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Department of Mechanical & Nuclear Engineering

Radiation Health

Brian Hinderliter, P.E., C.H.P., Ph.D.

Osher Lifelong Learning Institute

Spring 2012

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Course Description

- This course will provide an overview of nuclear science and technology and its application to the production of electricity.
- The course will explain how a nuclear reactor works and will describe the various types of nuclear reactor technologies currently available or under development.
- The course will also cover the entire nuclear fuel cycle including uranium mining, enrichment and fuel fabrication, as well as reprocessing and used nuclear fuel management and disposal.
- In addition, the course will explore the complex socio-political issues that are often intertwined in any discussion about a sustainable long-term environmental and energy policy that includes nuclear power.

Nuclear Engineering Faculty

- **Dr. Sama Bilbao y Leon (Director of Nuclear Engineering)**
  - PhD, Nuclear Engineering, University of Wisconsin, Madison
- **Dr. Ross Anderson**
  - PhD, Nuclear Engineering, University of Virginia
- **Dr. Brian Hinderliter**
  - PhD, Engineering Physics, University of Virginia, P.E. and CHP
- **Dr. Gokul Vasudevamurthy**
  - PhD, Nuclear Engineering, University of South Carolina, Columbia
- **Mr. Jim Miller**
  - MS, Nuclear Engineering, Penn State

Proposed Program

SESSION	TOPIC	INSTRUCTOR
# 1 March 21	Basic concepts in nuclear physics, types of radiation, radioactive decay, etc	James Miller
#2 **March 28**	**Radiation health effects**	**Brian Hinderliter**
#3 April 4	Nuclear power plant design, types of nuclear power plants, nuclear safety	Gokul Vasudevamurthy
#4 April 11	Current status of nuclear power in the world, advanced reactors, SMRs, nuclear power construction projects	Sama Bilbao y León
#5 April 18	The nuclear fuel cycle	James Miller
#6 April 25	Survey of large nuclear power accidents: Three Mile Island, Chernobyl and Fukushima Daiichi	Josh Bell Sama Bilbao y León
#7 May 2	Sociopolitics and nuclear power: used nuclear fuel management, Yucca Mountain, uranium mining	Invited Speakers
#8 May 8	Choice Topic: •Nuclear medicine and other applications of nuclear science and technology •The future of nuclear power: fast breeder reactors, fusion technology, nuclear power and other power sources. •History of the US Nuclear Navy	TBD

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Radiation in Our Environment

- Radiation Physics
  - Ionizing and Non-ionizing
  - Detection of ionization
- Radiation in the Environment
  - Natural – its been with us forever
  - Industrial and medical
- Biological Effects of Radiation
- Nuclear Power in Perspective

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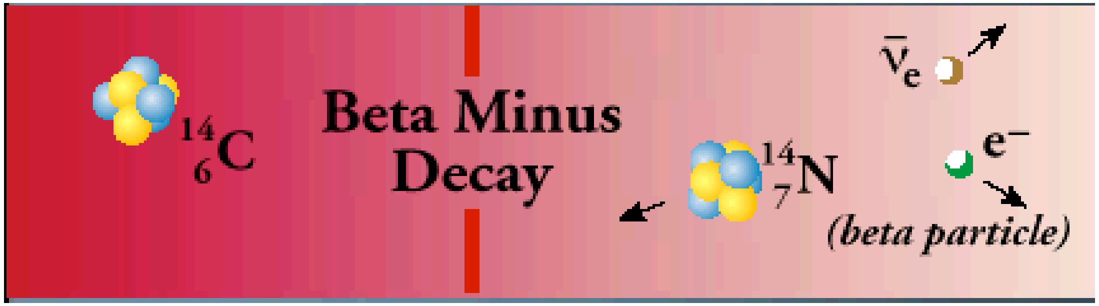
What is radiation?

- Radiation is Energy and Particles released by unstable atoms. Two main types of interest beta rays and gamma rays.
- Radioisotope is the unstable atom, C-14 for example.
  - Produced in the upper atmosphere
  - Part of everyone, used in carbon dating



Radiation Damage is caused by ionization

- We will use a unit for radiation of mrad which is the 10^{-5} joules/kg of energy deposited.
  - For water (tissue) c_p=4.18 J/(gm-K) so
  - 1 mrad of gamma heats water 2.4 10^{-9}K (very small)

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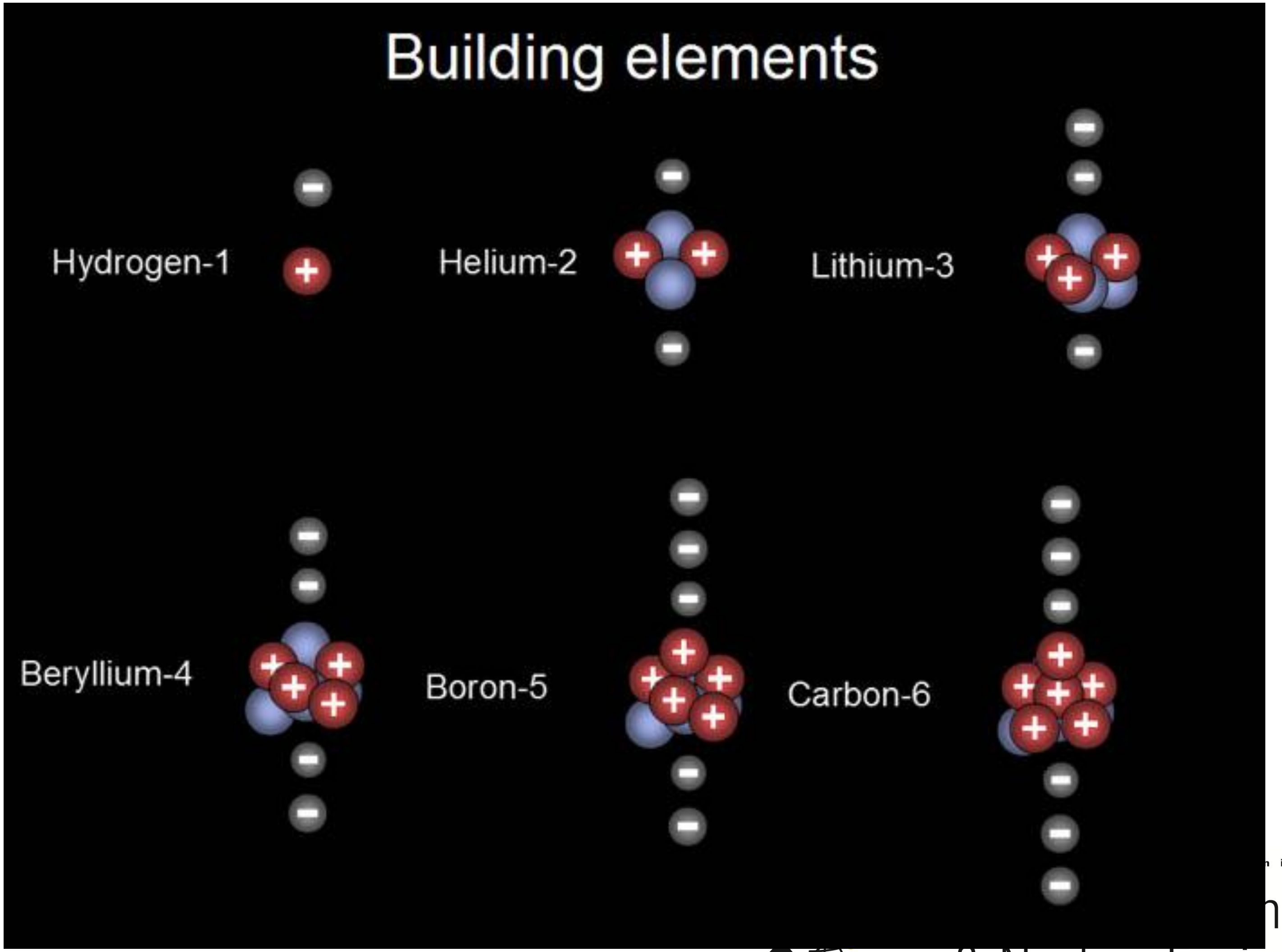
Schematic description of light elements



Radiation Types

- Ionizing-ability to remove electron from an atom
  - Gamma (photon from nuclear rearrangements, Co-60 1-2 MeV)
  - Beta (moving electrons, P-32)
  - X-ray (photons from electron shell rearrangements)
  - Alpha (He nuclides moving, from heavy metals U-238)
  - Neutron (predominantly nuclear reactors and high energy accelerators)
  - Other (electron capture)
- Non-ionizing
  - Laser
  - Electro-Magnetic
    - Cell phone
    - Microwave oven
  - Ultra-Violet

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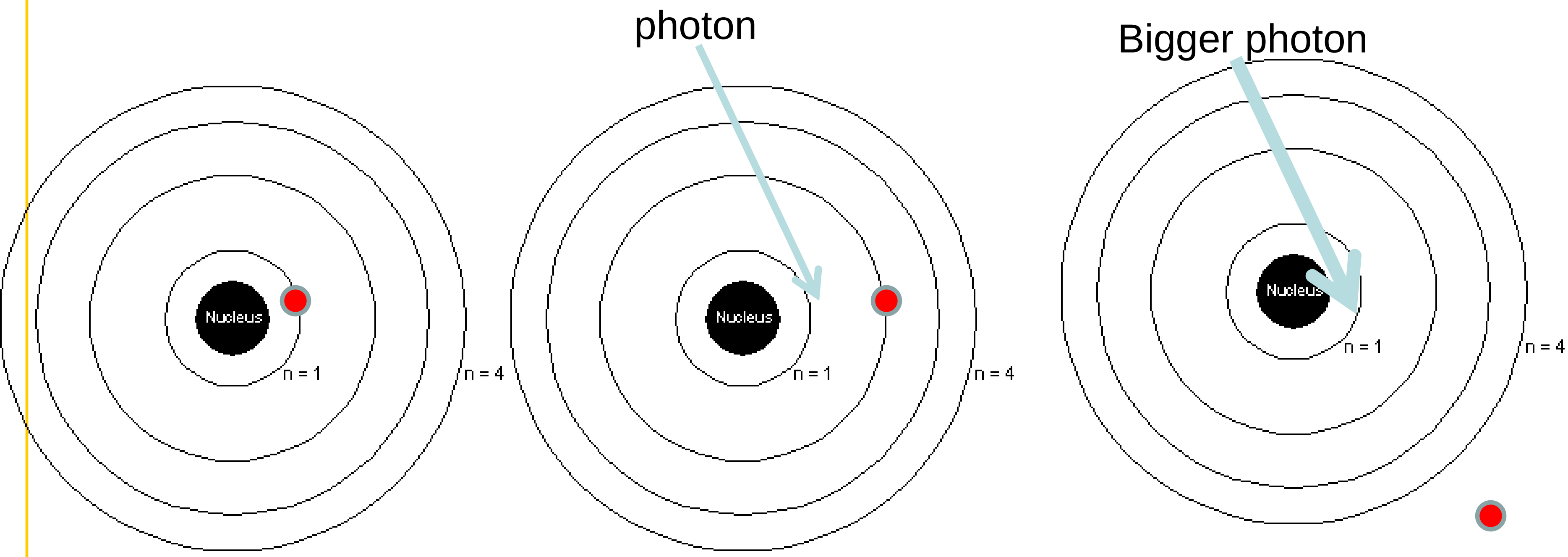
Excited and ionized atoms



ground state
state

excited state

ionized

$$K_{\alpha}^{H} = 13.6eV$$

$$K_{\alpha}^{Pb} = 87.95KeV$$

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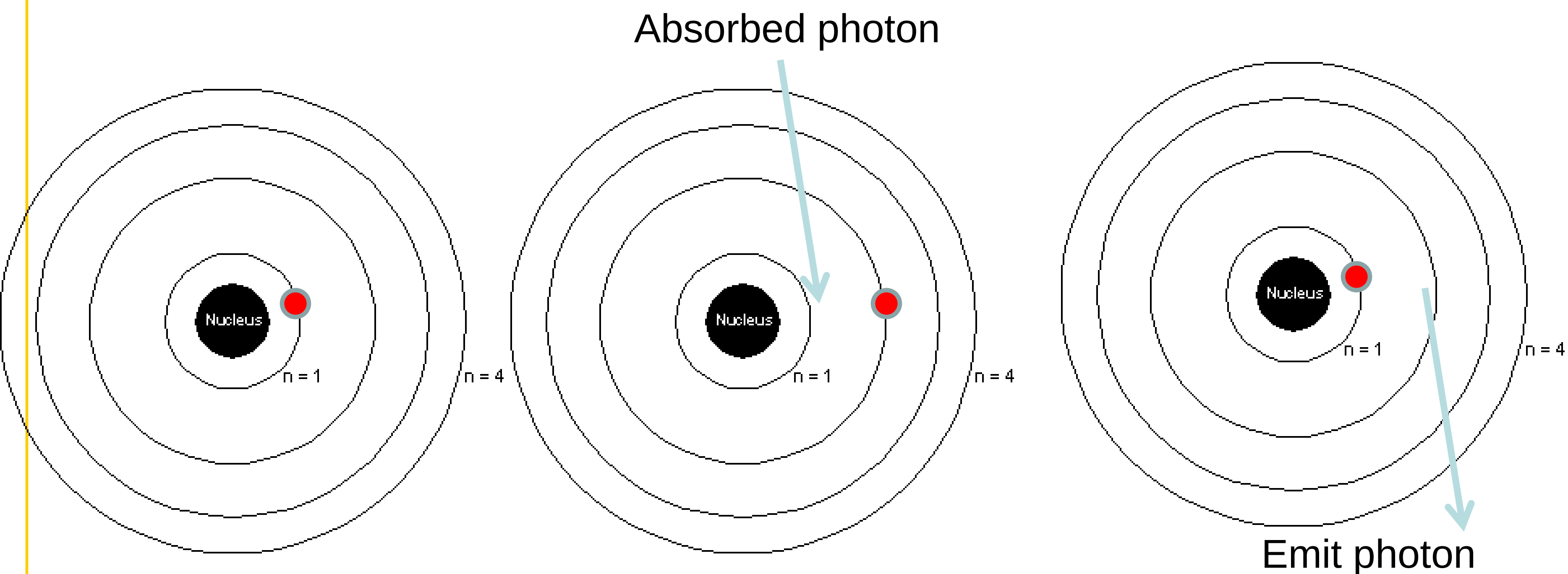
X-ray absorption and emission



ground state state

excited state

ground

Subcategory of ionizing radiation

- Directly ionizing
  - Strong interactions
  - Easily stopped
  - Converse if in body, deposition is local leads to dense damage (skin (hot particle), lungs (dust), thyroid (I-131)
  - Internal dosimetry
- Indirectly ionizing
  - Quite penetrating
  - Shielding is massive and expensive
  - External radiation risk

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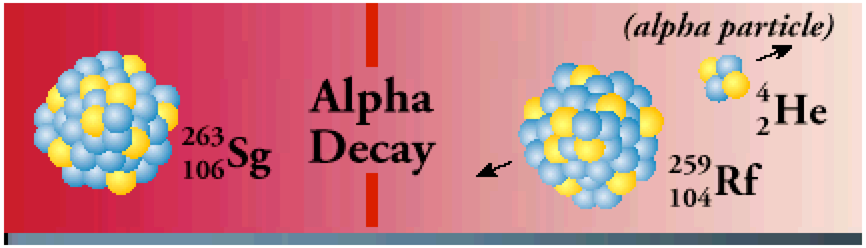
Alpha Radiation



- From heavy nuclides
- Large biological effect
- Uranium
  - In nuclear power plants
  - Decays in the ground and produces Radon
    - Basements in some houses

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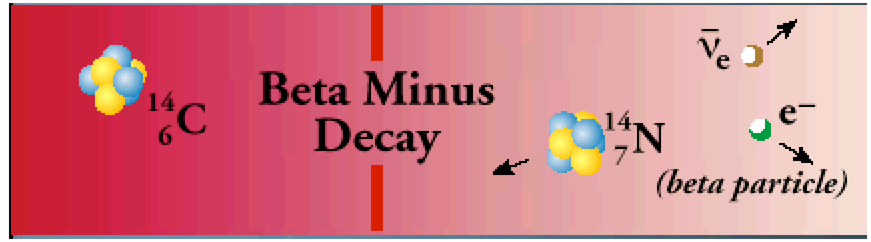
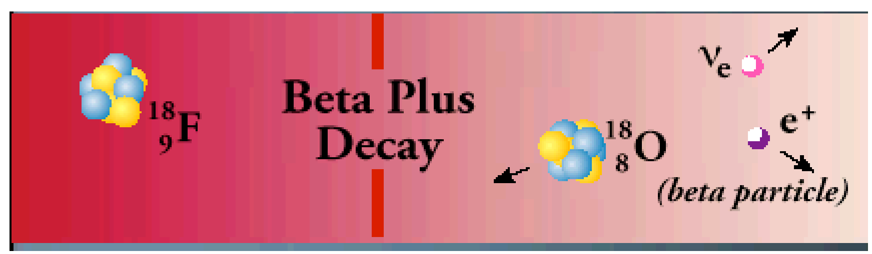
Beta Radiation

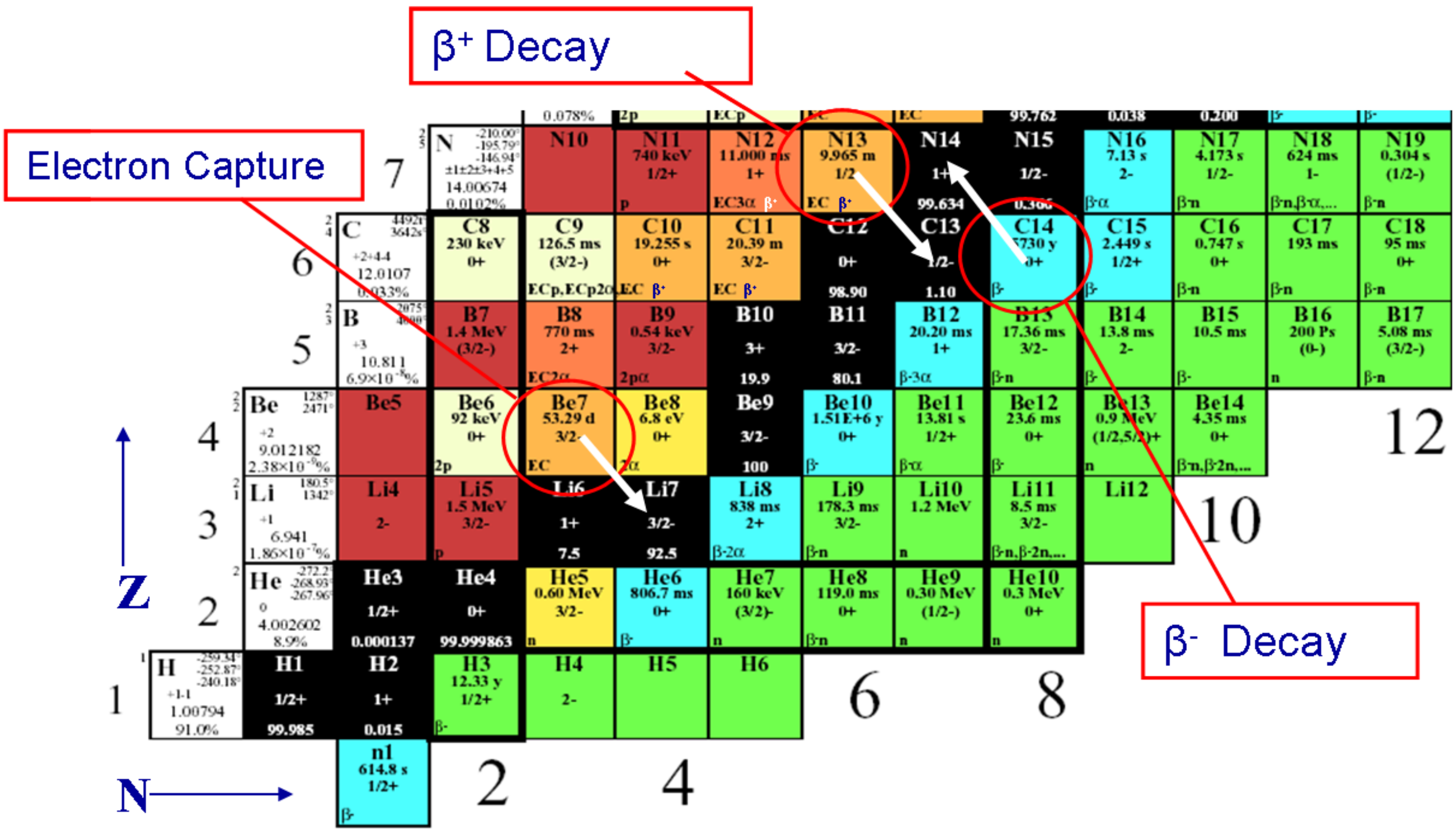
- Beta Minus (e-)



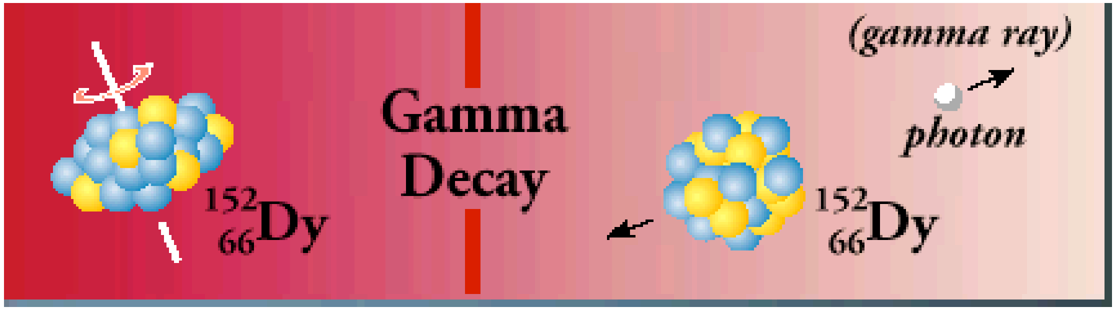
- Nuclear power plants waste (too neutron rich)
  - Neutron becomes a proton and electron
  - Fission products and activation products
- Beta Plus (positron – anti-electron)
  - Produced by accelerators for medical applications.



Results of Decay Processes



Gamma radiation



- Electromagnetic Wave generated from an unstable nucleus

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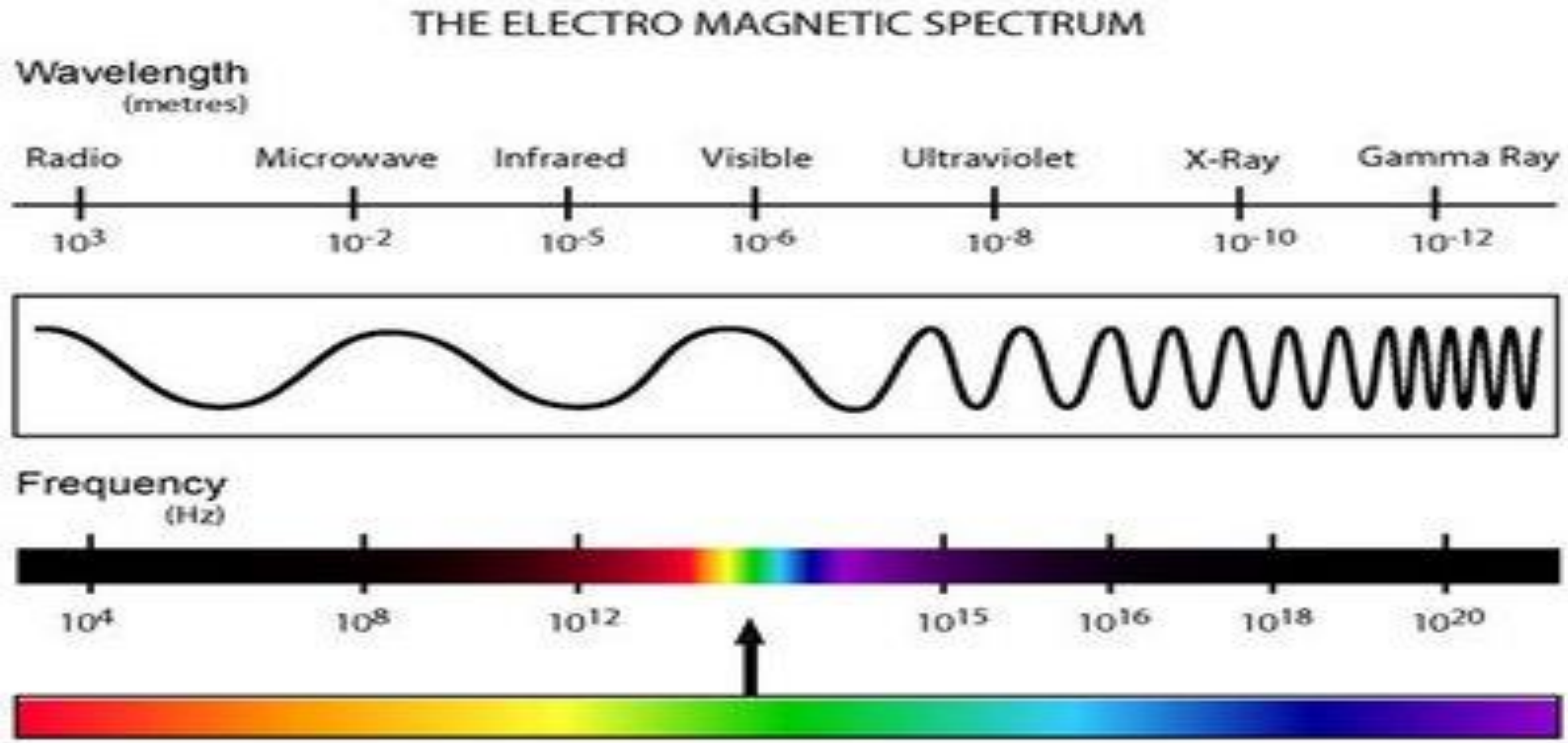
Electromagnetic Wave



- Blue sky – Rayleigh scattering
- Red sky – same reason

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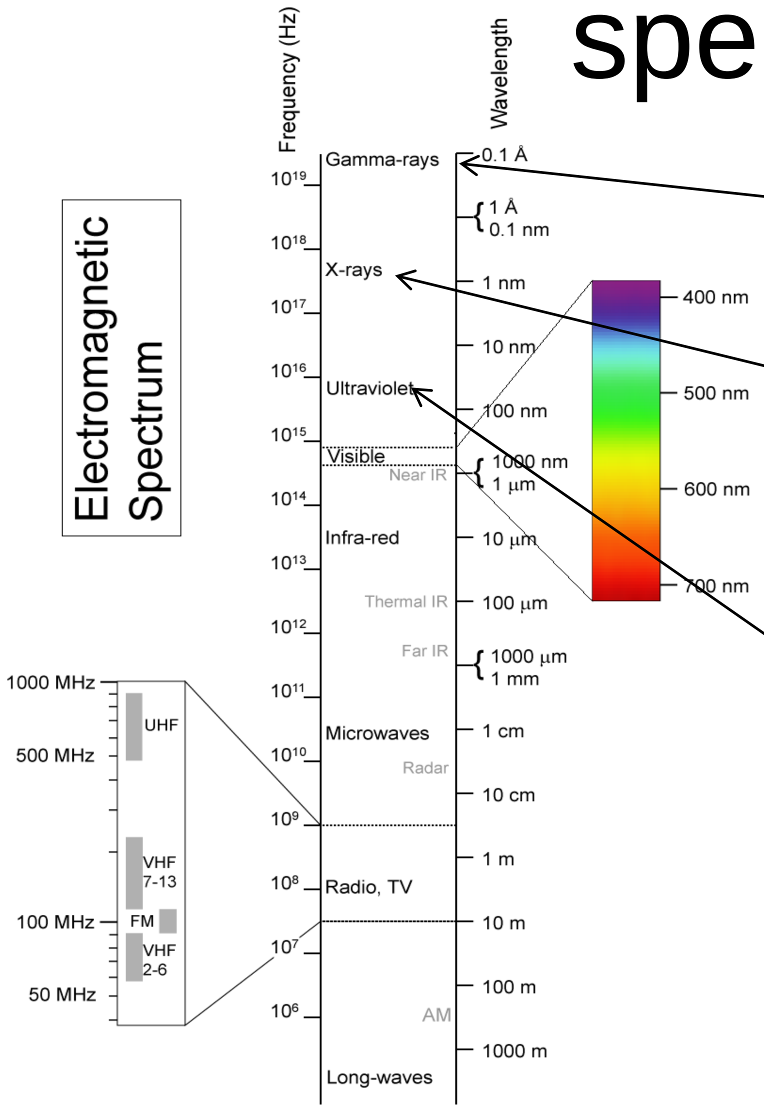
X-ray, γ rays and other EM spectra



Gamma rays (from the nucleus)

X-rays (from rearrangement of the orbital electrons of atoms)

UV damage from spring break near a beach

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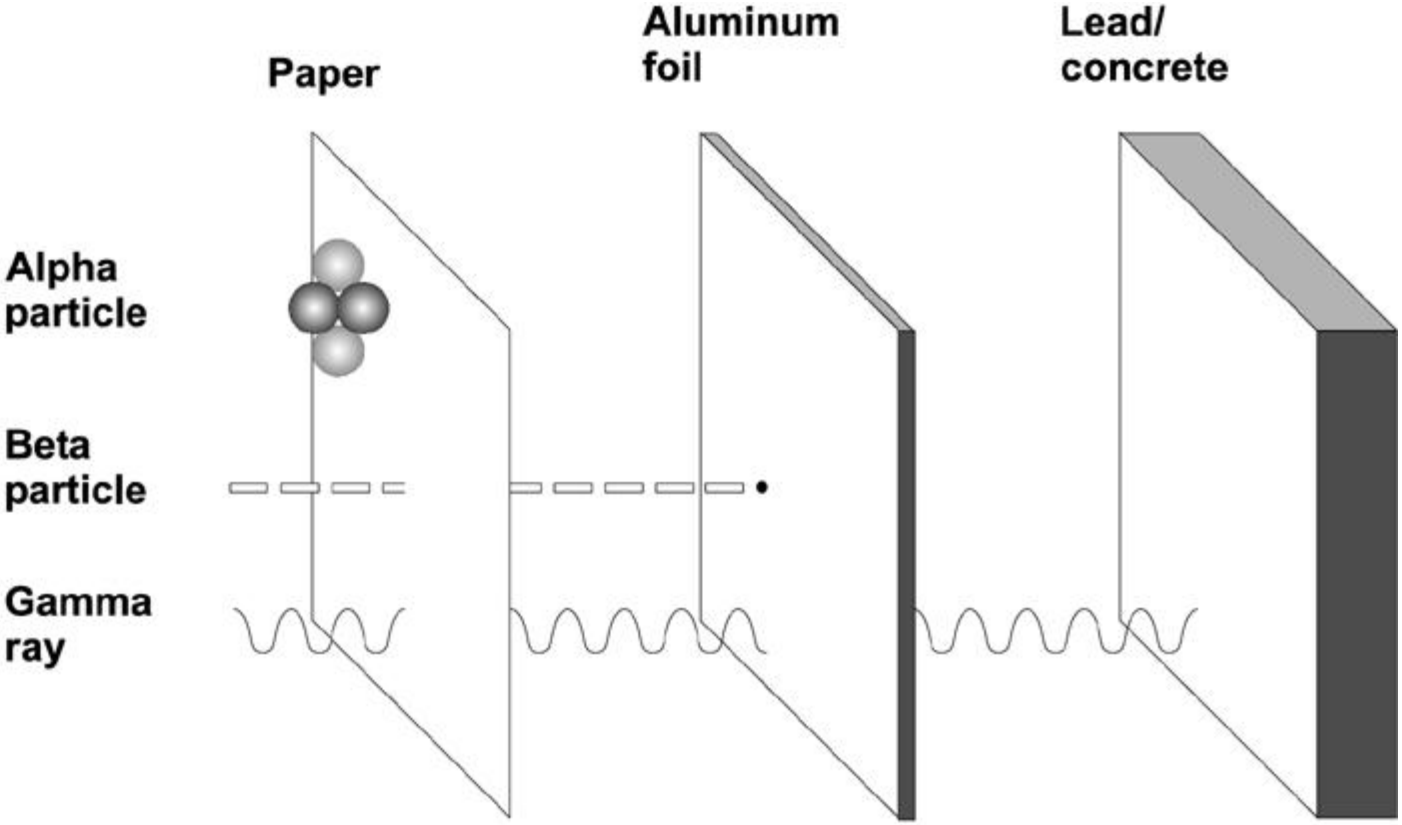
Penetration of Radiation



Alpha and beta are risks if they get inside you, internal hazard.
Gamma and neutrons are risks from outside you, external hazard.

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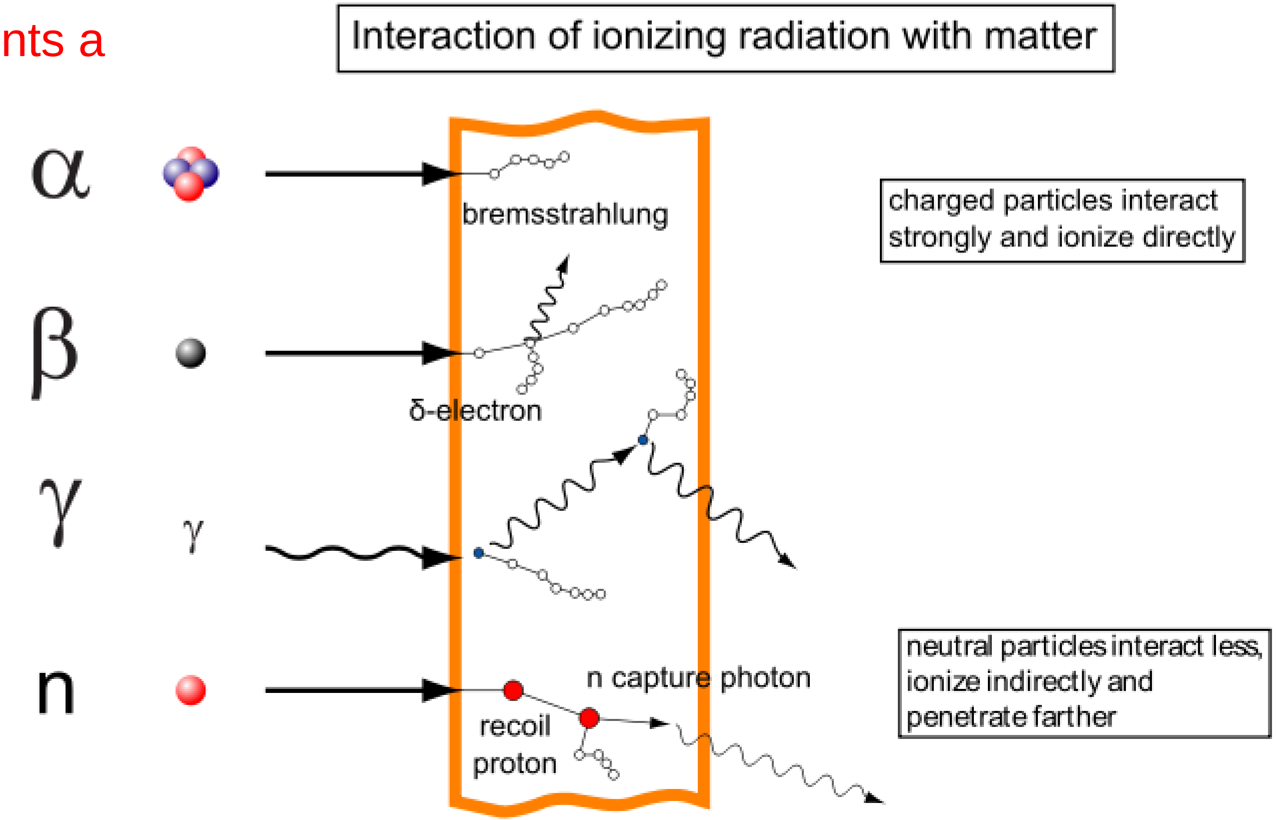
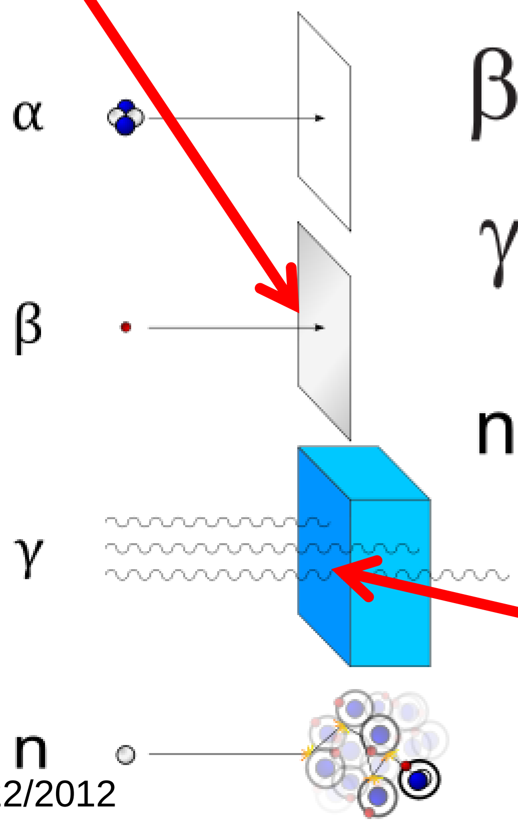
How do the radiation types interact?

Beta radiation is stopped by aluminum foil, plastic gloves, or skin. Presents a hazard if isotope is ingested.





Gamma radiation is stopped by heavy material, like the vest the X-ray technician at the dentist wears.

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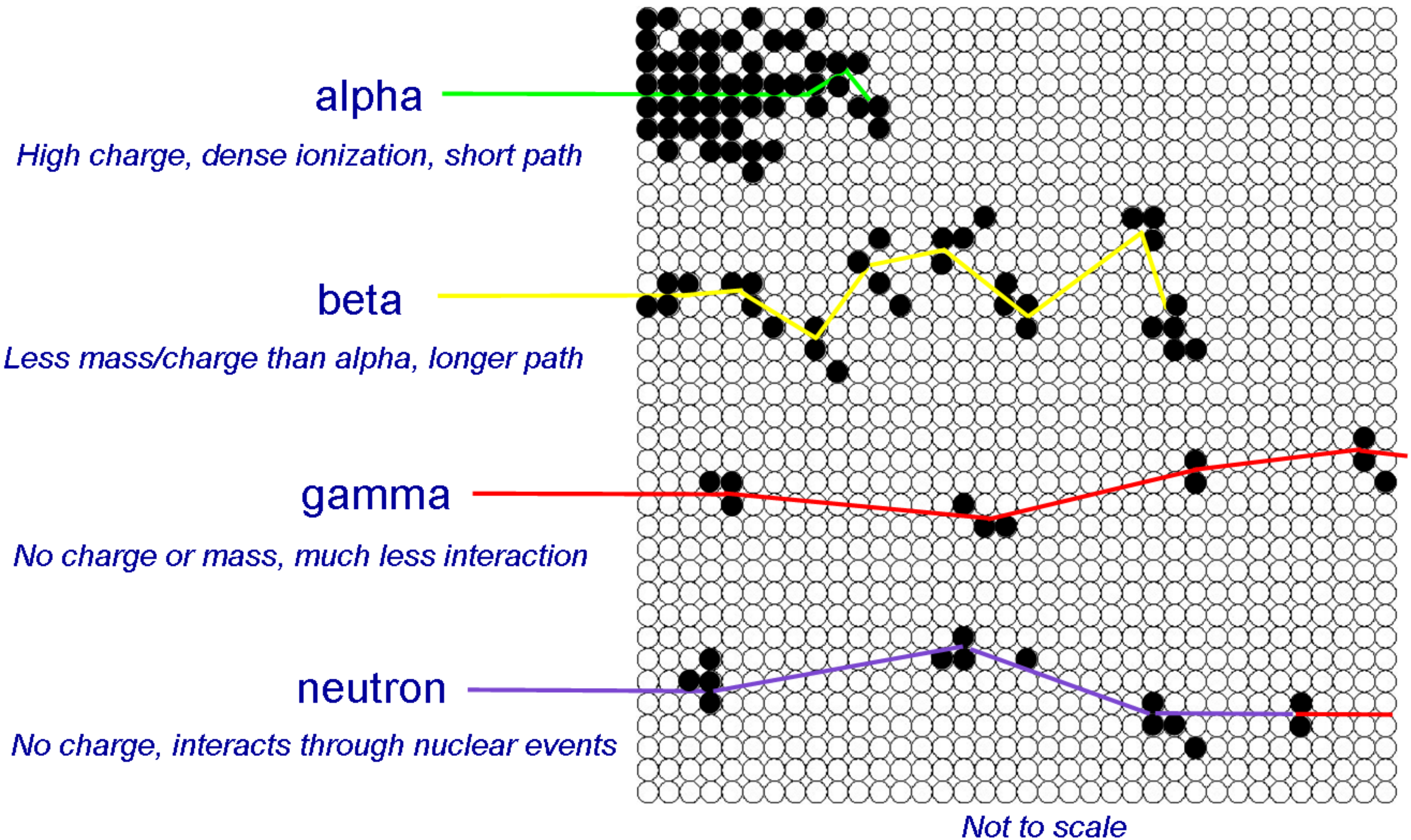
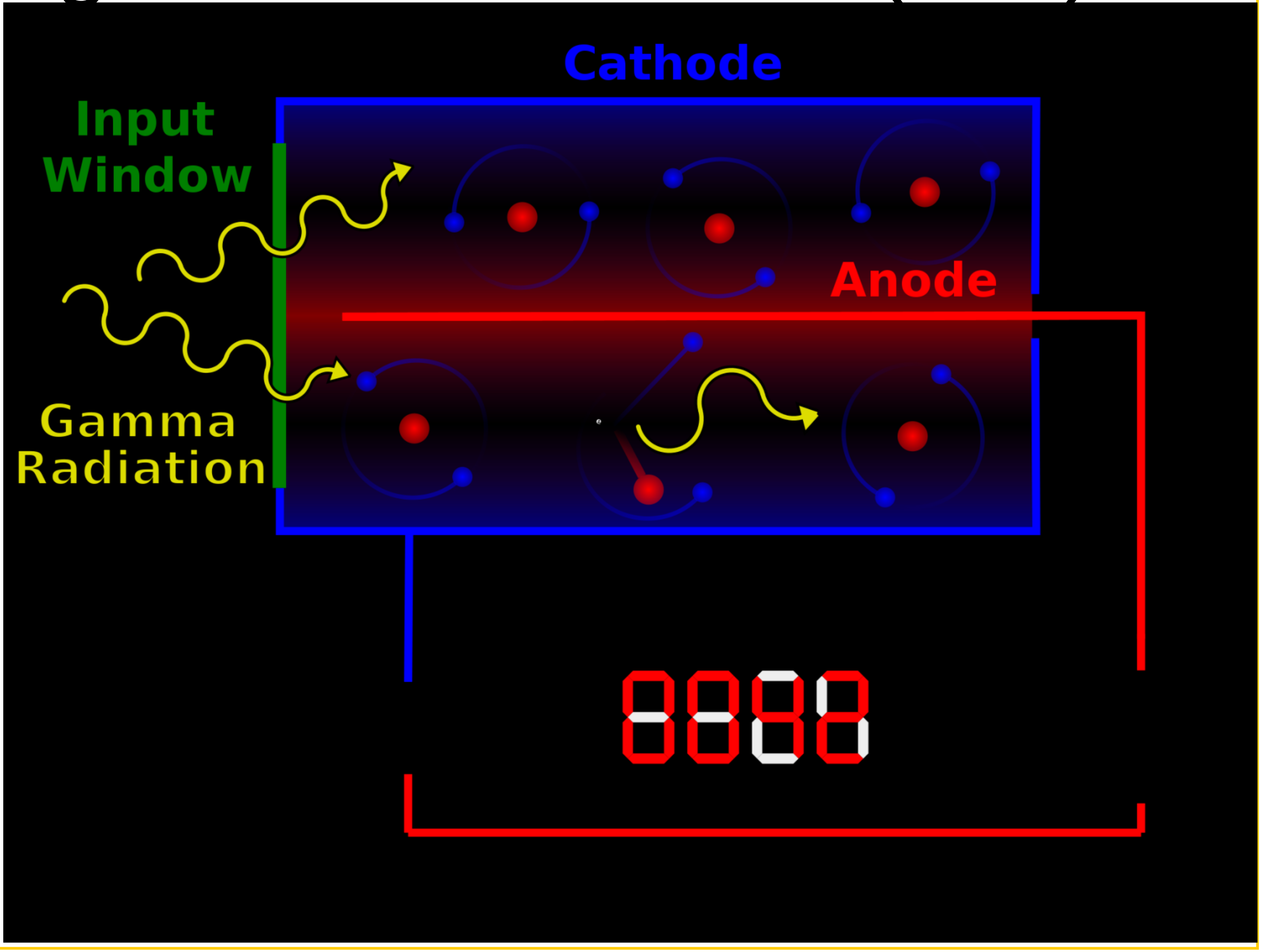
Linear Energy Transfer (LET) - How much energy is deposited per unit length of radiation path

Cell 30 microns 5 hits to DNA to kill the cell Alpha kills 2-10 cells



Geiger Muller Counter (GM)



Quantities of radiation

- Dose (rad)- energy in 100 ergs deposited per gram material (Gy=100rad)
  - Low versus high linear energy transfer (LET)
- Roentgen (R) ionization in air GM detector
- Effective Dose (rem)- dose times a quantity that weights (quality factor) how much of a particular damage the particular radiation does relative to gamma rays (Sv=100rem)

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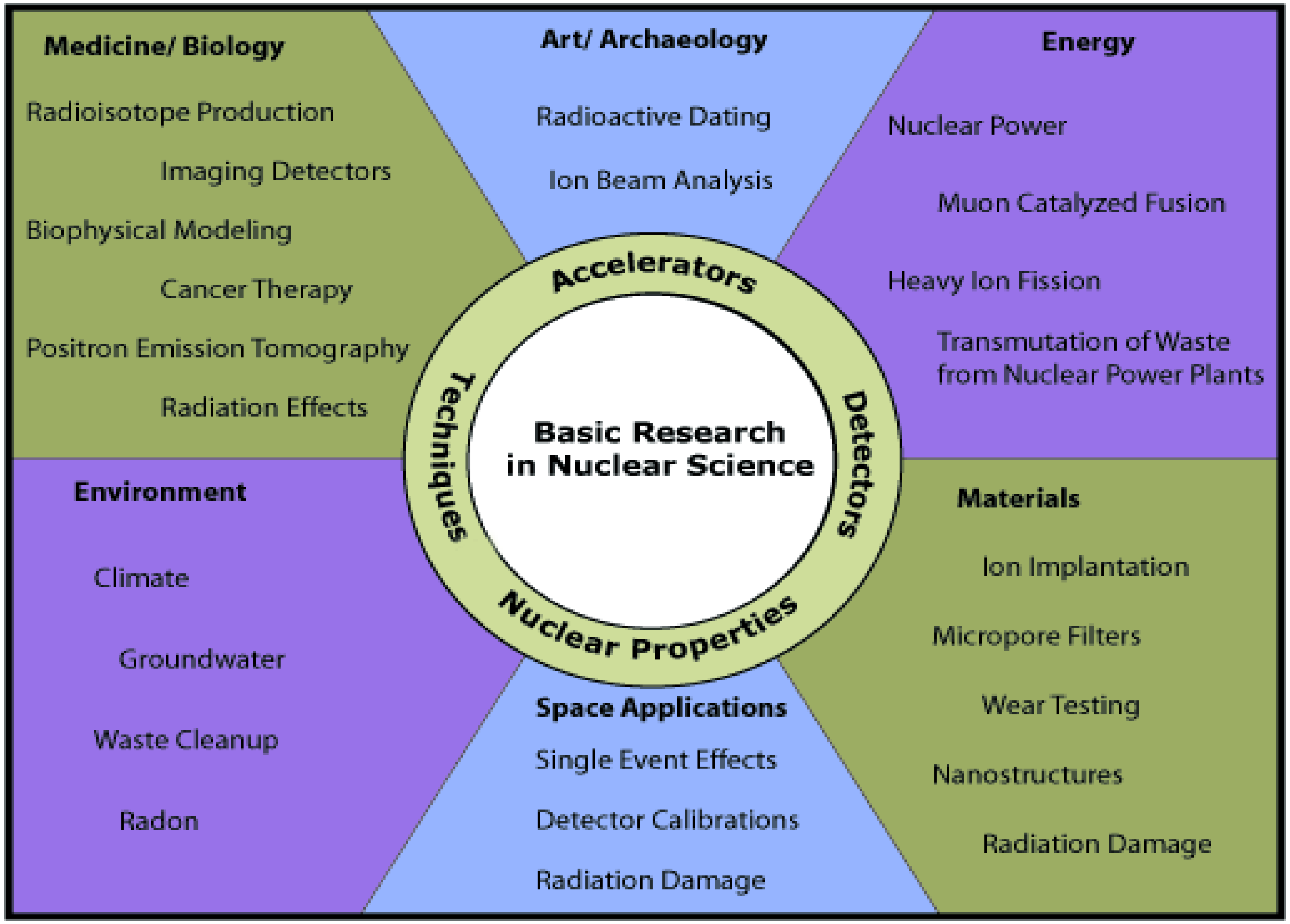
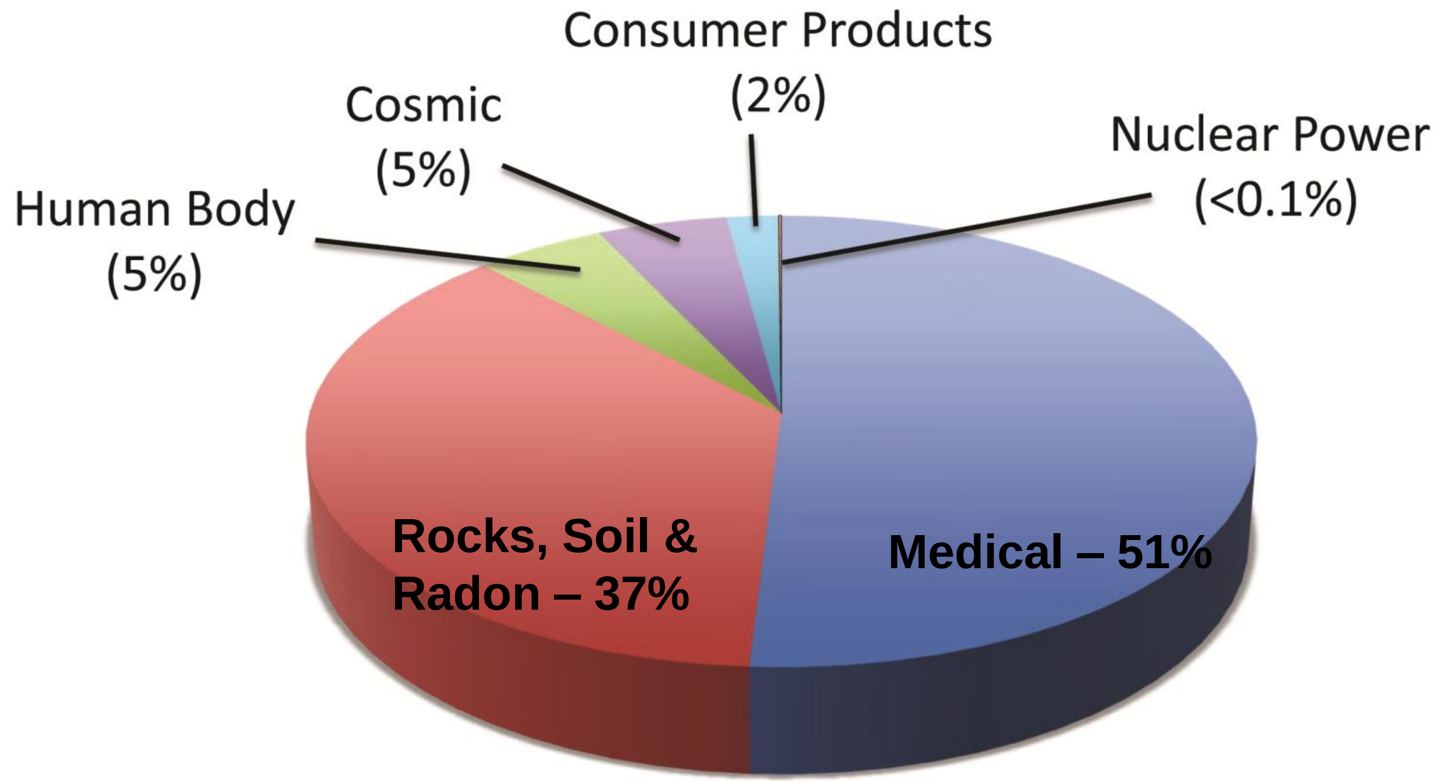
EXPOSURE TO PEOPLE

Radiation Science Applications



Sources of Radiation



The average American receives a radiation dose of 620 millirem per year.

Source: National Council on Radiation Protection and Measurement Report 160 (2006)

NATURAL BACKGROUND

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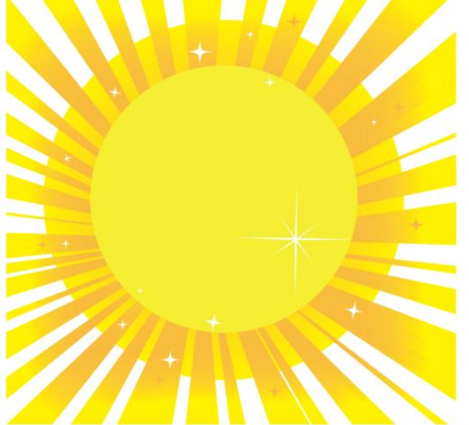
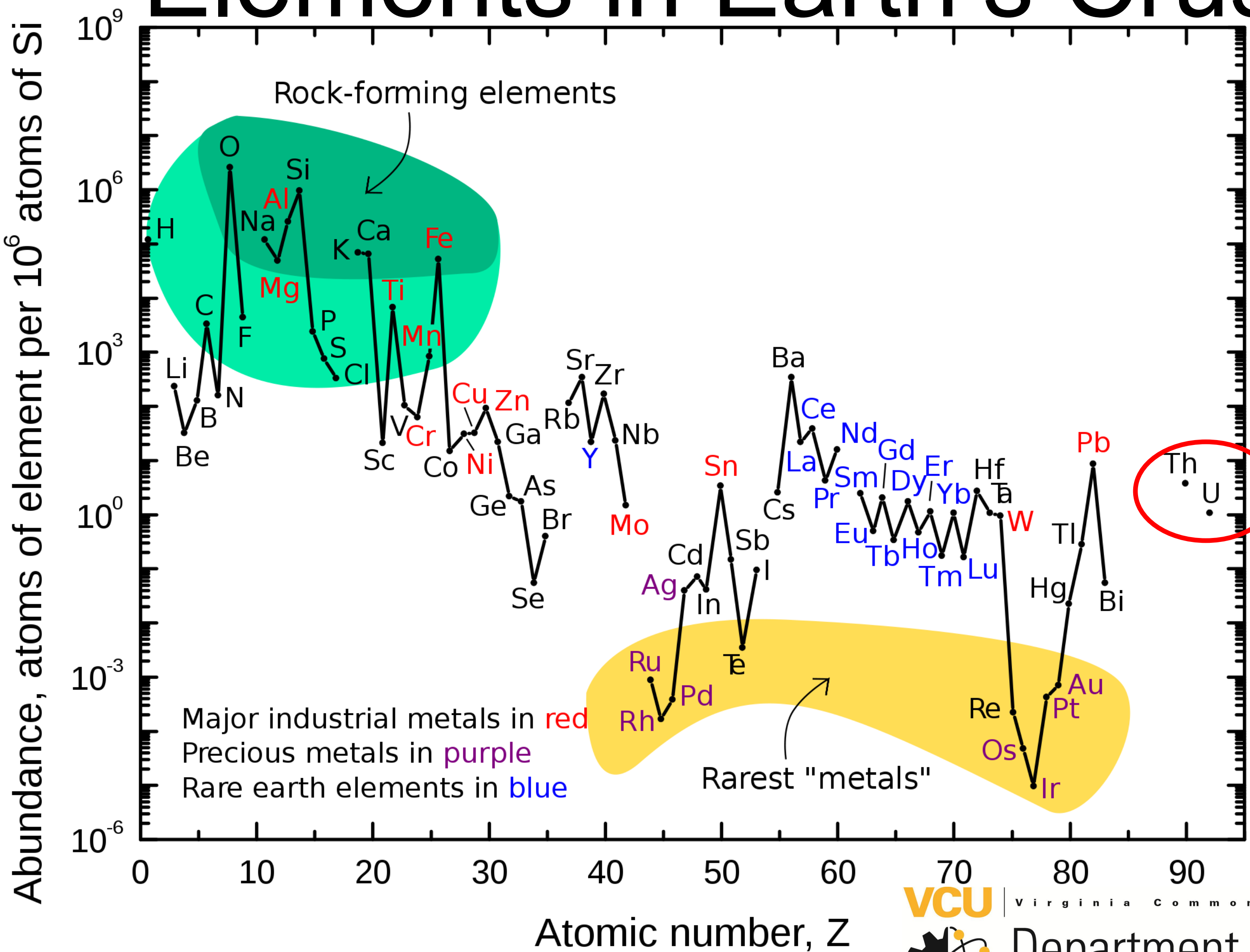
Cosmic Radiation
27 mrem sea level up to 47 mrem Denver



- Biggest nuclear power plant in the solar system
  - SUN
- Atmosphere protects from most radiation, especially charged particles
  - Northern lights
  - Poles regularly flip (what then??)

Elements in Earth’s Crust



Radioactive
Heavy
Metals
-fairly common
Even in VA

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Terrestrial (local dirt)

- Earth 5 billion years
- Uranium
  - Abundance earth's crust: 2.7 parts per million by weight, 0.25 parts per million by moles
  - Abundance solar system: 1 part per billion by weight, 4 parts per trillion by moles
- Radon (decay of uranium)
  - Inert gas, hard to stop
  - Formed in ground, pressurized so takes the path of least resistance (often to your basement)
  - 228mrem/yr average

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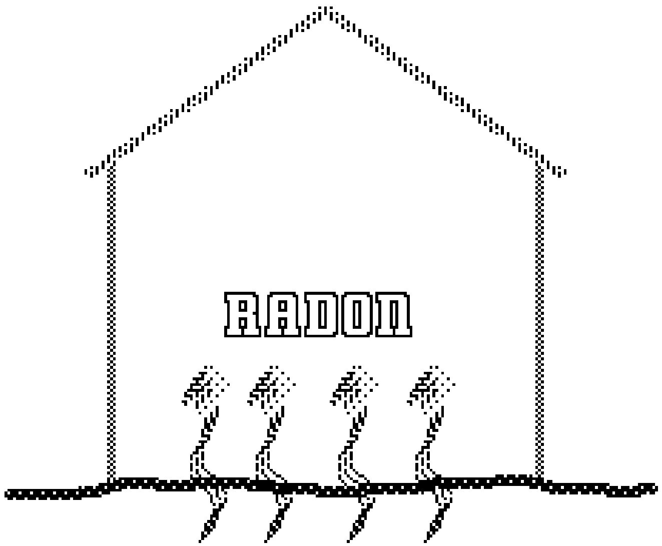
Radon – natural isotope

The radon problem



Coming to work one morning, Mr Watras triggered the radiation monitor when he went into the plant!!!

The monitor was of course placed there to check workers for radioactive contamination when they left work.

The radon level in the Watras home was measured to be 2500 picocuries per liter!

Uranium has a long lifetime. One of the decay products is radon, an inert gas (hard to contain). Pushes through rock to easiest path to low pressure.

http://hyperphysics.phy-str.gsu.edu/hbase/nuclear/radon.html

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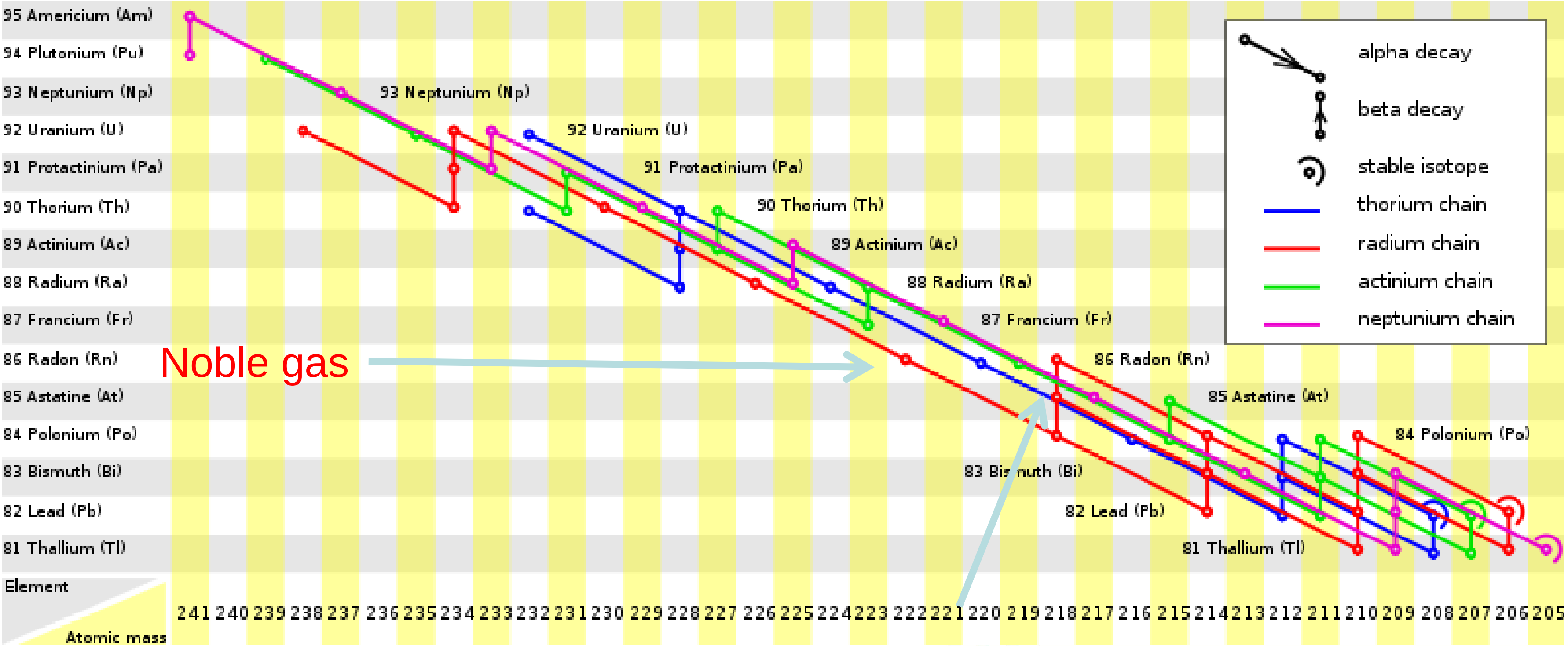
Radon and Progeny

- Radon decay actually follows one of four decay chains. Many decays per uranium!



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Home construction

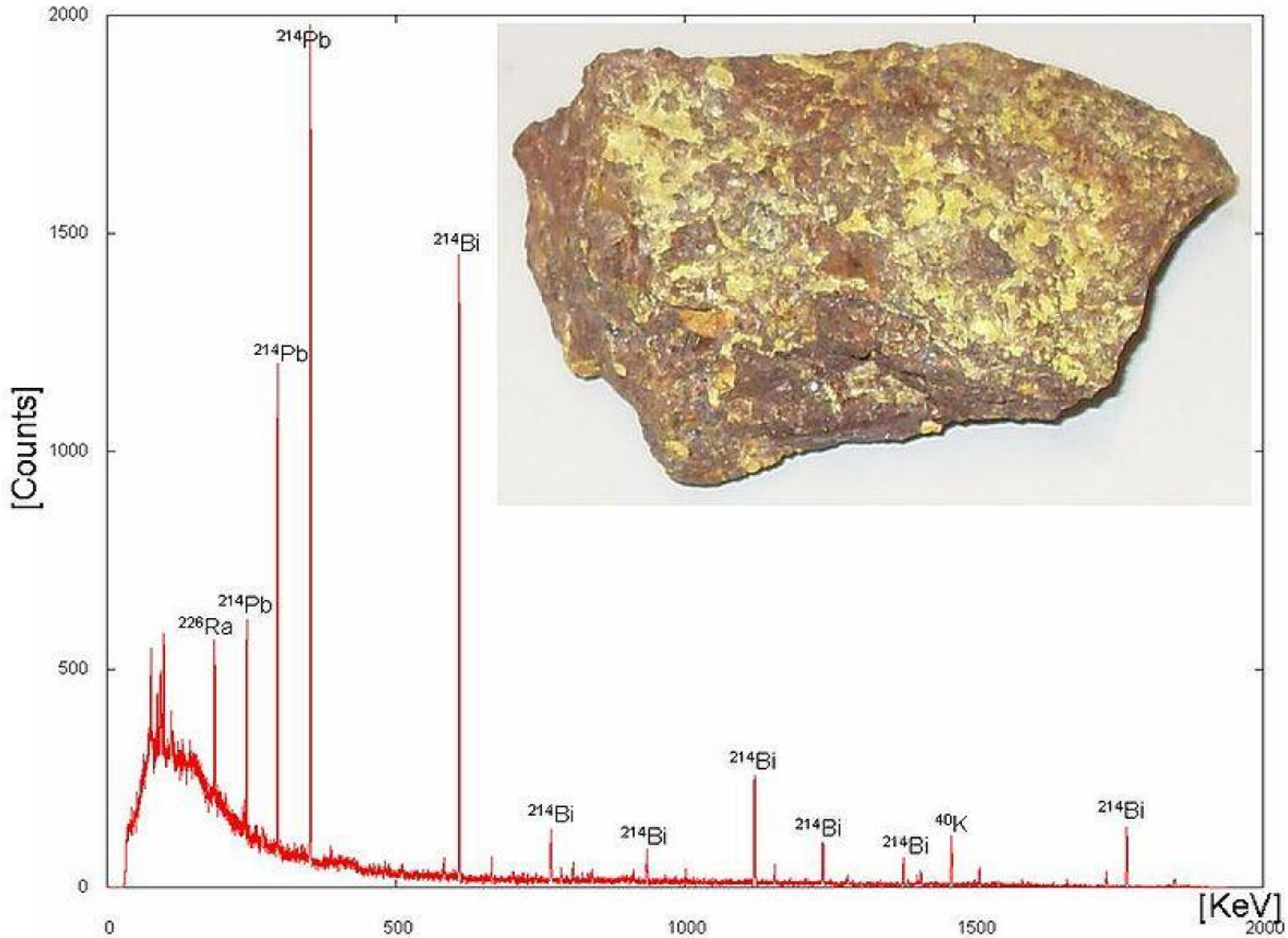
- Stone, brick, and concrete (7mrem)
- Varies by location
  - **

Radioactivity in Selected Building Materials (pCi/g)[a]

Source	Material	^{40}K	^{238}U	^{226}Ra	^{232}Th
Chang *et al* (1974), Taiwan	Wood	90	—	—	—
	Red brick	16	1.2	—	1.8
	Concrete	7	0.9	—	—
Hamilton (1971), United Kingdom	Clay brick	18	3	1.4	1.2
	Silicate brick (gravel)	10	0.2	0.2	0.1
	Granite	30	6	2.4	2.2
	Aerated concrete	19	0.4	2.4	0.4
	Natural gypsum	4	0.4	0.6	0.2
	Concrete block (fly ash)	(6–16)	(1–12)	(0.2–4)	(1.0–1.2)
Wollenberg and Smith (1966a and b), United States	Cement	3.4	1.1	—	0.4
	Silica sand	9	0.3	—	0.5
	Commercial sand	7	0.3	—	0.3
	Red brick	18	—	1.5	1.0
	Silica brick	6	—	0.5	0.4
	Light concrete	14	—	2.0	0.9
	Granite	40	—	3.0	4.5
	Sand	7	—	(<0.4–1)	<0.4
	Cement	4	—	0.7	<0.4
Kolb (1974), West Germany	Granite	34	—	2.8	2.1
	Brick	18	—	1.7	1.8
	Sand, gravel	<7	—	<0.4	<0.5
	Cement	6	—	0.7	<0.6
	Natural gypsum	<2	—	<0.5	<0.3
	Concrete	7	—	0.6	0.6

[a]From Harley (1978).

Radiation from rock containing Uranium



Food

- Food and water (40 mrem/yr)
  - Carbon-14
    - Everything you eat (except dirt)
    - Archeologists will be able to tell how old you are, eventually.
  - Potassium-40
    - Bananas
    - Sports drinks

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Food with Radon/Uranium

ALPHA RADIOACTIVITY OF FOODS[a]

Foodstuff	Maximum α activity observed per 100 g (pCi)
Brazil nuts	1400
Cereals	60
Teas	40
Liver and kidney	15
Flours	14
Peanuts and peanut butter	12
Chocolates	8
Biscuits	2
Milks (evaporated)	1–2
Fish	1–2
Cheeses and eggs	0.9
Vegetables	0.7
Meats	0.5
Fruits	0.1

[a]From Mayneord *et al* (1958).

Tobacco and other large leaf foods.

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People

- Humans are naturally radioactive
- Within the body is:

  Uranium, thorium, potassium, carbon, and tritium
- Over 12,000 decays per second

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MEDICAL EXPOSURES

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Medical Radiation Exposure per Procedure (average)

- X-Ray - Chest (10 mrem)
- X-Ray - Mammography (42 mrem)
- X-Ray - Skull (10 mrem)
- X-Ray - Cervical Spine (20 mrem)
- X-Ray - Lumbar Spine (600 mrem)
- X-Ray - Upper GI (600 mrem)
- X-Ray - Abdomen (kidney/bladder) (700 mrem)
- X-Ray - Barium Enema (800 mrem)
- X-Ray - Pelvis (60 mrem)
- X-Ray - Hip (70 mrem)
- X-Ray - Dental Bitewing/Image (0.5 mrem)
- X-Ray - Extremity (hand/foot) (0.5 mrem)

Computed Tomography

- CT Scans - Head (200 mrem)
- CT Scans - Chest (700 mrem)
- CT Scans - Abdomen/Pelvis (1000 mrem)
- CT Scans - Extremity (10 mrem)
- CT Scans - Angiography (heart) (2000 mrem)
- CT Scans - Angiography (head) (500 mrem)
- CT Scans - Spine (1000 mrem)
- CT Scans - Whole Body (1000 mrem)
- CT Scans - Cardiac (2000 mrem)

- ANS web

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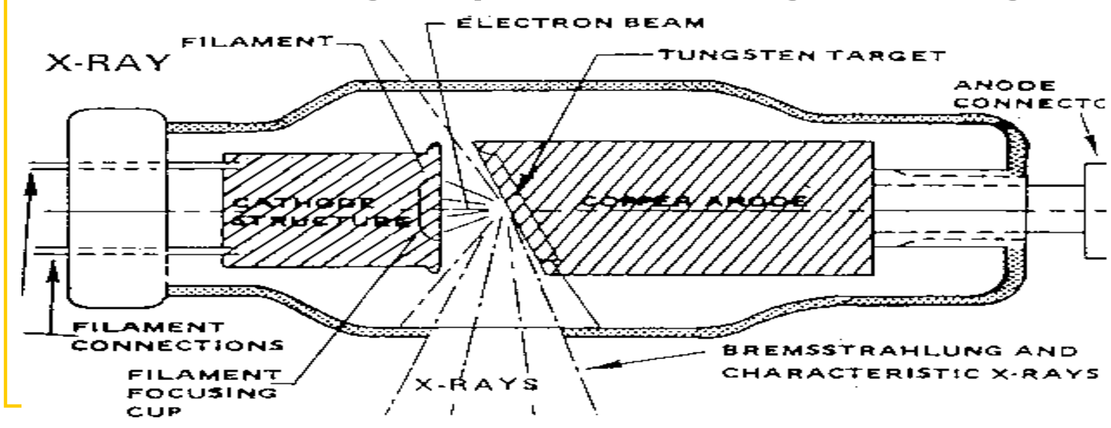
X-ray machine

- Roentgen was working with a cathode ray tube (old television or neon or fluorescent light)
  - Glass tube is evacuated and filled with a gas.
  - High Voltage is applied across the gas and the gas glows
  - Light emitted is in the visible wavelength range (different gases give different colors)



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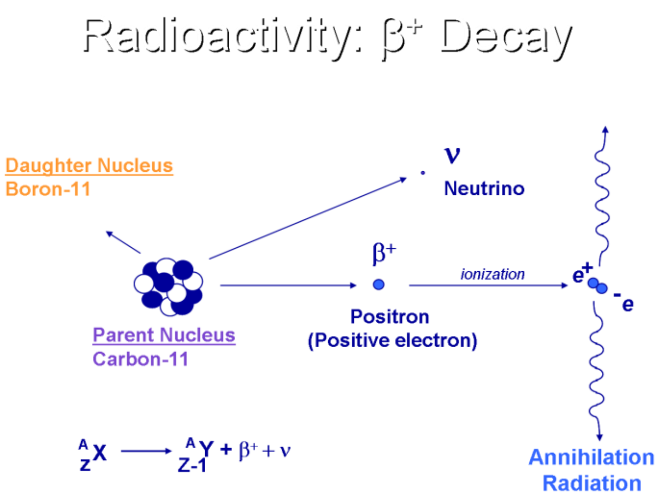
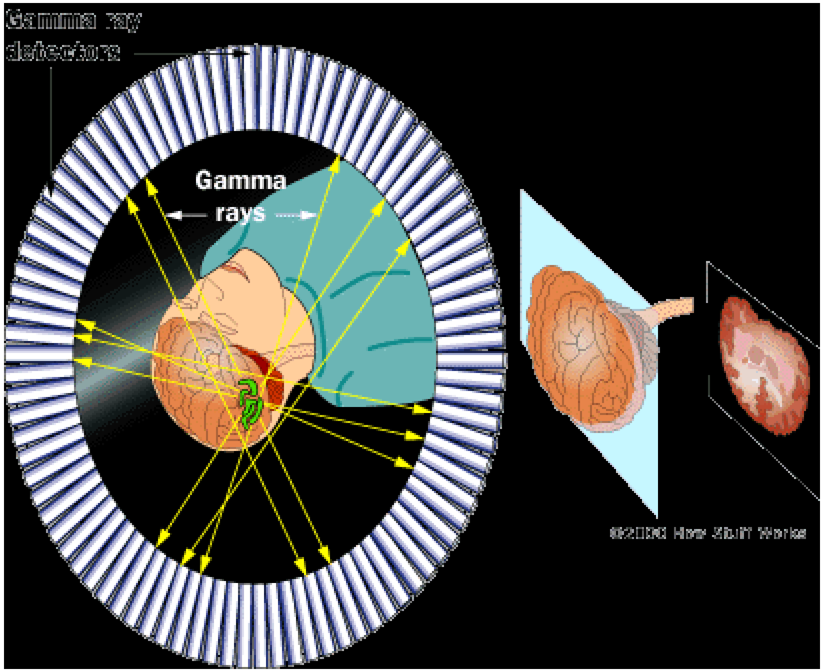
Positron in Nuclear Medicine





- Coincidence detection of two 511KeV photons
- Biological tracer

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Cardiac Pacemakers

- Need a stable, reliable, high power density energy source
- Use the decay of actinides (very heavy elements)
- Caution for disposal

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CONSUMER PRODUCTS

Consumer Products

- Porcelain crowns and false teeth
- Luminous watch dials
- Video display terminals
- Smoke detectors (why??)
- **other (orange is red and yellow)

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Irradiated Food

- Last longer, sometimes much longer
  - Kills bacteria and molds
- Does it leave food radioactive?
  - Does microwaved food boil you?
  - Does fire grilled food have fire?

Irradiate food is no more radioactive than it was to start with!

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Why irradiate foods?

Food-borne disease affects an estimated 76 million Americans every year and leads to nearly 325,000 hospitalizations. The Centers for Disease Control (CDC) estimate that irradiating even half of all meat could prevent 900,000 cases of food poisoning.

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Jet Travel

- Jet travel
  - 0.5 mrem/hr
- I've gone past luggage x-ray inspection at the airport (0.002 mrem)

Reference: NCRP Report #93
Ionizing Radiation Exposure of the Population of the United States (1987)

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Common Consumer Sources

- TV or computer screen which uses CRT technology (1 mrem)
- Smoke detector (0.008 mrem)
- luminous watches and dials (tritium)
  - Radium Dial Painters

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Manmade Sources

- Tobacco (polonium-210)
  - Smoke 1/2 pack of cigarettes every day of the year (18 mrem/yr)

- Combustible fuels (gas, coal, etc.)
  - C-14, Uranium
  - Both gaseous effluents and slag

Manmade Sources (Thorium)

- Ophthalmic glass (and potassium)
- Fluorescent lamp starters
- Lantern mantles
- Lightning rods
- Welding rods

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Industrial Radiography

- Corrosion and cracking in infrastructure (like an X-ray picture of a broken arm for bridges)
- Similarly for dams, ship hulls, …

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NUCLEAR POWER PLANTS

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Nuclear Reactors

- Generate electricity
- Power ships and submarines
- Research tool at national labs
- Space applications
- Generate radioisotopes for medical applications
  - Canada (Tc-99m)

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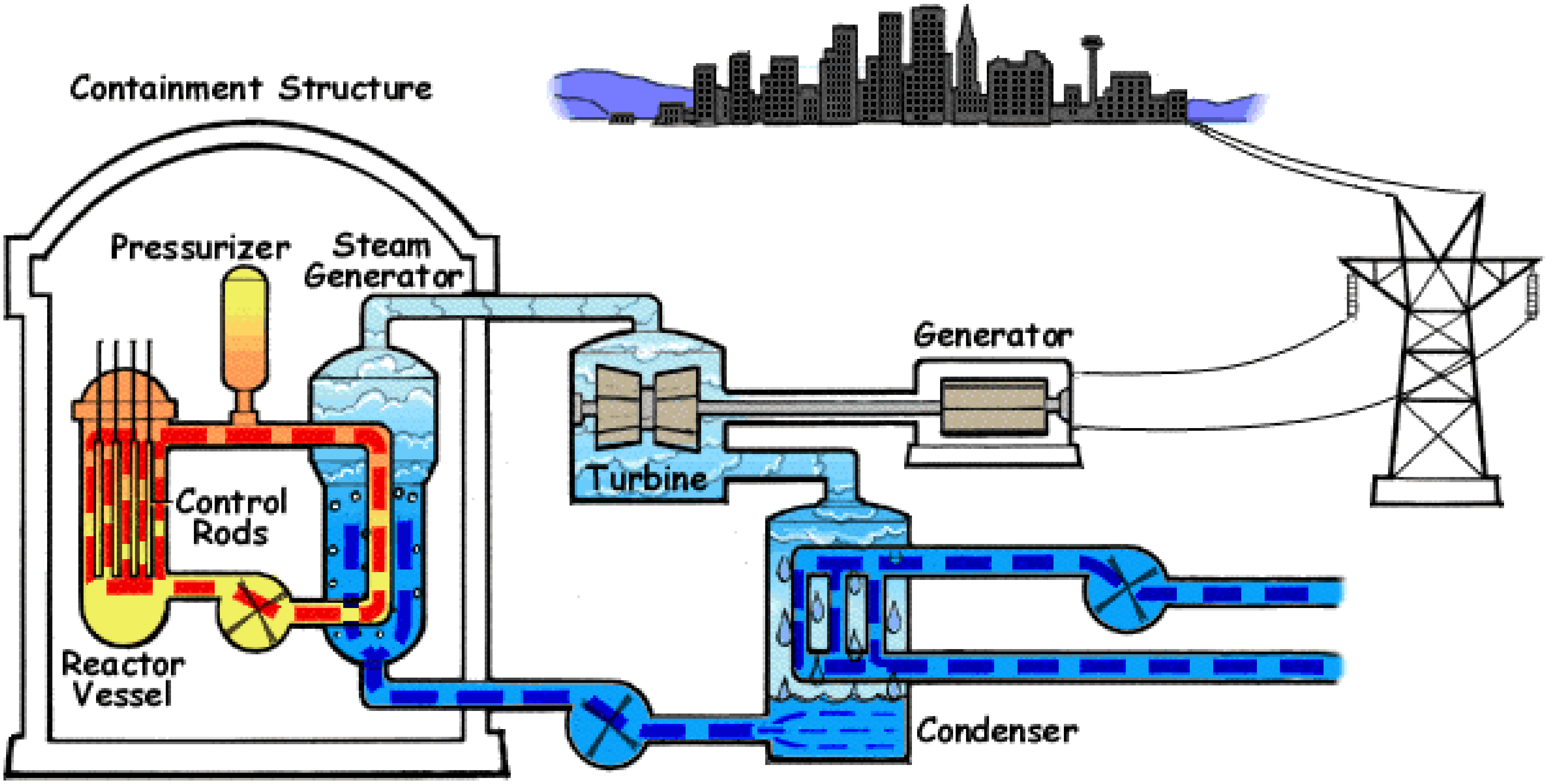
US Pressured Water Reactor Schematic



Wikipedia.com

Nuclear Power Plants

- We are surrounded by naturally occurring radiation.
- Less than 1 / 1000th of the average American's yearly radiation dose comes from nuclear power.
- This yearly radiation dose is 100 times less than we get from coal,[1] 200 times less than a cross-country flight, and about the same as eating 1 banana per year.[2]

1. National Council on Rad Protection and Measurements No. 92 and 95
2. CDR Handbook on Radiation Measurement and Protection

Virginia Nuclear

- Dominion Power
  - North Anna (another unit?)
  - Surry
- AREVA and Babcock & Wilcox – Lynchburg
  - Design, fuel processing
- AREVA/Northrop Grumman – Newport News (Huntington Ingalls Shipyard)
- VA Mining

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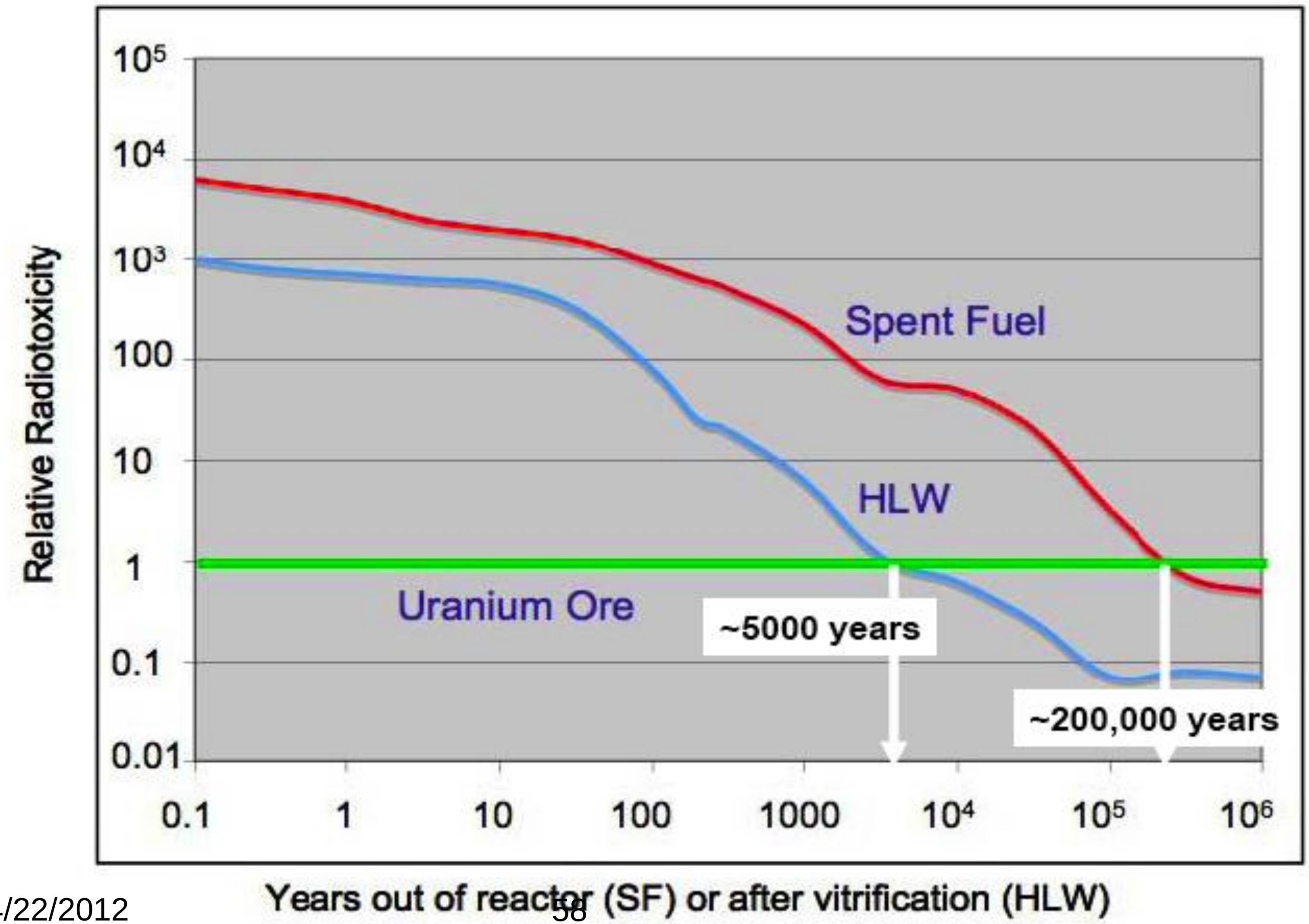
Live within 50 miles of power plant

- Nuclear power plant
  - 0.01 mrem
- Coal power plant
  - 0.03 mrem

Radioactivity Nuclear Spent Fuel



Source: Dr. Mick Apted, Monitor Scientific (2009)

Nuclear Fuel Waste

- If all the used fuel produced by U.S. nuclear power plants in nearly 50 years were stacked end to end, it would cover a football field to a depth of less than 10 yards.[1]
- 96% of this "waste" can be recycled.[2]
- Used fuel is currently being safely stored.
- The U.S. National Academy of Sciences and the equivalent scientific advisory panels in every major country support geological disposal of such wastes as the preferred safe method for their ultimate disposal.[3]

1. Nuclear Energy Institute: http://nei.org/keyissues/nuclearwastedisposal/storageofusednuclearfuel/
2. K.S. Krane, *Introductory Nuclear Physics*, John Wiley and Sons, 1988
3. *Progress Towards Geologic Disposal of Radioactive Waste: Where do We Stand?* Nuclear Energy Agency, OECD report, 1999 (http://www.nea.fr/rwm/reports/1999/progress.pdf)

Nuclear Power impacts, remove other sources (Coal Car?)

- **Near-term**
  - nuclear power can provide electricity for expanded mass-transit and plug-in hybrid cars.
  - Small modular reactors can provide power to islands (e.g. HI, PR, Nantucket and Guam) currently burning oil to generate electricity.[1]
- **Longer-term**
  - Nuclear power can reduce dependence on foreign oil by producing hydrogen for fuel cells and synthetic liquid fuels.

Photo: Hydrogencarsnow.com

1. U.S. Energy Information Administration

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