Measuring Radiation

Units for Measuring Radiation

- Decay Rate
  - Becquerel: 1 atom decaying per second, one dps, the SI unit for radioactivity.
  - Curie: 3.7×10^{10} dps, originally defined as the activity of 1 g ^{226}Ra.
- Specific Activity
  - Specific activity is the decay rate per unit mass of a specific isotope and measured in units of Ci/g or Bq/g with appropriate modifiers for order of magnitude.

Measuring Radiation

Millicurie and Microcurie are units of activity that describe the rate of radioactive decay as a function of time.

1 curie	Ci	=	2.22×10^{12} dpm
1 millicurie	mCi	=	2.22×10^{9} dpm
1 microcurie	µCi	=	2.22×10^{6} dpm

dpm = disintegration per minute

Measuring Radiation

- Half life
  - Time required for one-half of the radioactive atoms in a sample to decay or disintegrate.
  - Half-life can be measured in seconds, hours, days and years.
  - It is used to tell how long radioactive material must be stored before it can be discarded as normal waste.
    - Disposal cannot occur until 10 times the half-life has passed.

Measuring Radiation

- Common Half Lives
  - Tritium (^{3}H) – 12.3 years
  - Carbon (^{14}C) – 5,730 years
  - Phosphorous (^{32}P) – 14.3 days
  - Phosphorous (^{33}P) – 25.4 days
  - Sulfur (^{35}S) – 87.4 days
  - Iodine (^{125}I) – 60.14 days
  - Uranium (^{238}U) - 4.47E9 years

Measuring Radiation

- Decay Law
  - Rate at which quantity of radioactive material decays directly proportional to number of radioactive atoms present.
    - Expressed by the equation – $dN/dt = \lambda N$ (Equation 1)
    - dN/dt = the disintegration rate of radioactive atoms.
    - λ = decay constant
    - N is number of radioactive atoms present at time t
  - Further integration of this equation yields:
    - $N = N_0 e^{-\lambda t}$ (Equation 2)
    - Where N_0e is the initial number of radioactive atoms present and e is the base of the natural logarithms

Measuring Radiation

- Decay Law
  - Since activity (A) is proportional to N, the equations is expressed as
    - $A = A_0 e^{-\lambda t}$
  - T can be mathmatically shown the half life ($T_{1/2}$) of a particular radionuclide is related to the decay constant λ as follows
    - $\lambda = 0.693/T_{1/2}$
  - Therefore substituting this value into equation 3 gets

$$A = A_0 e^{-(0.693/T1/2)t}$$

Measuring Radiation

Radioactive Decay Equation

Use this equation to determine the activity of radioactive material at any given time.

$$A(t) = [A_0]\,[e^{(-\lambda t/T)}]$$

$A(t)$	= number of radioactive atoms at a given time
A_0	= number of radioactive atoms at time zero (originally)
e	= base of natural log
λ	= a constant (0.693)
t	= number of days of decay
T	= half-life (in days) of the radioactive material of interest

Half-life Problems

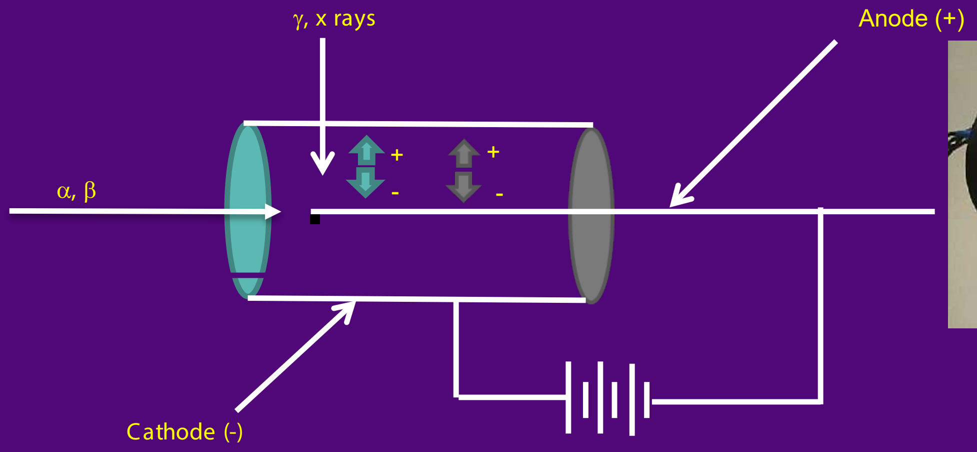
- Practice Problem
  - What is the half-life of a 100.0 g sample of nitrogen-16 that decays to 12.5 grams in 21.6 seconds?
  - 100/12.5=3
  - 21.6 x 3 = 64.8 seconds

Half-life Problems

- Practice Problem:
  - A researcher obtains 250 mCi of Phosphorous-32 ($T_{1/2}$ = 14.3 days). What is the activity in 60 days.
    - A_0 = 250 mCi
    - $\lambda = 0.693/14.3$ days $= 0.048 d^{-1}$
    - $A = A_0 e^{-\lambda t}$
    - $250e^{-(0.048)(60)} = 14.03$ mCi

Measuring Radiation

- Gas filled – Ion pairs formed by radiation collected by charged electrodes.



Measuring Radiation

- Gas filled
  - 3 types –
    - Ionization detects γ rays
    - Proportional detects α and β particles
    - Geiger-Mueller detects γ rays and β particles
  - Geiger-Mueller most widely used
    - Versatile
    - Dependable
    - Particularly sensitive to medium to high energy beta particles
    - Detect relative large sources of medium to high energy gamma or x-rays
    - Not very good at detecting low energy betas

Measuring Radiation

- Check a survey meter before using it to make sure it is appropriate to use.
  - Check the battery.
  - Check the calibration date.
    - State regulations require instruments that are used for measuring exposure rate and contamination to be calibrated every 12 months.
  - Check the capability of the meter using a radioactive source to ensure that the meter is working properly.

Measuring Radiation

- Scintillation detectors
  - Electron de-excitation produces light
  - Collected and turned into electrical current
  - 2 types
    - Solid scintillation detector
      - Common well counter employs 2″ x 2″ crystal of sodium Iodide within lead shielded wall.
      - Sample vial lowered into hollowed chamber for counting
      - Thin crystal NaI detectors useful for detecting emissions of I-125.

Measuring Radiation

- Scintillation detectors
  - 2 types
    - Liquid Scintillation Counter
      - Detects presence of low energy β and α particles
        - Sample and phosphor combined in solvent within the counting vial
        - Vial lowered into well between 2 photomultiplier tubes to be counted
        - Essential tool for counting H-3 and C-14.

Measuring Radiation

- Scintillation detectors
  - Sample mixed with an organic liquid (cocktail)
  - Produces light (scintillates) when exposed to radiation.
  - Advantages of LSC:
    - Good for low energy β emitters that are difficult to count by other methods
    - Very efficient ~100%
    - Count more than 1 nuclide at a time
    - Good for liquid samples.

Measuring Radiation

- Scintillation Detectors
  - Disadvantages of LSC:
    - Relatively high background (4-20 cpm)
    - Liquid samples required and some samples are difficult to liquefy.
    - Counting volume is small.
    - Not as efficient as surface barrier detectors for alpha emitters.
    - Mixed waste disposal problems

Measuring Radiation

- Counting Efficiencies
  - Active radiation detection system never see 100 % of disintegrations in radioactive sample
  - Due to factors in counting system and radionuclides in sample
    - Ratio of count rate (cpm) to disintegration rate (dpm) expressed as percent is the efficiency of counting system.
      - Cpm/dpm x 100% = efficiency
      - Efficiencies of counting system from various nuclides determined through calibration of system with standards of these same radionuclides

Measuring Radiation

- Counting Efficiencies
  - Due to every counting system registers certain number of counts from environmental radiation and electronic noise in the counter, the more correct formula is:
    - ^{cpm}sample – ^{cpm}background/^{dpm}sample x 100% = efficiency

Measuring Radiation

- Efficiency Problem:
  - A sample of 14C labeled compound is counted in a liquid scintillation counter. The sample count rate is 1500 cpm and the background is 35 cpm. If the counter is 80% efficient for 14C, what is the activity of the sample:
  - = (1500-35/0.80) dpm = 1831 dpm
  - =1831 dpm/2.22 x 10^{6} dpm = 8.2 x 10^{-4} μCi

Measuring Radiation

- Semiconductors/solid state
  - Electrons trapped in impurities and collected; analogous to gas filled detectors
    - Germanium for detecting γ rays
    - Silicon diode for detecting α and β particles.

Measuring Radiation

- Performing a meter survey
  - Areas that should be frequently surveyed include:
    - Waste storage areas
    - Source vial storage areas
    - Frequently used areas and equipment
    - Floor beneath work and storage areas
      - Perform surveys after using radioactive material or before leaving an area that is posted for radioactive usage.
    - Recommended exposure rates
      - Frequently occupied areas: less than 2 mrems/hour at 30 cm
      - Storage areas: less than 5 mrems/hour at 30 cm

Measuring Radiation

- Performing a Meter Survey
  - Pass the probe over the area to be surveyed moving the probe at about 2 cm/second.
  - Try to constantly maintain a distance of 1cm from the object or area.
  - Take care not to contaminate the probe while surveying.

Measuring Radiation

- Wipe Test
  - Wipe tests are used to test removable contamination from any radioactive material.
  - Best survey method for detecting low-energy beta emitters. Only way to detect contamination from H-3.
  - To compete a wipe survey:

1. 1. Cut filter paper or paper towels into 1.5″ x 1.5″ strips.
2. 2. Wearing disposable gloves, rub the paper over the
3. test area.

Measuring Radiation

❑ Wipe Test & Action Levels

- For most accurate results, a liquid scintillation detector should be used.
- The contamination level is equal to the difference of the count rate of the actual wipe and the control sample.
- You need to decontaminate if:
  - Radioiodine levels are greater than 200 dpm/100 cm^2.
  - Other radionuclide levels are greater than 2,000 dpm/100 cm^2.

<u>dpm = disintegrations per minute</u>

To convert measurements to " dpm" divide the liquid scintillation counter or gamma counter results (given in " cpm") by the counter's efficiency (refer to instrument's manual).

Measuring Radiation

- Survey Records
  - Be sure to document contamination and exposure rate surveys so that you can prove the survey was done.
  - Keep survey records in an easily accessible form for the Radiation Safety Officer or IDPH to examine.
    - UNI Environmental Health and Safety provides blank survey forms. Call 273-3445.

Biological Effects

- Stochastic effects
  - Effect that occurs long after radiation exposure (cancer is a stochastic effect)
- Nonstochastic effect
  - Dose dependent, have a threshold and are similar for everyone. Examples include erythema, redness of the skin.

Biological Effects

- Somatic Effects
  - Physical effects
  - May be immediate or delayed
- Genetic Effects
  - Birth defects due to irradiation to reproductive cells before conception
- Teratogenic Effects
  - Cancer or congenital malformation due to radiation exposure to fetus in utero

Biological Effects

- **Dose terms**
  - Absorbed dose
    - Energy imparted by ionizing radiation per unit mass of irradiated material. Rad or Gray
  - Dose equivalent
    - Product of absorbed dose and quality factor (QF, radiation weighting factor) which compensates for 'effectiveness" of different types of radiation in producing biological damage. SI unit is Sievert (SV). More common units are Rem or Roentgen effective man. Smaller dose = mrem.
  - Committed dose
    - Dose equivalent to given organs or tissues of reference received from intake of radioactive material over 50 year period following intake.

Biological Effects

Weighting Factors (Q, RBE)

LET in water (eV/nm)	Weighting factor w_R	Type and energy of radiation
0.2 - 35	1	photons (X-rays and γ's)
0.2 – 1.1	1	all electrons > 5 keV
20	5	slow neutrons < 10 keV
50	20	intermediate n's 0.1 - 2 MeV
	10	fast n's 2 - 20 MeV
	5	protons > 2 MeV
130	20	α-particles ~5 MeV, high energy ions

Effects of Acute, Whole-Body Gamma Radiation

Absorbed Dose	Probability of Survival
100 rad	Virtually certain
100 - 200 rad	Probable
200 - 450 rad	Probable
500 - 600 rad	Almost impossible
900 - 1200 rad	Possible in some cases with bone marrow transplant

Note: As a comparison, the estimated average annual whole body dose from all sources to the population is about 0.2 rad per year.

University of Northern Iowa

Limits for Occupational External Exposures to Ionizing Radiation

Investigation Levels (mrems per month)

	Level 1	Level 2
Whole body; head and trunk; active blood forming organs; gonads	200	400
Skin of whole body, extremities	2000	4000
Lens of eye	600	1200

Biological Effects

- **Minors**
  - Radiation dose limits for radiation workers under the age of 18 are 10 % of those listed above for adult workers.
- **Pregnancy**
  - The human embryo and fetus are particularly susceptible to damage from ionizing radiation. The National Council on Radiation Protection and Measurement (NCRP) recommends that the whole body dose received by a female worker during the 9 months of her pregnancy not exceed 500 mrem (one-tenth of the normal occupational dose limit).
  - Member of the Public (MOP)
    - 100 mrem per year or 2 mrem per hour

Biological Effects

- Dose pathways
  - Dose received by exposure depends on exposure mechanism
    - 2 broad pathways
      - Internal
        - More hazardous due to being deposited into various internal organs resulting in chronic rather than acute doses
          - Modes of Intake
            - Inhalation, Ingestion, Skin Absorption (Most significant for H-3), Wound penetration, Injection
        - Doses can be received from alpha and beta particles which would not otherwise be harmful.

Methods for Reducing Exposure

- ALARA
  - ‘As low as reasonably achievable’ exposure
- **How is this done?**
  - Time
  - Distance
  - Shielding

Methods for Reducing Exposure

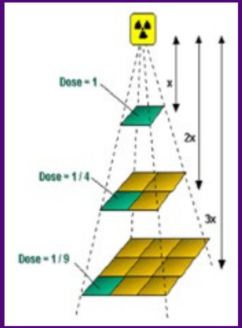
- Time
  - The less time you spend around radioactive material the less you are exposed
    - Methods
      - Do dry runs of the experiment
      - Use radioactive material only when necessary
      - Shorten time when near radioactive material
      - Ensure you do not hurry with the experiment just to prevent exposure which may lead to mistakes.

Methods for Reducing Exposure

- Distance
  - The further away from the source the less radiation you are exposed to.
  - Use forceps, tongs, and trays to increase the distance.

Methods for Reducing Exposure

- Inverse square law
  - Intensity of radiation follows Newton's Inverse Square Law
    - Doubling the distance from the source, you decrease the intensity by a factor of four
    - Tripling the distance from the source you decrease the intensity by a factor of 9.

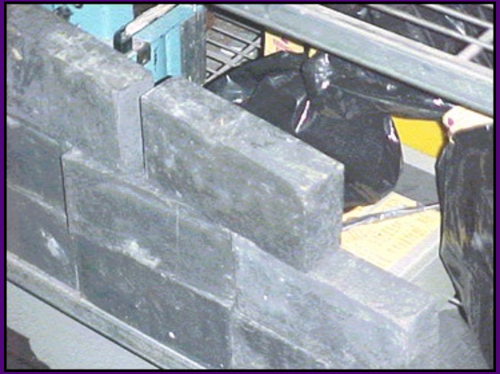


Methods for Reducing Exposure

- Shielding
  - Materials that absorb radiation
    - Low energy Beta Particles
      - Easily shielded by thin layers of rubber or aluminum or plastic

Methods for Reducing Exposure

- Shielding
  - Materials that absorb radiation
    - Gamma Rays
      - Thick, dense shielding such as lead bricks



Methods for Reducing Exposure

- Personal care
  - Do not work with unsealed radioactive material with open cuts, sores, or areas of exposed skin (even if bandaged).
  - Thoroughly wash hands before leaving laboratory
- Practice
  - Always practice procedures involving the use of radioactive materials prior to using the material

Methods for Reducing Exposure

- Safety Data Sheets (P32 as an example)
  - https://www.unmc.edu/ehs/radiation-safety/appendix3_p-32.pdf
  - https://resources.perkinelmer.com/corporate/content/msdsdatabase/sds_nex019000mc_us_en.pdf

Methods for Reducing Exposure

Always wear the proper PPE required when working with radiation and other hazardous materials.

- Proper PPE includes:
  - Safety glasses with side shields at all times while in the lab
  - Chemical splash goggles if liquids might splash or create aerosols
    - Especially important if wearing contact lenses to prevent material from getting under the lenses
  - Chemically resistant gloves recommended by the manufacturer for the material being used (usually double gloved) - do not use latex

Methods for Reducing Exposure (Continued)

- Proper PPE includes:
  - Lab coat
  - Face shields when handling highly corrosive liquids, a potential for explosion exists, or splashes of human blood or other potentially infectious materials are possible
  - Eye protection should be worn under a face shield
  - Remote pipetting devices
  - Respirator use is generally not necessary in university labs and is regulated.

Methods for Reducing Exposures

- Fume Hoods
  - Are vented enclosures intended to protect users from inhaling chemical vapors and dust.
  - Activities that may result in radioactive aerosols or volatile compounds should always be performed in fume hood.
  - Make sure that the fume hood allows sufficient air flow.
  - The sash on the fume hood should be lower than your chin to ensure an adequate breathing zone is provided.

Methods for Reducing Exposure

- Fume Hoods
  - Close sash when unattended.
  - Operations should be kept at least 6” from the front edge of the hood.
  - Minimize the amount of equipment in the hood.
  - Separate and elevate items in the hood using blocks or racks.
  - Using the hood as a storage area will decrease its efficiency.
  - Construction of seamless stainless steel

Methods for Reducing Exposure

- Bio-safety cabinets
  - Are used to provide a clean work environment and protection for users working with biological hazards.
  - Should be vented to outside air when working with volatile radioactive material.
  - Air is recirculated throughout the work area by a HEPA filter.
    - The filter removes only airborne particles, not chemical fumes.
  - Bio-safety cabinets should be used to prevent the transmission of airborne pathogens.

Methods for Reducing Exposure

Equipment Maintenance

- Areas where radioactive material was used or stored, must be surveyed prior to renovation or maintenance activities.
- All equipment in need of service must be surveyed to ensure it is free of contamination before service is performed.

Methods for Reducing Exposure

Personal Radiation Monitors

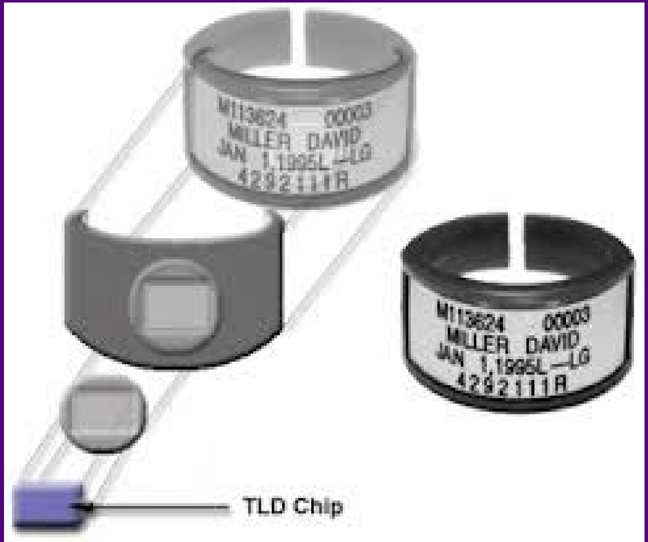
- Dosimetry
  - Science of determining the dose received by personnel from exposure to ionizing radiation
- Dose or Dose Equivalent
  - Exposure control, compliance, safety
- State & Federal Laws
  - Require individuals likely to receive dose greater than 10 % of the limits to be monitored

- Many types
  - Film badge
    - Small piece of radiation-sensitive film place in special holder containing various filters
    - Periodically badge replaced and sent to vendor for analysis
    - Worn on lapel
  - TLD or Thermoluminescence Dosimeters (film and phosphors)
    - Small chips of material (LiF or CaF2) when heated after exposure to penetrating radiation gives off light in proportion to dose received

Methods for Reducing Exposure

FILM BADGE DOSIMETER

TLD BADGE



Methods for Reducing Exposure

Wash your hands prior to leaving the lab!

Methods for Reducing Exposure

Laboratory Rules

1. Eating, and drinking are not permitted in radionuclide laboratories. (Smoking not allowed on campus)
   - Cosmetics will not be applied in laboratory.
2. Food and food containers are not permitted in the laboratory.
   - Do not use refrigerators for common storage of food and radioactive materials. Do not heat food or beverages in microwaves used to conduct research.
   - Food used only for research purposes and labeled"not for human consumption" is permitted.

Methods for Reducing Exposure

Laboratory Rules

3. Radionuclide work areas shall be clearly designated and should be isolated from the rest of the laboratory. The work area shall be within a hood if the radioactive material to be used is in a highly volatile form.
4. All work surfaces shall be covered with absorbent paper which should be changed regularly to prevent the buildup of contamination.
5. Work involving relatively large volumes or activities of liquid radioactive material should be performed in a spill tray lined with absorbent paper.

Methods for Reducing Exposure

Laboratory Rules

6. Protective clothing shall be worn when working with radioactive materials. This includes laboratory coats, gloves (double nitrile recommended), and safety glasses.
   - Sandals, bare feet and SHORTS are not permitted in laboratories.
7. Dosimeters shall be worn when working with relatively large quantities of radionuclides which emit penetrating radiation. (Not currently needed at UNI due to low activity of isotopes)
8. Mouth pipetting shall not be permitted in radionuclide laboratories (Use remote pipettors).

Methods for Reducing Exposure

Laboratory Rules

9. All containers of radioactive materials and items suspected or known to be contaminated shall be properly labeled with tape or tagged with the radiation logo and the word “RADIOACTIVE”.
10. All contaminated waste items shall be placed in a container specifically designed for radioactive waste. Sharp items such as needles or razor blades shall be placed in a cardboard box, plastic bottle, or sharps container.

Methods for Reducing Exposure

Laboratory Rules

11. A radiation survey shall be performed by the radionuclide user at the end of each procedure involving radioactive materials. (Survey form must be completed and a copy to be given to RSO during 6 month inventories.) All items found to be contaminated shall be placed either in the radioactive waste container or an appropriately designated area. Any surfaces found to be contaminated shall be labeled and decontaminated as soon as possible. The RSO shall be notified immediately if extensive contamination is found within the laboratory.
12. A record of the types and quantities of radionuclides possessed by each principal investigator at a given time shall be maintained.