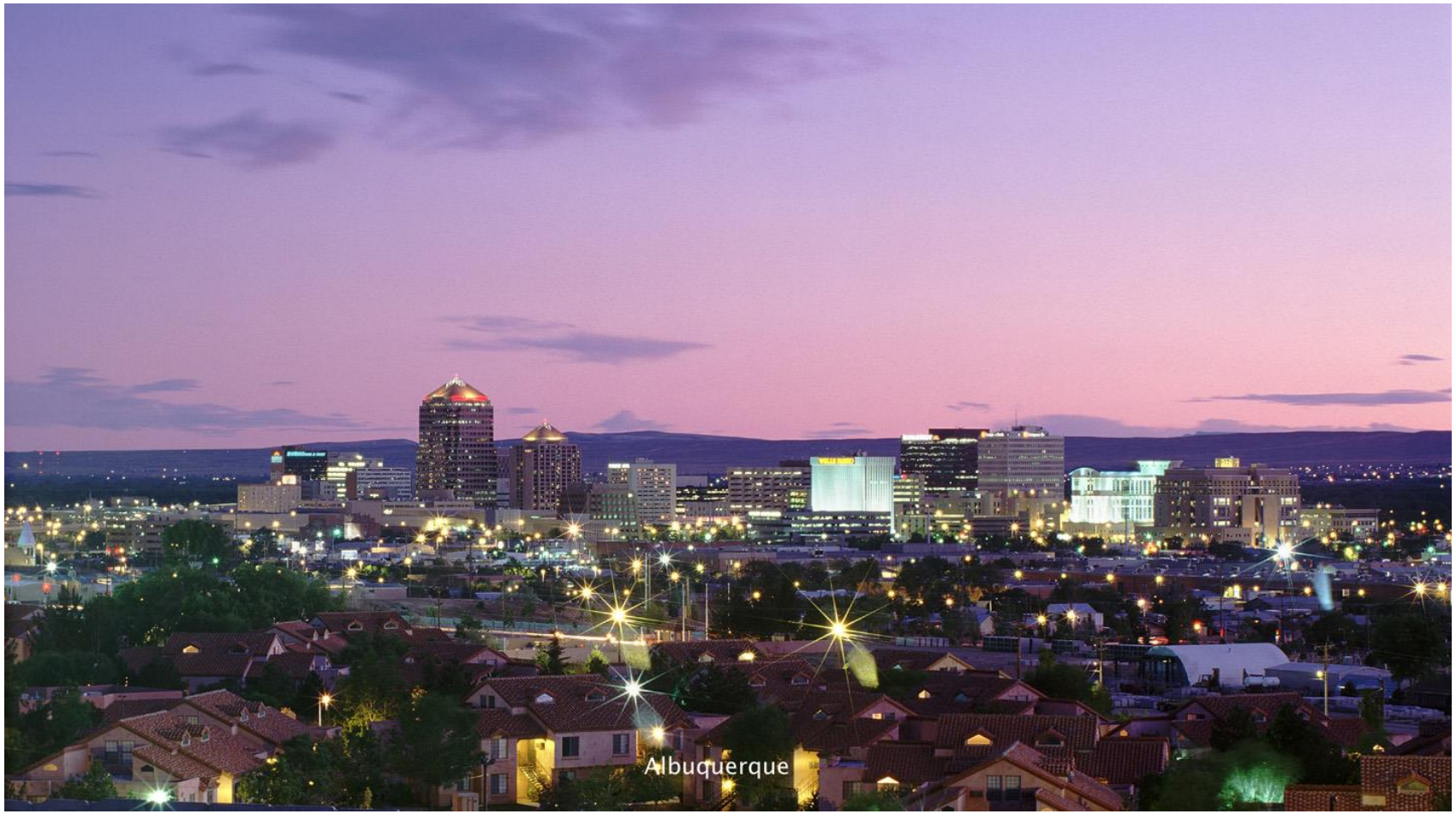
Air Sampling in Nuclear Facilities



DAY 1 – Fundamentals of Air Sampling

James Tom Voss, NRRPT, CHP

jtvoss@newmexico.com

WWW.VOSS-ASSOCIATES.COM

Technical Management Services

WWW.TMSCOURSES.COM

CLASS SCHEDULE

DAY 1 – Fundamentals of Air Monitoring

DAY 2 – DOE, EPA, and NRC Standards

DAY 3 – Methods of Extracting Representative Samples from Stacks and Ducts, the Work Area, and the Environment

DAY 4 – Types of Air Samplers and Monitors

DAY 5 – Hands-On Use of Air Samplers and Monitors

Fundamentals of Air Monitoring

Day 1

I. Dictionary
II.Types of Samples
III. Sample Collection and Analysis Methods
IV. Air Sampling Pumps
V. 29CFR1910
VI. 10CFR20 and 10CFR835 DAC Factors
VII. Airborne Activity
IIX. Radon Monitoring
IX. Conversions and Constants

START THE ALPHA 6 AND THE SAMPLING PUMP

CLASS QUIZ

Q 1:
Assuming radon and thoron concentrations are not changing how long will it take for the radon short-lived progeny to come into 90% equilibrium on the Alpha 6 filter ?

Q 2:
How long will it take for the thoron short-lived progeny to come into 90% equilibrium on the Alpha 6 filter ?

Q 3:
Which radon progeny drives the radon progeny effective half-life ?

Q 4:
Which thoron progeny drives the thoron progeny effective half-life ?

Q 5:
After we stop the sample pump how long will it take for the radon progeny on the filter to decay to less than 10% of its value when the pump was stopped ?

Q 6:
After we stop the sample pump how long will it take for the thoron progeny on the filter to decay to less than 10% of its value when the pump was stopped ?

We will check the Alpha 6 periodically to see the radon and thoron progeny collected on the sample filter.

Thorium-232 Decay Chain (including Thoron Progeny)

	1st Progeny		kev and % abundance
Th^{232}	Ra^{228}	α	3830(0.2), 3953 (23), 4010 (77)
1.41E10y		γ	59 (0.19), 125 (0.04)
		Ra x-rays	12 (8.4)
Ra^{228}	Ac^{228}	β^-	39 (100)
5.75y			
Ac^{228}	Th^{228}	β^-	606 (8), 1168 (32), 1741 (12)
6.13h		γ	338(11.4), 911(27.7), 969(16.6)
		Th x-rays	13 (39), 90 (2.1), 93 (3.5), 105 (1.6)
Th^{228}	Ra^{224}	α	5212(0.4), 5341(26.7), 5423(72.7)
1.91y		γ	84 (1.2), 132 (0.12), 216 (0.24)
		Ra x-rays	12 (9.6)
Ra^{224}	Rn^{220}	α	5449 (4.9), 5686 (95.1)
3.62d		γ	241 (3.95)
		Rn x-rays	12(0.4), 81 (0.126), 84 (0.209)

Rn^{220} is “thoron” gas, usually included with “radon” gas

Rn^{220}	Po^{216}	α	6288 (99.9), 5747 (0.1)
56s		γ	av. 550 (0.1)
Po^{216}	Pb^{212}	α	6779 (99.998)
0.15s			
Pb^{212}	Bi^{212}	β^-	158(5.22), 334 (85.1), 573 (9.9)
10.64h		γ	115 (0.6), 239 (44.6), 300 (3.4)
		Bi x-rays	11 (15.5), 75 (10.7), 77 (18), 87 (8)

Bi^{212} decays 64.7% of the time by β^- to Po^{212} and 35.93% by α to Tl^{208}

Bi^{212}	Tl^{208}	α	5767 (0.6), 6050 (25.2), 6090 (9.6)
60.6m	Po^{212}	β^-	625 (3.4), 1519 (8), 2426 (48.4)
		γ	727 (11.8), 785 (1.97), 1621 (2.75)
		Tl x-rays	10 (7.7)
Tl^{208}	Pb^{208}	β^-	1283(23.2), 1517(22.7), 1794(49.3)
3.05m	S	γ	511 (21.6), 583 (84.2), 860(12.46), 2614 (99.8)
		Pb x-rays	11 (2.9), 73 (2.0), 75 (3.4), 85 (1.5)
Po^{212}	Pb^{208}	α	8785 (100)
304ns	S		

Pb^{208} is Stable

Uranium-238 Decay Chain (including Radon Progeny)

	1st Progeny		kev and % abundance
U^{238}	Th^{234}	α	4039(0.2), 4147(23.4), 4196(77.4)
4.47E9y		γ	av. 66 (0.1)
		Th x-rays	13 (8.8)
Th^{234}	Pa^{234m}	β^-	76 (2), 96 (25.3), 189 (72.5)
24.1d		γ	63 (3.8), 92 (2.7), 93 (2.7)
		Pa x-rays	13 (9.6)

Pa^{234m} decays 99.87% of the time by β^- to U^{234} and 0.13% of the time by IT to Pa^{234}

Pa^{234m}	U^{234}	β^-	1236(0.7), 1471(0.6), 2281(98.6)
1.17m		γ	766 (0.2), 926 (0.4), 1001 (0.6)
		U x-rays	14(0.44), 95(0.115), 98(0.187)
Pa^{234}		IT	

Pa^{234}	U^{234}	β^-	484 (35), 654 (0.6), 1183(10)
6.70h		γ	131 (20.4), 882 (24), 946 (12)
	U x-rays		14(144), 95(15.7), 98(25.4), 111(11.8)
U^{234}	Th^{230}	α	4605(0.2), 4724(27.4), 4776(72.4)
2.45E5y		γ	53 (0.118), 121 (0.04)
Th^{230}	Ra^{226}	α	4476(0.12), 4621(23.4), 4688(76.3)
7.7E4y			
Ra^{226}	Rn^{222}	α	4602 (5.6), 4785 (94.4)
1600y		γ	186 (3.28)
	Rn x-rays		12(0.4), 81(0.18), 84(0.3), 95(0.14)

Rn^{222} is “radon” gas, usually included with “thoron” gas

Rn^{222}	Po^{218}	α	5490 (99.92), 4986 (0.08)
3.82d		γ	av. 512 (0.08)

Po^{218} decays 99.98% of the time by α to Pb^{214} and 0.02% of the time by β^- to At^{218}

Po^{218}	Pb^{214}	α	6003 (99.98)
3.05m	At^{218}	β^-	330 (0.02)
At^{218}	Bi^{214}	α	6650 (6), 6700
2s			
Pb^{214}	Bi^{214}	β^-	672(48), 729 (42.5), 1024 (6.3)
26.8m		γ	242(7.49), 295(19.2), 352(37.2)
		Bi x-rays	11(13.5), 75(6.2), 77(10.5), 87(4.7)

Bi^{214} decays 99.979% of the time by β^- to Po^{214} and 0.021% of the time by α to Tl^{210}

Bi^{214}	Po^{210}	β^-	1505(17.7), 1540(17.9), 3270(17.2)
19.9m		γ	609(46.3), 1120(15.1), 1764(15.8)
		Po x-rays	11(0.5), 77(0.36), 79(06), 90(0.3)
Po^{214}	Pb^{210}	α	7687 (99.989), 6892 (0.01)
146us		γ	797 (0.013)

Tl^{210}	Pb^{210}	β^-	1320 (25), 1870 (56), 2340 (19)
1.30m		γ	298 (79), 800 (99), 1310(21)
		Pb x-rays	11(13), 73(2.5), 75(4.3), 85(1.9)
Pb^{210}	Bi^{210}	β^-	17 (80.2), 63 (19.8)
22.3y		γ	47 (4.05)
		Bi x-rays	11 (24.3)

Bi^{210} decays ~100% of the time by β^- to Po^{210} and 0.000013% of the time by α to Tl^{206}

Bi^{210}	Po^{210}	β^-	1161 (99.9998)
5.01d	Tl^{206}	α	4650 (0.00007), 4690 (00005)
Po^{210}	Pb^{206}	α	5350(99.9989)
138.4d	S		
Tl^{206}	Pb^{206}	β^-	1520 (100)
4.19m	S		

Pb^{206} is Stable

DICTIONARY

10CFR835 – Occupational Radiation Protection

Activity Median Aerodynamic Diameter (AMAD) means a particle size in an aerosol where fifty percent of the activity in the aerosol is associated with particles of aerodynamic diameter greater than the AMAD.

Airborne radioactive material or airborne radioactivity means radioactive material dispersed in the air in the form of dusts, fumes, particulates, mists, vapors, or gases.

Airborne radioactivity area means any area, accessible to individuals, where:
(1) The concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the derived air concentration (DAC) values listed in appendix A or appendix C of this part; or
(2) An individual present in the area without respiratory protection could receive an intake exceeding 12 DAChours in a week.

ALARA means “As Low As is Reasonably Achievable,” which is the approach to radiation protection to manage and control exposures (both individual and collective) to the work force and to the general public to as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations.

Annual limit on intake (ALI) means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man (ICRP Publication 23) that would result in a committed effective dose of 5 rems (0.05 sieverts (Sv)) (1 rem = 0.01 Sv) or a committed equivalent dose of 50 rems (0.5 Sv) to any individual organ or tissue.

10CFR835 – Occupational Radiation Protection

Background means radiation from:

(1) Naturally occurring radioactive materials which have not been technologically enhanced;

(2) Cosmic sources;

(3) Global fallout as it exists in the environment (such as from the testing of nuclear explosive devices);

(4) Radon and its progeny in concentrations or levels existing in buildings or the environment which have not been elevated as a result of current or prior activities; and

(5) Consumer products containing nominal amounts of radioactive material or producing nominal amounts of radiation.

Contamination area means any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed the removable surface contamination values specified in appendix D of this part, but do not exceed 100 times those values.

Controlled area means any area to which access is managed by or for DOE to protect individuals from exposure to radiation and/or radioactive material.

Derived air concentration (DAC) means, for the radionuclides listed in appendix A of this part, the airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of 2400 m^3). For the radionuclides listed in appendix C of this part, the air immersion DACs were calculated for a continuous, non-shielded exposure via immersion in a semi-infinite cloud of radioactive material. Except as noted in the footnotes to appendix A of this part, the values are based on dose coefficients from International Commission on Radiological Protection Publication 68, *Dose Coefficients for Intakes of Radionuclides by Workers.*

Derived air concentration-hour (DAChour) means the product of the concentration of radioactive material in air (expressed as a fraction or multiple of the DAC for each radionuclide) and the time of exposure to that radionuclide, in hours.

Deterministic effects means effects due to radiation exposure for which the severity varies with the dose and for which a threshold normally exists (*e.g.*, radiation-induced opacities within the lens of the eye).

High contamination area means any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed 100 times the removable surface contamination values specified in appendix D of this part.

Monitoring means the measurement of radiation levels, airborne radioactivity concentrations, radioactive contamination levels, quantities of radioactive material, or individual doses and the use of the results of these measurements to evaluate radiological hazards or potential and actual doses resulting from exposures to ionizing radiation.

Occupational dose means an individual's ionizing radiation dose (external and internal) as a result of that individual's work assignment. Occupational dose does not include doses received as a medical patient or doses resulting from background radiation or participation as a subject in medical research programs.

Radiological area means any area within a controlled area defined in this section as a "radiation area," "high radiation area," "very high radiation area," "contamination area," "high contamination area," or "airborne radioactivity area."

Real-time air monitoring means measurement of the concentrations or quantities of airborne radioactive materials on a continuous basis.

Respiratory protective device means an apparatus, such as a respirator, worn by an individual for the purpose of reducing the individual's intake of airborne radioactive materials.

Special tritium compound (STC) means any compound, except for H2O, that contains tritium, either intentionally (*e.g.*, by synthesis) or inadvertently (*e.g.*, by contamination mechanisms).

Stochastic effects means malignant and hereditary diseases for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose without a threshold, for radiation protection purposes.

DICTIONARY

DOE Order 458.1 – Radiation Protection of the Public and the Environment

Absorbed Dose (D) — The average energy imparted by ionizing radiation to the matter in a volume element per unit mass of irradiated material. The absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 gray).

Actual or Likely Use Scenarios — The reasonably anticipated future uses of land or property considering the history of use and implementable use restrictions, designations or controls; affected populations, or ecosystems, natural resources, or historic or cultural significance. For real property considerations also include Federal and State use designations; local zoning and future land use plans; and proximity to residences, commercial, industrial or unique cultural or historic areas.

Airborne Discharges — Material released to the atmosphere in the form of dusts, fumes, particulates, mists, vapors, or gases.

Background Radiation — Radiation from:

(1) naturally occurring radioactive materials which have not been technologically enhanced (i.e., background radiation does not include TENORM);
(2) cosmic sources;
(3) global fallout as it exists in the environment (such as from the testing of nuclear explosive devices);
(4) radon and its decay products in concentrations or levels existing in buildings or the environment which have not been elevated as a result of current or prior activities; and
(5) consumer products containing nominal amounts of radioactive material or producing nominal amounts of radiation.

Collective Dose — The sum of the total effective dose to all persons in a specified population received in a specified period of time. For clearance of property the collective dose refers to the population potentially exposed to the cleared property. Collective dose is expressed in units of person-rem (or person-sievert).

Committed Effective Dose (E50) — The sum of the committed equivalent doses to various tissues or organs in the body (HT,50), each multiplied by the appropriate tissue weighting factor (wT)--that is, E50 = ΣwTHT,50 + wRemainderHRemainder,50, where wRemainder is the tissue weighting factor assigned to the remainder organs and tissues and HRemainder,50 is the committed equivalent dose to the remainder organs and tissues. Committed effective dose is expressed in units of rems (or sieverts).

Committed Equivalent Dose (HT,50) — The equivalent dose calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed equivalent dose is expressed in units of rems (or sieverts).

Dose — A general term for absorbed dose, equivalent dose, effective dose, committed equivalent dose, committed effective dose, or TED as defined in this Order.

Effective Dose (E) — The summation of the products of the equivalent dose received by specified tissues or organs of the body (HT) and the appropriate tissue weighting (wT)--that is, $E = \Sigma wTHT$. It includes the dose from radiation sources internal and/or external to the body. For purposes of compliance with this Order, equivalent dose to the whole body may be used as effective dose for external exposures. The effective dose is expressed in units of rems (or sieverts).

Effluent Monitoring — The collection and analysis of samples of liquid and gaseous effluents or measurements of liquid and gaseous effluents performed to characterize and quantify radiological contaminants and process stream characteristics, assess radiation exposures of members of the public, and demonstrate compliance with applicable standards.

Environmental Surveillance — The collection and analysis of samples of air, water, soil, foodstuffs, biota, and other media at the DOE site and surrounding environs and the measurement of external radiation to demonstrate compliance with applicable standards, assess radiation exposure of members of the public, and assess effects, if any, on the environment.

Equivalent Dose (HT) — The product of average absorbed dose (DT,R) in rad (or gray) in a tissue or organ (T) and a radiation (R) weighting factor (wR). For external dose, the equivalent dose to the whole body is assessed at a depth of 1 cm in tissue; the equivalent dose to the lens of the eye is assessed at a depth of 0.3 cm in tissue, and the equivalent dose to the extremity and skin is assessed at a depth of 0.007 cm in tissue. Equivalent dose is expressed in units of rems (or sieverts).

External Dose or Exposure — That portion of the dose received from radiation sources outside the body (i.e., external sources).

Internal Dose or Exposure — That portion of the dose received from radioactive material taken into the body (i.e., internal sources).

Maximally Exposed Individual — A hypothetical individual who – because of realistically assumed proximity, activities, and living habits – would receive the highest radiation dose, taking into account all pathways, from a given event, process, or facility.

Potential Dose — A calculated dose based on a postulated set of exposure conditions that have a reasonable probability of occurrence.

Public Dose — The dose received by members of the public from exposure to radiation and to radioactive material released by a DOE radiological activity whether the exposure is within a DOE site boundary or offsite.

Radiation Weighting Factor (wR) — The modifying factor used to calculate the equivalent dose from the average tissue or organ absorbed dose; the absorbed dose (expressed in rad or gray) is multiplied by the appropriate radiation weighting factor.

Reference Person — A hypothetical aggregation of human (male and female) physical and physiological characteristics arrived at by international consensus for the purpose of standardizing radiation dose calculations.

Remedial Action**s** — Those actions, consistent with permanent remedy, taken to control or remove radiological contaminants to prevent or to minimize doses to members of the public.

Representative Person — An individual receiving a dose that is representative of the more highly exposed individuals in the population. This term is the equivalent of, and replaces, ‗average member of the critical group'.

Residual Radioactive Material — Any radioactive material which is in or on soil, air, water, equipment, or structures as a consequence of past operations or activities of the Department or its predecessors.

Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) — Any naturally occurring radioactive materials whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities.

Tissue Weighting Factor (wT) — The fraction of the overall health risk, resulting from uniform, whole body irradiation, attributable to specific tissue (T). The equivalent dose to tissue, (HT), is multiplied by the appropriate tissue weighting factor to obtain the effective dose (E) contribution from that tissue.

Total Effective Dose (TED) — Sum of the effective dose (for external exposures) and the committed effective dose.

Whole Body — For the purposes of external exposure, head, trunk (including male gonads), arms above and including the elbow, or legs above and including the knee.

Engineered Controls—Use of physical components and systems to reduce dose, airborne radioactivity, and/or the spread of contamination (e.g., piping, containment devices, ventilation, filtration, or shielding).

High-Efficiency Particulate Air (HEPA) filter—A type of filter used in air handling, ventilation, contamination control, and respiratory protection when particulate airborne contamination is a concern.

40CFR50 NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

Ambient air means that portion of the atmosphere, external to buildings, to which the general public has access.

Reference method means a method of sampling and analyzing the ambient air for an air pollutant that is specified as a reference method in an appendix to this part, or a method that has been designated as a reference method in accordance with part 53 of this chapter; it does not include a method for which a reference method designation has been cancelled in accordance with §53.11 or §53.16 of this chapter.

Equivalent method means a method of sampling and analyzing the ambient air for an air pollutant that has been designated as an equivalent method in accordance with part 53 of this chapter; it does not include a method for which an equivalent method designation has been cancelled in accordance with §53.11 or §53.16 of this chapter.

Traceable means that a local standard has been compared and certified either directly or via not more than one intermediate standard, to a primary standard such as a National Bureau of Standards Standard Reference Material (NBS SRM), or a USEPA/NBS-approved Certified Reference Material (CRM).

Indian country is as defined in 18 U.S.C. 1151.

Exceptional event means an event that affects air quality, is not reasonably controllable or preventable, is an event caused by human activity that is unlikely to recur at a particular location or a natural event, and is determined by the Administrator in accordance with 40 CFR 50.14 to be an exceptional event. It does not include stagnation of air masses or meteorological inversions, a meteorological event involving high temperatures or lack of precipitation, or air pollution relating to source noncompliance.

Natural event means an event in which human activity plays little or no direct causal role.

Exceedance with respect to a national ambient air quality standard means one occurrence of a measured or modeled concentration that exceeds the specified concentration level of such standard for the averaging period specified by the standard.

ACRONYMS

α	Alpha
β-γ	Beta-Gamma
µCi	micro-Curie (1.0E-6 Curies)
AD	Aerodynamic Diameter
AED	Aerodynamic Equivalent Diameter
ALARA	As Low as Reasonably Achievable
ALI	Annual Limit of Intake
AMAD	Activity Mean Aerodynamic Diameter
ANSI	American National Standards Institute
ARA	Airborne Radioactivity Area
ASM	Canberra Alpha Sentry Manager
Bkg	Background Count Rate
BZA	Breathing Zone Air

CA	Contamination Area
CAM	Continuous Air Monitor
cc/min	Cubic Centimeters per Minute
CE	Collection Efficiency
CF	Conversion Factor
cfm	Cubic Feet per Minute
DAC	Derived Air Concentration
DOP	Dioctyl Phthalate
DP, dP or ΔP	Differential Pressure
dpm	Disintegrations per Minute
Eff	Detector Efficiency
GM	Geiger-Mueller
HT	Tritium Gas
HTO	Tritium Oxide
HiVol	High Volume Air Sampler

iCAM	intelligent Continuous Air Monitor
ICRP	International Commission on Radiological Protection
ITRI	Inhalation Toxicology Research Institute (Lovelace Respiratory Research Institute)
L/min	Liters per minute
LSC	Liquid Scintillation Counting
LowVol	Low Volume Air Sampler
M&TE	Measuring and Test Equipment
MCA	Multi-Channel Analyzer
MDA	Minimum Detectable Activity
MDC	Minimum Detectable Concentration
MDE	Minimum Detectable Exposure

mL	milli Liter (1.0E-3 Liters)
NIST	National Institute of Standards and Technology (NBS)
NRC	Nuclear Regulatory Commission
PAS	Personal Air Sampler
PAEC	Potential Alpha Energy Concentration
PF	Protection Factor
PIPS	Passivated Ion-implanted Planar Silicon
PTFE	Polytetrafluoroethylene
PPE	Personal Protective Equipment
PVC	Poly-vinylchloride
QA	Quality Assurance
QC	Quality Control

Radon	Rn-222
RAP	Radiological Assistance Program
RAS	Retrospective Air Sampling
R_B	Background Count Rate
RBA	Radiological Buffer Area
ROI	Regions of Interest
Rn-Tn	Radon-Thoron; term used for the progeny of Rn-222 and Rn-220
RWP	Radiological Work Permit
SA	Self Absorption
STC	Special Tritium Compound
T or t	Time
T_B	Background Count Time
T_E	Exposure Time

T_G	Gross Counting Time
T_S	Sampling Time
Thoron	Rn-220
TRU	Trans-Uranium or Tansuranic
V	Volume
WL	Working Level
WLM	Working Level Month

This section is intended to provide a basic understanding of;

1. radon and thoron interferences we encounter when we are sampling/monitoring for other alpha-emitting radionuclides.

2. method of operation and some of the limitations of our air sampling/monitoring equipment,

3. calculations needed to determine DAC and DAC-hr values, clearance of airborne radioactivity through ventilation, and dilution of airborne radioactivity through dispersion,

4. methods to determine the appropriate CAM alarm setpoints for operations, and

5. calculations directly in support of an RWP.

There is a Self-Assessment at the end of this section. You should be able to successfully complete the Self-Assessment.

RADON AND THORON INTERFERENCE

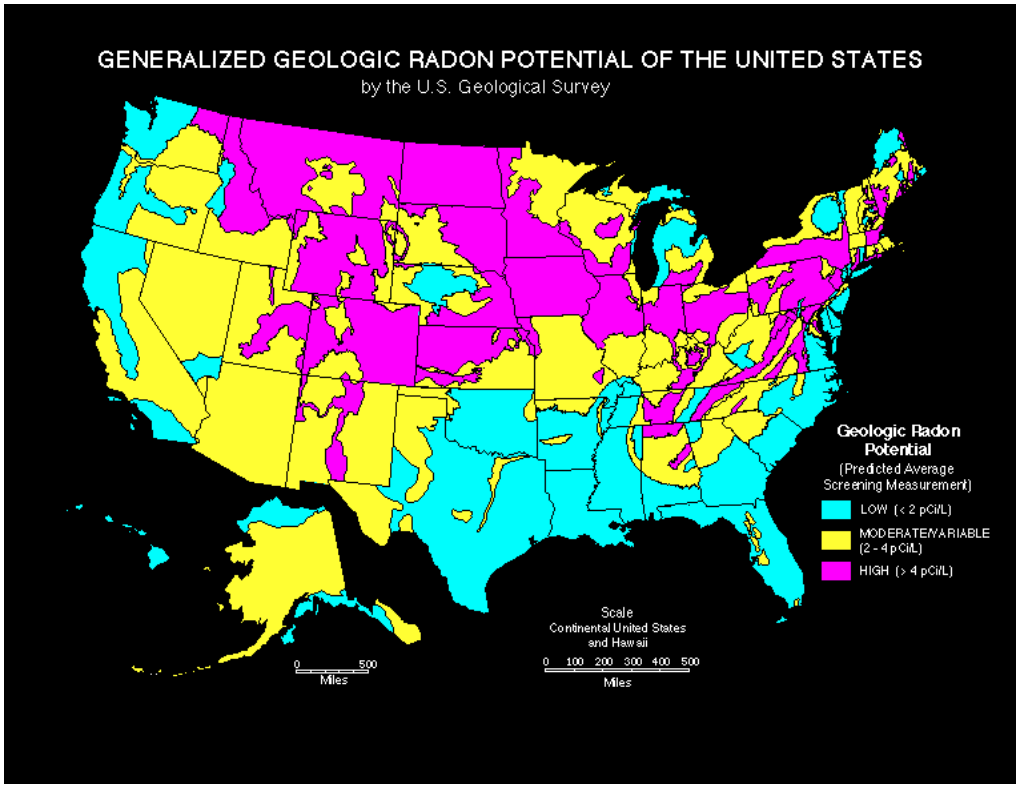
This section provides;

1. a map of the radon potential concentrations in the US,

2. a discussion of high radon and thoron concentrations,

3. a comparison of radon and thoron levels with the required detection levels for other alpha-emitting radionuclides

RADON POTENTIAL CONCENTRATIONS IN THE US



BLUE	LOW	< 2 pCi / L
YELLOW	MODERATE	2 - 4 pCi / L
MAGENTA	HIGH	> 4 pCi / L

Radon and Thoron Concentrations

- High radon concentrations in liquid waste treatment facilities
  > 40 pCi / L
- High radon concentrations in basement areas
  > 4 pCi / L
- High radon concentrations in underground bunkers
  > 15 pCi / L

- High thoron concentrations in thorium liquid waste treatment facilities
  > 40 pCi/L

- High thoron concentrations in thorium research area ventilation exhaust duct
  > 40 pCi/L

- Thoron typically is at a lower concentration than the radon concentration at LANL.

- Radon gas is Rn-222 and Thoron gas is Rn-220.
- It is the particulate progeny of these radionuclides that make it difficult to detect other alpha emitting radionuclides.
- Radon comes from U-238, Thoron comes from Th-232.
- U-238 and Th-232 typically are found together but the deposits have different ratios of U-238 to Th-232.

- The different ratios of U-238 to Th-232 is one of the factors in creating the different ratios of radon to thoron in the air.

- The major factor influencing the ratio of radon to thoron is the difference in the half-lives of radon gas and thoron gas.

- The half-life of Rn-222 (Radon) is 3.82 days and the half-life of Rn-220 (Thoron) is 56 seconds.

- Typical radon daily peaks and valleys occur between noon and 3 PM for high and between midnight and 3 AM for low concentrations.

- Typical daily difference between low and high radon / thoron concentrations is about 4, but variations in weather can double radon concentrations also.

- Typical radon concentrations in ventilated work areas with roughly filters are about 0.1 to 0.2 pCi per liter.

- Typical radon concentrations in HEPA-filtered work areas are less than
  0.1 pCi per liter.

- Radon concentrations go high > 1 pCi per liter when ventilation is off.

- The DAC factor for Pu-239 is 5E-12 uCi / ml
- 1 pCi / L = 1E-9 uCi / ml
- 0.1 pCi / L = 1E-10 uCi / ml
- 0.01 pCi / L = 1E-11 uCi / ml
- 0.005 pCi / L = 5E-12 uCi / ml

- The effective half-life of the radon progeny that affect our ability to detect other alpha-emitting radionuclides is about 30 minutes.

- The effective half-life of thoron progeny is 10.6 hours.

- Thoron can be much more of a problem because of this longer half-life of the thoron progeny.

CONTINUOUS AIR MONITORS

This section provides a basic understanding of;

1. Alpha CAM analysis methods and specifications,

2. Beta CAM specifications, and

3. Tritium sniffer specifications.

ALPHA SPECTRUM ANALYSIS ALGORITHMS AND ALARM STRATEGIES FOR CAMS (CONTINUOUS AIR MONITORS)

PURPOSE

This presentation will cover only some of the possibilities in alpha spectrum analysis algorithms and alarm strategies as they apply to alpha Continuous Air Monitors.

ALPHA SPECTRUM ANALYSIS ALGORITHMS AND ALARM STRATEGIES FOR CAMS

What are some of the analysis algorithms?

Algorithm	Description
Gross counting	Count all events in the detector above a set threshold; there is NO compensation for radon and thoron progeny
Single window counting	Count all events in the detector between the lower and upper discriminators

Two window counting

Count the events in the detector in a lower and upper alpha energy window and subtract a percentage of the upper window counts from the lower window counts.

Typically the lower window would be set for the alpha particle energies the user wishes to quantify and the upper window would be set for the interfering radon and thoron progeny.

Multiple ROIs (regions of interest)	3, 4, or 5 ROIs, individual low and high energy peaks, splitting peaks into low and high energy tails, subtraction K factors
Peak shape fitting	Subtraction of the low energy tail of the interfering radon and thoron progeny
	Self-Adapting peak shape fitting

TWO WINDOW COUNTING

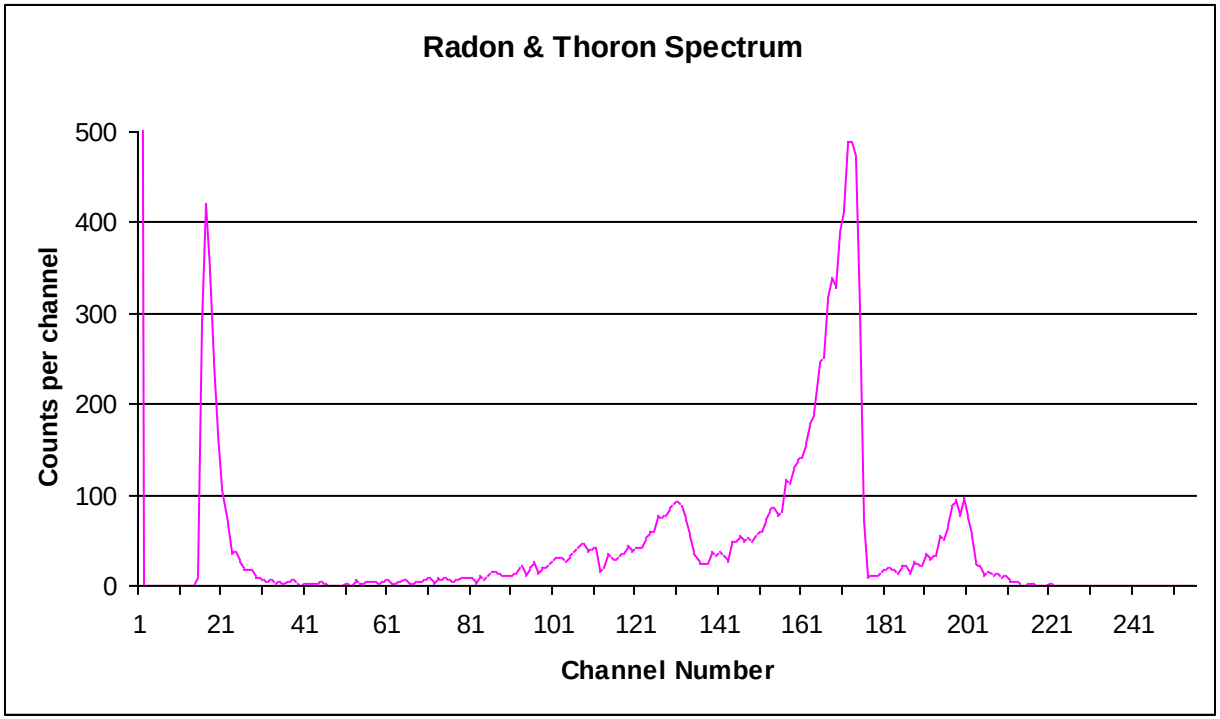
The Lower Window is adjusted for the detection of Pu-239.

The Upper Window is adjusted for the subtraction of radon & thoron that may interfere with the analysis of the radionuclides of interest in the Lower Window.

The Lower Window is from 4.65 MeV to 5.65 MeV (channel 100 to channel 125).

The Upper Window is from 5.65 MeV to 6.65 MeV (channel 125 to channel 150) for the Eberline Alpha 3 and 5 CAMs.

The Eberline Alpha 2 Upper Window is from 5.65 MeV to the high end of the spectrum (channel 125 to channel 255)



A percentage of the counts detected in the Upper Window is subtracted from the Pu-239 analysis window.

If the CAM is calibrated to detect lower energy alphas, the Lower Window is adjusted to be from 4.15 to 5.65 MeV (channel 87 to channel 125).

4 REGION ALGORITHM FOR THE ALPHA 6

Regions of Interest (ROI)

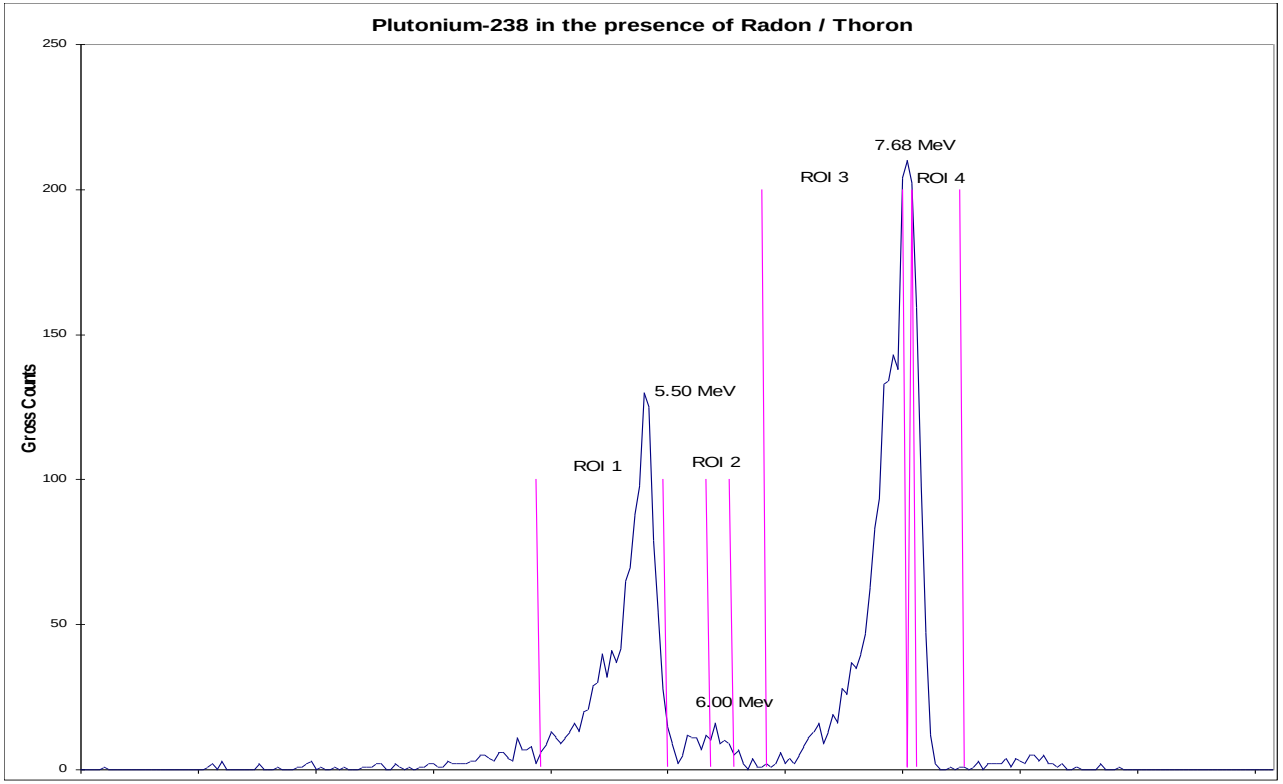
ROI 1 channels 100 to 121 Pu-239 5.15 MeV Peak

ROI 2 channels 136 to 143 Po-218 / Bi-212
(6.00 / 6.05 MeV High Energy Tail)

ROI 3 channels 146 to 178 Po-214
(7.68 MeV Low Energy Tail)

ROI 4 channels 179 to 185 Po-214
(7.68 MeV High Energy Tail)

ALPHA 6 PU-238 SPECTRUM



A 4 Region algorithm was implemented by Eberline for the Alpha 6 in 1987.

Using the assumption that one alpha peak will have an overall shape similar to other alpha peaks the following equation was developed.

$$\frac{\text{Region 1}}{\text{Region 2}} = \frac{\text{Region 3}}{\text{Region 4}}$$

Using the basic equation for peak shapes, the following relationship was developed.

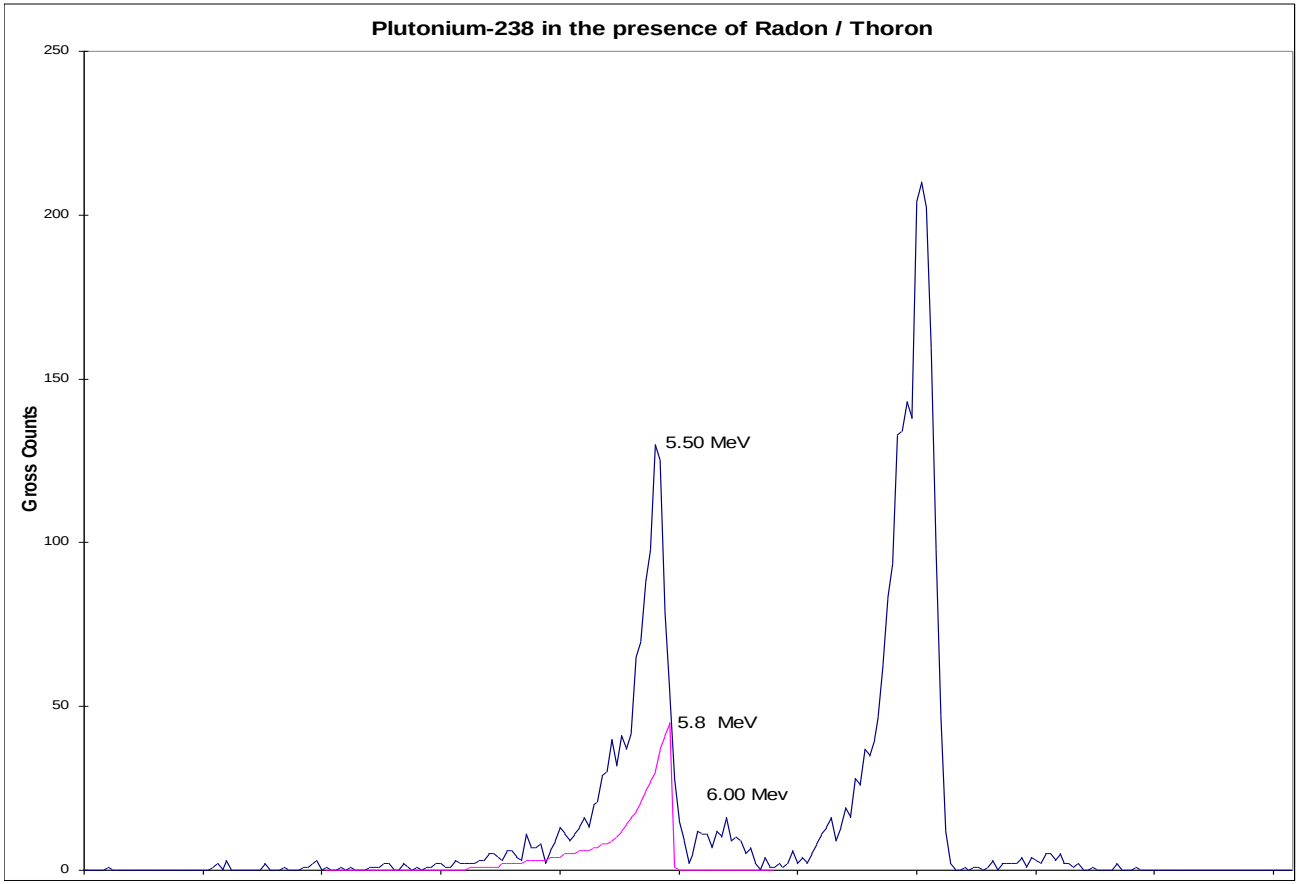
$$\text{Region 1} = \text{Region 2} \times \frac{\text{Region 3}}{\text{Region 4}}$$

If Pu is present then Region 1 will have more than the calculated value so the following equation is used.

$$\text{Pu} = \text{Region 1} - K \times \text{Region 2} \times \frac{\text{Region 3}}{\text{Region 4}}$$

The “K” factor is used to correct for differences in the width of the 4 ROIs.

“Exponential Fit” of the Low Energy Tail for the Canberra CAM



The Canberra Alpha Sentry CAM uses this equation.

exponential equation of the form

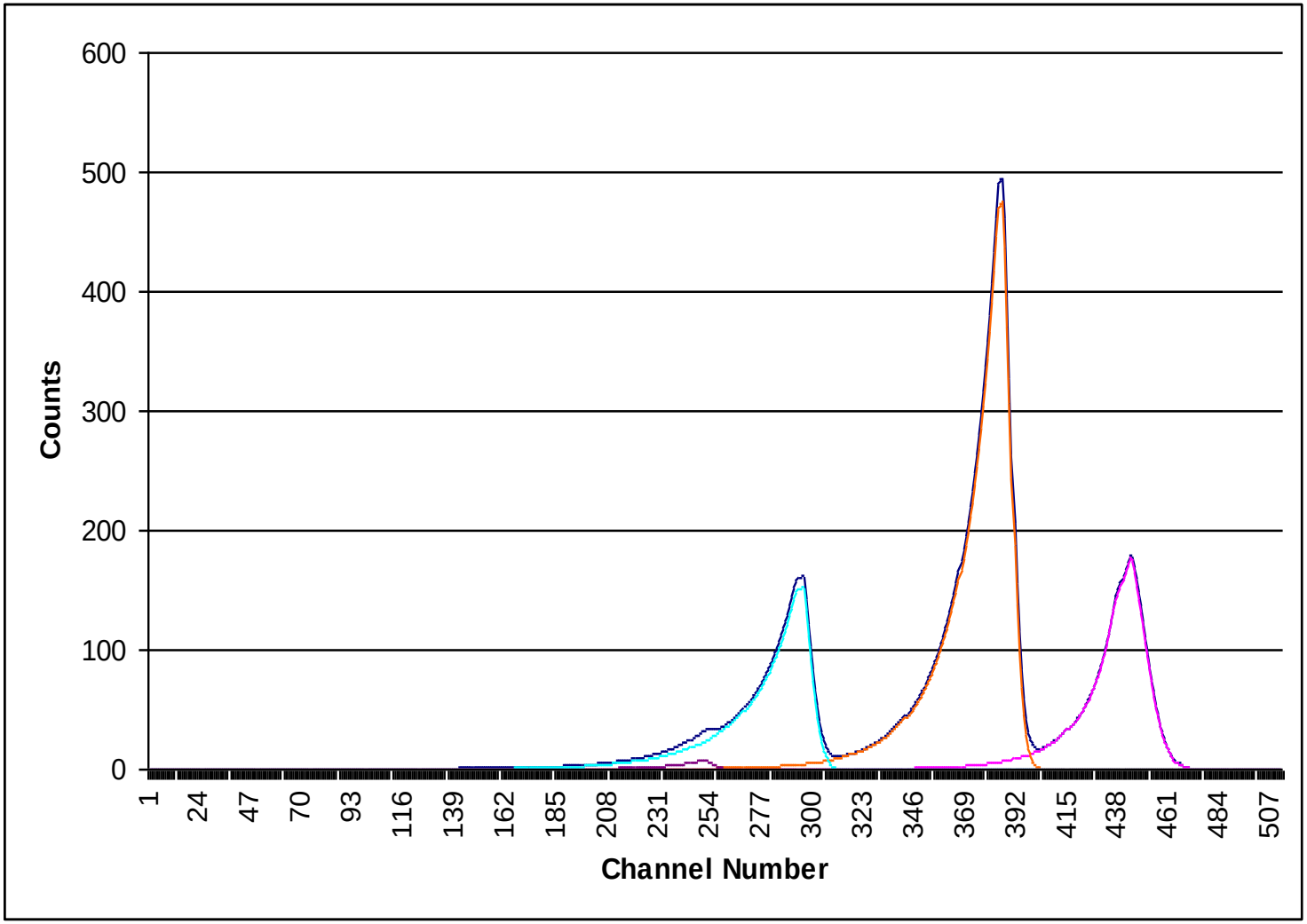
$$y = e^{mX} + b$$

(where *y* is the count, *m* is the slope, and *b* is the intercept)

Canberra Algorithm

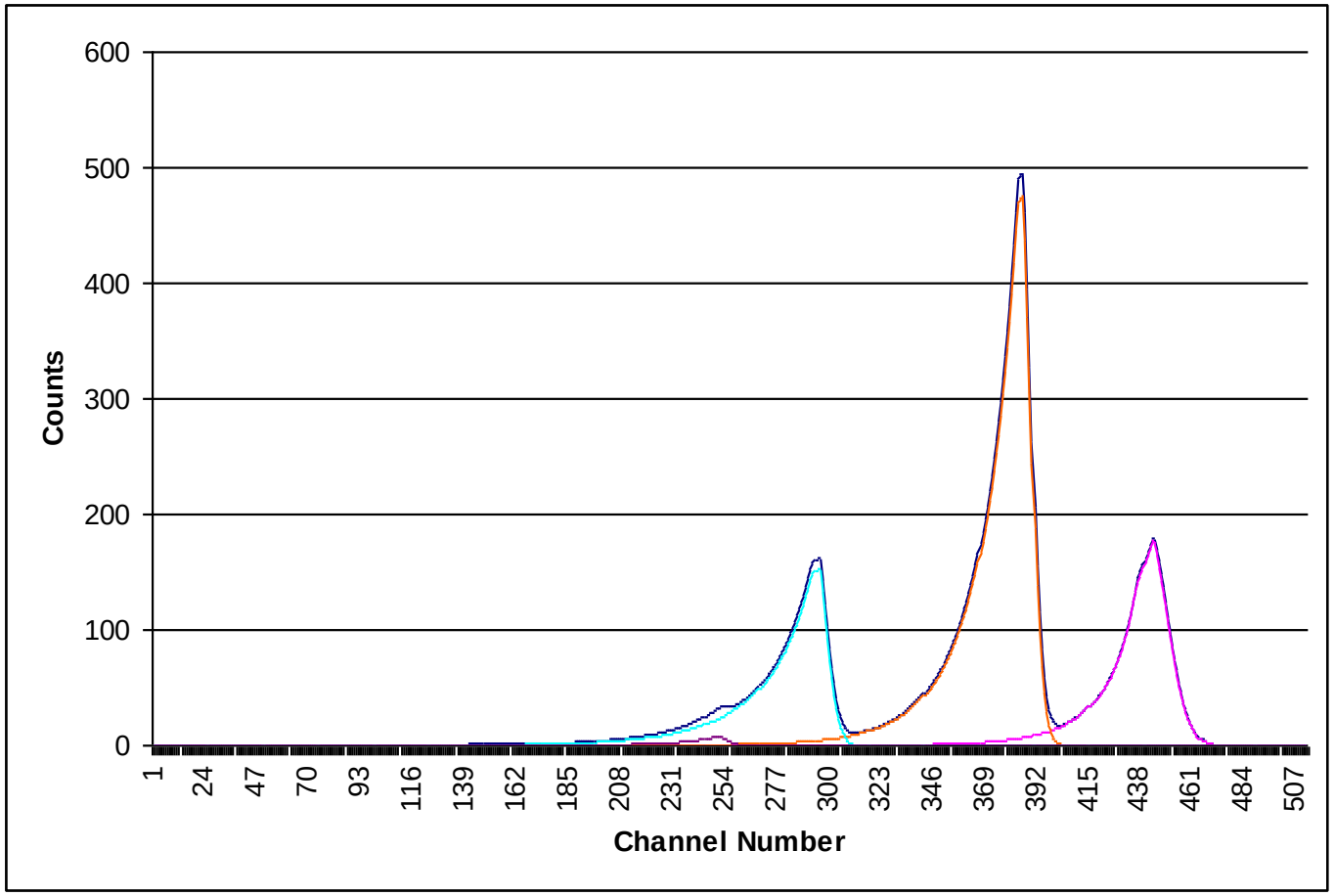
- Upper Energy is 5.8 MeV
- Analysis Window is 2.8 MeV wide
  (window is 3.0 MeV to 5.8 MeV)
- The counts due to radon and thoron are subtracted from the counts in the analysis window.

“Peak Shape” fitting in the Eberline Alpha7



“Peak Shape” fitting Algorithms

- The counts in each channel for the peaks of interest are plotted then a “least-squares” best fitting calculation is performed to fit each peak’s data to an optimum shape.
- The counts from this “fitted” peak are used to calculate the net counts and net activity for the each peak.
- The Eberline Alpha7, Lab-Impex “Smart” CAM, and the Bladewerz BZM and Alert use this form of “peak shape” fitting.
- The Harwell iCAM uses a similar method of “peak shape” fitting and Aquila/Canberra is developing another method of “peak shape” fitting for their CAMs.



Look at the small peak under the other peak curves around channel 254. This is the Pu-239 peak after all the peaks have been “fitted.”

CONCLUSIONS

There are many variables to consider.

There are many different ways those variables can be applied.

The user of the equipment needs to be aware of how the equipment will operate.

A subject matter expert is needed to determine the operational parameters of the equipment.

A subject matter expert is needed to setup the equipment and explain to the user how it will work.

BETA CAMS
(CONTINUOUS AIR MONITORS)

AMS-3 Algorithm
Gross counting using two detectors
Subtract the gamma events in the background detector form the sample detector.
Compensation for radon and thoron progeny is adjusted by using the Zero Set Control.

AMS-4 Algorithm
Two window counting
Count the events in the detector in a lower and upper energy window and subtract a percentage of the upper (alpha) window counts from the lower (beta) window counts. This is the “Alpha Subtract” parameter. In addition the AMS-4 uses the background detector counts to subtract the gamma events from the sample detector beta indications.

BETA CAM FUTURE DEVELOPMENTS

- The new generation of Alpha CAMs use depleted silicon detectors to provide both alpha and beta counting. Those CAMs also have an optional background detector to subtract gamma events from the beta counts in the sample detector.
- The combination of alpha and beta counting with gamma subtraction can improve the performance of the CAM for BOTH alpha and beta detection.
- A further improvement is to provide beta spectroscopy capability.

TRITIUM CAMS (SNIFFERS)

What are some of the variables we need to consider?

Detector type

Flow-thru ion chamber

Operating range

Overhoff 394C	0 to 10,000 uCi / M^3
Femto-Tech PTM-1812	0 to 20,000 uCi / M^3

Gamma interference in a 1 mR/hr field

Overhoff 394C	90 uCi / M^3
Femto-Tech PTM-1812	100 uCi / M^3

FUTURE DEVELOPMENTS FOR TRITIUM SNIFFERS

- The new generation of tritium sniffers will use pulse-height analysis to discriminate against radon and thoron interference.

- A further improvement is to provide separate indication of elemental and tritium oxide concentrations.

CALCULATIONS

This section provides a basic understanding of;

1. DAC and DAC-hr calculations,

2. Calculations for clearance of airborne radioactivity through ventilation, and

3. Calculations for dilution of airborne radioactivity through dispersion.

DAC and DAC-HR Calculations

Concentration is activity by volume.

$$\text{uCi / ml} = \frac{\text{Filter DPM}}{\text{sample volume in ml} \times 2.22\text{E6 DPM / uCi}}$$

$$\text{\# of DACs} = \frac{\text{Concentration in uCi / ml}}{\text{DAC factor in uCi / ml per DAC}}$$

Concentration in uCi / ml

Example:

Filter DPM = 160 DPM

Sampling Rate = 56.6 LPM

Sampling Time = 60 minutes

$$\text{uCi / ml} = \frac{160 \text{ DPM}}{56.6 \text{ LPM} \times 60 \text{ minutes} \times 1{,}000 \text{ ml / L} \times 2.22\text{E}6 \text{ DPM / uCi}}$$

Concentration = 2.12E-11 uCi / ml

Concentration in DAC

Example:
Concentration is 2.12E-11 uCi / ml
DAC factor for Pu-239 is 5E-12 uCi / ml per DAC

$$\text{\# of DACs} = \frac{\text{2.12E-11 uCi / ml}}{\text{5E-12 uCi / ml per DAC}}$$

$$\text{\# DACs} = \text{4.24 DAC}$$

DPM on a Filter for a 1 DAC Concentration

Example:
Concentration is 1 DAC of Pu-239
Sampling rate is 56.6 LPM
Sampling time is 60 minutes

Sample volume = 56.6 LPM x 60 minutes x 1,000 ml / L
Sample volume = 3.396E6 ml

# of DPM =
Sample volume x Concentration x 2.22E6 DPM / uCi =
3.396E6 ml x 5E-12 uCi /ml x 2.22E6 DPM / uCi
# of DPM = 37.7 DPM

DAC-HR Calculations

Example:
Concentration is 1 DAC of Pu-239
Sampling rate is 20 LPM (ICRP 23 Reference Man)
Sampling time is 60 minutes
Sample volume is 1.2E6 ml

If we sample a 1 DAC concentration for 1 hour we will collect 1 DAC-hr of activity on the filter.

1 DAC-HR =
Sampling rate x sampling time x Concentration

1.2E6 ml x 5E-12 uCi /ml x 2.22E6 DPM / uCi = 13.32 DPM

ICRP 23 Reference Man breathes at 20 LPM

Using the previous example, IF reference man breathes a 1 DAC concentration for 1 hour then the intake is 1 DAC-HR.

1 DAC-HR = 13.32 DPM inhaled

IF a CAM or FAS is sampling the same atmosphere as the person then the CAM or FAS filter activity will be a ratio of their sampling rates compared to Reference Man's breathing rate of 20 LPM.

$$\text{\# DPM on a FAS filter} = 13.32 \text{ DPM} \times \frac{\text{Sample flow rate}}{20 \text{ LPM}}$$

FAS filter DPM = 13.32 DPM x 56.6 LPM / 20 LPM = 37.7 DPM

HOWEVER, for this FAS sampling at 56.6 LPM whenever the activity on the filter reaches 37.7 DPM, then 1 DAC-HR of activity has been sampled.

This is true REGARDLESS of the airborne concentration and the sampling time ! !

THEREFORE, to determine the number of DAC-HRs on a filter all you need to know is the sampling rate and the DPM on the filter.

From a previous slide

1 DAC-HR for Reference Man for Pu-239 is 13.32 DPM.

$$1 \text{ DAC-HR on a FAS filter} = 13.32 \text{ DPM} \times \frac{\text{Sampler LPM}}{20 \text{ LPM}}$$

For a FAS sampling at 56.6 LPM

$$\#\text{ DAC-HRs on the FAS filter if the activity is 151 DPM} = \frac{\text{Filter DPM is 151}}{13.32 \text{ DPM} \times 56.6 \text{ LPM} / 20 \text{ LPM}} = 4.0 \text{ DAC-HR}$$

Clearance of Airborne Radioactivity Through Ventilation

Our nuclear facilities and other laboratory areas have a ventilation design criteria of 7 room volume changeovers each hour. That ventilation provides a way to clear airborne radioactivity from the room.

The following equation can be used to determine what the concentration in the room will be a some time after the initial event or how long it will take to clear the airborne radioactivity from the area.

$$C_T = C_0 \times e^{-0.693NT}$$

Where

C_T is the concentration at time ‘T’ after the “puff” release

C_0 is the concentration prior to time ‘T’

N is the # of air volume turnovers in 1 hour

T is the time after C_0 we want to calculate the new concentration for, ‘T’ is in hours

Example 1:

Shortly after a “puff” release you determine the present airborne radioactivity concentration is 2,000 DAC.

What will be the airborne concentration 30 minutes from now?

‘T’ = ½ hour

$C_T = C_0 \times e^{-0.693NT} = 2{,}000 \text{ DAC} \times e^{-0.693 \times 7 \times ½}$

$C_T = 2{,}000 \text{ DAC} \times e^{-2.43} = 2{,}000 \text{ DAC} \times 0.088 =$ **176 DAC**

Example 2:

Shortly after a “puff” release you determine the present airborne radioactivity concentration is 180,000 DAC.

How long to you have to wait before someone can re-enter the area wearing an APR which has a PF (protection factor) of 100?

$C_T = C_0 \times e^{-0.693NT}$

$C_T / C_0 = e^{-o.693NT}$

$100 / 180{,}000 = e^{-o.693x\ 7x\ T}$

Natural log $100 / 180{,}000 = -0.693 \times 7 \times T$

$-7.5 = -4.85T$

$T = -7.5 / -4.85 = 1.55$ Hours

Dilution of Airborne Radioactivity Through Dispersion

The following discussion is based on the assumptions of "puff" releases where the material is dispersed into the room quite rapidly and the SME has a general idea of the amount of material that was released.

Airborne Activity General Dispersion Model

Assume a 1 µCi (37 kBq) release of respirable Pu239 inside a large room measuring 12 x 12 x 3 meters with a ventilation turnover rate of 7 volumes per hour. The General Dispersion Model uses this 2π formula for volume.

$$V = 2/3 \times \pi \times R^3$$

Volume of the airborne			
Radioactive cloud in cm^3	5.65E4	2.09E6	2.09E9
@ distance R	30 cm	1 M	10 M
Concentration			
@ distance R			
in µCi / cc	1.77E-5	4.78E-7	4.78E-10
in Bq / M3	6.55E5	1.77E4	17.7
in DAC	8.85E6	2.39E5	239
Time for airborne			
wave front to reach R	13 sec	43 sec	7.15 min

Major Points to Consider for the General Dispersion Model

1 The airborne concentration within 30 cm of the release point is 30.5 times higher than the concentration at 1 meter and 37,000 times higher than the concentration at 10 meters. IF you are standing at the release point you can potentially inhale much more activity than your co-workers.

2 The time it takes for the airborne radioactive cloud to reach a CAM 10 Meters away is 7.15 minutes. IF you are standing at the release point you will not get a warning from the CAM for more than 7 minutes.

Activity in DPM vs Particle Size for Oxide Forms of Radioactive Material

	0.5µ	**1µ**	**5µ**	**10µ**	**50µ**
U234	8.7E-3	0.07	9	69.7	8700
U235	3.0E-6	2.4E-5	3E-3	0.02	3
U238	4.7E-7	3.8E-6	5E-4	3.8E-3	0.47
Np237	1.0E-3	8.0E-3	1.0	8	1000
Pu238	25	201	2.5E4	2E5	2.5E7
Pu239	0.09	0.73	91	730	9.1E4
Pu240	0.33	2.7	333	2670	3.3E5
Pu241	151	1210	1.5E5	1.2E6	1.5E8
Am241	5.1	41.1	5140	4.1E4	5.14E6

Air Sample Filter Media

- Typical filter media are Millipore SSWP, SMWP, Fluoropore, RW-19, and LB5211.

- The rated pore sized for the surface collection filters range from 1.2 microns to 5 microns. The particle collection efficiency is 100 % for particles $\geq$ the rated pore size. However, the particle collection efficiency for smaller particles down to 0.3 microns is greater than 99 %.
-
- The LB5211 filter media used on most FASs does not have a rated pore size but has a particle collection efficiency greater than 99.97 % for 0.3 micron and larger particles.
-
- The particle collection mechanisms of the filter media include; mechanical filtration, impaction, embedment, and electrostatic collection.

Calculating Activity vs Particle Size

1. Volume of the particle is $V = 1/6\pi d3$.
2. Use the density of the isotope from a standard reference.
3. Mass of the particle is $M = V \times \text{density}$.
4. Activity of the particle is $A = M \times \text{specific activity}$.

Correct the activity of the particle for the oxide form if you need to; the molecular weight of Pu238 is 238, multiply the calculated activity by 238/270 to get the activity of the dioxide form.

For particles larger than about 1µ the aerodynamic diameter is approximately equal to the physical diameter times the square root of the density. The 1µ particle in our example would have an equivalent aerodynamic diameter of 3.4µ (1µ x the square root of 11.46). This must be taken into account in air sampling/monitoring .

CAM Alarm Setpoints

This section provides a basic understanding of;

1. Calculating DAC-hr alarm setpoints for CAMs

2. Calculating concentration alarm setpoints for CAMs, and

3. Strategies for determining appropriate alarm setpoints for CAMs.

DAC-HR Alarm Setpoints for CAMs

From a previous slide
13.32 DPM of Pu-239 inhaled by an individual is 1 DAC-hr
Assuming a CAM sampling at 56.6 LPM

DPM on a CAM filter for1 DAC-HR of activity =
13.32 DPM x CAM Sampling Rate / 20 LPM =
13.32 x 56.6 / 20 = 37.7 DPM

Multiply the DPM by the CAM efficiency to get the CPM equivalent to 1 DAC-HR

37.7 DPM x 0.25 Eff = 9.425 CPM for 1 DAC-HR

An 8 DAC-HR alarm setpoint for this CAM would be 75 CPM

From a previous slide

DPM on a CAM filter for a 1 DAC-HR exposure =

20 LPM x 1E3 ml / L x 60 min x DAC factor x 2.22E6 DPM per uCi x CAM sampling rate / Reference Man breathing rate =
20,000 ml x 60 min x 2.22E6 DPM per uCi x CAM sampling rate / 20 LPM

Combining constants we get 1.332E11 x DAC factor x CAM sampling rate = # DPM on the filter for 1 DAC-hr

This lets us calculate the # DPM on a CAM filter for a 1 DAC-HR exposure to ANY radionuclide if we know its DAC factor.

From the previous slide
DPM on a filter for a 1DAC-HR exposure =
1.332E11 x DAC factor x CAM sampling rate

DAC factor	CAM Flow Rate LPM	DPM For 1 DAC-h	CAM Eff.	CPM For 1 DAC-h	CPM For 8 DAC-h

Example;

DAC factor for U-230 is	4E-11 uCi / ml
CAM sampling rate is	28.3 LPM
CAM Efficiency is	25%

Calculate the DPM on the filter for a 1 DAC-HR exposure

Calculate the CPM alarm setpoint for 1 DAC-hr

Calculate the CPM alarm setpoint for 8 DAC-hr

DPM on a filter for a 1DAC-HR exposure =
1.332E11 x DAC factor x CAM sampling rate

DPM on a filter for a 1DAC-HR exposure =
1.332E11 x 4E-11 x 28.3 = 151 DPM

CPM for a 1 DAC-HR alarm setpoint =
DPM x CAM Efficiency = 151 DPM x 0.25 = 38 CPM

Multiply 94 CPM by 8 to get the equivalent 8 DAC-HR alarm setpoint

DPM on a filter for a 1DAC-HR exposure =
1.332E11 x DAC factor x CAM sampling rate =
1.332E11 X 1E-10 x 28.3 = 377 DPM

CPM to equal 1 DAC-h = DPM x CAM Eff. = 94 CPM
CPM to equal 8 DAC-h = 8 x 94 CPM = 752 CPM

DAC factor	CAM Flow Rate LPM	DPM For 1 DAC-h	CAM Eff.	CPM For 1 DAC-h	CPM For 8 DAC-h
1E-10 uCi / ml	28.3	377	0.25	94	752

DAC Alarm Setpoints for CAMs

CPM on a filter to equal 1 DAC =
DAC factor x 2.22E6 DPM / uCi x 1E3 ml / L x CAM sampling rate x sample time in minutes x CAM Eff =

DAC factor x 2.22E9 x sampling rate x sample time x CAM Eff.

Example;

DAC factor for U-230 is	4E-11 uCi / ml
CAM sampling rate is	28.3 LPM
Sample time is	60 minutes
CAM efficiency is	25%

CPM for 1 DAC = 4E-11 x 2.22E9 x 28.3 x 60 x 0.25

CPM for 1 DAC = 38 CPM for a 60 minute sample time

Example:

CPM alarm setpoint for 1 DAC for a 30, 60, and 120 minute exposure.

CPM alarm setpoint for 8 DAC for a 30 , 60, and 120 minute exposure.

DAC factor	CAM Flow Rate LPM	Sample Time in Minutes	CAM Eff.	CPM For 1 DAC	CPM For 8 DAC
1E-10 uCi / ml	28.3	30	0.25	47	376
1E-10 uCi / ml	28.3	60	0.25	94	752
1E-10 uCi / ml	28.3	120	0.25	198	1,504

Establishing CAM Alarm Setpoints

Alpha 2 and 3 CAMs Maximum Indication is 5,000 CPM

Alpha 5 CAM Max Indication is 10,000 CPM

AMS-3 Beta CAM Maximum Indication is 100,000 CPM

Alpha6, Alpha7, Canberra Alpha Sentry, and AMS-4 Maximum Count Rate is ~ 500,000 CPM

Establishing CAM Alarm Setpoints

Use the calculations that appear later in this presentations for establishing appropriate CPM alarm setpoints for Alpha 2, 3, 5, and AMS-3 CAMs

The Alpha7, Canberra Alpha Sentry, and AMS-4 CAMs Alarm Setpoints can be set directly in their menus. These CAMs have both fast and slow alarms that can be used.

Establishing CAM Alarm Setpoints

The Alpha 6 uses a “sigma” multiplier as the alarm parameter.

The alarm will be annunciated by the Alpha 6 if the current Pu count rate is higher than the “sigma” multiplier times sigma. Sigma is basically the square root of the current net Pu CPM indication.

To determine the effective CPM alarm setpoint simply multiply the sigma multiplier by itself. That is, if the sigma multiplier is 6, then the effective alarm setpoint is 6 x 6 (36 CPM).

Calculations in Direct Support of the RWP

This section provides a basic understanding of calculations for;

1. Resuspension of loose surface contamination,
2. Concentration from DPM and sampler flow rate, and
3. Conversion of DPM / M3 to uCi / ml.

Resuspension of Loose Surface Contamination

The following discussion is based on the assumptions of "average" loose surface contamination with very little disturbing influences on the surface contamination. This calculation provides an initial estimate of the potential airborne radioactivity due to the concentration of the loose surface contamination. You should anticipate that the airborne concentration will increase if people are working in the area. However, you should also consider the influence of local ventilation on the dilution or the unintended increased resuspension of the airborne radioactivity.

Use a Resuspension factor of 5E-6 / M

Concentration =

$$\frac{\text{\# DPM}}{100\ \text{cm}^2} \times \frac{\text{5E-6}}{\text{M}} \times \frac{\text{1 M}}{\text{100 cm}} \times \frac{\text{uCi}}{\text{2.22E6 DPM / uCi}}$$

uCi / ml = # DPM x 2.25E-16

Example :
1,500 DPM / 100 cm2 average Pu-239 contamination

uCi / ml = 1,500 x 2.25E-16 = **3.375E-13 uCi / ml**

$$\text{\# DACs} = \frac{\text{3.375E-13 uCi / ml}}{\text{5E-12 uCi /ml per DAC}} = \textbf{0.0675 DAC}$$

Calculating Concentration from DPM on a Filter

$$\textbf{uCi / ml} = \frac{\text{\# DPM on the filter}}{\text{sample rate in ml/min x sample time in min x 2.22E6 DPM/uCi}}$$

Example:
Assume 1,400 DPM on the filter,
2 CFM sample rate, and
one hour sample time

$$\textbf{uCi / ml} = \frac{\text{1,400 DPM on the filter}}{\text{56,600 ml / min x 60 minutes x 2.22E6 DPM/uCi}}$$

$$\textbf{uCi / ml} = \frac{\text{1,400 DPM on the filter}}{\text{7.54E12}} = \text{1.86E-10 uCi / ml}$$

Calculating # DACs from DPM on a Filter

$$\textbf{\# DACs} = \frac{\text{Concentration in uCi / ml}}{\text{DAC factor in uCi ml}}$$

Example:
Assume 1.86E-10 uCi / ml
DAC factor is 5E-12 uCi / ml per DAC

$$\textbf{\# DACs} = \frac{\text{1.86E-10 uCi / ml}}{\text{5E-12 uCi / ml per DAC}} = 37 \text{ DAC}$$

Conversion of DPM / M^3 to uCi / ml

Example:
Concentration is stated as 4.44 DPM / M^3

$$\textbf{uCi / ml} = \frac{4.44 \text{ DPM} / M^3}{2.22E6 \text{ DPM} / \text{uCi} \times 1E6 \text{ ml} / M^3}$$

uCi / ml = 2E-12 uCi / ml

Self Assessment

As an SME you should be able to calculate the appropriate CPM alarm setpoints for both DAC-HRs and DAC.

Remember that DAC-HRs is directly related to DPM on the filter and the sampling rate. The duration of the sampling time and the actual airborne concentration are NOT needed to calculate the DPM setpoint for DAC-HRs.

The duration of the sampling time IS needed to calculate the appropriate DPM alarm setpoint for the # of DACs you want to detect. You MUST take the sampling time into consideration to establish an alarm setpoint.

Calculate the CPM alarm values for the various DAC-h levels.

DAC factor	CAM Flow Rate LPM	DPM For 1 DAC-h	CAM Eff.	CPM For 1 DAC-h	CPM For 8 DAC-h
2E-12 uCi / ml	30		0.35		
5E-13 uCi / ml	42		0.28		
6E-7 uCi / ml	56		0.36		
7E-9 uCi / ml	28.3		0.22		

Calculate CPM alarm values for various DAC concentrations.

DAC factor	CAM Flow Rate LPM	Sample Time	CAM Eff.	CPM For 1 DAC	CPM For 100 DAC
3E-12 uCi / ml	56.6	30 min	0.33		
3E-12 uCi / ml	42	60 min	0.27		
3E-12 uCi / ml	30	120 min	0.38		
3E-12 uCi / ml	45	90 min	0.28		

TYPES OF SAMPLES

Particulates

Air sampling for particulates includes both solid and liquid aerosols. The particulates may be radioactive, toxic, nuisance, or a combination of these characteristics. It is important to know the particle size distribution of the aerosols. Further the density of the particles must be taken
into account.

Gases

Air sampling for gases may be for radioactive, toxic, nuisance, or oxygen deficient atmospheres or a combination of these characteristics. The gases sampled are single molecules but may be heavier than air.

Special Cases

Air sampling may involve both particulates and gases in the same sample. There are radioactive isotopes that are gases but have particulate progeny. Those progeny initially exist as single molecules but will quickly agglomerate onto dust particles in the air, then they react as true particulates for air sampling purposes. However, before those particulate progeny do agglomerate onto dust particles they will react more like gas molecules which will affect the sampling technique required.

Special Cases

Vapors of metals or organics may change to particles as they cool or as they react with the atmosphere.

II SAMPLE COLLECTION AND ANALYSIS METHODS

A. Passive and Diffusion

B. Flow Through

C. Grab

D. Filtration

E. Absorption and Adsorption

F. Bubblers

G. Impactors

H. Particle Separators

I. Affect of Sample Inlets on Collection

A. Passive and Diffusion

Passive and diffusion sampling of air requires the substance being sampled to come into contact (or near contact) with the container, collection media, or detection assembly.

An example is the Electret for sampling radon and thoron. A charged disc is placed inside a container which has an opening through which air can migrate.

The radon and thoron in the air will ionize the air inside this container due to the radioactive decay of these gases and their progeny. The ionization of the air then causes the charged disc to lose part of its charge. When the Electret is collected later the remaining charge on the disc is determined and the amount of charge lost is related to the radon and thoron concentration of the air the Electret was exposed to.

B. Flow Through

Flow through chamber applications include sampling for radioactive substances, both gas and particulate.

When sampling for radioactive substances the typical flow through chamber is a version of the air ionization chamber used for the detection of gamma detection. The actual gamma radiation background must be subtracted from the total signal level to determine the concentration of the radioactive substance.

C. Grab

The basic technique in grab sampling is to cause the air to be sampled to flow through or into the collection container.

This can be accomplished by using a pump and when the container is sufficiently purged simply close the outlet and inlet valves on the container.

Another technique used is to fill the sampling container with water and when the inlet and outlet valves are opened the water flowing out draws the air to be sampled into the container.

D. Filtration

Filtration is the most widely used method for collecting samples of aerosols.

The methods and equipment range from high volume samplers (up to about 40 cfm) for environmental or short-term workplace sampling, to low-volume lapel samplers (6 lpm or less) for collecting aerosols in the breathing zone of individual workers.

Low-pressure-drop, cellulose filters are commonly used, and samples can be easily reduced to ash or dissolved for analysis without the filter material interfering with the analysis.

Concerns for penetration of particles into the filter matrix are a function of the type of filter and the filter analysis method. Membrane filters with their superior front-surface collecting characteristics are preferred over fiber-type filters when alpha particle spectroscopy is applied. Shielding by the filter media is seldom a concern for detection of gamma radiation.

Filter Media Characteristics for Alpha CAMs

Filter Type	Pore Size	dP	FWHM keV
Millipore			
Fluoropore	5 um	0.5"Hg	370
Fluoropore	3 um	0.8"Hg	300
SMWP	5 um	2.0"Hg	450
SSWP	3 um	3.1"Hg	350
AW19	1.2 um	3.8"Hg	450
Durapore	5 um	4.3"Hg	490
AP40	0.7 um	2.6"Hg	490
Bladewerx			
Speclon 1.5	1.5 um	2.6"Hg	300
Speclon 5.0	5 um	0.4"Hg	370
Whatman			

Filter Media Characteristics for Alpha CAMs

Filter Type	Pore Size	dP	FWHM keV
Bladewerx			
Speclon 1.5	1.5 um	2.6"Hg	300
Speclon 5.0	5 um	0.4"Hg	370
Whatman			
GFA	0.3 um	2.8"Hg	490
EPM 2000	0.6 um	1.8"Hg	1,000
Gelman			
A/E Glass	1.0 um	2.3"Hg	1,000
Versapor 3000	3.0 um	2.3"Hg	450
Hollingsworth & Vose			
HV LB5211	0.3 um	1.0"Hg	650

The rated pore size is for >99.99% collection efficiency for that size particle and greater. All of these filters have >99% collection efficiency for particles as small as 0.3 um. The stated pressure drop is for a 40 mm collection diameter with an air flow rate of 2 ACFM and barometric pressure of 23.1"Hg. The FWHM is for Po-214 at 7.68 MeV and was determined using a 25 mm collection diameter and a 25 mm diameter diffused junction detector with a spacing of 4 mm.
The pressure drop will be higher and the FWHM will be broader at higher barometric pressures.

Absorption and Adsorption

Absorption and adsorption are both used in air sampling and are sometimes hard to distinguish from each other.

Absorption is a process in which atoms, molecules, or ions enter some bulk phase - a gas, liquid, or solid material.

Adsorption is a process in which a gas or liquid aerosol accumulates on the surface of a solid or liquid, forming a film of molecules or atoms. Sorption refers to both absorption and adsorption while desorption is the reverse of either process.

Anhydrous calcium sulfate is an example of absorption where water vapor (or tritium oxide) is collected by passing an air stream through a cartridge containing the anhydrous calcium sulfate. The moisture content of air can then be measured by gravimetric or other methods and tritium oxide in the air can be measured directly or indirectly using either a radiation detector or liquid scintillation counting.

Silica gel, zeolites, and activated charcoal are examples of adsorption where toxic or radioactive substances are collected by passing an air stream through a cartridge containing one of these materials. The radioactive substances collected by these materials can be measured directly or indirectly using radiation detectors. Toxic substances collected by these materials are typically extracted from the materials before they are measured.

Bubblers

Bubblers consist of a vacuum pump and a liquid container which has an inlet tube going to near the bottom of the bubbler. The vacuum pump pulls air to be sampled into the inlet tube and the air goes through the tube to the bottom of the liquid container where the air “bubbles” into the liquid and rises to the top of the liquid container where the air is drawn off by the vacuum pump. Water is the typical liquid used but other liquids may be used depending on what substance is desired to be collected.

Bubblers are used to collect both gases and aerosols and these may be radioactive or toxic gases and aerosols.

In some cases real-time analysis of the substances being collected are possible by using chemicals in the liquid which will react with the substances being collected.

The substance collected in the liquid may be analyzed at some later time also.

An example of a bubbler sample collection technique is the elemental tritium and tritium oxide bubbler. Elemental tritium is used in several applications and must be adequately monitored for in order to apply safety controls. Elemental tritium is not as hazardous as tritium oxide but elemental tritium quickly converts to the oxide form upon exposure to the atmosphere. Typically the air being sampled is drawn through a series of collection vials with an appropriate liquid in them and the tritium oxide is effectively collected in those vials but the elemental tritium passes through them.

The air stream is then directed to a catalyst and heater section where the elemental tritium is converted into tritium oxide. From there the tritium oxide (which was elemental tritium just before) is drawn through another set of collection vials identical to the first set. The first set of vials contains the tritium oxide from the original sample while the second set of vials contains the elemental tritium which was converted to the oxide form. When the contents of the vials are analyzed a measurement of elemental tritium and tritium oxide can be derived.

Impactors

Impactors are used to collect aerosols, either solid or liquid particles. A vacuum pump pulls air through a opening small enough to increase the velocity of the air stream to a level such that large particles in the air cannot deviate from their straight flight and therefore "impact" on a plate. Smaller particles can go around the impactor plate because they have less kinetic energy than the larger particles. Multiple impactor plates in series and with higher and higher air velocities separate the particles in distinct size ranges.

The cascade impactor and the Andersen sampler are examples of impactor particle collection techniques.

Particle Separators

Cyclone separators use a method similar to impactors in that the larger particles cannot follow the main air stream at some velocities. The large particles then drop out the bottom of the cyclone separator while the air stream with much smaller particles go out the top of the cyclone separator.

Just as with multi-stage impactors, multi-stage cyclone separators can be used to collect a range of particle sizes.

Affect of Sample Inlets on Collection

The design of the sample inlet is critical to the efficacy of the collection system.

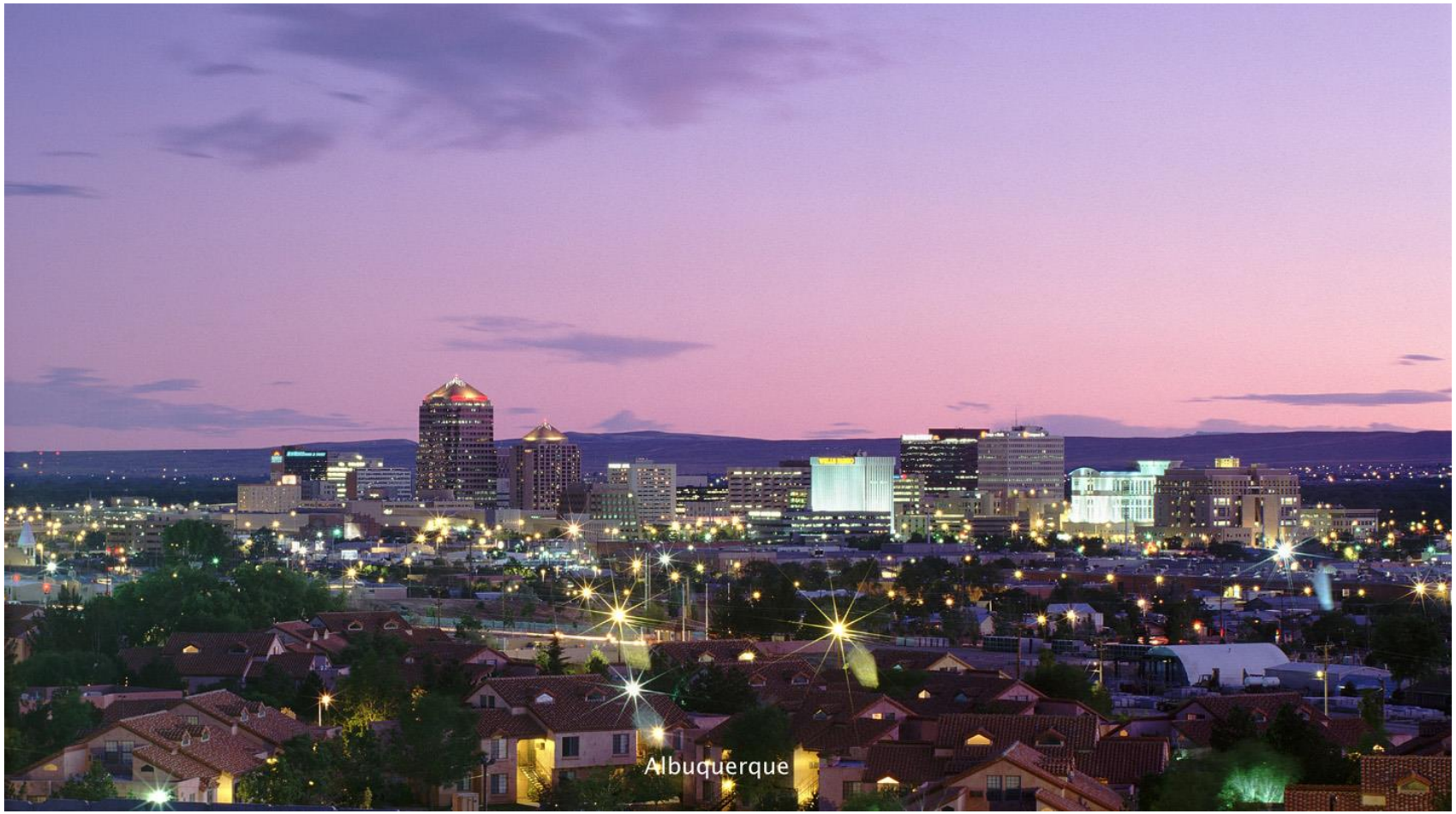
The use of non-conductive materials should be avoided for the collection of aerosol particles due to electrostatic collection of those particles on the sample inlet before they get to the point of collection.

The use of non-reactive materials should always be used regardless of whether sampling for gases or aerosols.

The length, inside diameter, and bends in the sample inlet should be sized so as to minimize loss of any of the sample in the sample inlet itself.

Calculations should be performed on transport velocities to ensure that the collection of aerosols remains isokinetic throughout the sampling system.

Air Sampling in Nuclear Facilities



DAY 1 – Fundamentals of Air Sampling