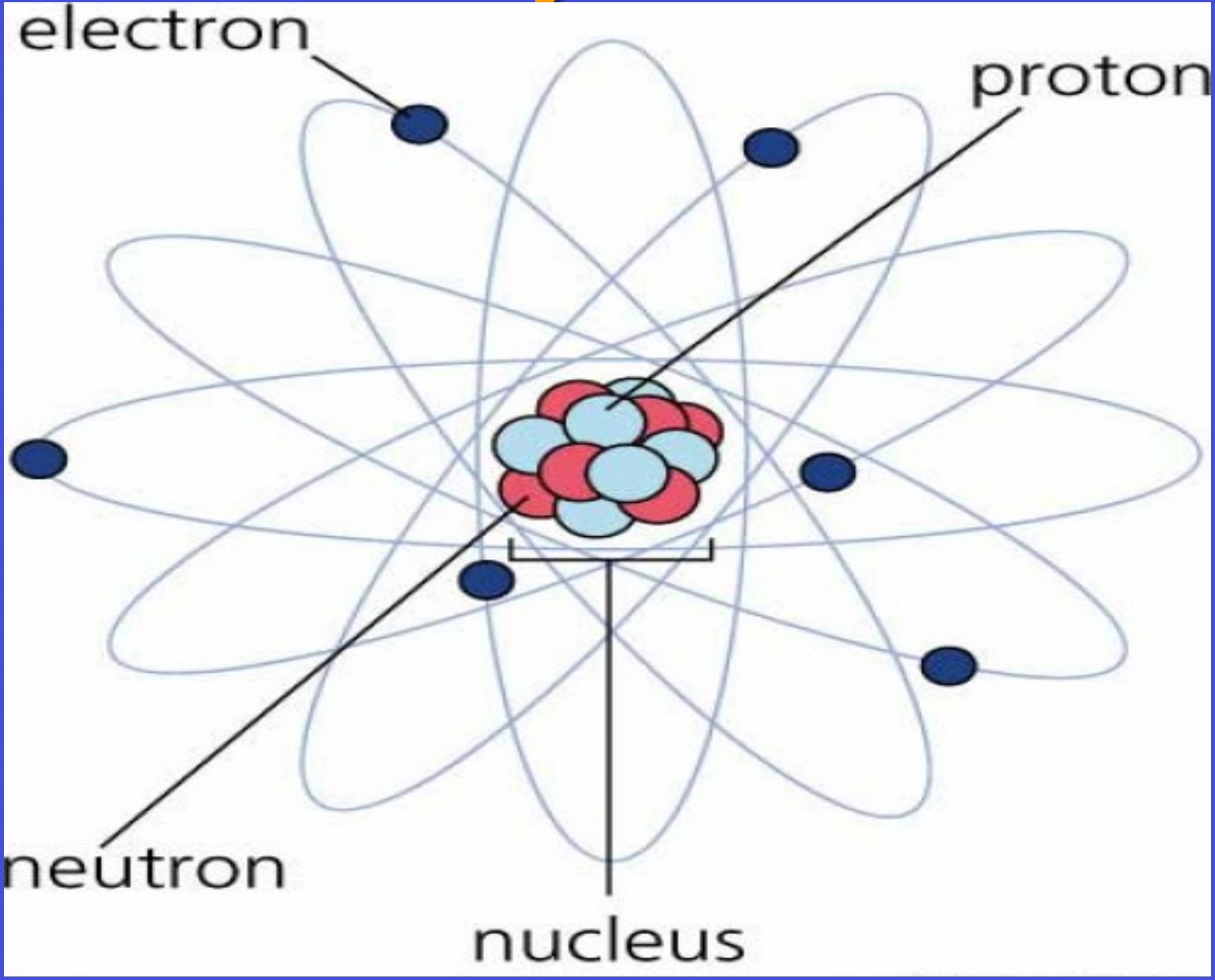
2013 Training Session

Training Outline

- Basic Atomic Structure
- Introduction to Radioactivity
- Radiation Sources
- Biological Effects
- Radiation Risks
- Radiation Limits

Anatomy of Atom



Atoms (nucleus & electrons)

Nucleus: (center core of atom contains)

Z protons and N neutrons

A atomic number = Z + N (nucleons)

Mass of nucleus = A >>electrons mass

Electrons:

Same number electrons as protons in neutral atom

Electrons surround and orbit nucleus

Isotopes

Atoms with same number protons (same atomic number - A) but different number of neutrons in nucleus

(Mass number – Z differs but not atomic number)

- ^{238}U versus ^{235}U atomic number Z = 92

Chemistry of isotopes identical!

^{238}U same chemistry as ^{235}U

Stable & Unstable Atoms

- Only certain combinations of neutrons & protons form stable nuclei
- Too many or too few neutrons for same number of protons then nucleus has excess energy & is unstable (radioactive)

Unstable atoms become more stable by reducing excess energy through release of particles and energy

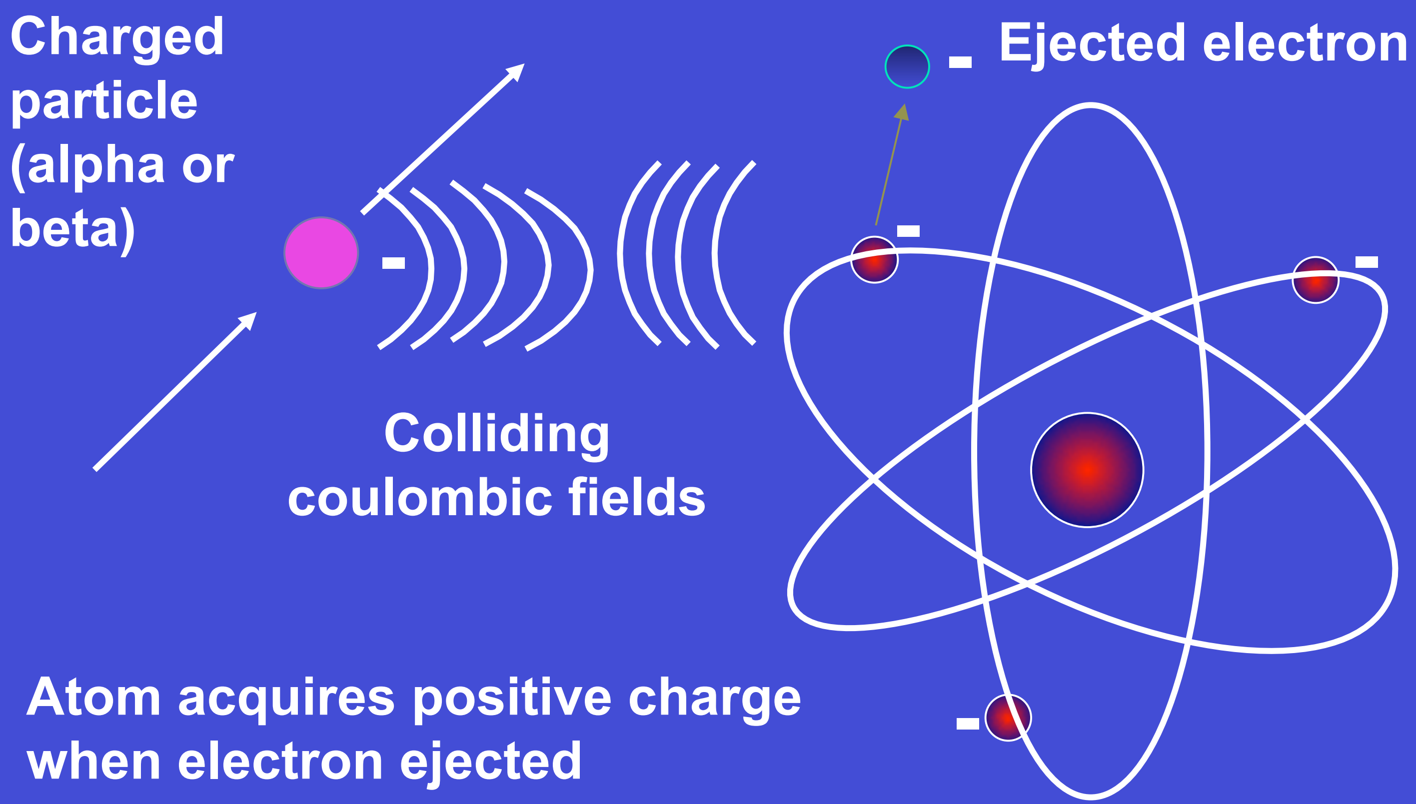
Unstable nuclei known as radioactive atoms and undergo decay

Ionizing radiation

- Occurs from addition or removal of electrons from neutral atoms
- Four main types of ionizing radiation alpha, beta, gamma and neutrons

α	**Alpha (helium nucleus)**
β	**Beta (electron or positron)**
γ	**Gamma (X-ray)**
n	**Neutron**

Ionization



Charged particle (alpha or beta)
-
Colliding coulombic fields
- Ejected electron
-
-
-
Atom acquires positive charge when electron ejected

Alpha Particle (He- 4 A=4, Z=2)

- PHYSICAL CHARACTERISTICS
  - Large mass

    2 protons Z = 2, 2 neutrons, no electrons

    Positive charge +2
  - Highly charged particle emitted from nucleus of atom
  - Positive charge +2 causes alpha particle (+) to strip electrons (-) from nearby atoms as it passes through material, thus ionizing these atoms

- SHIELDING
  - Stopped by

    outer layer of skin,

    few centimeters of air

    or one sheet of paper

- BIOLOGICAL HAZARD
  - No external radiation hazard
  - Internally deposits large amount of energy in small volume of body

Beta Particle (e^{-1} or e^{+1})

- PHYSICAL CHARACTERISTICS
  - Small mass emitted from nucleus of atom with electrical charge of -1
  - Cause ionization by displacing electrons from their orbits
  - Same as electron
  - (or positron)
  - Ionization caused by repulsive force between beta particle (-) & atoms electron (-)

- RANGE
  - Limited penetrating ability (< 10 feet in air) because of negative charge

- SHIELDING
  - Most beta particles shielded by plastic, glass, metal foil, safety glasses

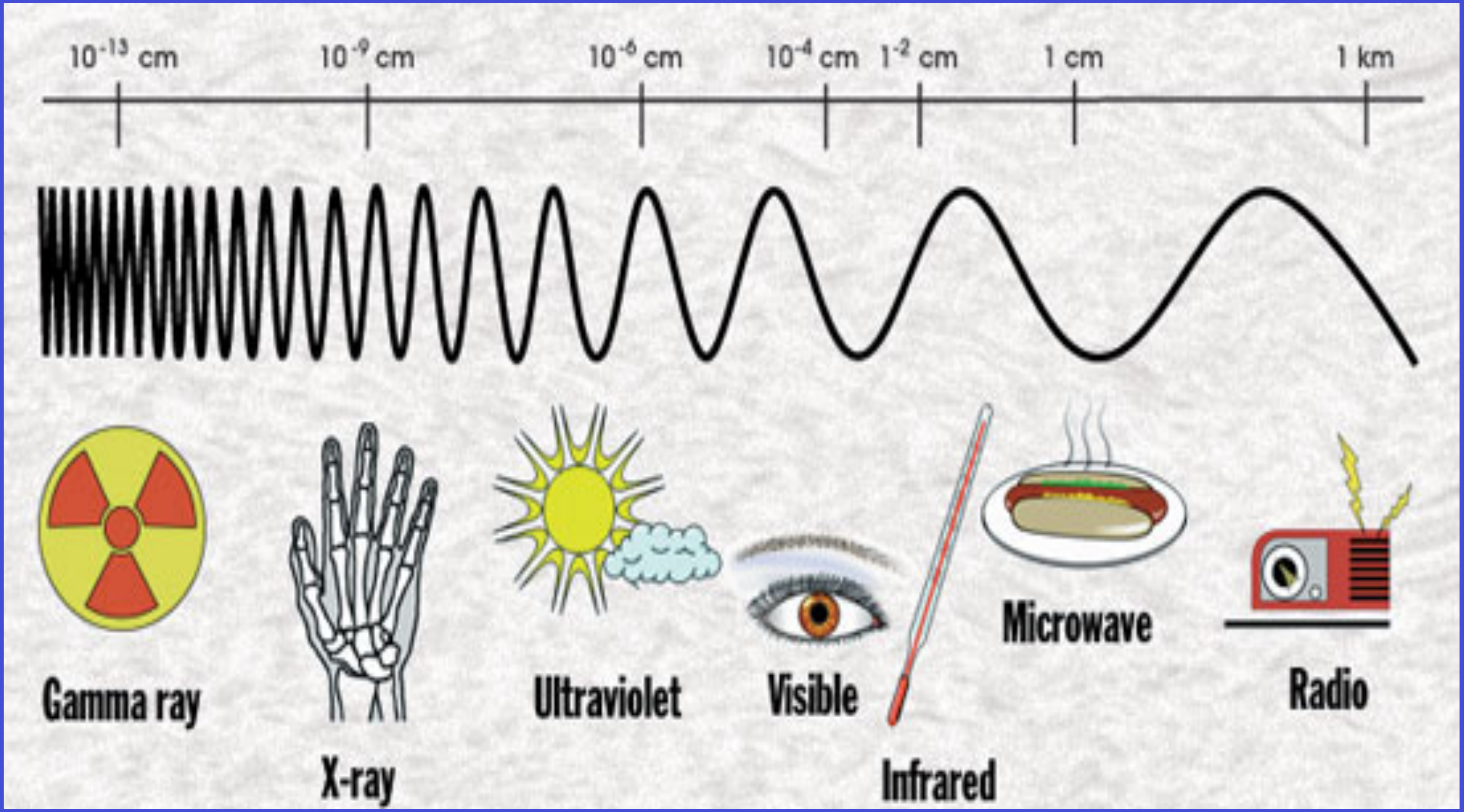
- BIOLOGICAL HAZARD
  - An internal hazard due to short range
  - Hazardous to skin & eyes

Gamma/X Rays (γ or x)

- PHYSICAL CHARACTERISTICS
  - Electromagnetic wave or photon with no electrical charge
  - Gamma rays similar to x rays, but from nucleus
  - Gamma/x ray radiation ionizes by direct reaction with orbital electrons
  - Energy of gamma/x ray radiation transmitted directly to target
- RANGE
  - Gamma/x rays have no charge or mass
  - Very penetrating
  - Range in air - few hundred feet
- SHIELDING
  - Best shielded by dense materials

    (concrete, lead or steel)
- BIOLOGICAL HAZARD
  - Produces radiation exposure to whole body

Radiation Spectrum



Physics of nuclear reactions

$$X^{A1}_{Z1} + X^{A2}_{Z2} \rightarrow X^{A3}_{Z3} + X^{A4}_{Z4}$$

- Conservation of total energy

  Total E (1+2) = Total E (3+4)

Conservation of nucleon number

$$A1 + A2 = A3 + A4$$

- Conservation of electic charge

$$Z1 + Z2 = Z3 + Z4$$

- Conservation of momentum

$$\underline{mv}1 + \underline{mv}2 = \underline{mv}3 + \underline{mv}4$$

Example nuclear reactions

Decay U-238 by alpha emission

$$U^{238}_{92} \rightarrow Th^{234}_{90} + He^{4}_{2} + KE$$

Fission of U^{235}_{92} by neutron capture

$$U^{235}_{92} + n^{1}_{0} \rightarrow Ba^{140}_{56} + Kr^{94}_{36} + 2n^{1}_{0} + KE$$

Solar fusion reaction of hydrogen

$$4\ H^{1}_{1} = He^{4}_{2} + 2\ e^{0}_{+1} + KE$$

Radioactive decay of Co-60

$$Co^{60}_{27} = Ni^{60}_{28} + e^{0}_{-1} + KE$$

Brief History of Radiation Health Effects

1895 - Roentgen announces discovery of X-rays

1896 - Reports of skin effects (burns) in x-ray researchers

1902 - First cases of radiation induced skin cancer reported

1906 - Pattern for differential radiosensitivity of tissues was discovered

1927 - Genetic effects of radiation including cancer risk
recognized by Hermann Joseph Muller genetic effects in fruit flies
Hermann Joseph Muller awarded Nobel Prize in 1946

1900's – 1930's Many physicians and companies marketed radioactive substances
- patent medicine , radiation cures, radioactive quackery.
Marie Curie warned effects of radiation on humans not well understood.
Curie died of aplastic anemia caused by radiation poisoning.

1932 - Eben Byers, famous American socialite, died of cancer 1932
His death drew public attention to dangers of radiation.

Brief History of Radiation Health Effects

1928 Second International Congress of Radiology - ICRP

International Commission on Radiation Protection

1929 US National Council on Radiation Protection & Measurements - NCRP is US equivalent to ICRP

1929 - 1970 US radiation exposures set by

Federal Radiation Council - FRC

FRC composed of US Secretaries of

- Agriculture, Commerce, Defense,
- Health, Education, Welfare and Labor,
- Atomic Energy Commission Chairman

Brief History of Radiation Health Effects

After 1970 FRC transferred to EPA
Environmental Protection Agency

Standards for radiation exposure used by EPA
called Radiation Protection Guides - RPGs

RPG's approved by US President
Binding on all US agencies

Most non US countries base radiation policy on
ICRP standards

Radiation standards by ICRP, NCRP & EPA
not identical.

Standards continually revised as membership of
US agencies change

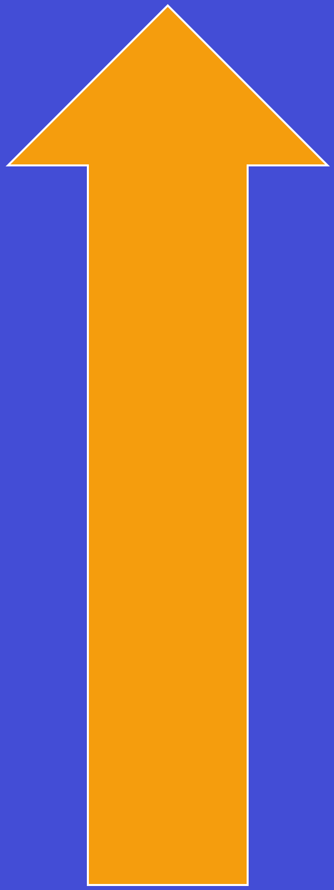
Types of Radiation Effects

Acute Effects: Short-term time effects
Very large radiation doses can kill humans
Lethal dose (LD) 50% population in 60 days termed $LD_{50/60}$
$LD_{50/60}$ from acute, whole body radiation ~400 to 500 rads (4-5 Gy)
Temperature rise in tissue caused by radiation less than 1°F
Biological response from X-ray radiation may result in
1) removal of electrons 2) changes in molecular structures

Chronic Radiation Effects Long-term effects (e.g., background radiation)

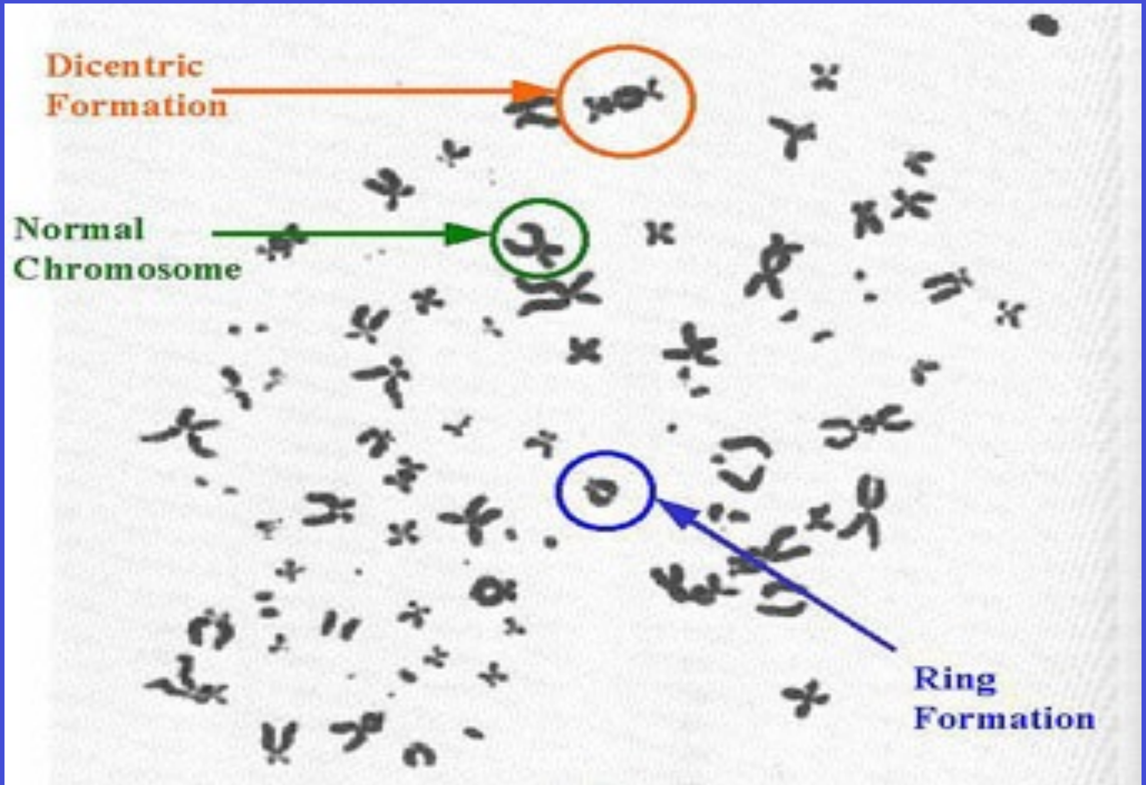
Deterministic Radiation Effects
Various radiation effects occur at high doses above **threshold**
Effects vary but eliminated if doses below 100 rad
Severity of these effects increases with dose rate

Increasing Sensitivity to Radiation



- Lymphocytes
- Erythrocytes, Granulocytes
- Epithelial Cells
- Endothelial Cells
- Connective Tissue
- Bone Cells
- Nerve Cells
- Brain Cells
- Muscle Cells

Radiation-Induced DNA Damage



Chromosome damage following radiation exposure

Radiation-induced structural changes to DNA can be readily observed (Figure 2-2)

Mechanisms of Radiation Injury

Radiation can directly interact with cell with producing damage
However, abundance of water in cells and body,
Radiation likely to interact with water molecule

Radiation interaction with water produces chemical species
called free radicals (H^+) and ($\cdot OH^-$)

Free radicals can produce compounds e.g.,
hydrogen peroxide (H_2O_2) with high chemical toxicity

DNA and repair methods capable of protecting body

Only small damage fraction not repaired or repaired incorrectly

If DNA damaged, effects are
- damage repaired before end of cell's growth cycle
- cell dies
- very small chance cell survives and DNA mutates

Table: Acute Whole Body Radiation Effects

Syndrome	Symptoms	Dose (rad)
Radiation sickness	Nausea, vomiting	> 100 rad
Hemopoietic	Significant disruption of production of blood products)	> 250 rad
$LD_{50/60d}$	Death in half population	> 250 - 450 rad
GI	Failure of GI tract lining, loss of fluids, infections	> 500 rad
CNS	Brain death	> 2,000 rad

Total dose, dose rate, fractionation scheme, volume of irradiated tissue and radiation sensitivity affect a given organ's response to radiation.

Radiation more effective at causing damage when dose higher and delivered over short period

Fractionating dose (spread over time) reduces total damage since body can repair damage

Man-Made Sources

- Medical radiation ~ 48%
- Nuclear weapon tests < 0.1%
- Consumer products ~ 2%
- All energy production & research < 0.1% or < 0.5 mrem
- Industrial uses < 0.1%
- Fukushima: Dose ~ 1 ft elevation

Medical Radiation

- X-rays - medical (CT's, etc.) & dental
- Radioactive material for diagnosis
  ^{131}I, ^{99}Tc, ^{32}P, ^{3}H, ^{14}C
- Radioactive material for therapy
  ^{60}Co, ^{137}Cs, ^{226}Ra, neutrons
- Annual dose ~298 mrem ~48% total

LINEAR NO-THRESHOLD RADIATION DOSE ASSUMPTION

Linear extrapolation of effects at higher doses predicts small radiation doses have small risk of causing a cancer

Straight-line assumption no threshold, dose response relationship (LNT) simplest mathematical assumptions

Slope of LNT used as risk for risks for all radiation exposure

LNT hypothesis implies that any radiation increases cancer

So radiation doses minimized by ALARA

As Low As Reasonably Achievable

Normal incidence of cancer (~30%)- low cancer risk by radiation Stochastic effects extrapolated from higher doses

LNT expected to provide most conservative, highest risk estimates

US radiation setting bodies limited to

- No deliberate exposure to radiation justified unless some benefit

- All radiation exposure must be kept "As Low As Reasonably Achievable"

ALARA

- Radiation doses to individuals should not exceed mass maximum permissible doses - MPD's.

No evidence for harm at low radiation levels

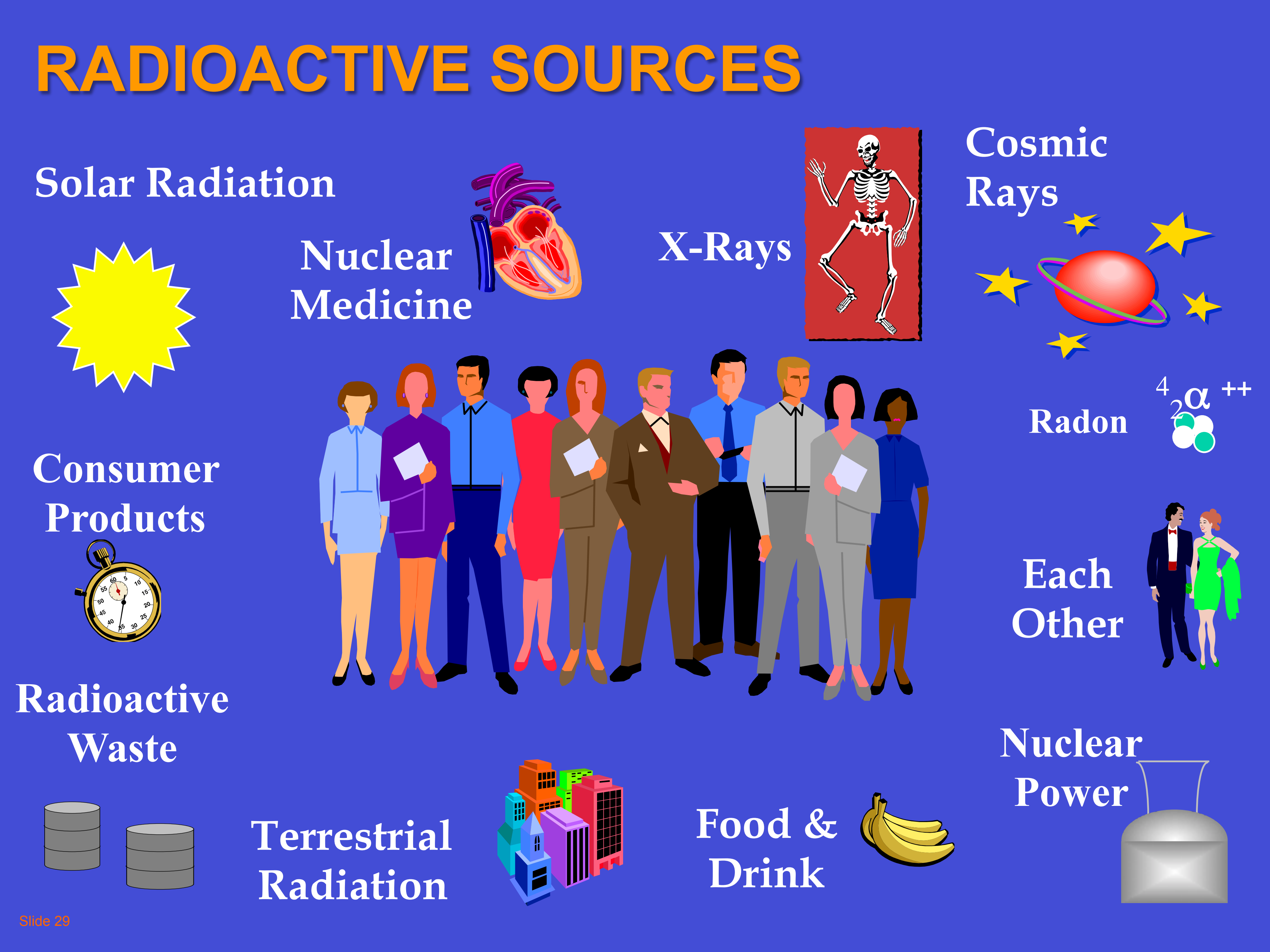
But following assumptions made

- Linear non threshold dose relationship LNT applies for any radiation exposure (>0)
- no threshold for radiation doses below which no health effects occur
- No biological recovery from radiation effects at any dose level

Risk of low radiation exposure only from

CANCER

- No observable workers injuries for exposures at regulatory levels
- Regulatory dose limits far below threshold for observable stochastic effects


RADIOACTIVE SOURCES
Solar Radiation
Nuclear Medicine
X-Rays
Cosmic Rays
Radon
$^{4}_{2}\alpha^{++}$
Consumer Products
Each Other
Radioactive Waste
Nuclear Power
Terrestrial Radiation
Food & Drink
Slide 29

Natural Sources (2006 NCRP)

- Cosmic radiation ~ 5%
- Terrestrial radiation ~ 3%
- Internal radiation ~ 5%
- Radon / Thoron ~ 37 %

Average Total Annual Dose

620 mrem

Total average US radiation exposure

(NCRP report 160 - 2006)

Prior US level - 360mrem

Industrial, security, medical, education & research activities (2006)
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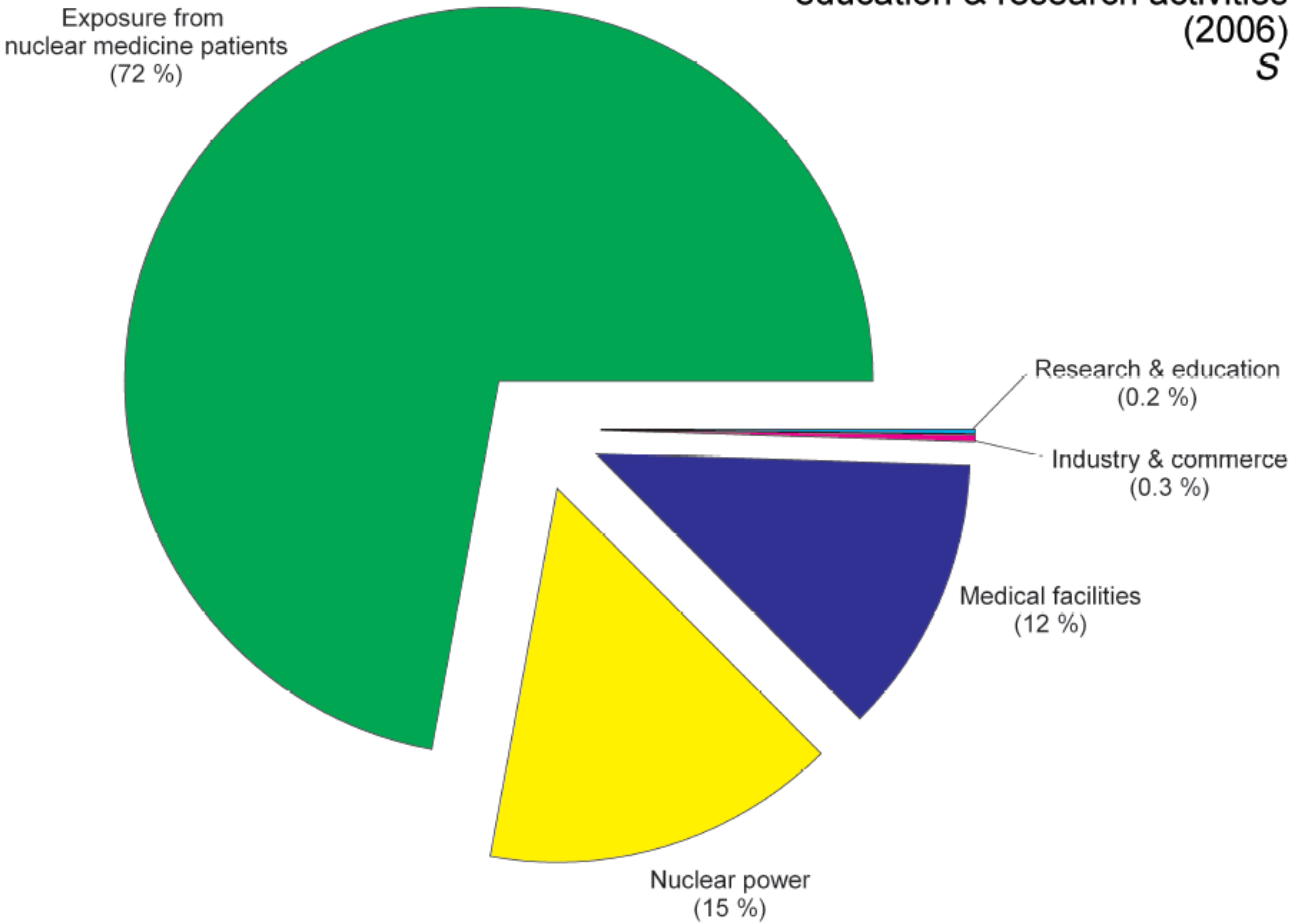
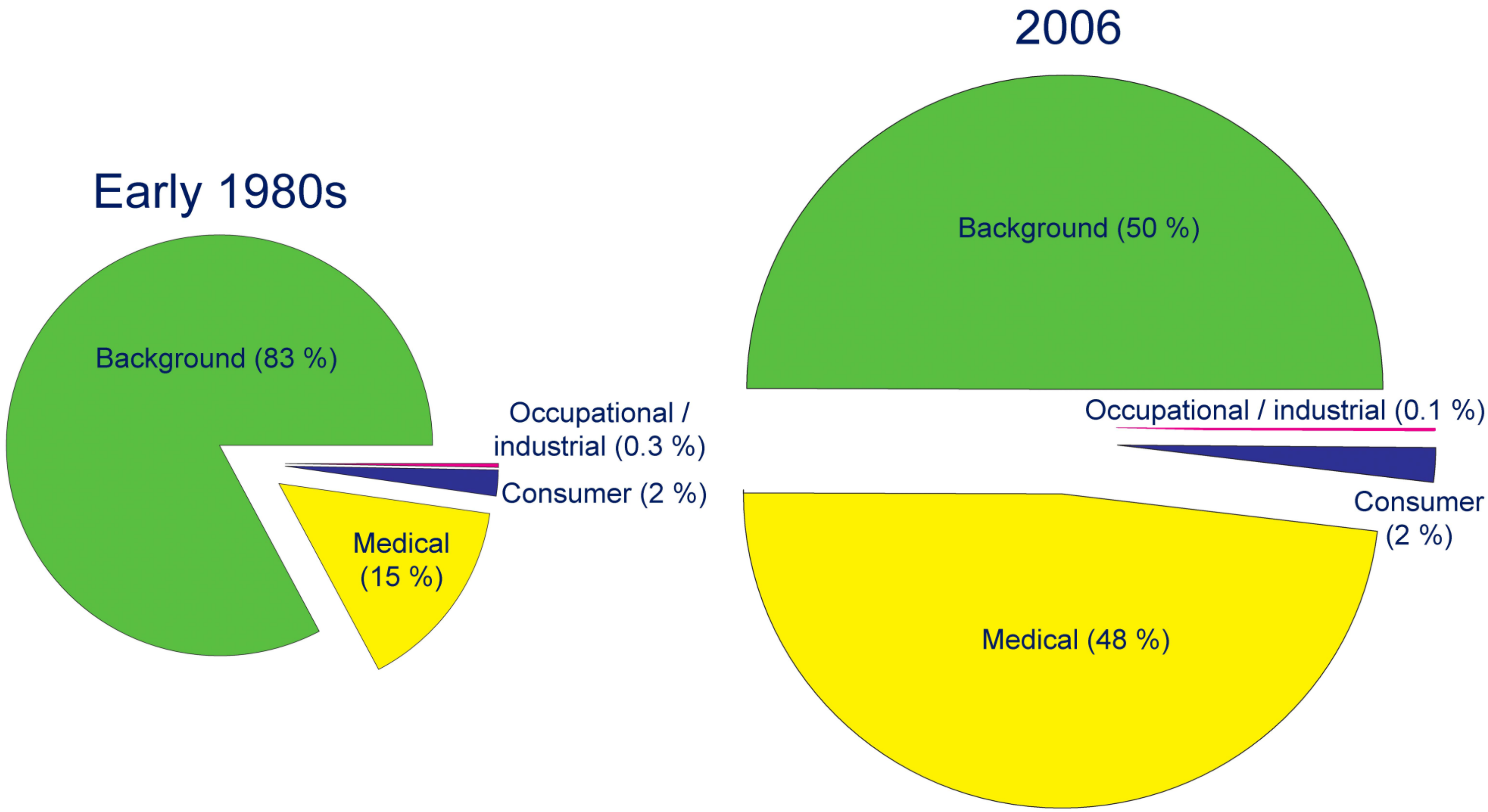


NCRP Report No. 160, *Ionizing Radiation Exposure of the Population of the United States*



	Early 1980s	**2006**
Collective effective dose (person-Sv)	835,000	1,870,000
Effective dose per individual in the U.S. population (mSv)	3.6	6.2

All Categories
S and E_{US}