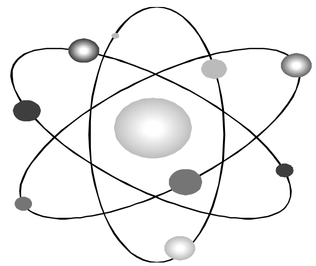
Radiation Safety Training

…it concerns your health!

Charlie Freeman, RSO
SUNY Genseseo

Atomic Structure



Nucleus

- Contains Protons and Neutrons
- Small Size (~1E-14 m)
- Relatively Large Mass
- Extremely Large Density
- Large amount of Stored Energy

Orbiting Electrons

- “Cloud” of orbiting electrons surrounds nucleus
- Cloud is relatively large (~1E-10 m)
- Low mass
- Small amount of Stored Energy
- Responsible for Chemical Bonds

Nomenclature

- Element Designation
  - "X" = Element Symbol
  - "Z" = # protons in nucleus
    - "Atomic #" (each element has a unique Z, see periodic table)
  - "N" = # neutrons
  - Atomic mass # = "A"
    - A = Z + N
    - Isotope: same Z, different N and A

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

For Example

${}^{16}_{8}$O = O-16 = Oxygen 16

${}^{17}_{8}$O = O-17 = Oxygen 17

${}^{197}_{79}$Au = Au-197 = Gold 197

Example: P-32

- 15 protons
- 17 neutrons
- A = 32
- Z =15

$$^{32}_{15}P$$

Ion

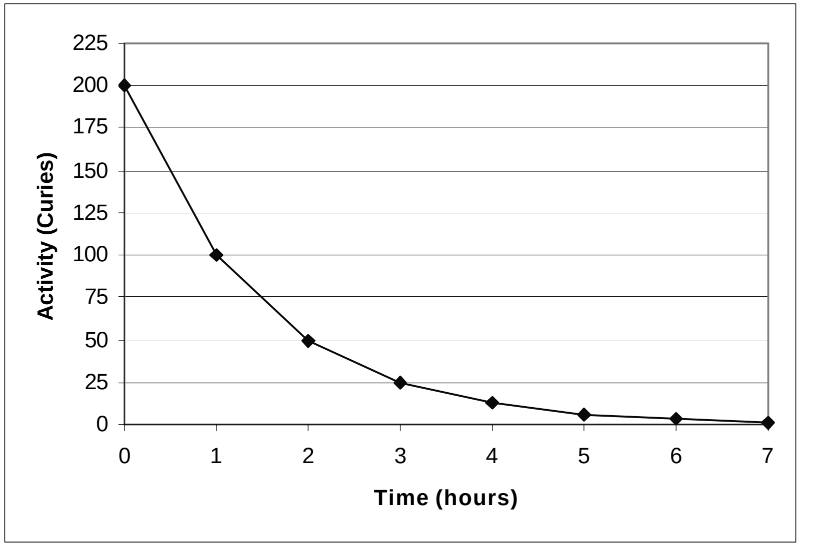
- In an electrically neutral atom or molecule, the number of electrons equals the number of protons
- Any atom or molecule with an imbalance in electrical charge is called an ion
- Ions are chemically unstable, and will seek electrical neutrality by reacting with other atoms or molecules.

Radioactivity

- Definition: A collection of unstable atoms that undergo spontaneous transformation that result in new elements. The degree of radioactivity is given by the number of decays that occur per unit time (decays per minute)
- Units of measure:
  - Dpm, dps
  - Curie (Ci): 1 Ci = 3.7E10 dps
  - Bequerel (Bq): 1 Bq = 1dps

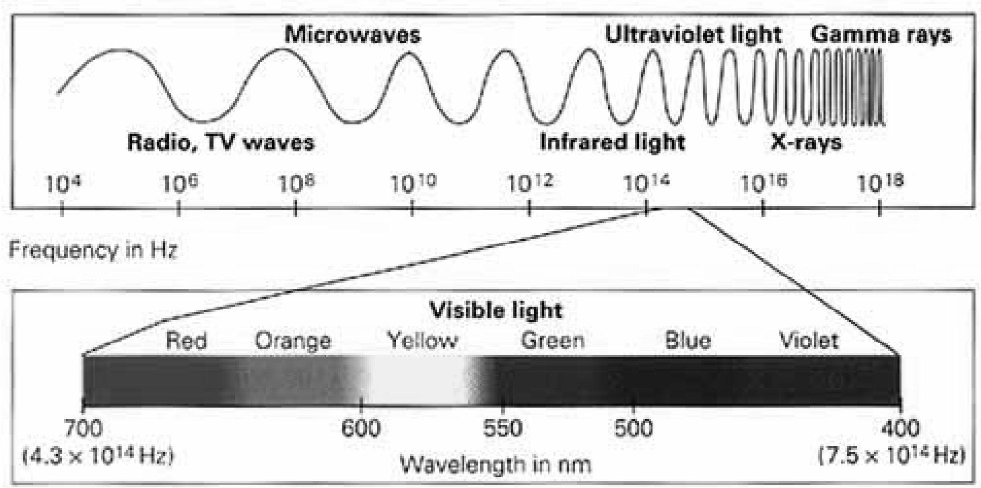
Half-Life & Decay Law

- The activity of a sample of radioactive atoms decreases over time
- Half-life: how long it takes for activity of sample to decrease by a factor of ½.



Radiation

- Definition: Energy in the form of particles and/or waves
- Particles:
  - Alpha particles (2 protons, 2 neutrons)
  - Beta particles (electrons or positrons)
  - Neutrons
- Waves: Electromagnetic Radiation
  - X-rays
  - Gamma rays



Ionizing vs. Non-ionizing Radiation

- Ionizing
  - Directly ionizing (charged particles): beta +, beta -, alpha
  - Indirectly ionizing (non-charged particles or waves): gamma rays, X-rays, neutrons
- Non-ionizing
  - Infrared, visible, microwaves, radar, radio waves, lasers

Types of Nuclear Decay

- Beta Decay:
  - Beta Minus Decay: $^{1}_{0}n \longrightarrow {}^{0}_{-1}\beta + {}^{1}_{1}p + {}^{0}_{0}\bar{\nu}$
  - Beta Plus Decay: $^{1}_{1}p \longrightarrow {}^{0}_{+1}\beta + {}^{1}_{0}n + {}^{0}_{0}\nu$
  - Electron Capture: $^{1}_{1}p + {}^{0}_{-1}e \longrightarrow {}^{1}_{0}n + {}^{0}_{0}\nu$
- Alpha Decay: $^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$
- Gamma Decay: Excited nucleus emits gamma ray photon when it de-excites

Gamma Decay

- Occurs in nuclides having the same number of neutrons and protons, but capable of existing at a higher energy level
- Transition from an excited state to a lower level is accompanied by emission of gamma ray.
- A Gamma ray, like light, is electromagnetic radiation and is made up of photons having no charge and no mass.

X-Rays

- Photons produced when orbiting electrons transition to lower energy levels
- Also produced when electrons experience sharp deflections as a result of interaction with an electric field of a nucleus
  - Bremsstrahlung (braking) radiation
- Once produced, they are identical to gamma rays.
- X-Rays produced by orbiting electron transitions have discrete energies, corresponding to the energy levels of the orbiting electrons.
- X-Rays from Bremsstrahlung have a broad band of energy levels.

Neutrons

- Produced either in spontaneous fission or in nuclear reactions
- Example: Pu-Be source (neutron howitzer)
  - Pu-239 undergoes alpha decay
  - Alpha particle interacts with Beryllium nuclei
  - This causes nuclear reaction producing neutrons

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

Biological Effects of Radiation

- Types of Exposure
  - Acute: large amounts of radiation received in a short amount of time.
  - Chronic: small amount of radiation received over a long period of time
- Types of Biological Effects
  - Short Term Effects (Acute Radiation Syndrome)
  - Long Term Effects (takes years to show up)
  - Genetic effects (passed on to offspring)

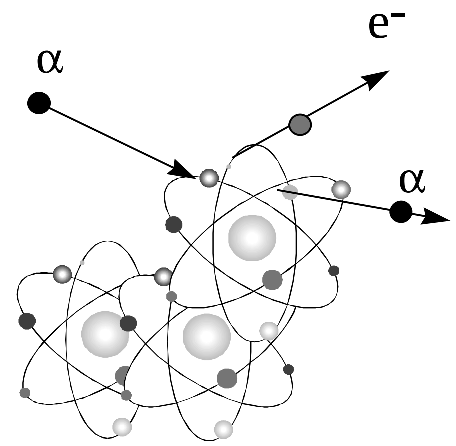
Types of Biological Effects

- Short Term Effects (Acute Radiation Syndrome 150-350 rem)
  – Anorexia, Nausea, Fatigue, Vomiting, Epilation (Hair loss), Sterility, Diarrhea, Hemorrhage, Mortality
- Long Term Effects
  – Increased Risk of Cancer
  – 0.07% per rem lifetime exposure (based on LNT curve)
  – Normal cancer risk 30%
- Genetic Effects
  – Never observed in humans, but have been observed in fruit flies.

Sequential Pattern of Biological Effects

- Latent Period
  - The time lag following the initial radiation event and before the first detectable effect occurs.
- Period of Demonstrable Effects on Cells and Tissues
  - Period during or immediately following latent period when certain discrete effects can be observed.
- Recovery Period
  - Following exposure to radiation, recovery can take place to a certain extent.

Cellular Effects



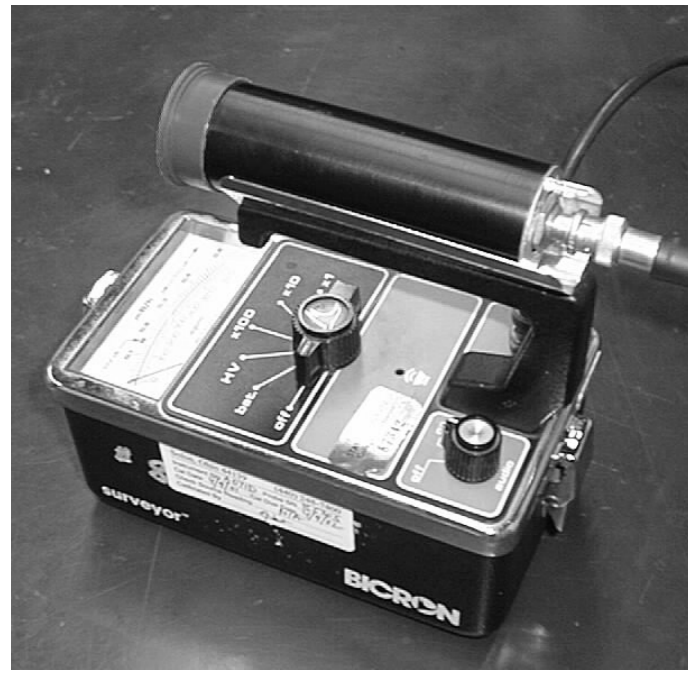
- Ionization within body tissues
- Ionization events cause many derivatives of water to be formed
  - Peroxides
  - Free Radicals
  - Oxides
  - Hydroxides
- These compounds are unstable and are damaging to the chemical balance of the cell.
- Cells often can recover from damage
- Repeated insults may cause damage to be permanent
  - Cell Death
  - Cell Dysfunction: tumors, cancer, cataracts, blood disorders
  - Organ Dysfunction at High Acute Doses

Internal vs. External Dose

- External Dose
  - Radiation source outside of the body
- Internal Dose
  - Radiation source within body

Radiation Detection

- Geiger Counter
  - Survey meter
  - Very Simple to Use
  - Sensitive to X-rays, Gamma Rays, and Betas above 45 keV
  - Reads in mR/hr (milli-rem per hour)



Radiation Detection

- Bonner Sphere
  - Survey meter
  - Sensitive to Neutrons
  - Reads in mR/hr (milli-rem per hour)
  - A little more complicated to use.

Characteristics of Ionizing Radiation

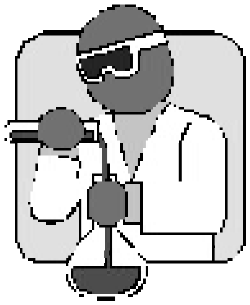
- Beta Particles (+ and –)
  - Moderate penetration (10 feet in air or 1 cm water per MeV)
  - Can produce X-Rays upon interaction with matter (bremsstrahlung)
  - Moderate energy deposition along path of travel
- Alpha Particles
  - Low penetration (few sheets of paper or several inches of air)
  - Stop in dead layer of skin, therefore pose no external hazard.
  - High energy deposition along path of travel
- Gamma and X-Rays
  - High penetration (several hundred feet air or inches of lead)
  - Low energy deposition along path of travel

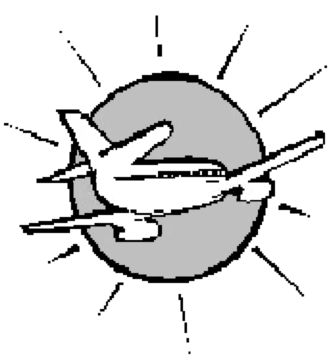
Background Radiation Exposure

- Natural Sources
  - Cosmic (protons and other particles from outer space are incident on Earth’s atmosphere. Interact with atoms in atmosphere and produce secondary particles like muons, electrons, photons, neutrons)
  - Terrestrial (Primarily Potassium, Throium, and Uranium)

Background Radiation Exposure (cont'd)

- Man-made sources
  - Healing Arts (e.g. diagnostic and theraputic X-rays, radiopharmaceuticals)
  - Nuclear Weapons Tests fallout
  - Industrial Activities
  - Research: Particle Accelerators, Neutron generators, Electron microscopes
  - Miscellaneous: Air Travel, Transportation of Radioactive Material





Consumer Products

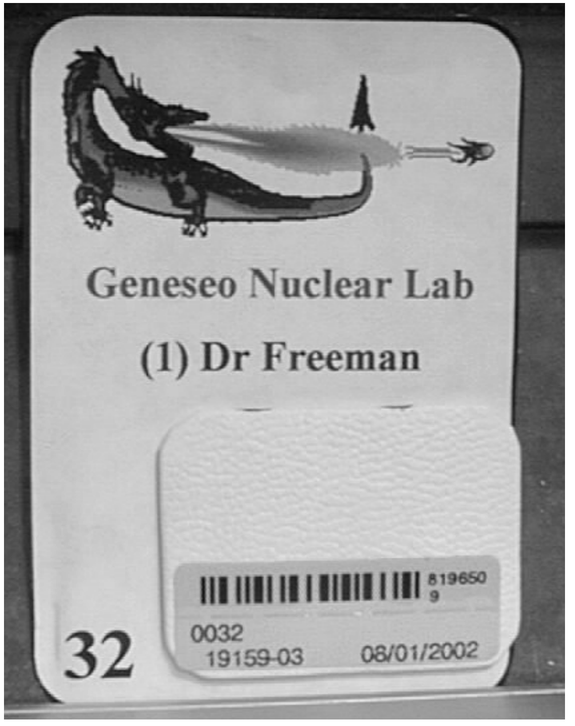
- Building Materials (Potassium-40)
- Tobacco (Po-210)
- Smoke Detectors (Am-241)
- Welding Rods (Th-232)
- Television (X-Rays)

Measuring Radiation Exposure

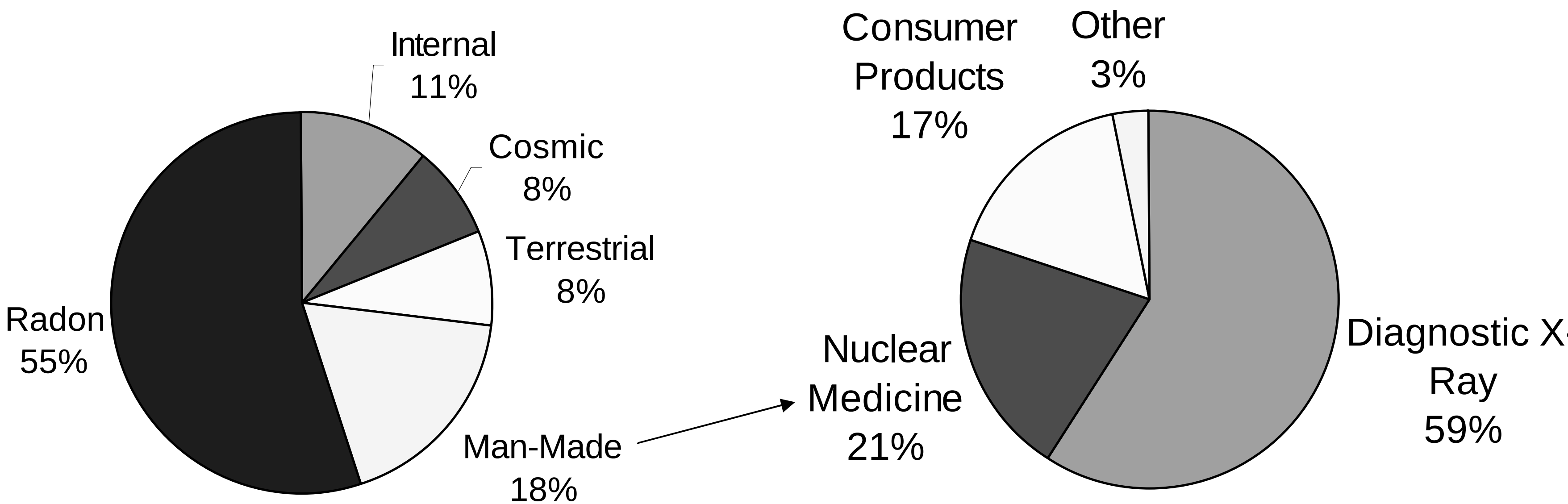
- “rem”: The unit of radiation exposure that characterizes biological damage to humans
- Stands for “Roentgen Equivalent Man”
- Newer unit is called the “Sievert” (Sv)
- Conversion factor: 1 Sv = 100 rem

Personnel Monitoring

- "Radiation badge"
  - Distributed to faculty and authorized student users.
  - Worn on the shirt while using radioactive materials.
  - Measures radiation exposure due to X-Rays and Gamma Rays.
  - We are well below the limit which requires use of personnel monitoring.



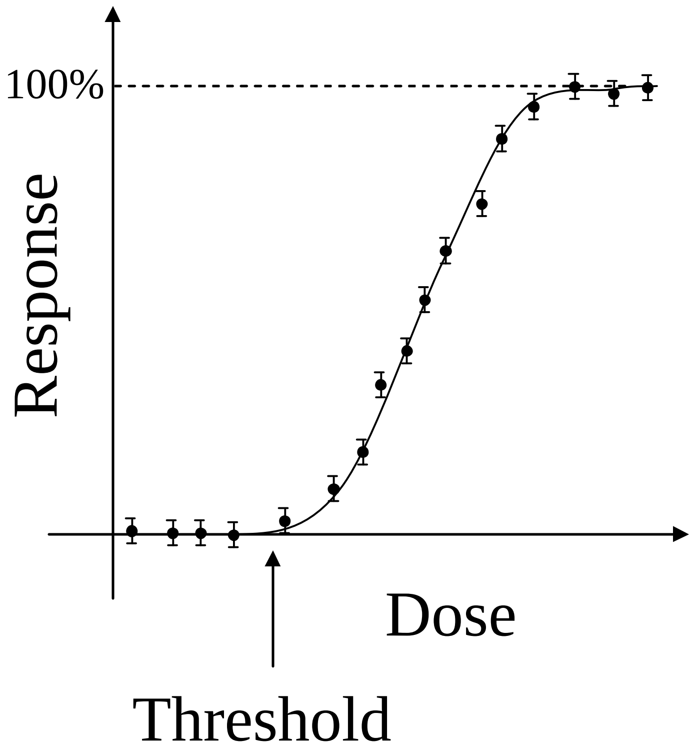
Annual Dose from Background Radiation



Total US Ave. Dose Equivalent = 360 mrem/year

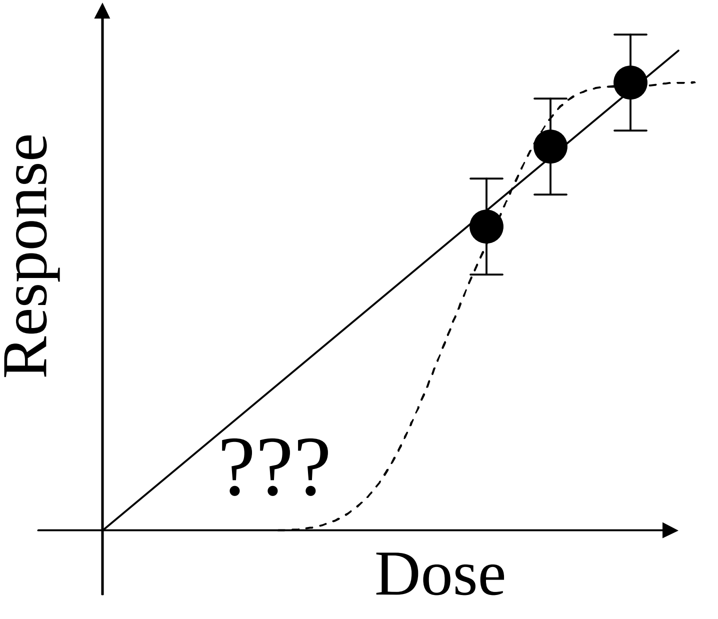
Dose Response Curves: Short Term Effects

- Well-known from animal studies and Hiroshima bomb victims.
- All short term effects show threshold. No biological effect unless dose is above the threshold.



Dose Response Curves: Long Term Effects

- Dose response curves for Long term effects are much more uncertain.
- Little data exist for low-exposure rates
- Possible Dose Response Curves:
  - LNT (Linear No Threshold)
  - Threshold
- To be extra safe, all standards for allowed exposure are based on LNT model, which assumes *all radiation is harmful.*



Assumptions and Conclusions Used to Formulate Current Radiation Standards

- Assumptions
  - All radiation may be harmful
  - Linear Non-Threshold Relationship
  - No repair mechanism exists
- Conclusions
  - Data concerning low dose and low dose rates is inconclusive, therefore not applicable
  - Extrapolation of high dose and high dose rate data to low dose and low dose rate regions using above assumptions is conservative.

Federal Exposure Limits

- Occupational Limits
  - – 5 rem /year = 5000 mrem/yr (deep dose)
  - – 15 rem/year = 15,000 mrem/yr (eye dose)
  - – 50 rem/year = 50,000 mrem/yr (shallow dose)
- Members of General Public
  - – 100 mrem /year
- Declared Pregnant Females (Occupational)
  - – 500 mrem/term (evenly distributed)

Effects of Acute Whole Body Exposure

Absorbed Dose (Rad)	Effect
10,000	Death in Few Hours
1,200	Death within days
600	Death within weeks
450	LD 50/30
100	Probable Recovery
50	No observable effect
25	Blood changes definite
5	First blood change observable

Natural background exposure: 0.360 rem/yr
Max dose received at TMI accident: 0.080 rem
Chest X-Ray: 0.008 rem

Average annual radiation dose by occupation, mrem/yr

Industrial radiographer	490
Airline flight crew member (elevated cosmic radiation)	350
Nuclear power plant worker	310
Worker in Grand Central Station (high background radiation)	120
Medical personnel (X-rays and nuclear medicine procedures)	70
DOE & DOE contractors	45

Putting Risk into Perspective…

The Following are all equivalent risks, corresponding to a 1 in 1,000,000 chance of death

- Smoking 1.4 cigarettes in a lifetime (lung cancer)
- Eating 40 tablespoons of peanut butter (aflatoxin)
- Spending two days in New York City (air pollution)
- Driving 40 miles in a car (accident)
- Flying 2500 miles in a jet (accident)
- Canoeing for 6 minutes (drowning)
- Receiving a dose of 10 mrem of radiation (cancer)

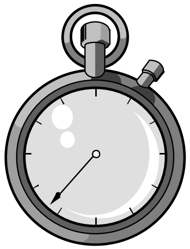
(Adapted from DOE Radiation Worker Training based on work by B.L. Cohen, Sc.D.)

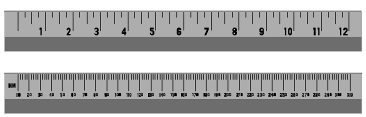
Putting Risk in Perspective…

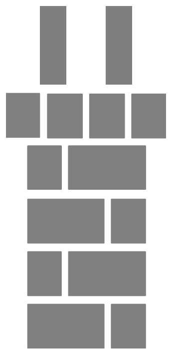
Average Loss of Life Expectancy

Activity	Days of Life Lost
Being an unmarried male	3500
Smoking 1 pack per day of cigarettes	2250
Being an unmarried female	1600
Employed as a coal miner	1100
Being 25% overweight	777
Alcohol abuse	365
Employed as a construction worker	227
Employed in general industry in U.S.	60
Radiation dose of 100 mrem/year for 70 years	10
Drinking coffee	6

Minimizing Exposure to Radiation







- Time
  - The less time spent around radiation reduces your exposure
- Distance
  - Inverse Square Law. Standing twice as far away reduces radiation exposure by a factor of 4.
- Shielding
  - Alpha particles: sheet of paper
  - Beta Particles: Piece of plastic
  - Gamma and X-Rays: Lead
  - Neutrons: Water or Paraffin (Wax)

ALARA

- ALARA:
  - As Low as Reasonably Achievable
- Need to take reasonable measures to limit radiation exposure.

Radiation Safety Program

- Radiation Safety Officer, RSO
  - Education, Training
  - Oversees overall radiation safety program
  - License
  - Inspections and surveys
- Radiation Safety Committee
  - Meets 3x per year
  - Consists of users of all labs which use radiation plus representative from administration
  - Oversees enforcement of proper and safe procedures.
  - Approves users
- State of New York
  - Grants us license for use of radiation. Performs inspections of facilities.

Types of Radiation at SUNY Geneseo

- Radioactive sources
  - Sealed sources
  - Unsealed sources (liquid)
- Radiation producing equipment
  - Van de Graaff Accelerator
  - X-Ray Machine
  - Scanning Electron Microscope
- Neutron howitzer

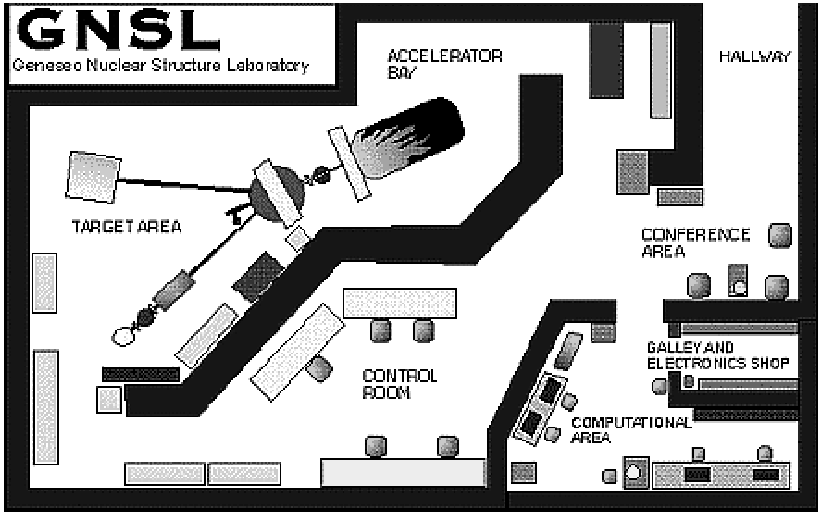
Radioactive Sealed Sources

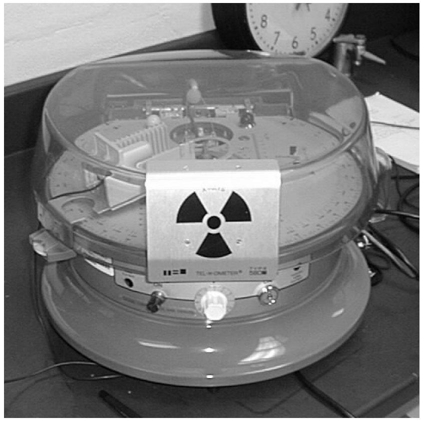
- Sealed Sources
  - Stored in Nuclear Lab, Greene Storage Area, and 2nd floor of Greene
  - Cabinets should be locked at all times
  - Radioactive sources should not be left lying around unattended.
  - Radioactive material encased in plastic or some shielding to prevent contamination.

Handling Radioactive Material

- Remember: Time Distance and Shielding -- ALARA
- Do not eat or drink while using radioisotopes.
- Do not touch active area of plated sources (grab from sides)
- Wash hands immediately after handling isotopes.
- If source appears damaged, do not handle it.
- Report all accidents and mishaps connected with radioisotopes to RSO.
- Do not take radioactive sources out of the laboratory.
- Do not lose radioactive sources. This causes major problems!

Radiation Producing Equipment





- Van de Graaff Accelerator (Greene)
- X-Ray machine (Greene)
- Scanning Electron Microscope (Bailey)
- Transmission Electron Microscope (Bailey)
- No Radiation hazard unless machines are ON.
- External Radiation Hazard only (no internal risk)

Neutron Howitzer

- Highest activity radiation source on campus.
- Located in Greene Storage Area
- Generates Neutrons and gamma rays
- Water acts as a shield for neutrons (cuts neutron dose down by a factor of ~20)
- Water itself not radioactive
- If water leaks, then neutrons from source not shielded and pose greater hazard.

Posting Requirements

- Our Radioactive Materials License Requires all rooms using radiation to post information on the door
  - Radiation Sign
  - Contact Sheet (names and phone numbers of people to call in case of an emergency)
  - Notice to Employees

Final Thoughts

- Amount of Radiation used on campus is very small.
- Do not be afraid of radiation, but treat it with respect.
- Time, Distance, Shielding -- ALARA!
- Notify me if you ever have questions or concerns.
- Please complete the Rad Safety Quiz online at

http://www.geneseo.edu/~freeman/rso/quiz