Radiation Sampling & Measurement

- Additional reading, Cember Ch 13, Evaluation of Protective Measures
- Electronic CFRs

Radiation & Contamination Surveys

- Systematic set of measurements made to determine
  - Type of radiation source
  - Dose rate
  - Surface contamination
  - Atmospheric contamination

Choosing Survey Instruments

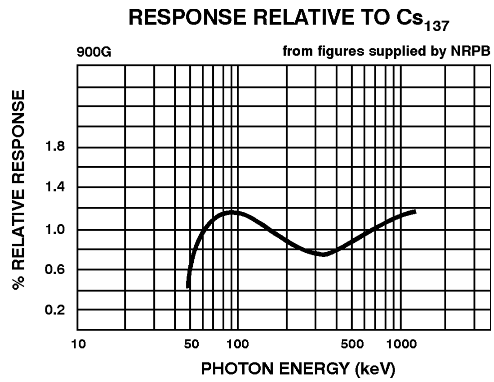
- Must respond to radiation
  - Radiation must penetrate to active region
  - Gas-filled: window "thin enough"
  - Photons - crystal thickness depends on energy
- Sufficiently sensitive
  - Too low: will not detect material
  - Too high: instrument overwhelmed

Response Time

- Time to attain 63% final reading
- RC gives time constant
  - Low value means responds more quickly
    - Less sensitive
  - High value means responds more slowly
    - More sensitive

Energy Dependence

- Instrument may under or over respond to radiation depending on the energy



Energy Dependence Example

- GM tubes have good energy response to X- & Gamma rays
  - Increased response in the 40 KEV to 100 KEV range
  - Due to the Compton effect
  - Electrons knocked from gas as well as metal wall of tube.
  - Smaller tubes have more pronounced response to low energy photons.
- Tin selectively absorbs low energy photons.
- Shielding tube with tin flattens response in 50 KEV to 1.5 MEV by +-15%.

Example, continued

- For photons <50 KEV
  - Tin absorbs even more
  - response drops rapidly as energy drops <50 KEV.
- Windows in Tin shield allows detection of
  - 30 KEV to 50 KEV photons and
  - Greater than 50 KEV photons.

Sensitivity

- Size is another variable with GM tubes
- The smaller the size, the less sensitive and therefore the better for measuring very high radiation levels.

Felületi szennyezettség

- Felület szkennelése érzékeny detektorral
- Egy másik detektorral a felületi dózisintenzitást mérjük
- Fennáll a veszélye a személyzet elszennyeződésének(belégzés/lenyelés)
- A mennyiséget dörzsmintával határozzuk meg.

Dörzsminta

- Hasznos, ^{14}C, ^{35}S, ^{90}Sr esetében
- Olyan nuklidok meghatározására is alkalmas, melyeket hordozható szennyezettségmérővel nehéz kimutatni
- Általában 100 cm^2 felületről veszik le
  - Szállítás esetén 300 cm^2 felület célszerű

Leak Testing

- Current NRC regulations require leak tests of sealed sources every 6 months
  - Some sources exempted by manufacturer
  - Source is wiped using filter paper or cotton swab
  - Was important for radium seeds in past
    - Due to buildup of radon gas
    - Today, less than 280 leaking sources reported per year
    - Over 25,000 gauge sources alone

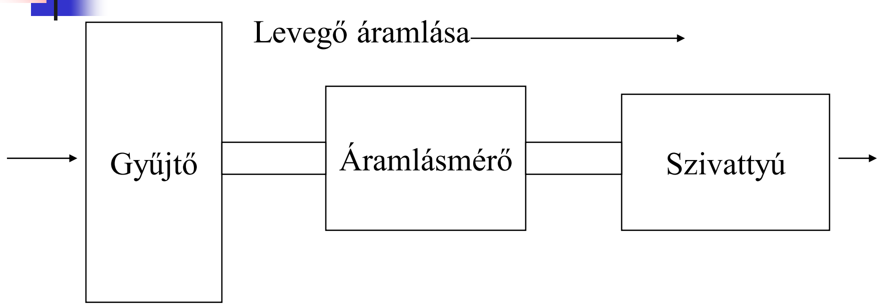
Levegő mintavétel

- Nincs 100%-os hatékonyságú módszer
  - Bizonyos mennyiségű radioaktivitás kikerülhet a levegőbe
  - A belélegzés a leggyakoribb bejutás a szervezetbe
  - Napi felvételek
    - Táplálék = 1.9 kg
    - Víz = 2.2 kg
    - Levegő = 26 kg
- A tüdő érintkezési felülete
  - 50 - 100 m^2
- A levegőben lévő koncentráció és a szemcseméret fontos!

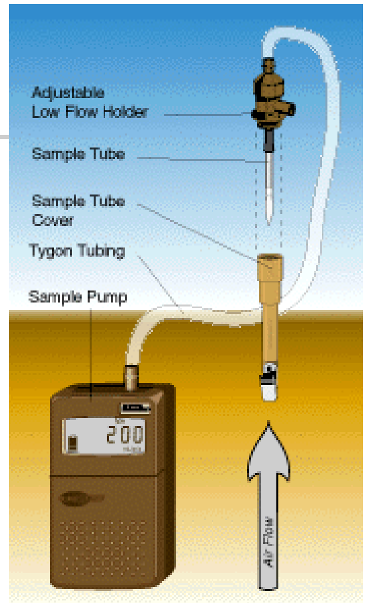
Levegő mintavétel

- 3 fő komponensből áll:
- Szívó egység
  - Vákuum szivattyú
- Gyűjtőegység
  - Gyűjti a légszennyező anyagokat
  - A szennyező kémiai formájának megfelelő
- A levegőminta térfogatát mérő egység

Levegő mintavétel



Példa (személyi)



Vákuum szivattyúk

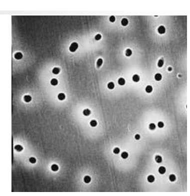
- Pozitív kiszorításúak
  - Forgólapátos, mozgó dugattyús, rezgő membrános
  - Kis térfogatok gyűjtésére alkalmas
  - A levegőt egy adott térfogaton szívják át
  - Nagy ellenállás mellett is állandó térfogatárammal szív
  - Nagyon poros levegőhöz is alkalmazható
- Centrifugálszivattyúk
  - Nagy térfogat gyűjtésére alkalmas
  - Növekvő ellenállással csökken a térfogatáram

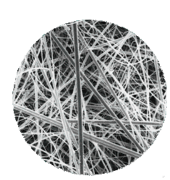
Szivattyúk

- Nagy térfogatáram, forgó
- Személyi

Gyűjtőegység

- Szűrő
  - Membrán (felület)
  - Mélységi (üvegszál)
- Adszorbens
- Absorbens





Szemcsegyűjtés

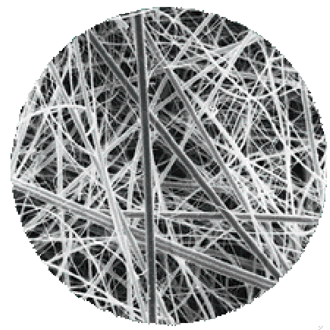
- A típusa a gyűjteni kívánt szemcse típusától függ
  - Papír, üvegszál és membránzita
- Szita vagy mélységi szűrők
  - A pórusméretnél nagyobb szemcséket gyűjtik
  - A szűrő szálai közt visszatartott szemcséket gyűjti
- Ütköztetéses gyűjtő
  - Pórusméretnél kisebb szemcséket is gyűjti

Mélységi szűrők

- Random szálak hálója
- Szerves gyantakötés rögzíti
- A szemcsék a szálak hálójában elekadnak
  - Whatman 40
- Üvegyszűrő AE típus
  - Nagy áramlási sebesség 4-5 l/min/cm^2 at 0,69 bar nyomáskülönbség mellett
- Nincs kötőanyag a szálak között
- Alfasugárzó és lágy-bétasugárző izotópok felhalmozódhatnak és önabszorpció léphet fel

Üvegszálas szűrők

- Szennyvizek lebegőanyag tartalmához és légszennyezők súlyszerinti elemzéséhez alkalmazzák,
- Nagy térfogatáram, nedvességálló, nagy szennymegkötő kapacitás



Önabszorpciós korrekció

- C1 = beütésszám a szűrő elülső oldalán
- C2 = beütésszám a szűrő hátsó oldalán
- C3 = beütésszám a szűrő elülső oldalán, amikor egy tiszta szűrővel lefedik

$$\%\ \text{önabszorpció} = \frac{C_2 - C_3}{2C_1 + C_2 - C_3} \times 100$$

Ütközéses gyűjtők

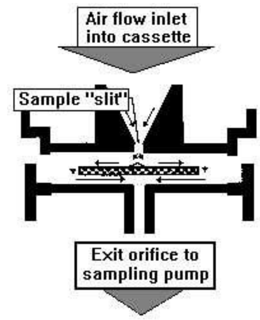
- A szemcsék egyenes irányban repülnek
- A szűrő pórusaiban a légáram elhajlik
- A szemcsék tovább repülnek egyenes irányban és ütközve megkötődnek
- Növekvő sebességgel nő a gyűjtés hatásfoka

Ütközéses gyűjtők

- Üvegszálak és papírszűrőwithin megy mátrixban
- Memebránszűrő egységek szűrőfelületen
- Alfa-sugárzók esetén önabszorpciós korrekció szükséges
  - Az alfa-részecskék jobban elnyelődnek a szálakban, mint a detektorokban

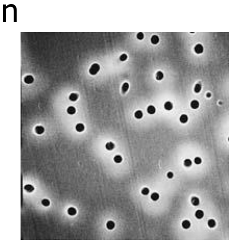
Ütközéses mintavevők

- Particles in the airstream accelerate through the tapered slit (see diagram at right).
- Below the slit is a slide coated with a sticky sampling medium.
- The airflow is aimed directly at the sampling medium and then forced to make a sharp 90 degree turn at the surface of the slide.
- The velocity, combined with the mass of the particles in the airstream, causes the particles to impact and adhere to the sampling medium instead of following the airstream to the exit at the back of the cassette



Polycarbonate Membrane Filters

- Smooth glass-like surface with cylindrical pores for maximum particulate capture
- Precise pore sizes and pore distribution for absolute filtration and separation
- Very low extractables
- Biologically inert.
- Excellent chemical resistance and thermal stability.
- Captured samples distributed in one plane.
- Low tare weights, non-hygroscopic, and low trace element level.



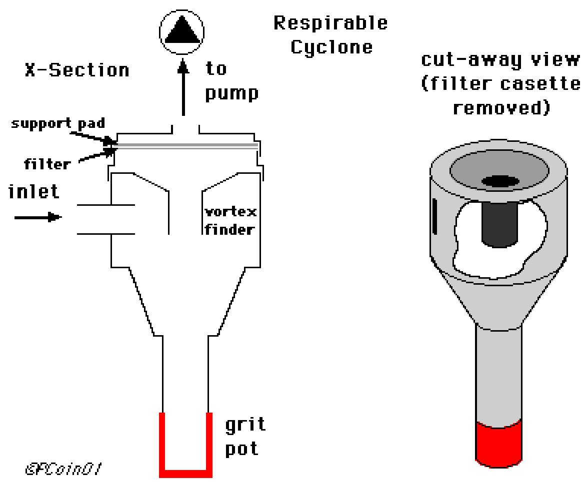
Membrane Filters

- High retention efficiency for respirable particulate for membrane filters
- Membrane filters retain strong electrostatic charge
  - Windowless counters can distort electric field around anode
  - prevent this by treating filter with dioxane and petroleum ether
- Can be up to 99.9% efficient

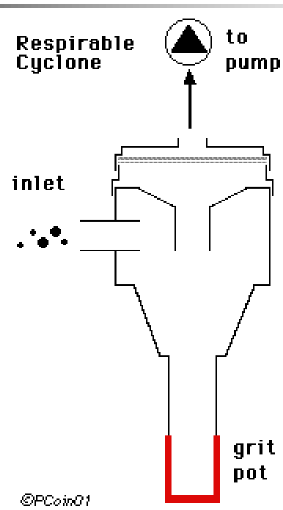
Membrane Filters

- 0.45 to 5 micron pore size
- Thin = 0.1 mm
- Plastic film
  - Millipore is a popular brand
- Mixed cellulose esters (MCE)
  - 0.8 micron pores
  - Godd for 15 lpm per cm2 at 10 psid across filter

Respirable Cyclone Filter



Cyclone Filter Function



Gaseous Collection Devices

- Adsorption
- Absorption
- Grab samples
- Immersion monitoring

Gaseous Collection Devices

- Adsorption
  - Gas binds as mono-layer to surface of adsorbants
    - Silica gel (SiO_2)
    - Activated alumina ($Al_2O_3 \cdot 3H_2O$)
    - Molecular Sieves (synthetic Na or Ca alumino-silicates of high porosity)

Adsorption

- Collection (Binding capacity) depends on
  - Surface area of adsorbent
  - Partial pressure of gas
  - Temperature
  - Called adsorbent isotherm
- Drive off gas by heating or use chemical absorber

Adsorption

- Radon gas sampling
  - Carbon granules packed in a canister
  - Passive 4 to 7 day exposure
  - Container sealed
  - Gamma radiation from radon daughters counted

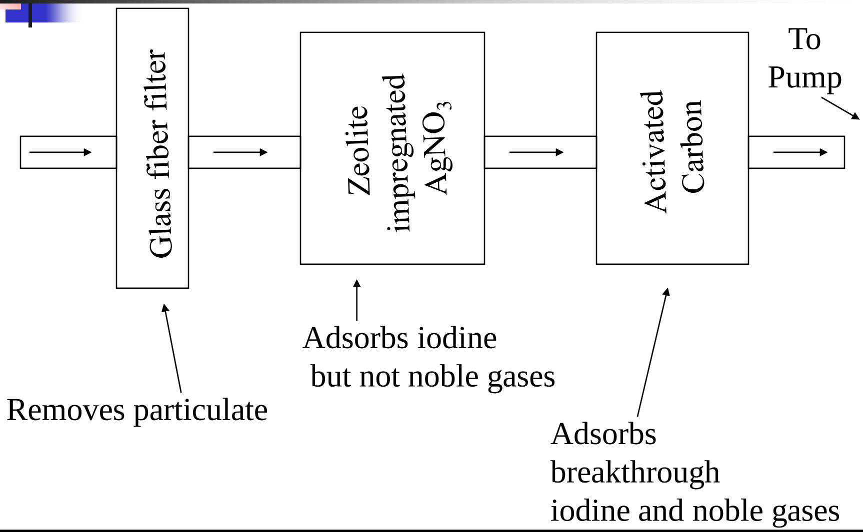
Adsorption

- Radioiodine sampling: Activated Carbon
  - Carbon granules impregnated with TEDA
    - Triethylenediamine
    - Chelating agent
    - Binds iodine to prevent desorption
  - Also binds noble gases, such as ^{133}Xe
  - How to collect iodine without noble gases?

Adsorption of Iodine without Noble Gases

- Instead of activated carbon, use zeolite impregnated with $AgNO_3$
- Captures only elemental and organic iodine but NOT noble gases
- Place activated carbon after zeolite cartridge to collect breakthrough iodine
  - Breakthrough occurs when all adsorption sites are filled
  - Prevents contamination of lines and pumps

Typical Sample Train for Iodine



Collection of Gas Contaminant by Absorption

- Sample is bubbled through a liquid
- Contaminant interacts with liquid
- Bubble tritium through water
  - Aliquot is counted using LSC
  - Atmospheric concentration is calculated from this aliquot
- Bubble $^{14}CO_2$ through solution
  - 0.5 N NaOH
  - $Na_2{}^{14}CO_3$ precipitates

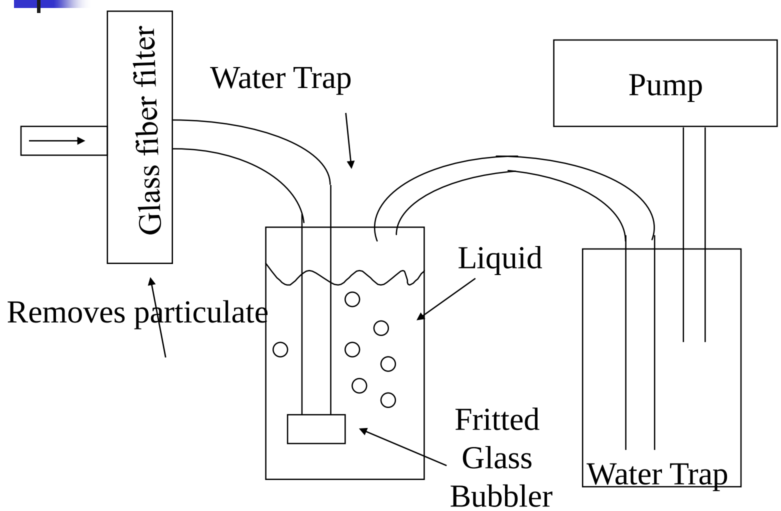
Absorption

- Gases and vapors
- Chemical interaction between contaminant and a liquid solution to trap the contaminant
- Gas must remain in contact with liquid long enough to interact
  - Efficiency based on this
  - Low flow increases efficiency
  - Excess reactant increases efficiency

Absorption

- Interaction occurs between contaminant and surface
- Desorption
  - Heating, extraction
- When fritted glass bubbler used can achieve efficiencies up to 100%

Typical Absorption Setup



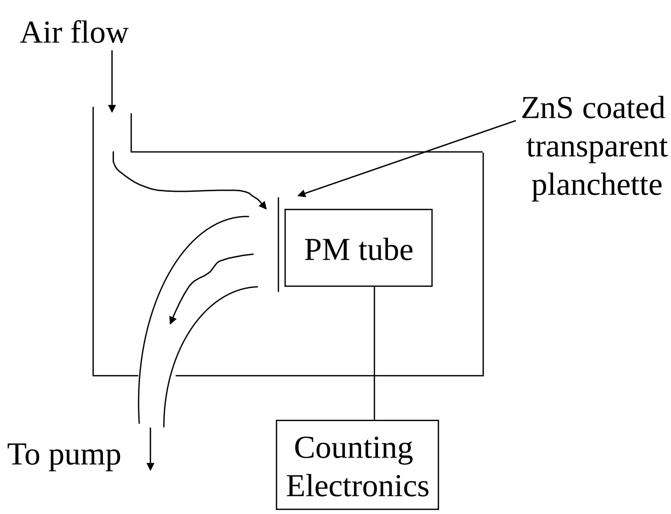
Grab Sample

- Evacuated container opened to atmosphere
  - Tedlar bags
- Transfer container to ionization chamber
- Measure activity directly
- Lucas Cell
  - Evacuated container with flat glass face coated with scintillating medium
    - Normally ZnS (Ag activated)
  - Coupled directly to a photomultiplier tube
  - Useful for radon, other alpha emitters

Annular Impactor

- Radon usually associated with 2 to 3 g/cm^3 particles
- Generally transuranics 10 g/cm^3 or more
- Light particles can make complex turns and more dense particles collect on surface and cause scintillations.
- Usually use for heavy particles, alpha emitters

Annular Impactor



Commercial Impactor

Annular Kinetic Impactor

- Adjustable annular kinetic impactor heads collect
  - alpha
  - beta,&
  - gamma-emitting contaminants,
  - Plutonium,
  - Fission products,
  - Radon decay products, and
  - Size specific dust particles.
- Adjust stopping distance (nozzle to impactor distance) and vary particle velocities allows collection of size specific dust particles.
- Example
  - 30 CFM with a ¼"gap collects particles of 2.5 μm and larger on greased impaction plate.
  - For a particle cut size of 10 μm or larger a flow rate of 5-6 CFM is use.

Immersion Gas Monitoring

- Counter is immersed in chamber
- Contaminated air flows through chamber surrounding counter
- Useful for beta-gamma emitters, except
  - ^{3}H and
  - ^{14}C

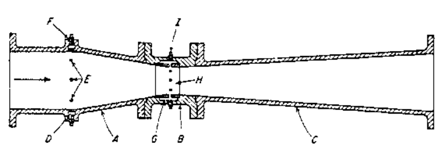
Air Volume Measurement

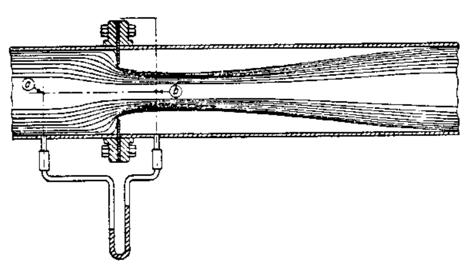
- Spirometer - most basic
- Water displacement
- Bubble
- Dry Gas

Rate Meters

- Rotameter
    - Uses viscosity of air to determine flow from pump
    - Must be calibrated for different gases
- Orifice meter
    - Pressure difference across orifice
    - Critical flow
    - Correct for temp changes
- Positive displacement pumps
    - Use volume of stroke

Ratemeters: Rotary, Venturi, Orifice





Sample Collection Efficiency

- Two identical collectors in series
- Measure activity in first and second solutions (A1, A2)
- If collectors are identical then efficiency is:

$$\varepsilon = 1 - \frac{A_2}{A_1}$$

Aerosol Loss in Sample Lines

- Some settling or plating out of radionuclides may occur in sample lines
- Special materials must be used in some cases to prevent chemical reactions with nuclides
- Depends on
  - Particle terminal settling velocity
  - Velocity of the air in the lines
  - Length of the line
  - Radius of line

Losses in Sample Lines

- Particles settle out on walls
- Radioiodine can react with copper lines
- Particles can impact at bends and be deposited
- When rapid temperature changes occur, liquid may condense and collect particles in sample line
- Electrostatic charges built up on walls may plate out particles

Sample Considerations

- Representative Sampling
- Sample Size
- Particle Sizing
- Short Lived Activity
- Natural Airborne Activity

Representative Sampling

- Samples must represent the air that is under concern
- Airborne contamination can vary significantly in time and location
- Typically have workers wear air sampling apparatus as near as possible to mouth and nose region
- Fixed air samplers typically show little correlation to personal air samplers

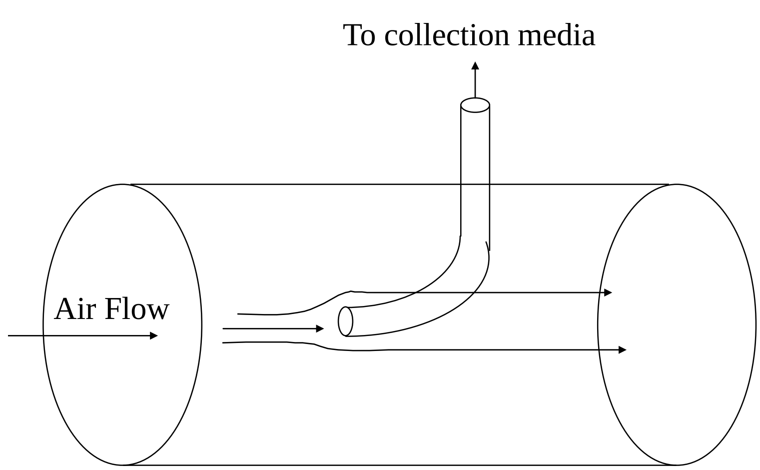
Representative Sampling

- Sampling a duct or chimney is different
- Air may be moving at a high velocity
- Airborne particles follow streamlines of flow
- Isokinetic sampling ensures that the particle sizes collected are identical to the size of the particles within the sample stream

Isokinetic Sampling

- If gas is drawn through sampler slower than the speed of the air
  - Gas must flow around sampler
  - Large particles cannot change direction quickly
  - Larger particles are preferentially collected
  - Overestimate concentration of large particles
- If gas is drawn faster than speed of the air
  - Smaller deposition of particles
  - Larger particles cannot change direction, not as many collected

Isokinetic Sampling



Isokinetic Sampling

- Magnitude of particle size collection error increases as increasing mass size if not isokinetic (anisokinetic)
- Try to stay about 8 pipe diameters from any bends
  - Can affect particle size distribution
- Critical orifice will keep sampling flow rate steady

Sample Size

- Sample must be large enough to represent mean atmospheric concentration
- Sample size is determined by the MDA of the counting system used

Sample Size

- MDA
  - Minimum detectable activity
  - in Bq or μCi
- V = Sample size or volume in liters
- S = sampling rate in L/minute
- t = sampling time in minutes
- C = concentration desired to measure

Sample Size

- For long lived nuclides

$$C = \frac{MDA}{V} = \frac{MDA}{S \times t}$$

Gas Sample Size Example

- How much time should a sampler be run at a rate of 2 liters per minute
  - To detect 10% of DAC for ^{133}Xe
  - DAC = 1×10^{-4} μCi/ml
  - MDA is 2000 Bq.

Gas Sample Size Example

- MDA = 2000 Bq
- S = 2 L/min
- C =

$$1 \times 10^{-5} \frac{\mu\text{Ci}}{\text{mL}} \times \frac{1000\ \text{mL}}{1\ \text{L}} \times \frac{3.7 \times 10^{4}\ \text{Bq}}{1\ \mu\text{Ci}} = 370\ \frac{\text{Bq}}{\text{L}}$$

$$t = \frac{MDA}{C \times S} = \frac{2000\ \text{Bq}}{370\ \frac{\text{Bq}}{\text{L}} \times 2 \frac{\text{L}}{\text{min}}} = 2.7\ \text{min}$$

Gas Sample Size Example

- Sample train for Xe-133 will need the following (in order)
  - Particulate filter
  - Silver zeolite filter to remove iodines
  - Activated carbon to collect ^{133}Xe noble gas
- Alternatively
  - Immersion monitor connected to MCA

Particulate Sample Size Considerations

- Number of airborne particles corresponding to DAC is typically small
- Can lead to problems with air sampling since only a single particle may be the difference between exceeding or meeting a DAC

Example

- What is the activity of a single 1 µm diameter ^{238}U particle?

$$SA = \frac{1620 \text{ yr} \times 226}{4.5 \times 10^{9} \text{ yr} \times 238} = 3.4 \times 10^{-7} \frac{\text{Ci}}{\text{g}}$$

$$19.1 \frac{\text{g}}{\text{cm}^3} \times \frac{1 \times 10^{6} \text{ cm}^3}{1 \text{ m}^3} \times \frac{\frac{4}{3}\pi\left(\frac{1 \times 10^{-6} \text{ m}}{2}\right)^3}{\text{particle}} \times \frac{3.7 \times 10^{-7} \text{ Ci}}{\text{g}}$$

$$= 2.96 \times 10^{-17} \frac{\text{Ci}}{\text{particle}} = 2.96 \times 10^{-11} \frac{\mu\text{Ci}}{\text{particle}}$$

Example, continued

- What is the particle concentration corresponding to the DAC of 6×10^{-10} µCi/ml (assume the DAC is not changed based on size)?

$$\frac{6 \times 10^{-10} \frac{\mu\text{Ci}}{\text{ml}}}{2.96 \times 10^{-11} \frac{\mu\text{Ci}}{\text{particle}}} = 20 \frac{\text{particles}}{\text{ml}}$$

Examples, continued

- What is minimum size, if
  - the # of particles is not considered
  - want to detect 10% of the DAC
  - MDA is 200 Bq
  - collection efficiency is 99%?

$$V = \frac{MDA}{C \times \varepsilon} = \frac{200\ \text{Bq}}{6 \times 10^{-10}\ \frac{\mu\text{Ci}}{\text{ml}} \times \frac{1 \times 10^{6}\ \text{mL}}{\text{m}^{3}} \times 0.1 \times \frac{3.7 \times 10^{4}\ \text{Bq}}{\mu\text{Ci}} \times 0.99}$$

$$V = 91\ \text{m}^{3}$$

Examples, continued

- What is the # of particles to be detected to determine concentration at 10% of the DAC
  - 2 particles per ml at ± 10% at the 95% confidence level.
  - This translates to 2 ± 0.2 particles at the 95% confidence level.
  - 95% confidence level = 0.2 = ±1.96σC

$$\sigma_C = \frac{0.2}{1.96} = 0.1$$

Examples, continued

- Determine the concentration

$$\sigma_C = 0.1 = \sqrt{\frac{C}{V}} = \sqrt{\frac{2}{V}}$$

$$V = 192 \text{ m}^3$$

Particle Size

- Particle diameter of 1 μm used
- Actual particle sizes are measured by their aerodynamic behavior rather than size
- DAC may be adjusted if particle size is larger or smaller than "standard" 1 μm AMAD
- This is default size for NRC, ICRP

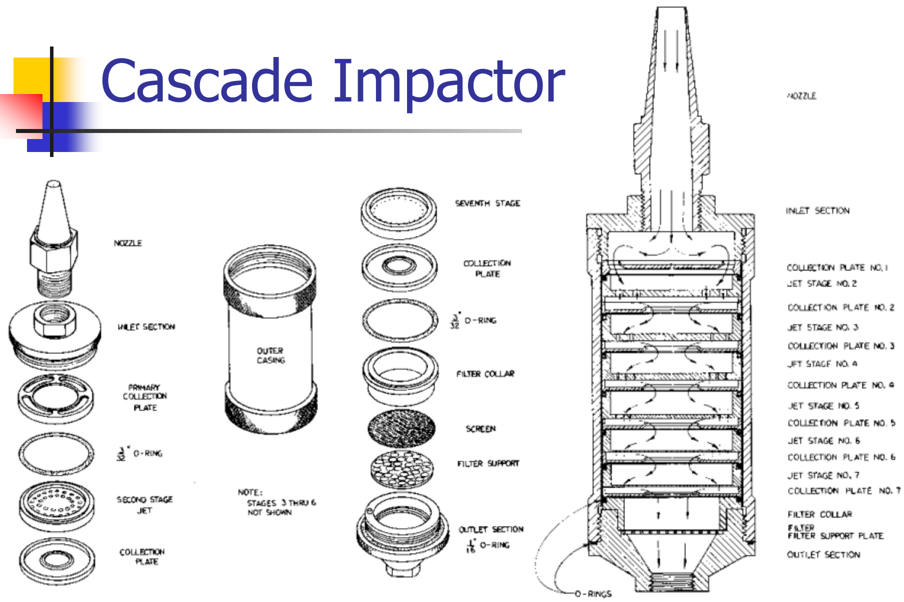
Particle Sizing

- Inhalation and deposition of particles is dependant on the particle size
- Pulmonary deposition pattern changes with particle size
- Determine particle size using cascade impactors
  - Cyclones
  - Measurement

Cascade Impactors

- Works on the principal that particulate matter has some inertia and will tend to travel in a straight line
- Particles which cannot change direction rapidly impact on collection surface

Cascade Impactor



Cascade Impactor – cont'd

Cyclones

- Used to collect only respirable particles
- Not typically used to determine actual size of particles
- Normally used to collect particles smaller than 10 microns
- Used more often when particle size is known or not important

Measurement

- Particles are placed on slides and physically counted
- Use grids on a microscope and a scale to determine size distribution

Cascade Impactor Classification of Particles

- Each stage in a cascade impactor is associated with a certain mass median diameter
  - particle size collected with 50% efficiency by that stage
  - Collected particles may be examined radiometrically
- Total amount of material collected on each cascade impactor stage is measured

Particle Sizing

- Particles that impact at each stage have the same settling velocity
  - May not necessarily be of the same shape, size or density
  - Said to be aerodynamically equivalent
  - Standards based on activity mean aerodynamic diameter
  - Standards also assume unit density particles of 1 g/cm3

Converting MMAD to AMAD

- Relationship between aerodynamically equivalent sizes d_1 and d_2 and densities ρ_1 and ρ_2 is given by equation

$$\frac{d_1}{d_2} = \sqrt{\frac{\rho_2}{\rho_1}}$$

Example

- What is the AMAD of the ^{238}U particle used in the previous example?
- $d_1 = 1\ \mu m$
- $\rho_1 = 19.1\ g/cm^3$
- $\rho_2 = 1\ g/cm^3$
- $d_2 = ?$

AMAD Example

$$d_2 = \frac{d_1}{\sqrt{\frac{\rho_2}{\rho_1}}} = \frac{1\ \mu\text{m}}{\sqrt{\frac{1\frac{\text{g}}{\text{cm}^3}}{19.1\frac{\text{g}}{\text{cm}^3}}}} = 4.3\ \mu\text{m}$$

Statistics Associated with Particle Size Measurement

- Mass Median Diameter
  - Found by cascade impactor
  - Geometric standard deviation can be found graphically on log probability paper
  - The standard deviation may also be calculated
  - log *d* is the overall mean

$$\sigma = \sqrt{\frac{\sum f_i \left(\log \bar{d}_i\right)^2}{N} - \left(\log d\right)^2}$$

CMD (Count Median Diameter)

- Based on the number of particles of a size category
- N = number of particles
- f = fraction of particles in the size category
- $\bar{d}$ = average diameter of particles

$$\mathrm{CMD} = \log^{-1}\left(\frac{\sum f_i \log \bar{d}_i}{N}\right)$$

More measures

- SMD = Size Median Diameter
  - Based on the size of the particles in each category
- MMD = Mass Median Diameter
- $\mathrm{Log(MMD)} = \mathrm{Log(CMD)} + 6.9 \times (\mathrm{Log}(\sigma_{CMD}))^2$
- $\mathrm{Log(SMD)} = \mathrm{Log(CMD)} + 5.757 \times (\mathrm{Log}(\sigma_{CMD}))^2$
- $\mathrm{Log}\ d = \log \mathrm{MMD} - 6.9 \log 2\ \sigma_g$
- Note that when computing confidence intervals that the standard deviation is MULTIPLIED, not added

Example

- If the AMAD is 1 micron, and the standard deviation of the particle size is 1.5 microns, what is the 68% confidence interval?
- $1 \times 1.5 = 1.5$
- $1 \div 1.5 = 0.66$
- So the 68% confidence interval is 1.5 to 0.66 microns

Why Statistics Are Different?

- Recall that particles are log-normally distributed in size
- In order to use "normal" statistics the log must be taken of each prior to performing any operation

Comparison

- Log 1 = 0
- Log 1.5 = 0.176
- Upper limit
  - 0 + 0.176 = 0.176
  - Inverse log 0.176 = 1.5
- Lower limit
  - 0 - 0.176 = -0.176
  - Inverse log -0.176 = 0.66

Example

- If the AMAD is 1 micron, and the standard deviation of the particle size is 1.5 microns, what is the 95% confidence interval?
- Upper limit
- 1 micron × 1.51.96 = 2.21 micron
- 1 micron × 1.5-1.96 = 0.45 micron

Example

- Alternative method
- Log 1 = 0
- Log 1.5 = 0.176
- Upper limit
  - (0 + 0.176) × 1.96 = 0.345
  - Inverse log 0.345 = 2.21
- Lower limit
  - (0 - 0.176) × 1.96 = -0.176
  - Inverse log -0.345 = 0.45

Short Lived Activity Calculations

- Decay occurs during collection time
- Activity on collector will not continuously build up since it decays away as it sits on the filter

Short Lived Activity

- A(t) = activity on the filter at any time
- C = air concentration
  - activity per unit volume (Bq/L)
- Q = flow rate through filter
  - Volume per unit time (L/min)
- t = time of collection
- λ = decay constant of nuclide

Short Lived Activity

$$A(t) = \frac{QC}{\lambda}\left(1 - e^{-\lambda t}\right)$$

$$A(t) = \frac{\frac{\text{L}}{\text{min}} \times \frac{\text{Bq}}{\text{L}}}{\text{min}^{-1}}\left(1 - e^{-\text{min}^{-1} \times \text{min}}\right)$$

Short Lived Activity

- If the sample is collected a long time (5 to 10 times the half life) then

$$A(t) = \frac{QC}{\lambda}$$

$$A(t) = \frac{\frac{\text{L}}{\text{min}} \times \frac{\text{Bq}}{\text{L}}}{\text{min}^{-1}}$$

Decay During Counting

- If decay occurs during collection, it is important during counting as well
- N = number of counts from sample
- N_0 = initial count rate at start of counting time
  - UNITS MUST MATCH
- λ = decay constant for nuclide
  - UNITS
- t = time of count

Decay During Counting

$$\dot{N}_0 = \frac{N\lambda}{1 - e^{-\lambda t}}$$

Example

- ^{41}Ar is sampled at a rate of 2 L/min from an air cooled reactor.
- Sampler is run for 4 hours between filter change outs.
- Sample is taken to the counting lab where
  - it takes 45 minutes to prepare.
  - it is counted for 30 minutes
  - 17,000 counts are obtained
  - counting efficiency of 25%.
- What is the ^{41}Ar concentration in the air?
- Does it meet the effluent limits of 10 CFR 20?

Example

- The sample decays during
  - Collection
  - Sample preparation
  - Counting
- Correct for each one
- Is isokinetic sampling necessary for gases?
  - Particle size distribution changes
  - Representative sample

Example

- What is initial count rate at start of counting?
- N = 17,000 counts
- t = 30 minutes
- λ = 0.693/1.83 hr = 0.693/110 min = 6.3 × 10-3 min^{-1}

Example, continued

$$\dot{N}_0 = \frac{N\lambda}{1 - e^{-\lambda t}}$$

$$\dot{N}_0 = \frac{17{,}000 \text{ counts} \times 6.3 \times 10^{-3} \text{ min}^{-1}}{1 - e^{-6.3\times10^{-3}\text{ min}^{-1} \times\ 30 \text{ min}}}$$

$$\dot{N}_0 = 621 \text{ cpm}$$

Example, continued

- The count rate when the sample was initially placed into the counter was 621 cpm
- Note that if a correction was not applied, a count rate of 567 would have been determined
- Since the counter is 25% efficient, the number of transformations per minute is 4 × 621 = 2484 transformations per minute

Example, continued

- The sample took 45 minutes to prepare, thus 45 minutes of decay took place.
- A = 2484 tpm
- t = 45 minutes
- λ = 0.693/1.83 hr = 0.693/110 min = 6.3×10^{-3} min-1
- $A = A_0 e^{-\lambda t}$
- $2484 = A_0 e^{-0.0063 \times 45}$
- A_0 = 3298 tpm

Example, continued

- The sample also had time to decay during the collection period. The concentration of the activity can be found using 13.27.
- Q = 2 Lpm = 2000 mL/min
- t = 4 hours = 240 min
- λ = 0.693/1.83 hr = 0.693/110 min = 6.3 $\times 10^{-3}$ min^{-1}
- A = 3298 tpm

$$C = \frac{A(t) \times \lambda}{\left(1 - e^{-\lambda t}\right) Q}$$

$$C = \frac{\left(3298 \frac{\text{t}}{\text{m}} \times \frac{\mu\text{Ci}}{2.2 \times 10^{6} \frac{\text{t}}{\text{min}}}\right) \times 0.0063 \frac{1}{\text{min}}}{\left(1 - e^{-0.0063\ \text{min}^{-1} \times 240\ \text{min}}\right) 2000 \frac{\text{mL}}{\text{min}}}$$

Example, continued

- C = 6.05 × 10^{-9} µCi/mL
- 10 CFR 20 effluent limit is 1 × 10^{-8} µCi/mL

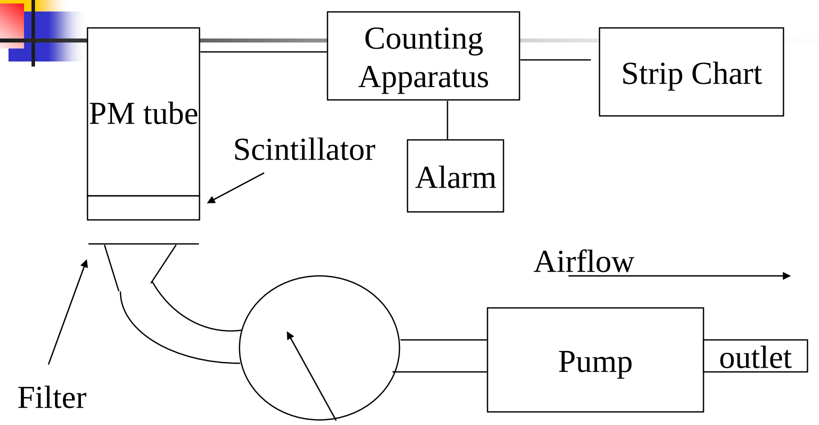
Continuous Monitoring Systems

- Area Monitors
  - Radiation levels monitored
  - Irradiators, reactors
- Liquid Activity
  - Discharges from reactors, other facilities
- Airborne Activity

Continuous Air Monitor (CAM)

- Fixed Filter
  - Filter paper changed on a periodic basis
  - Alarm based on a rate of increase in activity level
    - Steeper increasing rate of slope means higher, more hazardous concentration
- Moving Paper
  - Filter Paper continuously moves
  - Alarm based on a quantity of activity being present

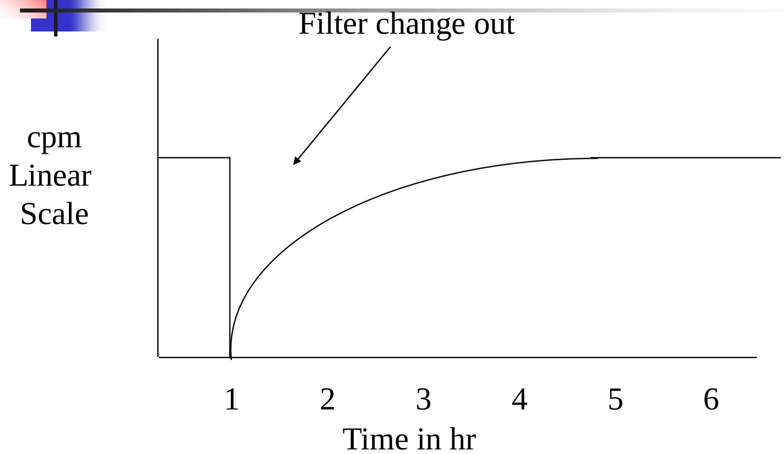
Continuous Air Monitor



Fixed Filter Behavior

- New filter installed
  - All activity is due to cosmic and background
- Radiation levels gradually build from radon and thoron collecting on filter
  - Equilibrium reached after about 4 hours
  - Count rate levels off
  - May be some gradual changes over time as radon concentrations in air change

Fixed Filter Change Out



Fixed Filter Behavior

- Sudden rise indicates release of contaminant
  - Rate of rise in cpm indicates severity of release if it is a long lived contaminant
- Short lived and long lived contaminants produce different traces
- Net rate of activity accumulation = deposition rate - decay rate

Fixed Filter Behavior

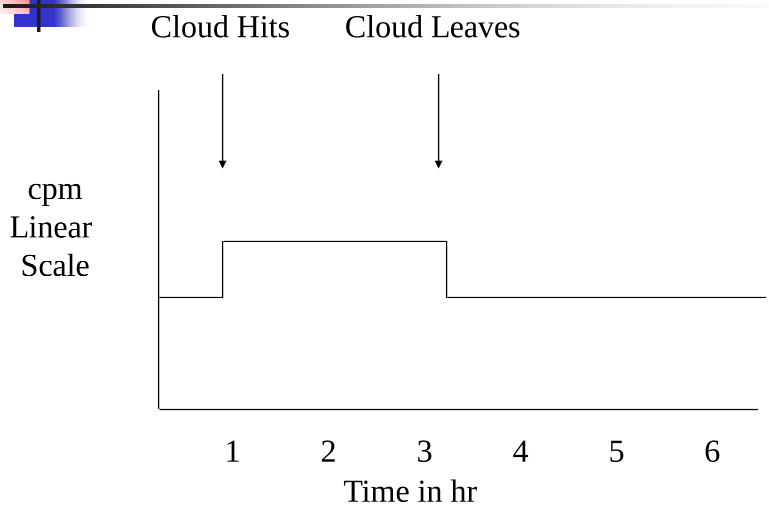
- For short lived: Rapid decay
- For long lived: negligible decay
- Equation for fixed filter activity
- Q = Flow rate (L/min)
- ε = filter collection efficiency
- C = concentration of activity (Bq/L)
- t = time of collection
- A = net count rate above background

Fixed Filter Behavior

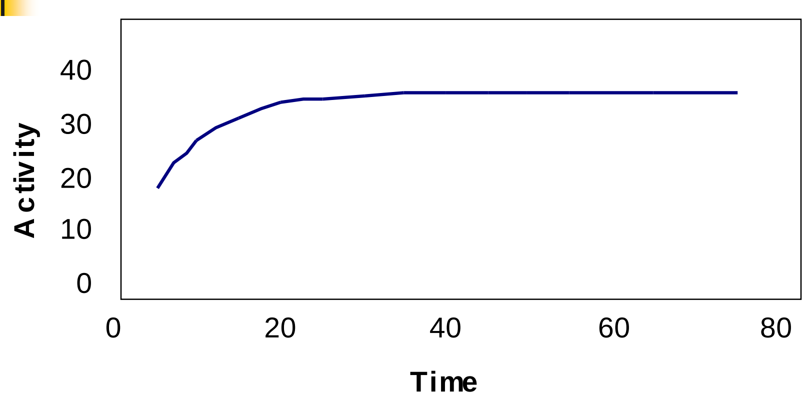
- Fixed filter activity described by

$$A = \frac{CQ\varepsilon\left(1 - e^{-\lambda t}\right)}{\lambda}$$

Extremely Short Half Life



Fixed Filter Short Lived

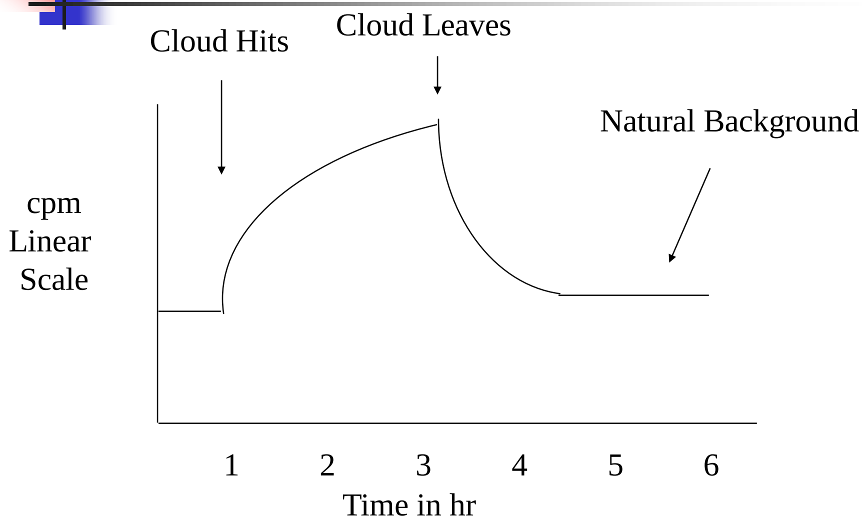


- 5 minute half life nuclide
- Nuclide remains present

Fixed Filter Short Lived

- If the release is a puff over several minutes, rather than a continuous generation over time, the resulting trace goes up to a new value, then will decrease to equilibrium radon/background count level after it has had time to decay

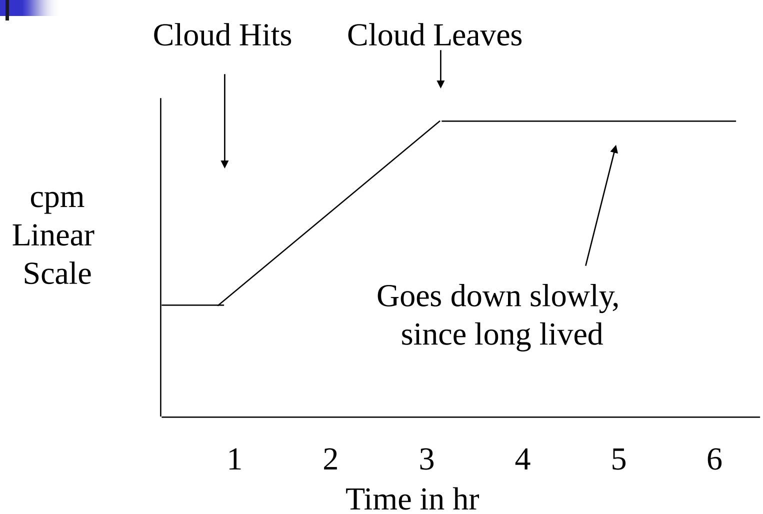
Small Puff, Short Half Life



Fixed Filter, Long Half Life

- Activity builds up continuously, without any apparent decay since long half life
  - Half life about 10 times longer than sampling time
- Activity goes up linearly on linear scale as long as activity is present

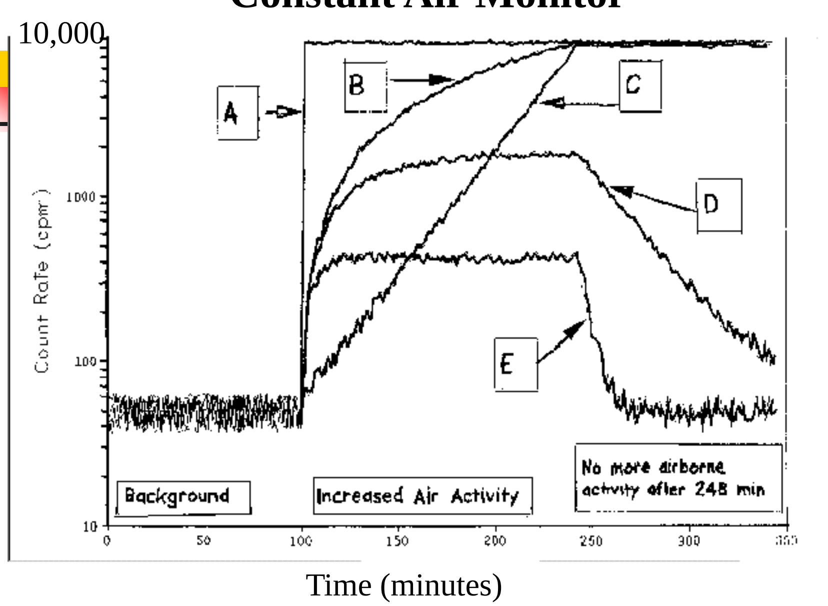
Fixed Filter Long Lived



1996 CHP Exam Q3

- Using the CAM fixed filter strip chart on the following page determine the following
- A. The trace which represents the presence of a short term "puff" release of a long lived radionuclide with no additional releases during the sampling period is:

Constant Air Monitor



Analysis

- Trace A
  - Not possible since no real time for buildup of activity on the filter
  - Would be best associated with an explosion or other short release

Analysis

- Trace B
  - Buildup on the filter on linear paper is linear, on semi-log, looks like the curve described by trace B, most likely answer
  - Note that it builds till the release stops at 248 min to a level which does not decay after the release stops

Analysis

- Trace C
  - A linear buildup on semi-log paper is not what is expected; see trace B description
- Trace D
  - This trace shows decay after the release stops
  - Short lived nuclide
- Trace E
  - Also short lived

Part B

- The trace which represents the presence of a nuclide with a half life of approximately 20 minutes
- Trace A, B, and C
  - Long lived nuclide, since no decay after airborne

Analysis

- Trace D
  - Equilibrium reached after about 100 minutes
  - This equates to about 5 half lives
  - Shows decay after airborne stops
  - Most likely
- Trace E
  - Very rapid buildup indicates half life on the order of 1 or 2 minutes

Analysis Part C

- The trace which represents the presence of an exponentially increasing concentration of a long lived radionuclide is:
- Trace A
  - Long lived, but does not show exponential buildup
- Trace B
  - Long lived, but is a linear buildup of activity

Analysis

- Trace C
  - Straight line on log paper means exponential increase
- Trace D, E
  - Both are short lived

Analysis Part D

- Using the following information calculate the average airborne radioactive material concentration (in μCi/cc) during the release period for the trace labeled as "B":
- Airborne concentration constant during release, Airborne levels return to pre-release levels at t = 248 min, 3 cfm flow rate, 20% detector eff, Filter eff = 98%, 2.84×10^4 cc/ft3, 28.3 L/ft^3

Analysis

- Change in activity collected = amount collected - amount decayed
- Since long lived activity, decay is negligible so that: Change in activity collected = amount collected

$$\frac{dA}{dt} = Q\frac{\text{m}^3}{\text{min}} \times C\frac{\text{Bq}}{\text{m}^3}$$

$$C\frac{\text{Bq}}{\text{m}^3} = \frac{\dfrac{dA}{dt}}{Q\dfrac{\text{m}^3}{\text{min}}}$$

$$C\frac{\mu\text{Ci}}{\text{cc}} = \frac{\dfrac{dA}{dt}\dfrac{\mu\text{Ci}}{\text{min}}}{Q\dfrac{\text{cc}}{\text{min}}}$$

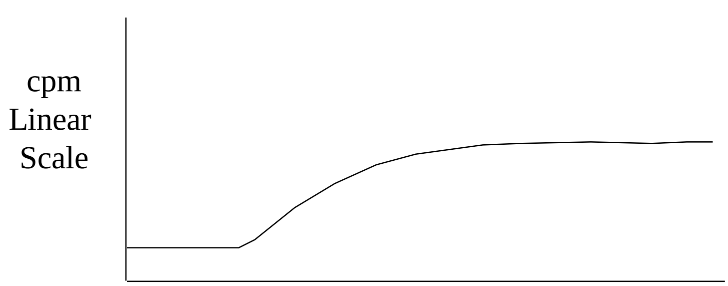
$$C = \frac{\dfrac{1.9\times10^3\ \text{cpm}\times\dfrac{\text{decay}}{0.2\ \text{counts}}\times 0.98\times\dfrac{\mu\text{Ci}}{2.2\times10^6\ \text{dpm}}}{148\ \text{min}}}{3\dfrac{\text{ft}^3}{\text{min}}\times 2.83\times10^4\dfrac{\text{cc}}{\text{ft}^3}}$$

$$C = 3.4\times10^{-10}\frac{\mu\text{Ci}}{\text{cc}}$$

Moving Filter CAM Interpretation

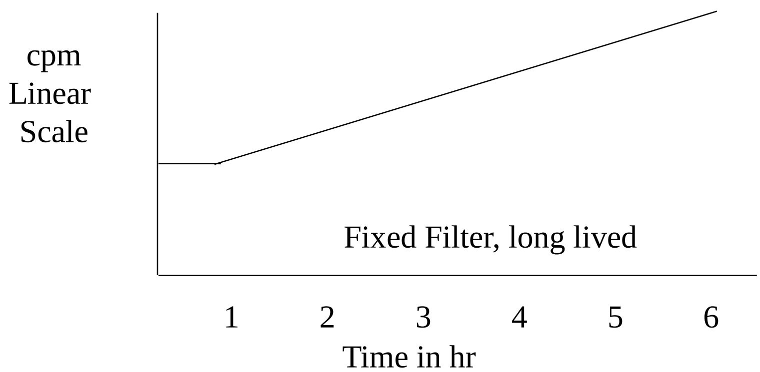
- More complex than fixed filter
- Since filter is constantly moving
  - Long lived activity will build then level off rather than going up exponentially as long as the contaminant is present
  - Short lived will be similar
- Assume that the contaminant is present longer than it takes for the filter to traverse the sensitive detection area

CAM Analysis



Moving Filter, long lived

CAM Analysis



CAM Analysis, continued

- Very short half life response will look identical to a fixed filter short half life response
- Intermediate half life response has a shape in between the two

Natural Airborne Activity

- Radon and its decay products will collect on air samples
- Contributes to background
- Reaches equilibrium in 4 hours if remains constant
  - not always true
  - Big problem when temperature inversions occur
- Try to remove the influence of radon

Radon Problems

- Radon progeny is short lived
  - Typical nuclides of concern are long lived
- Count sample many hours later after radon progeny has time to decay away if possible
- May perform calculation to remove influence of radon progeny

Radon Removal

- The limiting activity in the radon chain is Pb-214
  - $T_{1/2}$ = 26.8 minutes
- The limiting activity in the thoron chain is Pb-212
  - $T_{1/2}$ = 10.6 hr
- Count sample several hours after collection (let 26.8 hr nuclide to decay away)
- Count again at about 2 Pb-212 half lives

Finding Long Lived Activity

- C_2 = Count rate at about 20 hours
- C_1 = Count rate at about 4 hours
- C_{LL} = Long lived activity
- Δt = time between counts
- $\lambda = 0.0655\ h^{-1}$ (^{210}Pb)

$$C_{LL} = \frac{C_2 - C_1 e^{-\lambda \Delta t}}{1 - e^{-\lambda \Delta t}}$$

Short Lived Activity

- Separating out short lived activity from natural activity can also be done
- Count the same way as for long lived
- λ_C = Decay constant for contaminant
- $C_1 = C_{n1} + C_{C1}$
- $C_2 = C_{n2} + C_{C2}$

$$C_{C1} = \frac{C_2 - C_1 e^{-\lambda_n \Delta t}}{e^{-\lambda_C \Delta t} - e^{-\lambda_n \Delta t}}$$

Example

- A 1 m^3 sample was collected which was expected to contain ^{90}Y (no ^{90}Sr) which has a half life of 64.1 hours.
- Radon was also expected in the sample
- The sample was counted at 4 hours after collection
- A count of 800 dpm was obtained.
- A count at 24 hours yielded 400 dpm
- What was the activity concentration of ^{90}Y in the air?

Example

- C_1 = 800 dpm
- C_2 = 400 dpm
- λ_C = 0.693/64.1 hr = 0.0108 hr^{-1}
- λ = 0.0655 h^{-1}
- Δt = 20 hours

$$C_{\mathrm{C1}} = \frac{C_2 - C_1 e^{-\lambda_n \Delta t}}{e^{-\lambda_C \Delta t} - e^{-\lambda_n \Delta t}}$$

Example, continued

$$C_{\mathrm{C1}} = \frac{400 - 800 e^{-0.0655 \times 20}}{e^{-0.0180 \times 20} - e^{-0.0655 \times 20}}$$

$$C_{\mathrm{C1}} = 344 \text{ dpm}$$

$$A = \frac{344 \text{ dpm}}{1 \text{ m}^3 \times 10^6 \frac{\text{mL}}{\text{m}^3} \times 2.22 \times 10^6 \frac{\text{dpm}}{\mu\text{Ci}}}$$

$$A = 1.5 \times 10^{-10} \frac{\mu\text{Ci}}{\text{mL}}$$

References

- ANSI/HPS N13.1-1999, Sampling and Monitoring of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities
- http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr60a_00.html
  - This is an online address to electronic CFRs

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