*i*CAM - The intelligent Continuous Air Monitor

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iCAM Technical Training

- Introduction to iCAM
- The Rn Compensation Algorithms
- iCAM Performance
- iCAM Configuration Parameters
- Results Downloading & Interpretation
  - Archive download, conversion and plotting
  - Spectra - downloading, plotting and interpretation

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i CAM - The intelligent CAM

- A light & compact integrated unit
  - stand alone or network operation
- All the required facilities on board for alpha & beta activity monitoring plus optional gamma dose rate, alarms, data logging, communications & setup
- Innovative features, including
  - sophisticated Rn compensation (pat.pending)
  - Live spectrum display & trend graphs
  - Radon/Thoron reporting
  - Long term low level measurements
  - Support for optional G64 Gamma detector

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i CAM - Headline Features

- Simple to use - Power on & go
  - Calibrations automated
  - No setup of compensation mechanism
- Rn compensation adapts to difficult conditions
- Comprehensive alarm & output facilities
  - ability to set alarms on 3 timescales
- Graphical display view of data trends and spectra
- Rn/Th and gamma background reporting
- True ambient gamma doserate option
  - with add-on G64 detector
- Stack/duct discharge & discharge rate monitoring
  - preset stack flow rates, or optional 4-20 mA stack flow rate input

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iCAM - Instrument Features

- Top air inlet with high collection efficiency onto the filter
- Local alarm indications by highly visible light stack, and 2 tone sounder
- User information & interaction via
  - Graphical display
  - Alarm & status lights
  - Power & operational lights
  - User functions keypad
- Air outlet at top or bottom
  - user selectable
- Power and connections at bottom
  - via glands or connectors

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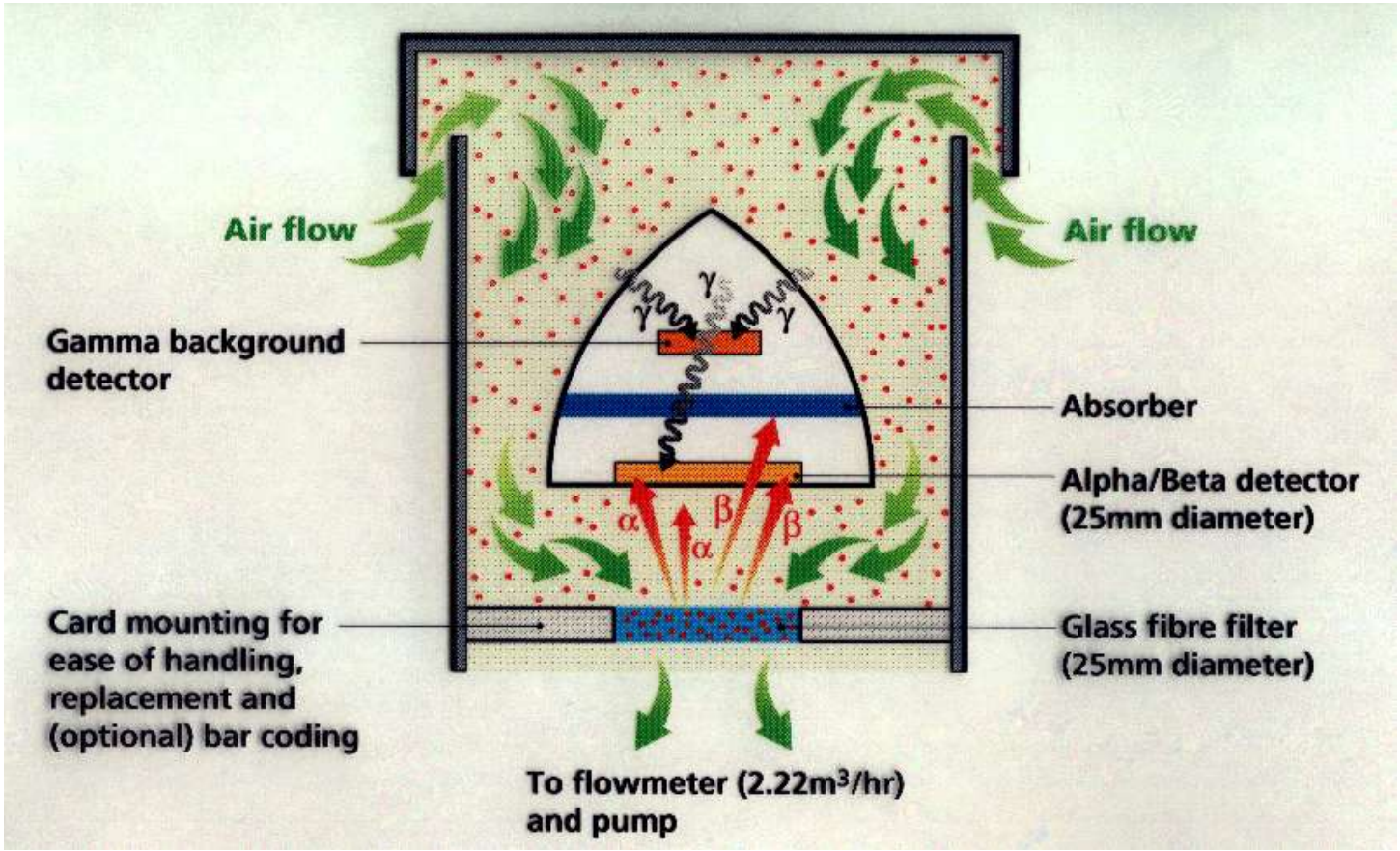
Air Sampling



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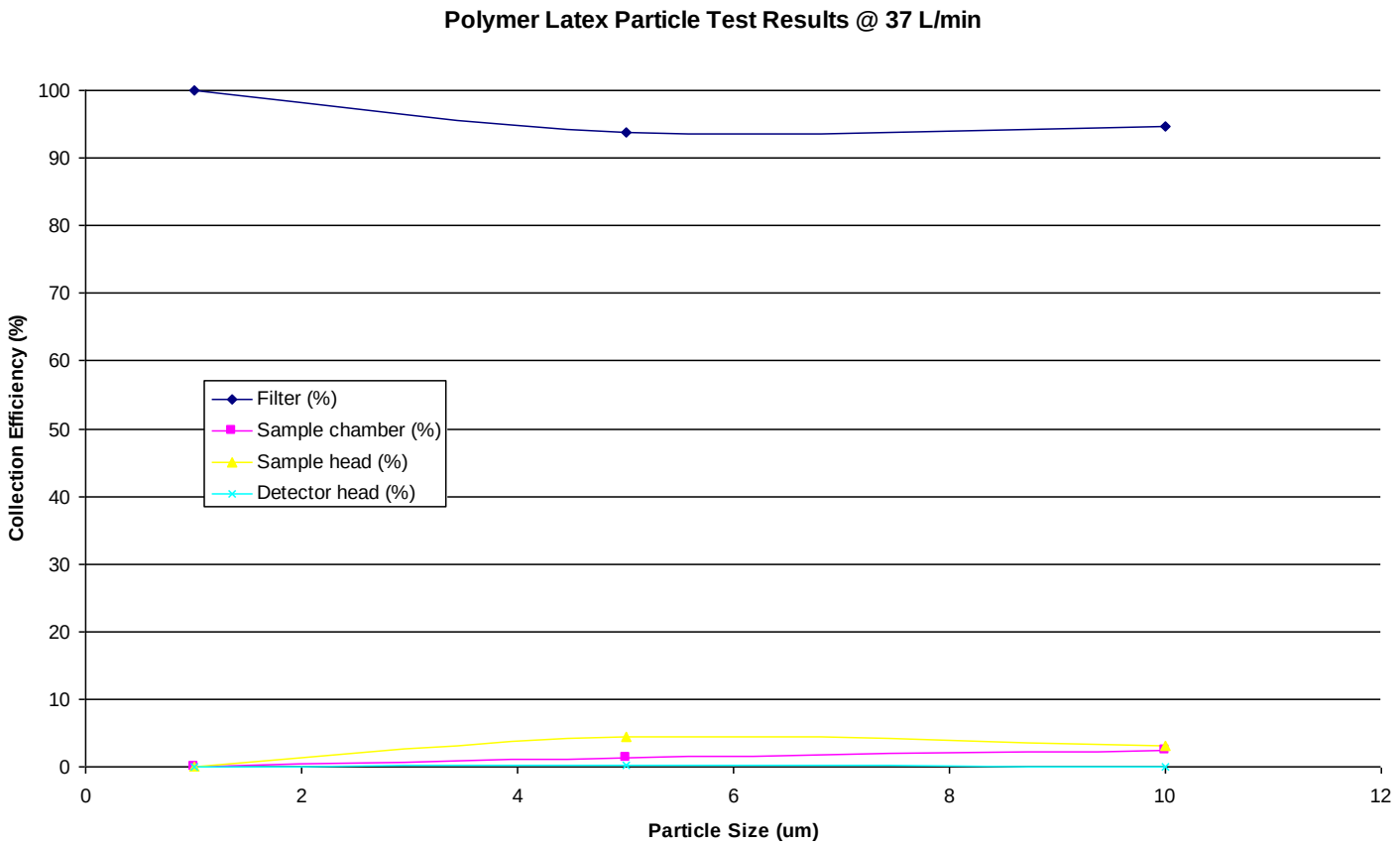
Sampling Nozzle Performance



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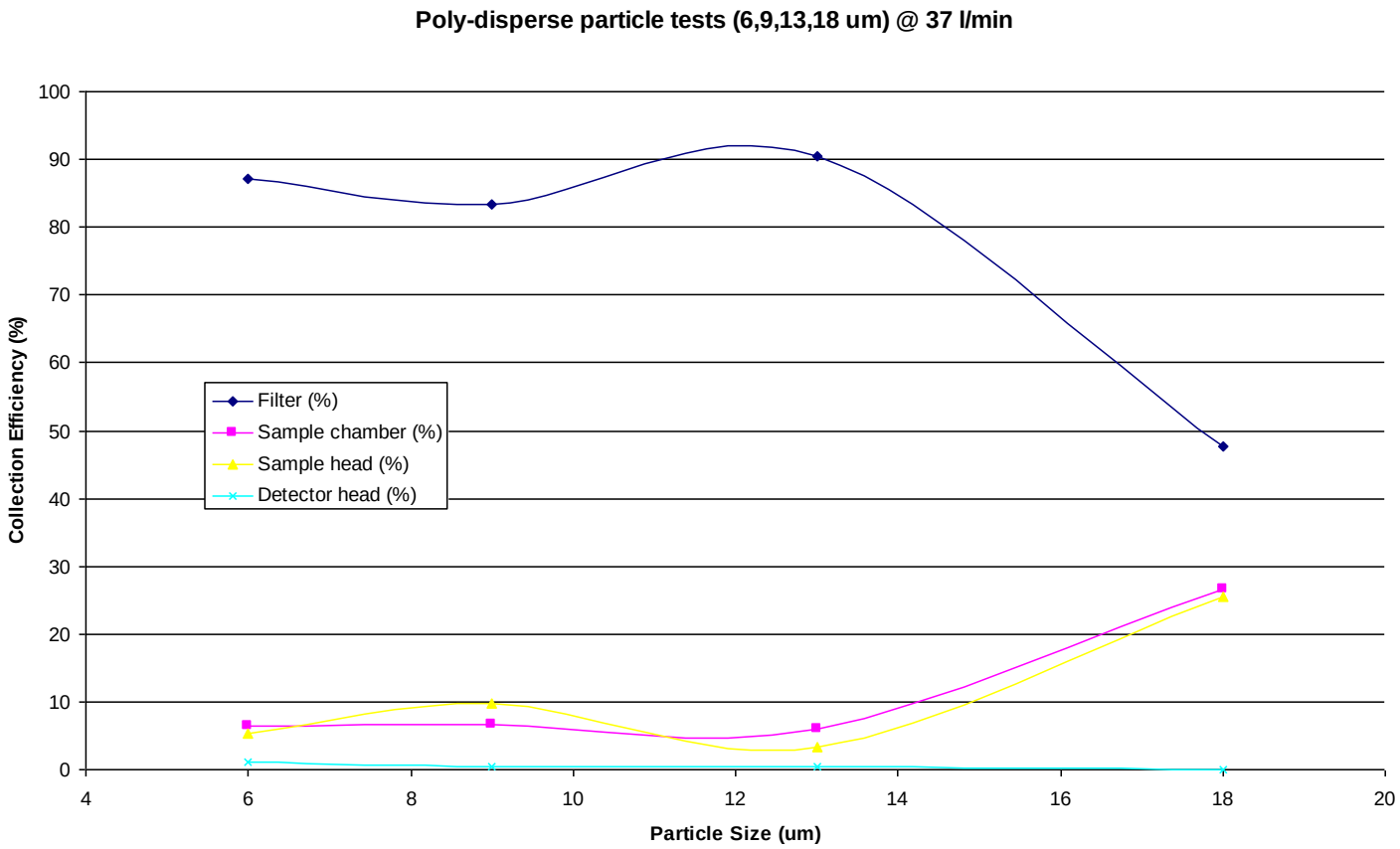
Sampling Nozzle Performance



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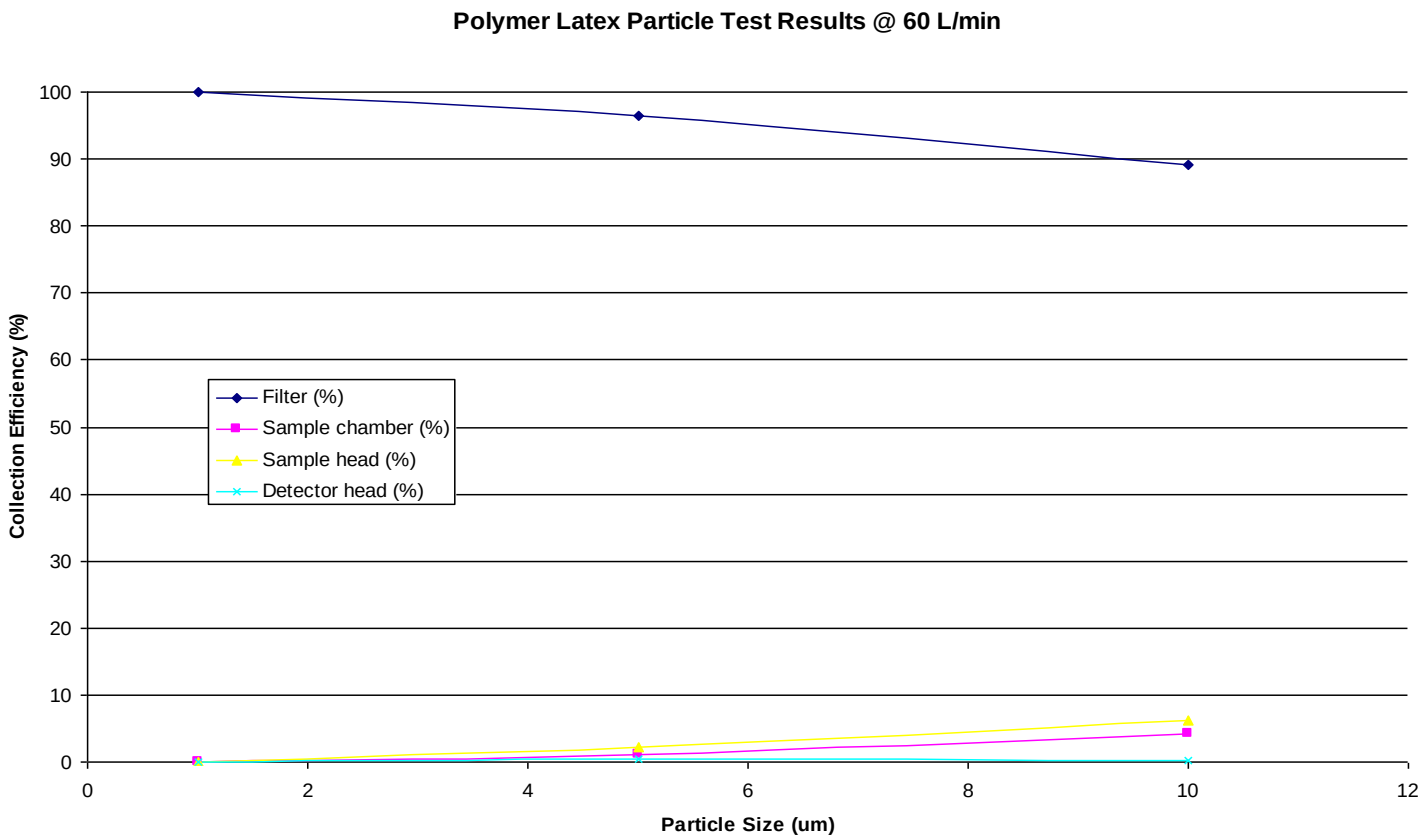
Sampling Nozzle Performance



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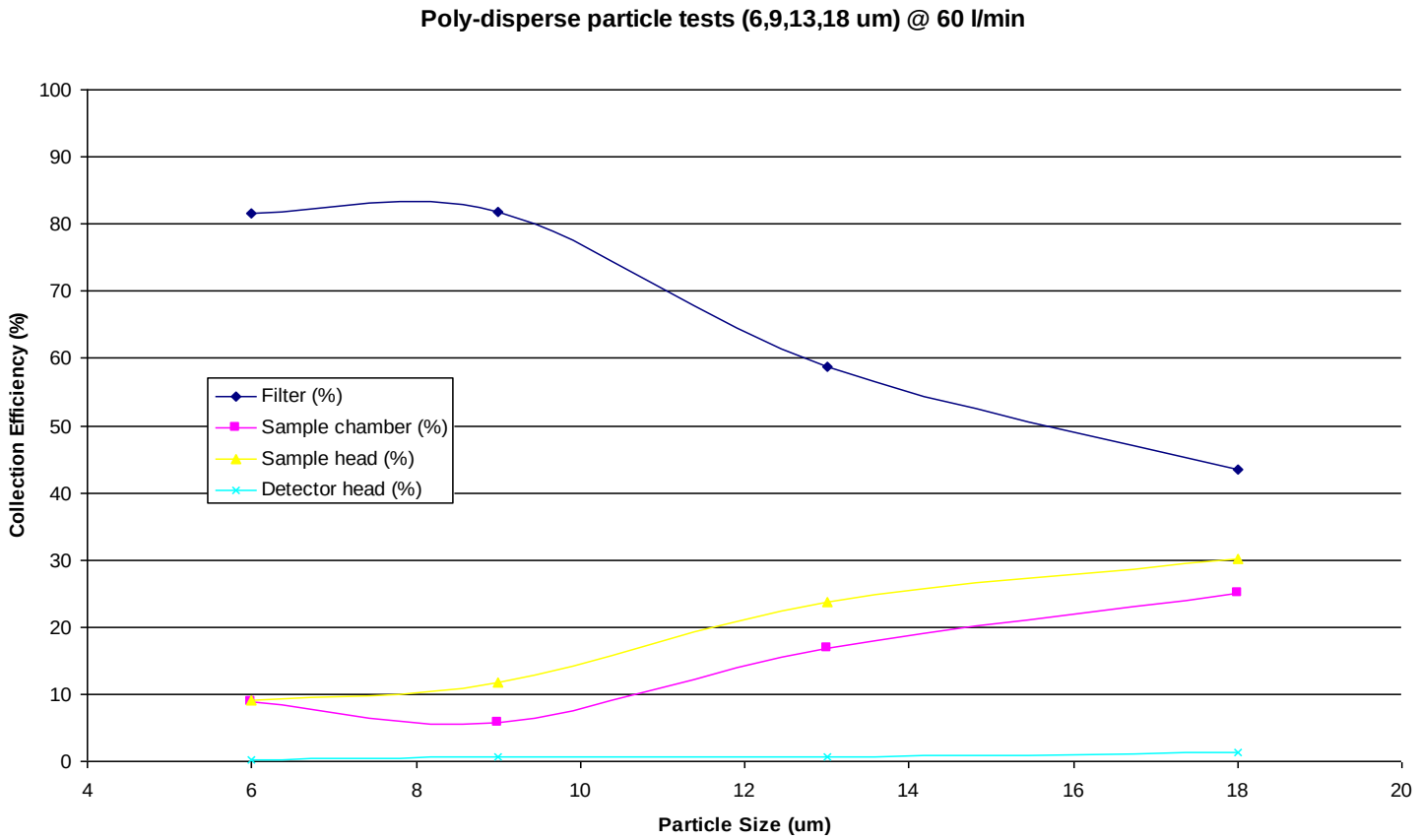
Sampling Nozzle Performance



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Detection Requirements

- To detect hazardous levels of respirable alpha and beta emitting particulates in air
- The Alpha Hazard
  - 1 DAC of $^{238, 239, 240}Pu$ & ^{241}Am = 0.1 Bq/m^3
    - (2000 DAC hrs = 1 Annual Limit of Intake)
  - 1 DAC of ^{235}U = 0.7 Bq/m^3
  - 1 DAC of ^{242}Cm = 4 Bq/m^3
- The Beta Hazard
  - 1 DAC of mixed fission products (typ) = 117 Bq/m^3

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Measured Activity

- Instrument measures activity on the filter
  - A (Bq) = C/E
    - C = signal count rate (cps) E = efficiency
- Integrated activity concentration is calculated
  - IAC (Bq hrs/m^3) = A/F
    - F = sample flow rate
    - Divide by the DAC value to give DAC hrs
- Activity concentration is calculated:
  - AC (Bq/m3) = (IACT+DT - IACT)/DT
    - DT = Difference Time, normally 1 hour
    - Divide by the DAC value to give DACs

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Activity on the Filter

- After 1 hr at 1 DAC (0.1 Bq/m^3), ^{239}Pu activity on filter = 0.22 Bq, giving 0.062 cps, or 3.7 cpm
- Typical Radon count rates are 500 cpm, with up to 10,000 cpm in poorly ventilated areas
- Alpha Spectrometry is used to separate Radon from activity of interest in a 256 channel MCA

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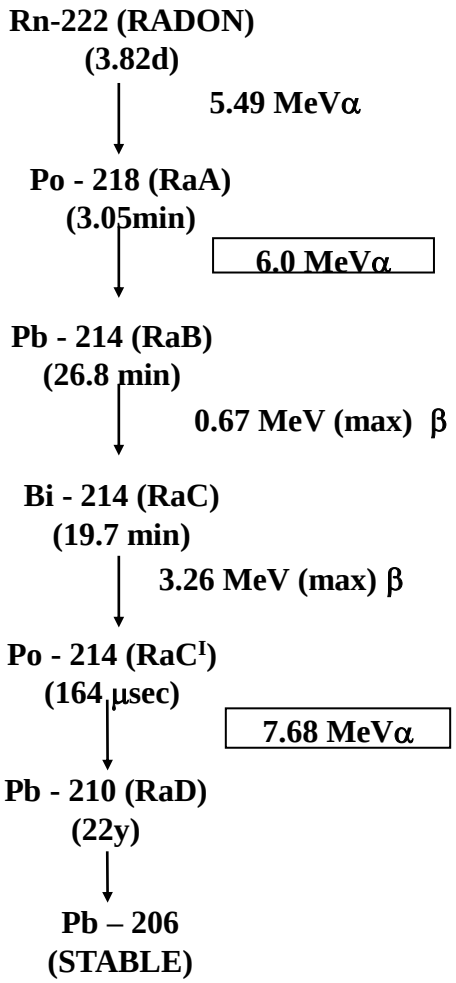
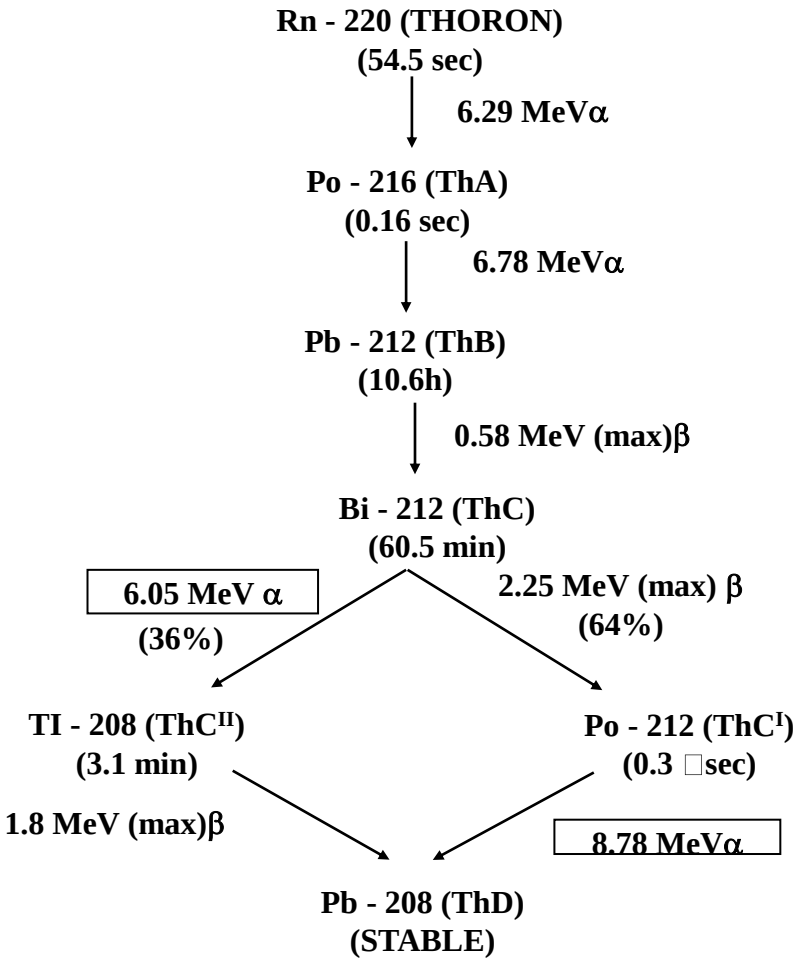
Radon & Thoron Decay





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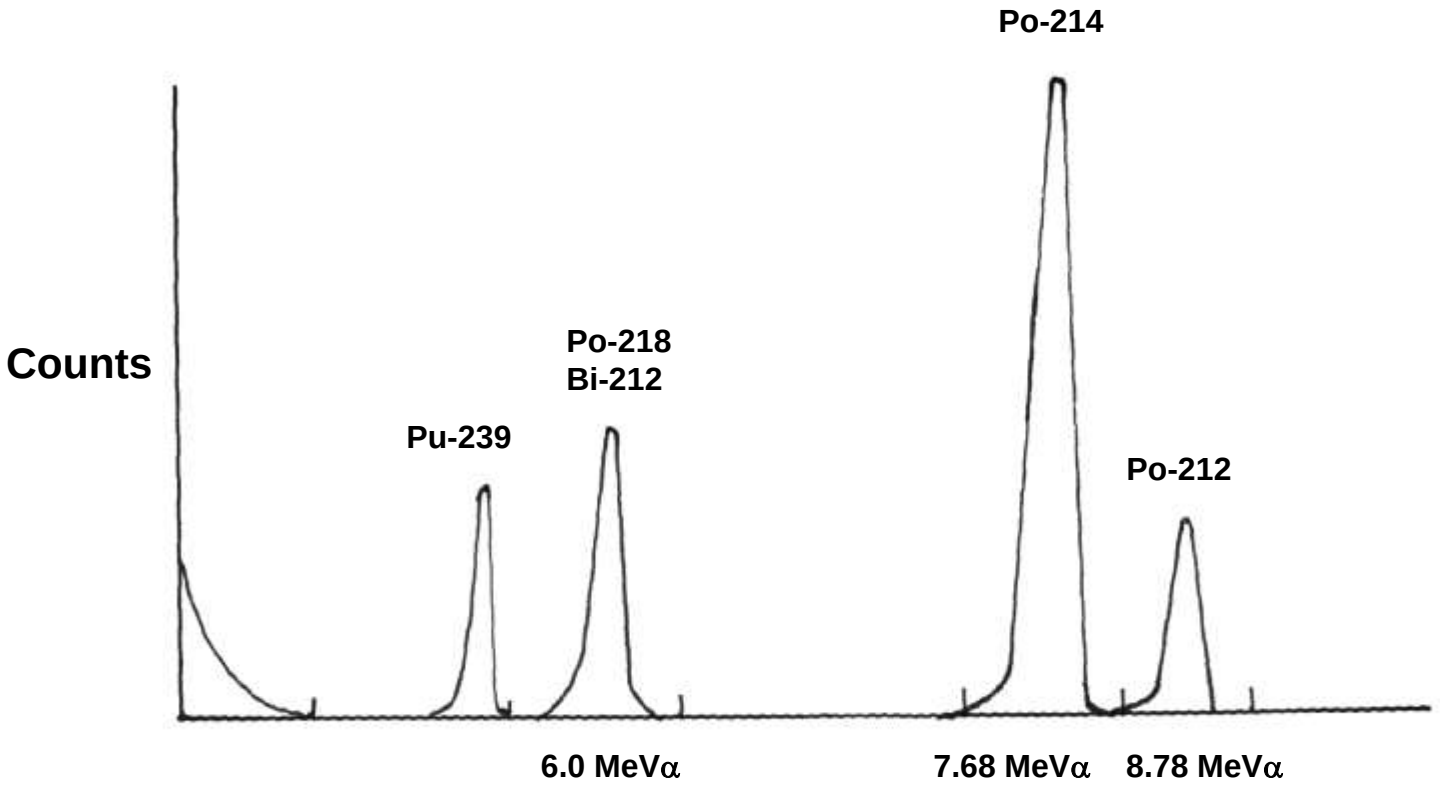
Idealised Filter Spectrum



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Energy Loss Mechanisms

- Self absorption in material on the filter
  - minimised by use of GFA filter
- Variable path length in air (5 to ~26 mm)
  - (approx. 100 keV/mm initially, rising at low energies)
- Variable path length through detector varnish/surface layer

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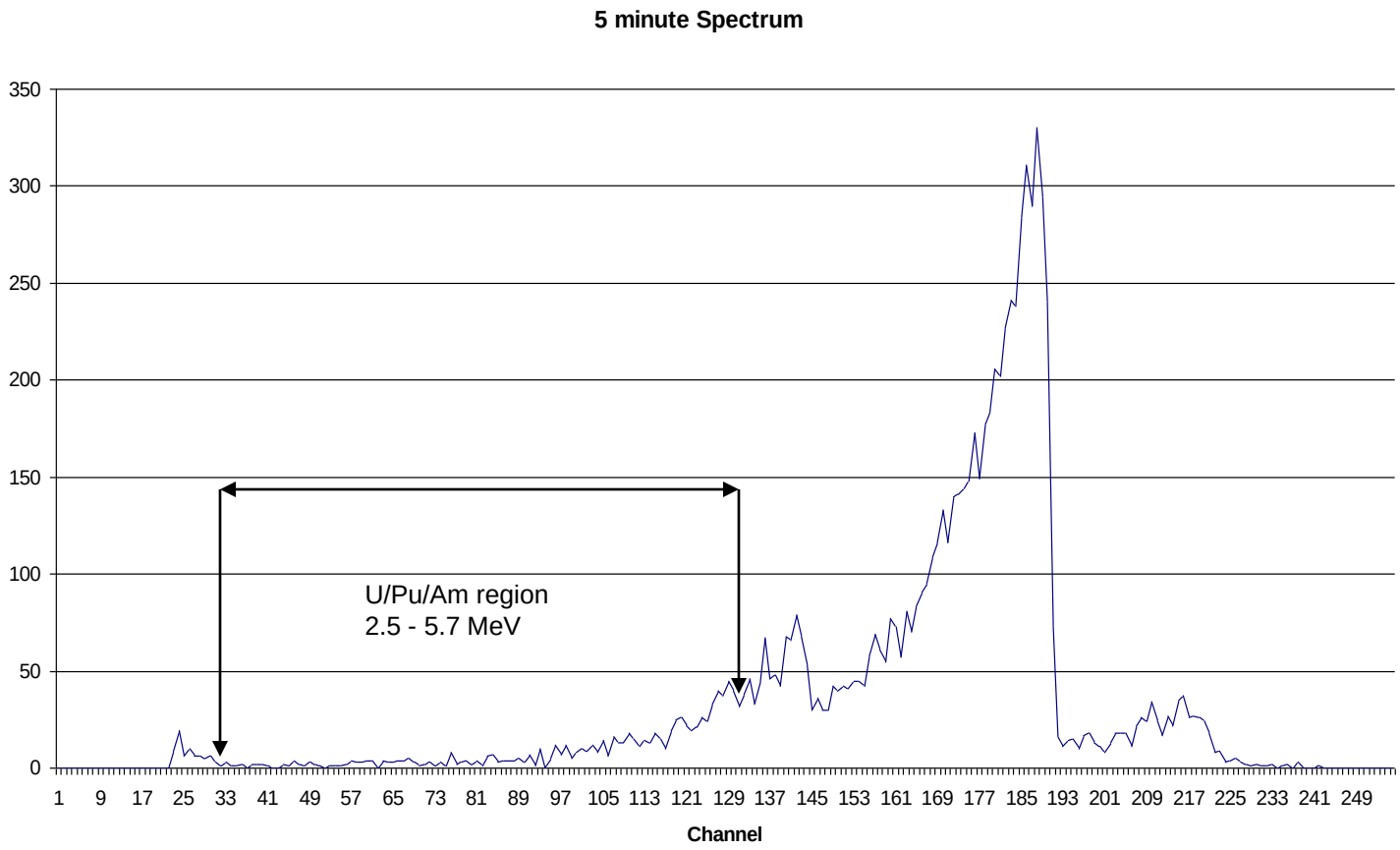
Typical Filter Spectrum



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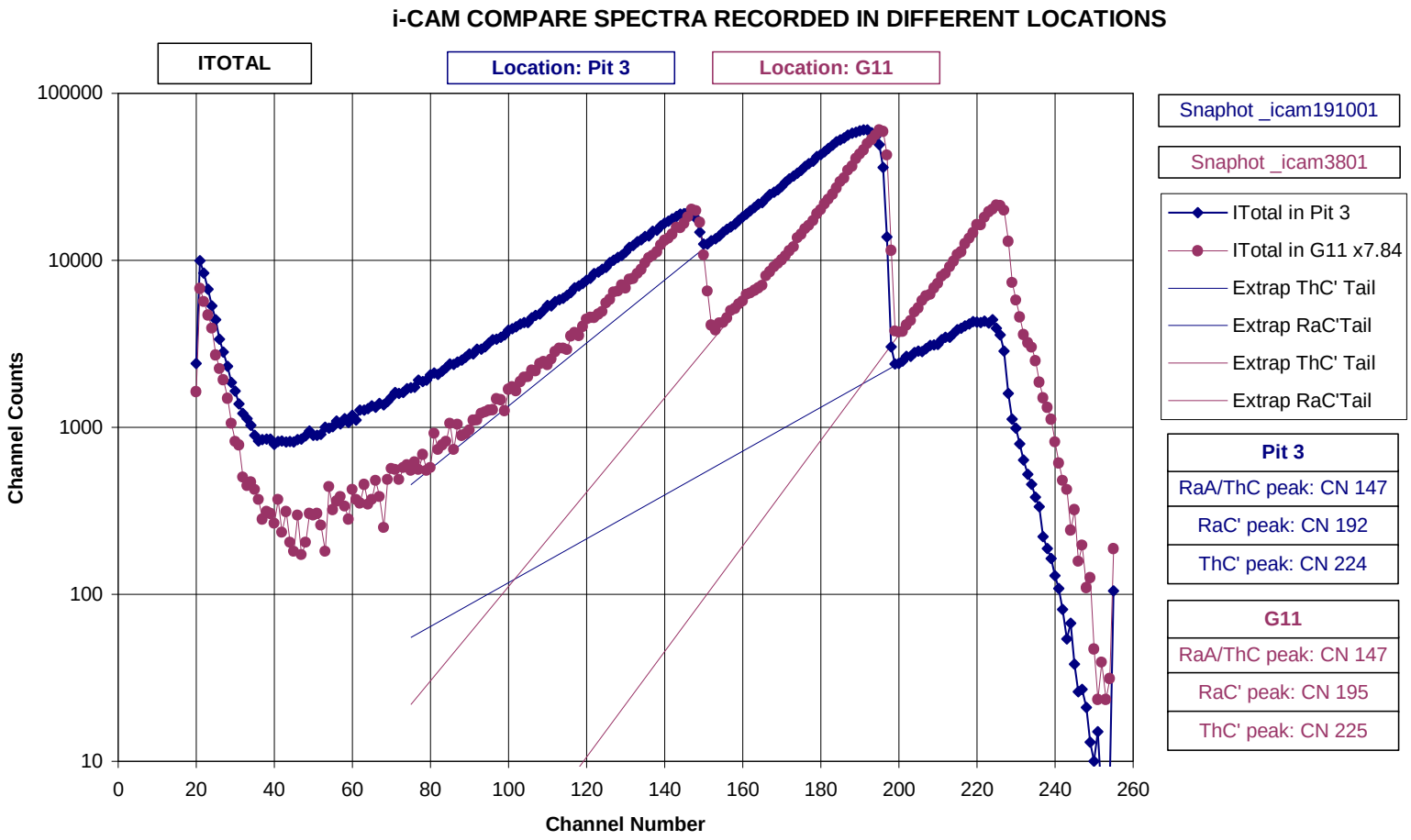
Spectrum Shape Changes



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Radon/Thoron Compensation

- Filter spectrum captured over typically 5 min for activity measurement ***and*** 1 hour for shape analysis
- Patented algorithm does successive exponential fit & strip to remove each component of the background individually
  - Adapts to changes in levels of individual components,changes in the attached/unattached fraction, changes in spectrum shape due to time, filter loading, particle size etc
- Results:
  - lower alarm levels & lower false alarm rate, especially in difficult conditions
  - extended filter lifetime
  - ability to make measurements and set alarms over long timescale simultaneously with the foreground measurement

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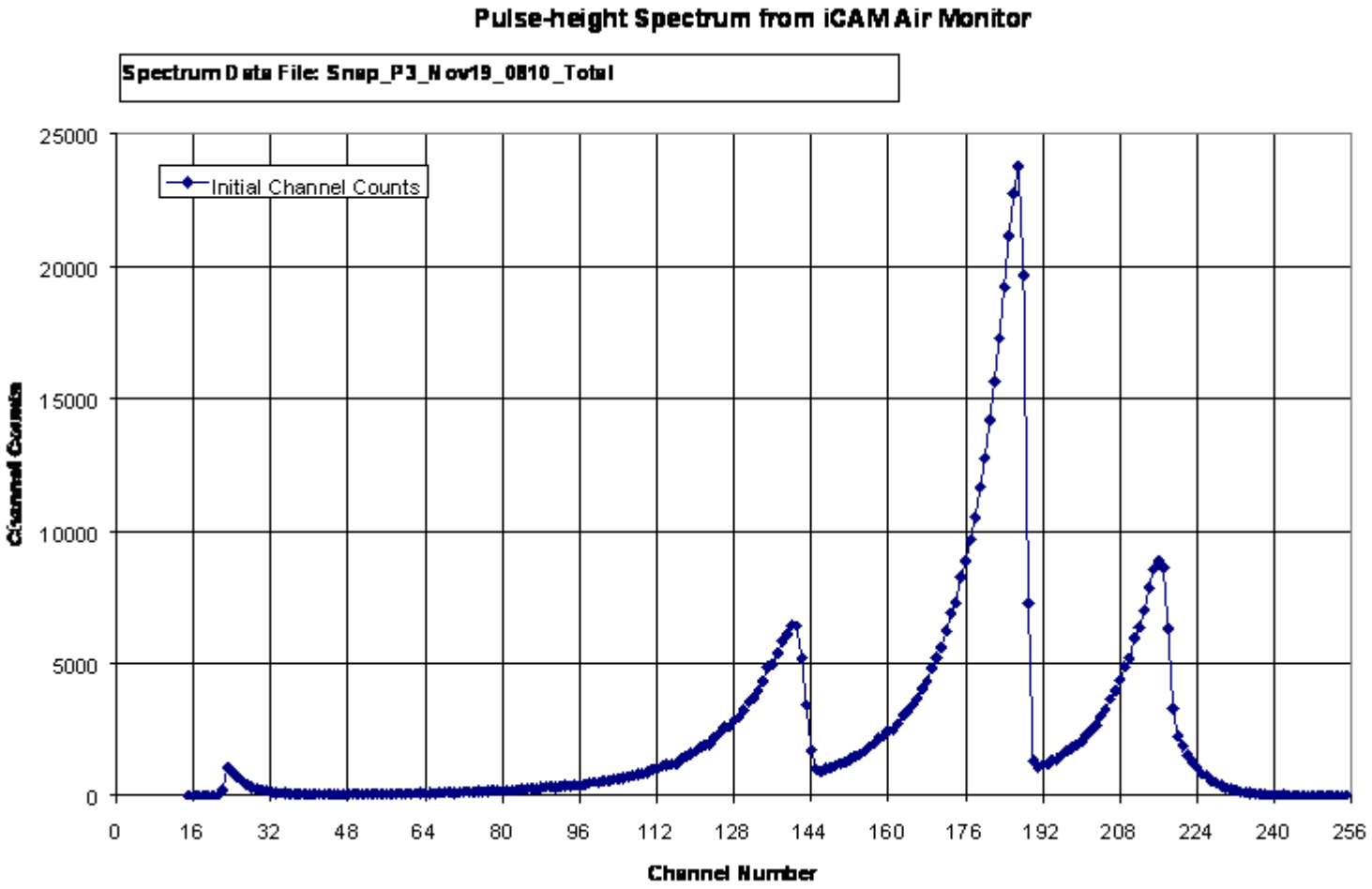
Spectrum Stripping: Raw Spectrum



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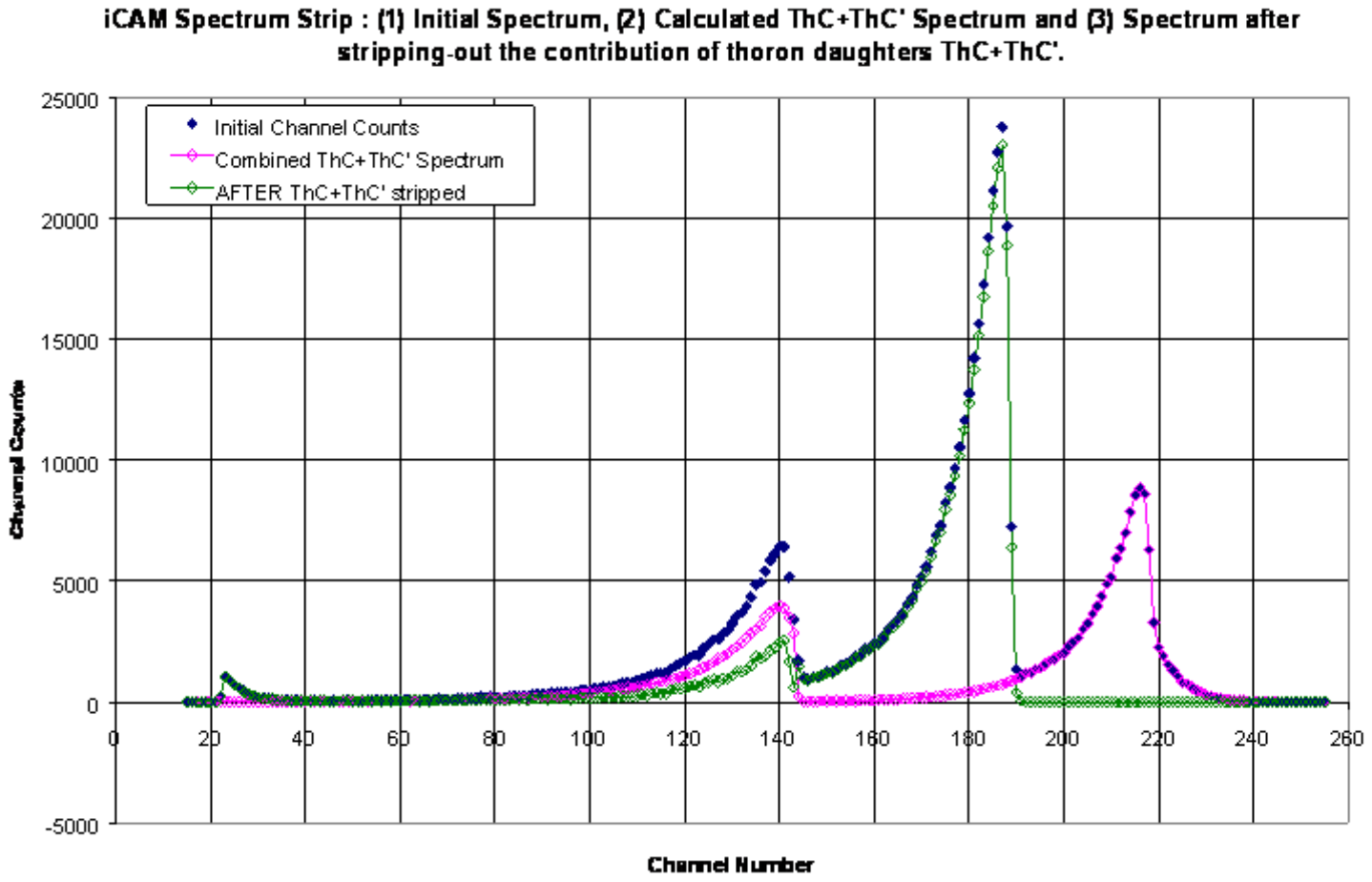
First Stage Strip



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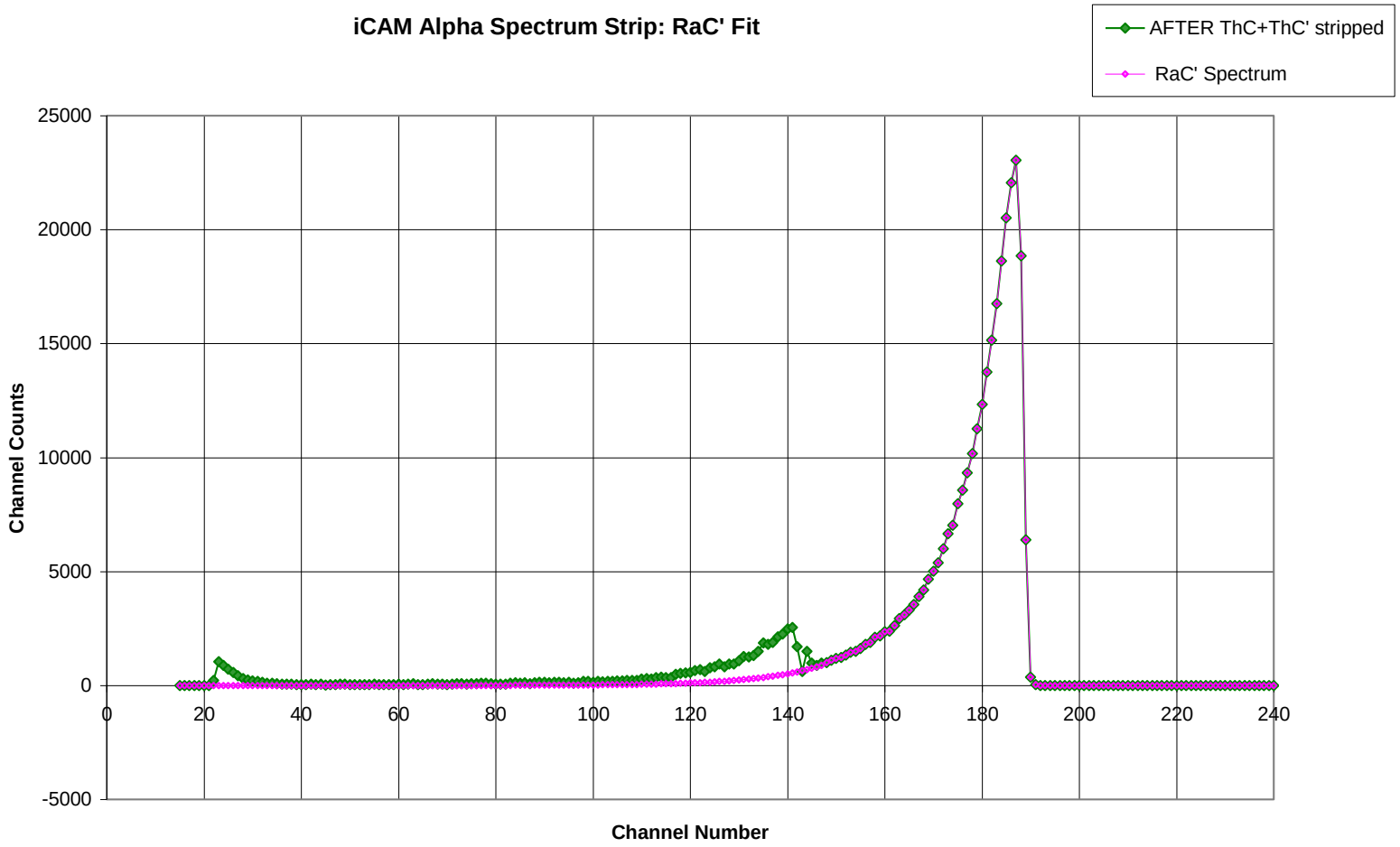
^{214}Po (RaC') Peak Fit



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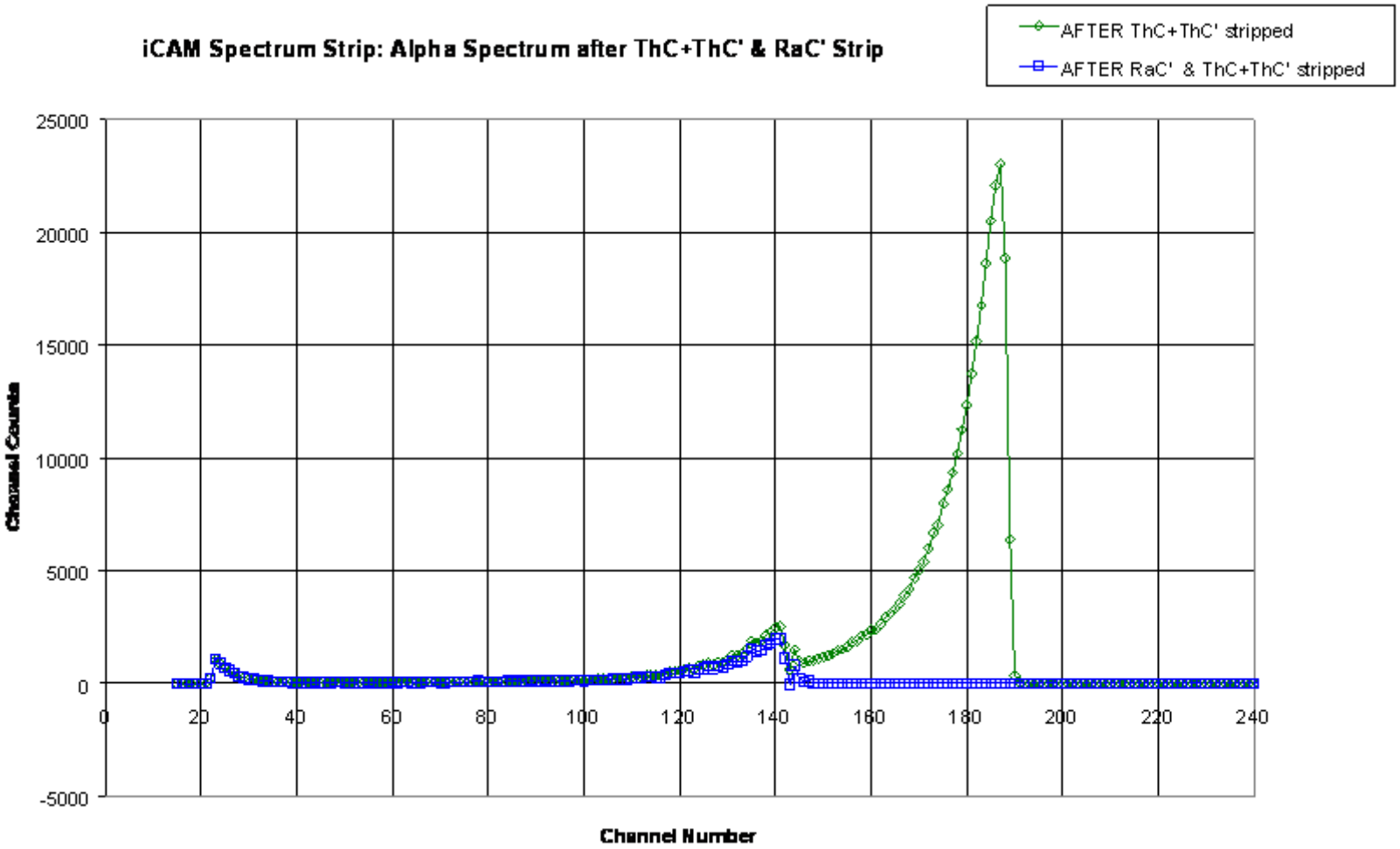
Second Stage Strip



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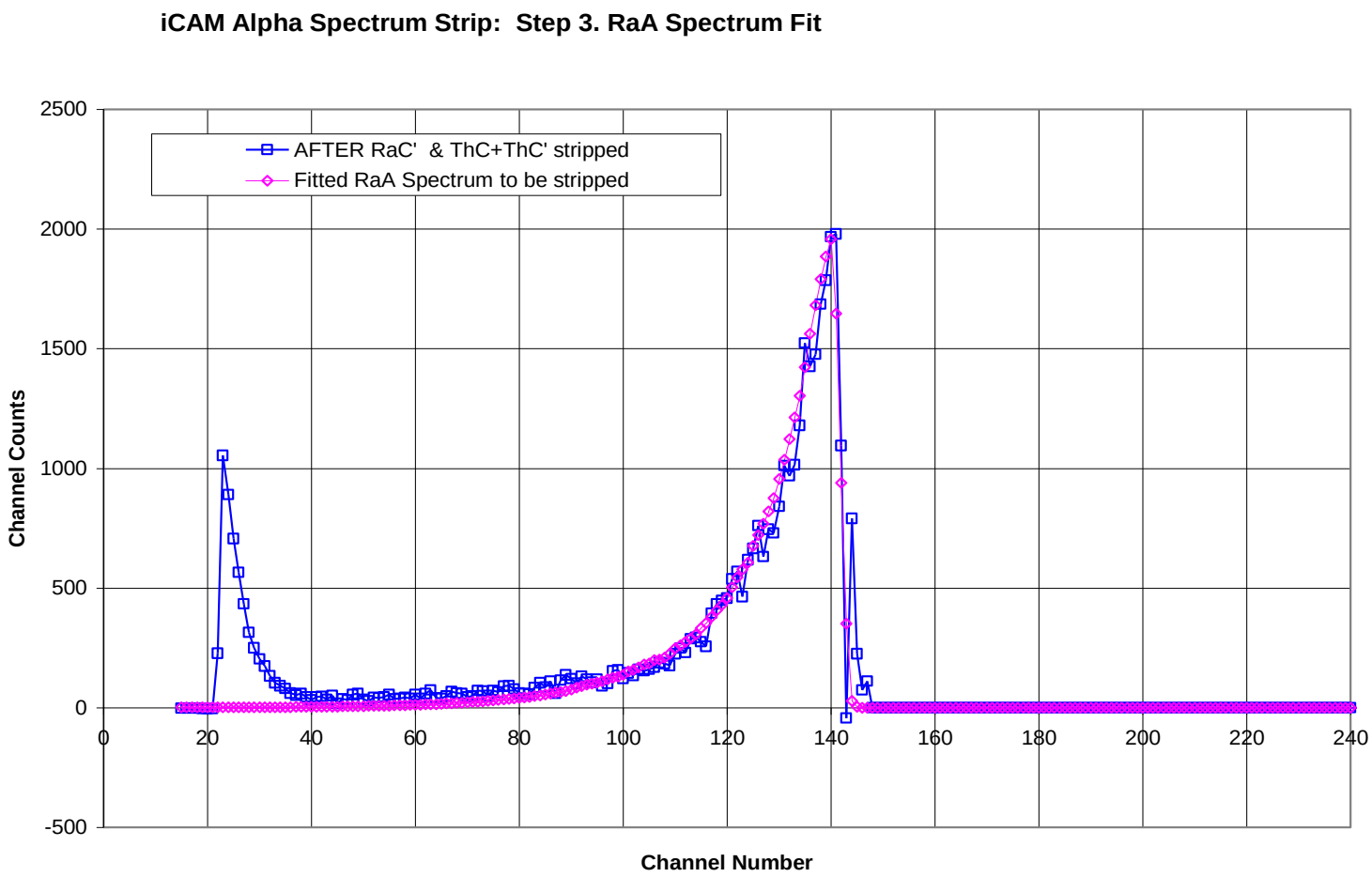
218Po (RaA) Peak Fit



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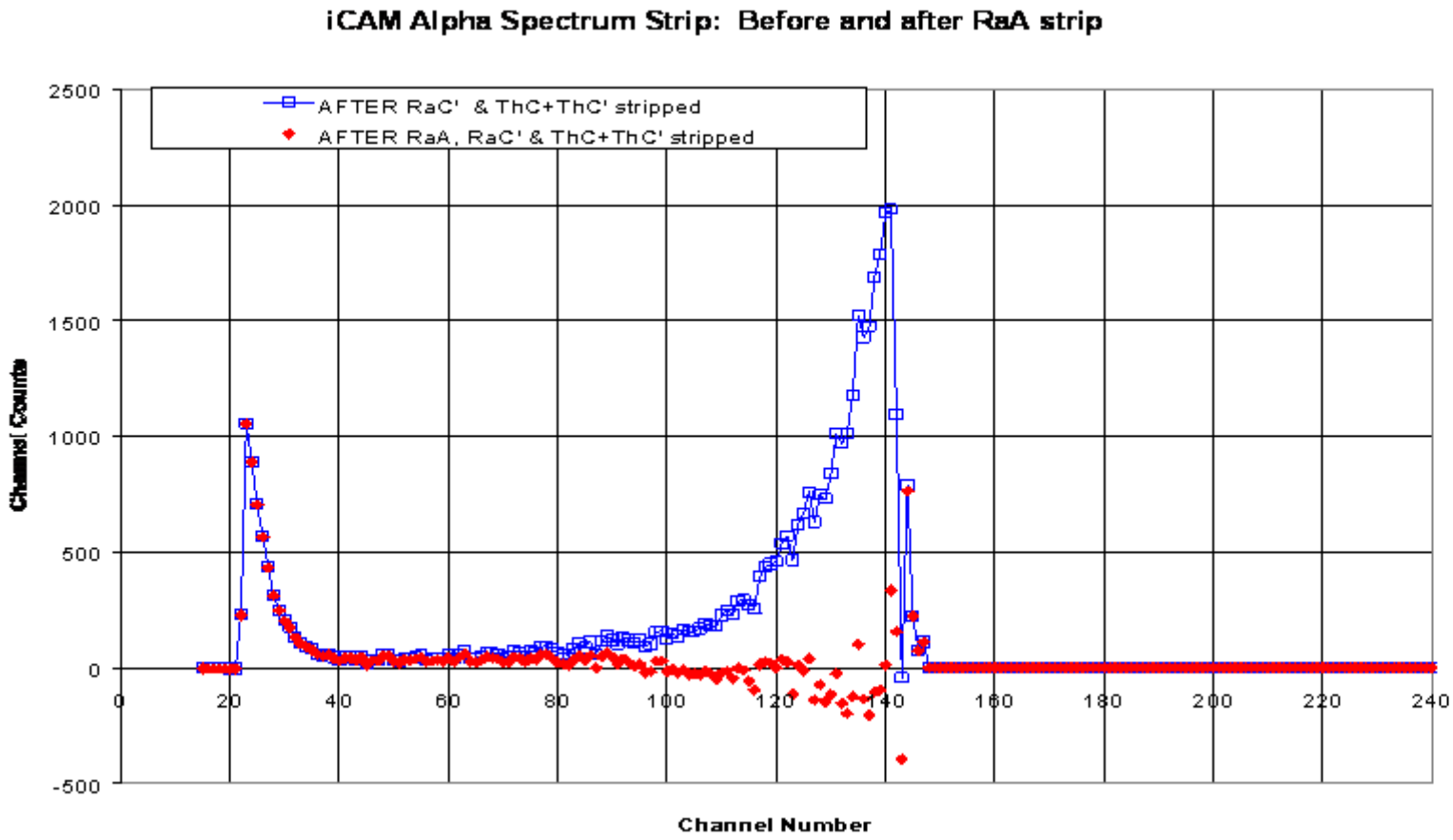
Third Stage Strip



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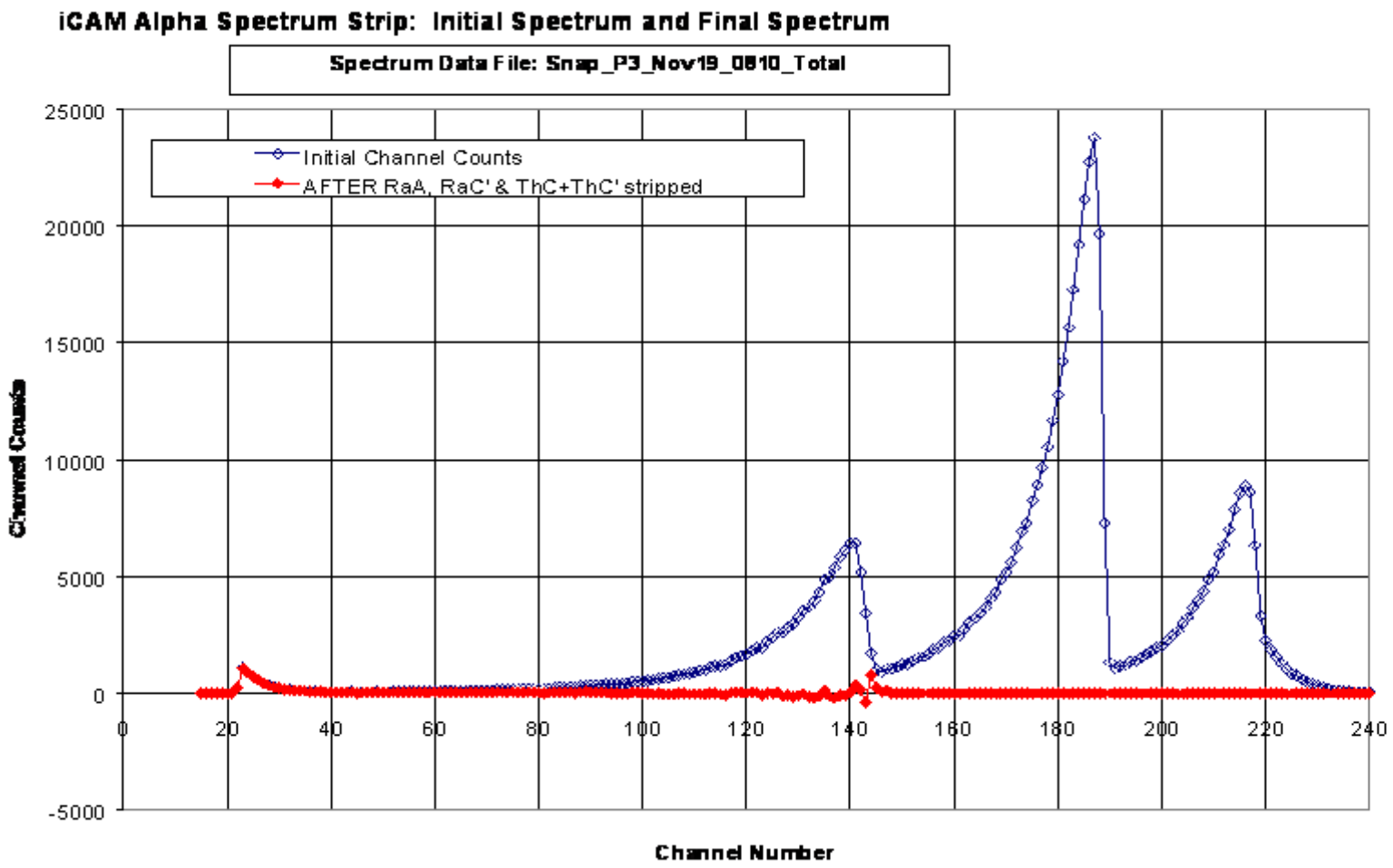
Fully Stripped Spectrum



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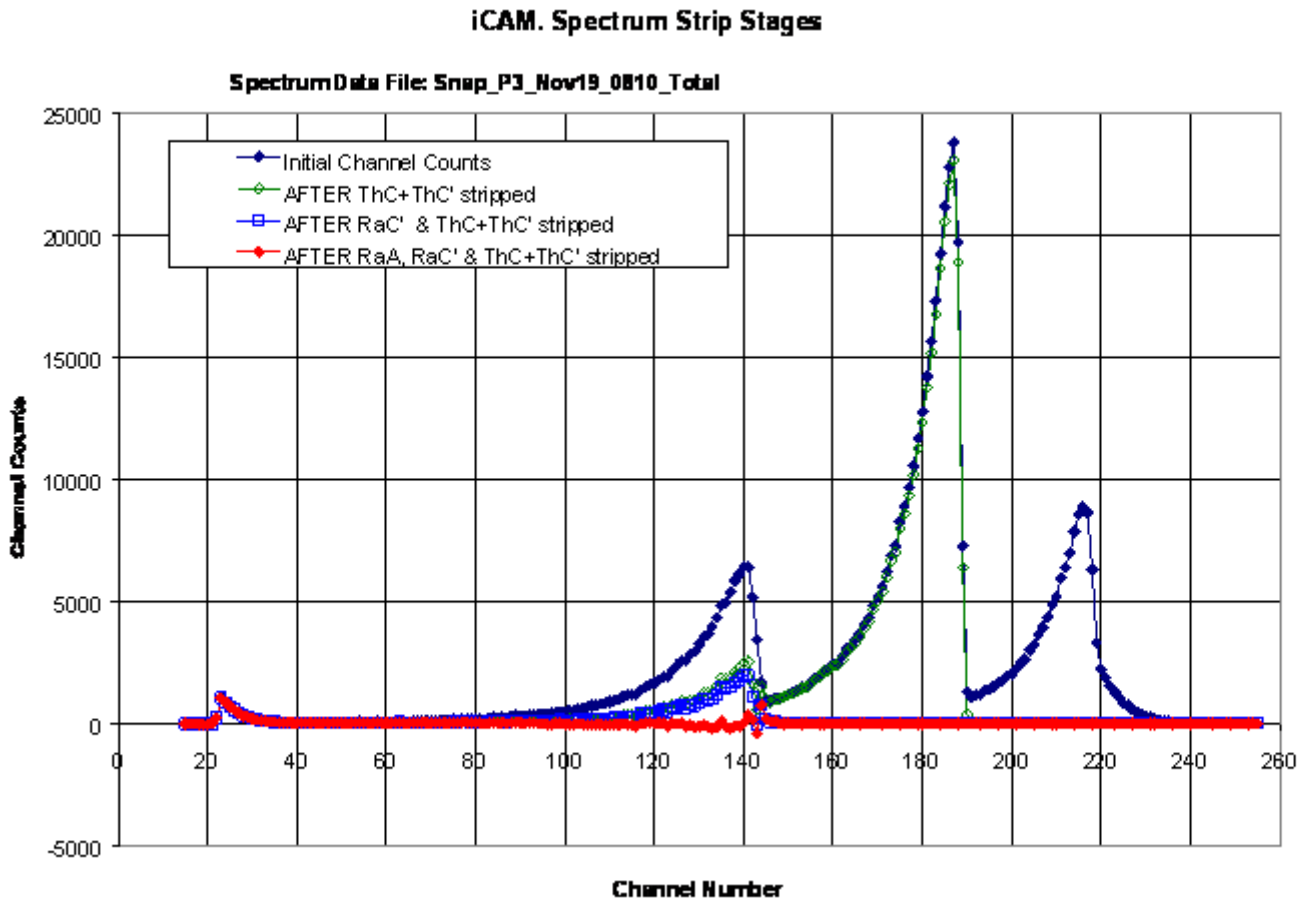
Spectrum Stripping Stages



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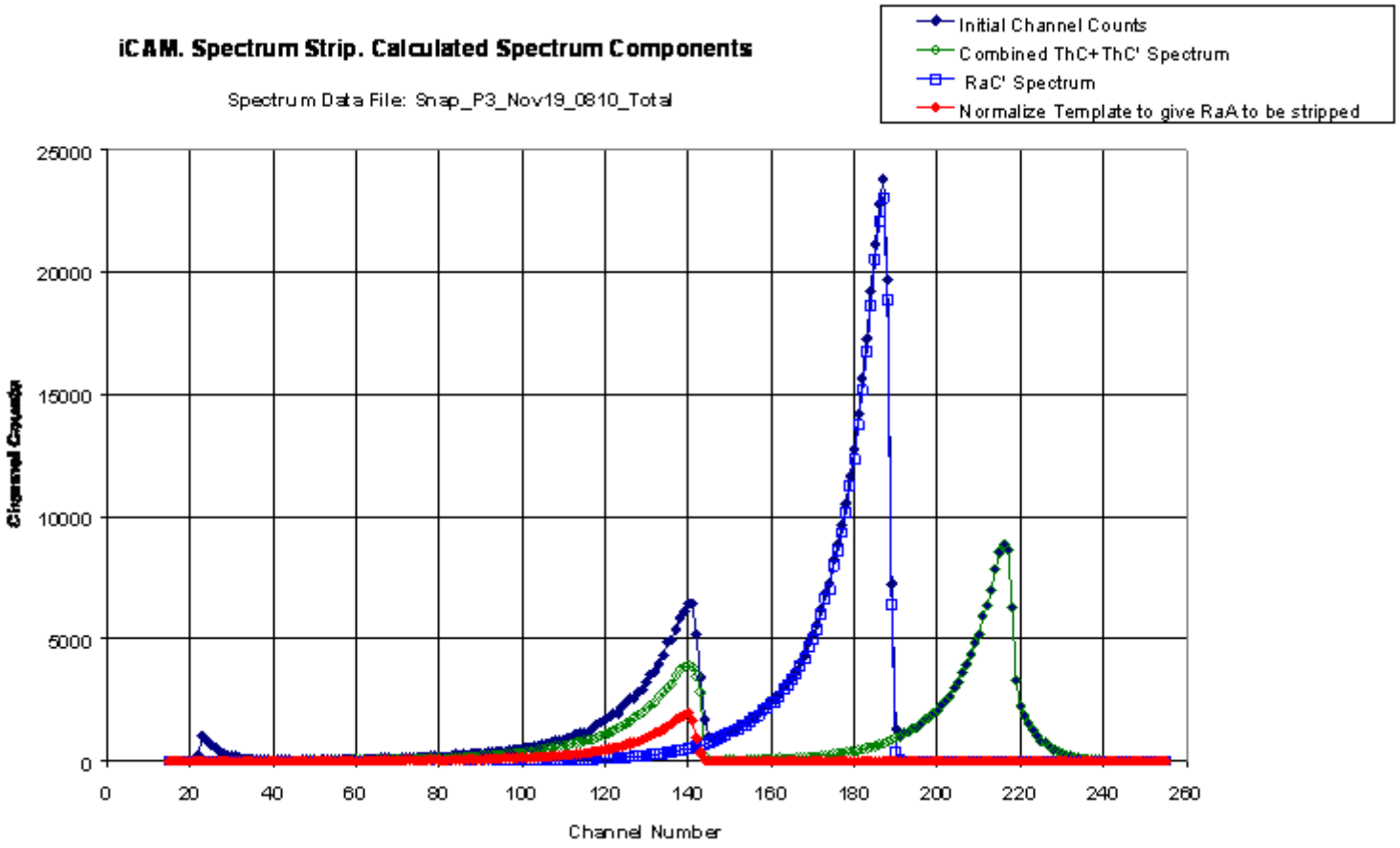
Spectrum Stripping: Components



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i CAM - Algorithm Benefits

- Elimination of systematic errors enables long term low level monitoring
- iCAM can monitor and alarm over three timescales simultaneously:
  - Primary measurement over typically 5-20 minutes, with 5 - 8 DAC hr alarm level
  - ‘Chronic’ Long term alpha measurement over 1 - 2 hours, allowing alarm levels as low as 1 - 2 DAC hrs
  - ‘Quick’ alarm over last 15 seconds only - a fully compensated measurement allowing alarm level in the 30 - 40 DAChr range
  - Level1 can be set to low level ‘Chronic’ alarm, Levels 2 & 3 to ‘Primary’ with optional ‘Quick’ alarm
- All measurements/alarms updated every 15 s

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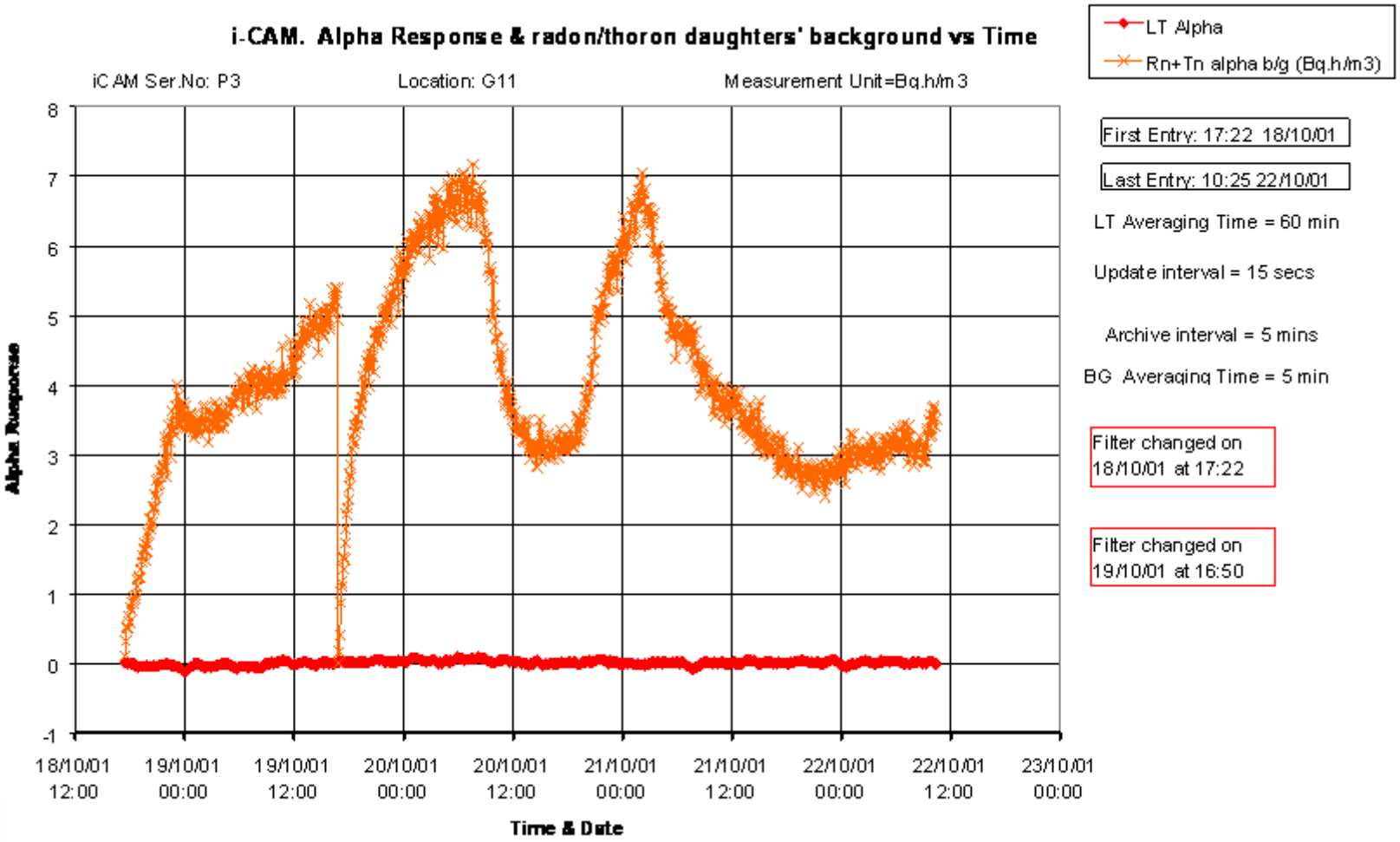
i CAM - Short term Alpha Measurement



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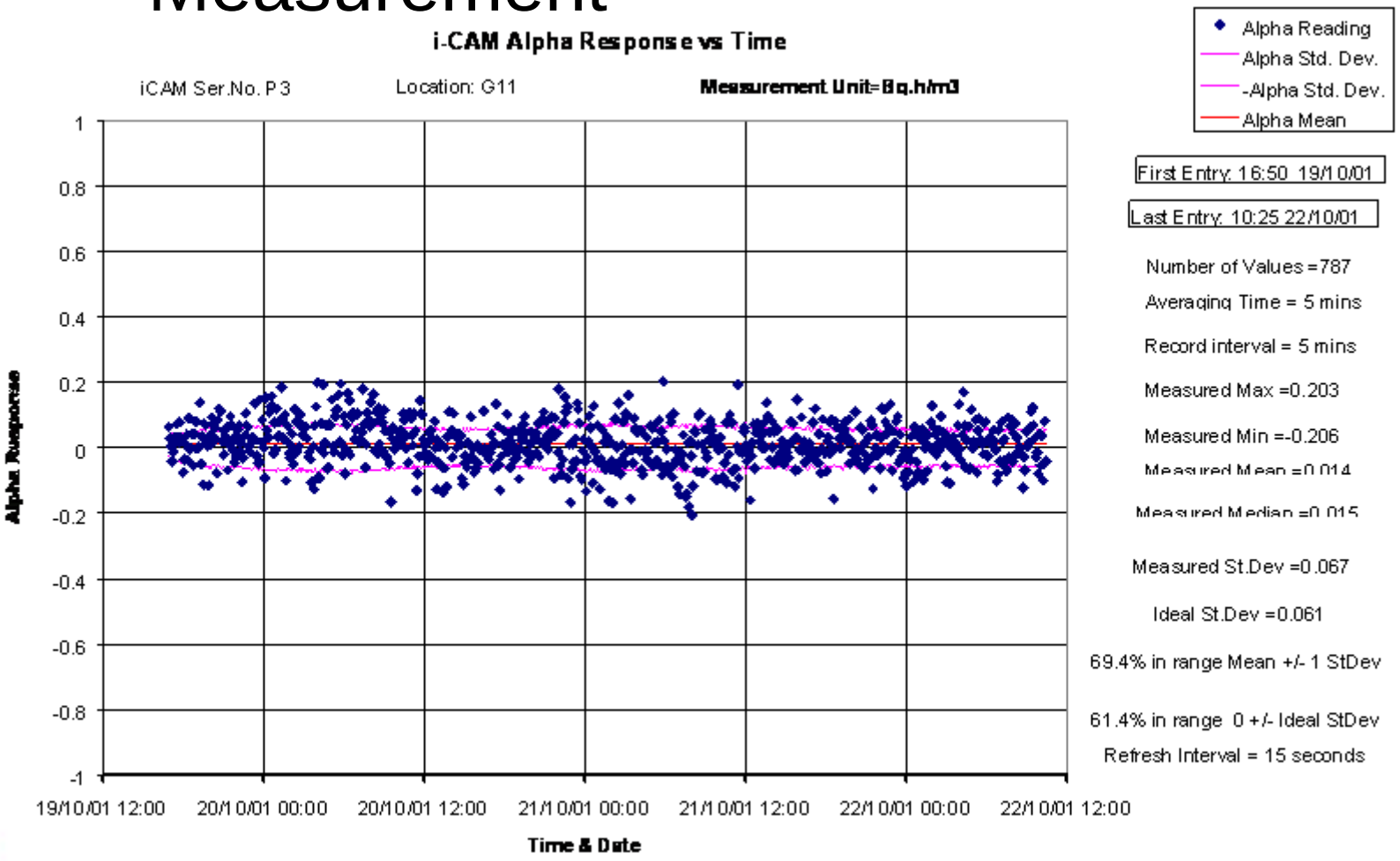
i CAM - Short term Alpha Measurement



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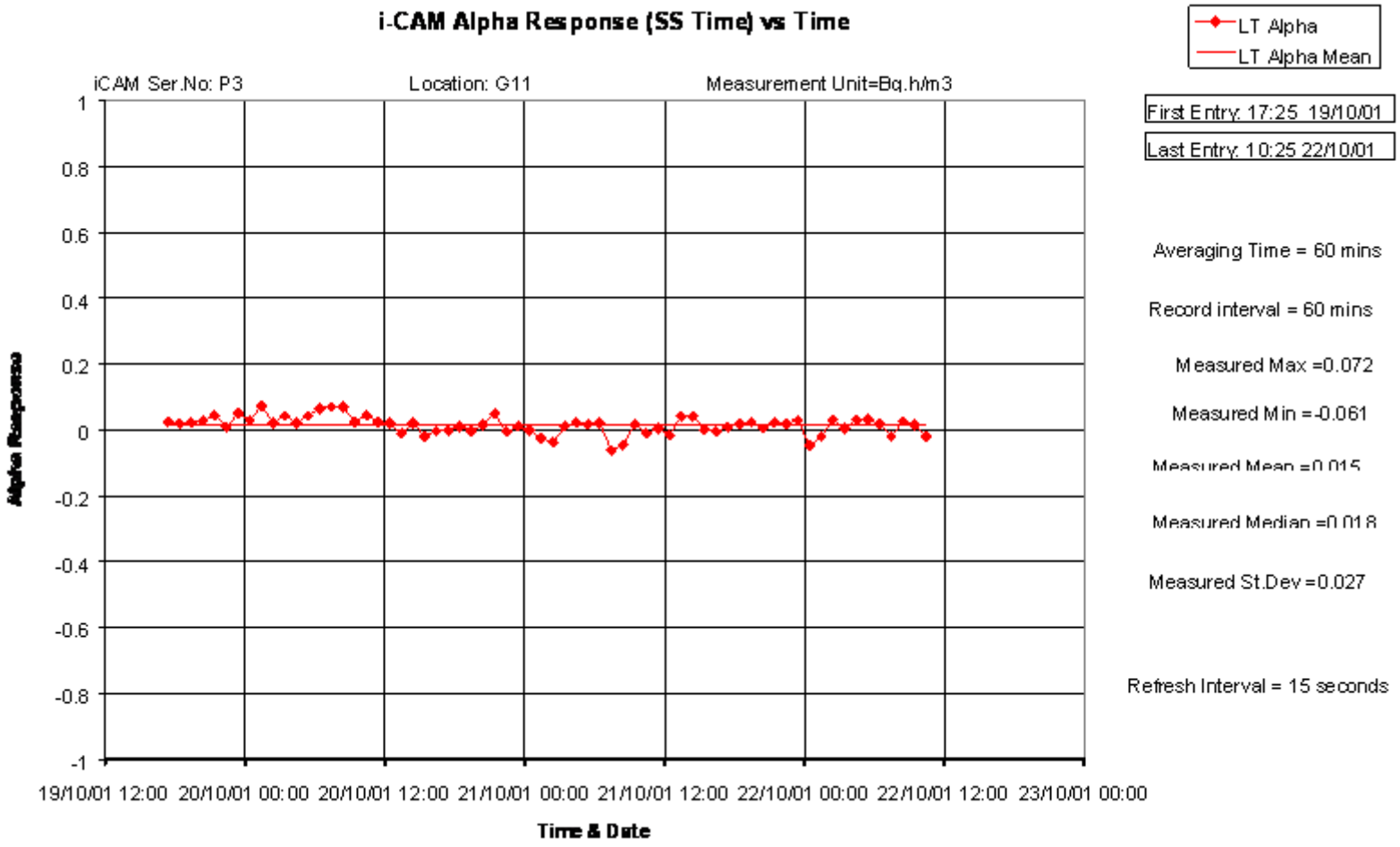
i CAM - Long Term Alpha Measurement



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i CAM - Alpha Detection Efficiency

i-CAM. Alpha-ray Detection Efficiency		**4π Detection Efficiency**	
Condition	**Alpha Emission Energy Range**	**Standard Test Source (19 mm diameter)**	**Filter (25 mm diameter)**
With background compensation:	Energies up to 5. 7 MeV	28 %	24.5 %
	Cm-244 (5.8 MeV)	-------	< 5 %
	Cm-242 (6. 1 MeV)	-------	negligible
Without background compensation:	All alpha energies	28 %	24.5 %

- 0.0435 cps for 1 DAChr on filter (1 DAC ^{239}Pu = 0.08 Bq/m^3)
- Capability to measure ^{244}Cm if window opened up to 5.8 MeV

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Alpha Measurement Uncertainties vs Rn and Th Concentration

	Radon (^{222}Rn) & Daughters' Concentrations in Air (Bq/m^3)					F	Thoron (^{220}Rn) Daughters' Concentrations in Air (Bq/m^3)				Mean Gross Alpha Background Reading			C'nt Time	Standard Deviation in Compensated Alpha Reading			Minimum Alpha Activity Alarm Level		
A	^{222}Rn	RaA	RaB	RaC	RaC'	F	ThB	ThC	ThC'	ThC''	Bq	Bq.h/m^3	DAC-h	min	Bq	Bq.h/m^3	DAC-h	Bq	Bq.h/m^3	DAC-h
1a	10	10	10	10	10	1	0	0	0	0	30	13	160	5 m	± 0.28	± 0.12	± 1.50	1.1	0.5	6
														20 m	± 0.14	± 0.06	± 0.75	0.6	0.25	3
2a	10	9.5	7.5	6.5	6.5	0.7	0	0	0	0	22.5	9.5	120	5 m	± 0.25	± 0.10	± 1.3	1	0.4	5.3
														20 m	± 0.13	± 0.05	± 0.65	0.5	0.2	2.6
3a	10	9	6	4	4	0.5	0	0	0	0	17	7	90	5 m	± 0.22	± 0.09	± 1.15	0.9	0.37	4.6
														20 m	± 0.11	± 0.045	± 0.58	0.45	0.18	2.3
4a	10	8	4	3	3	0.4	0	0	0	0	12.5	5	65	5 m	± 0.20	± 0.08	± 1.05	0.8	0.33	4
														20 m	± 0.10	± 0.04	± 0.55	0.4	0.16	2
5a	10	6.5	1	0.2	0.2	0.15	0	0	0	0	4	1.7	20	5 m	± 0.14	± 0.06	± 0.75	0.6	0.25	3
														20 m	± 0.07	± 0.03	± 0.4	0.3	0.12	1.5
6a	0	0	0	0	0	0	0.1	0.1	0.064	0.036	4	1.7	20	5 m	± 0.14	± 0.06	± 0.75	0.6	0.25	3
														20 m	± 0.07	± 0.03	± 0.4	0.3	0.12	1.5
1b	20	20	20	20	20	1	0	0	0	0	60	26	320	5 m	± 0.40	± 0.17	± 2.1	1.6	0.7	8.5
														20 m	± 0.20	± 0.09	± 1.05	0.8	0.35	4.2
2b	20	19	15	13	13	0.7	0	0	0	0	45	19	240	5 m	± 0.35	± 0.14	± 1.8	1.4	0.57	7.5
														20 m	± 0.18	± 0.07	± 0.9	0.7	0.29	3.7
3b	20	18	12	8	8	0.5	0	0	0	0	34	14	180	5 m	± 0.31	± 0.13	± 1.63	1.3	0.52	6.5
														20 m	± 0.16	± 0.065	± 0.82	0.65	0.26	3.3
4b	20	16	8	6	6	0.4	0	0	0	0	25	10	130	5 m	± 0.28	± 0.11	± 1.48	1.13	0.47	5.7
														20 m	± 0.14	± 0.055	± 0.75	0.57	0.24	2.8
5b	20	13	2	0.4	0.4	0.15	0	0	0	0	8	3.4	40	5 m	± 0.2	± 0.085	± 1.06	0.85	0.35	4.25
														20 m	± 0.1	± 0.17	± 0.53	0.42	0.17	2.1
6b	0	0	0	0	0	0	0.2	0.2	0.128	0.072	8	3.4	40	5 m	± 0.2	± 0.085	± 1.06	0.85	0.35	4.25
														20 m	± 0.1	± 0.17	± 0.53	0.42	0.17	2.1

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Notes on Alpha Uncertainty Table

The table shows :

1 the mean gross alpha background reading due to short-lived daughters of the naturally –occurring radioactive gases ^{222}Rn (radon) and ^{220}Rn (thoron).

2 the uncertainty (standard deviation) in the measured net alpha reading after compensating for the radon and thoron alpha background .

3 the recommended minimum activity alarm level under the stated conditions

In each case the reading is given in terms of

4 the activity of interest accumulated on the filter (Bq),

5 the integrated airborne activity concentration (Bq.h/m3) and

6 the integrated airborne activity concentration in DAC-hours.

Derived Air Concentration (DAC) is taken to be 0.08 Bq/m3 for ^{239}Pu (Class W)

CT (= Count Time) The averaging time (rolling-average) that is updated at 15 second intervals
Measurement uncertainties are given for the following representative conditions

F= Radon Daughter Equilibrium Factor.

CASE 1: **F= 1** Radon daughters are in equilibrium. (This condition is rare inside buildings)
CASE 2: **F= 0.7** Unfiltered ventilation at approximately 0.5 air changes per hour.
CASE 3: **F= 0.5** Unfiltered ventilation at approximately 1 air changes per hour.
CASE 4: **F= 0.4** **REFERENCE CONDITION (International Standard IEC 61578)**. Free unfiltered ventilation at approximately 2 air change per hour.
CASE 5: **F= 0.15 REFERENCE CONDITION (International Standard IEC 61578).** Filtered ventilation at approximately 6 air changes per hour.
CASE 6: Thoron daughters only, no radon

Cases 1a to 4a: ^{222}Rn concentration = 10 Bq.m^3
Cases 1b to 4b: ^{222}Rn concentration = 20 Bq.m^3

NOTE: Measurement Errors (Standard Deviation) and Recommended Minimum Alpha Activity Alarm Levels are approximately

7 proportional to the square root of the radon (^{222}Rn) concentration and

8 inversely proportional to the Averaging Time (CT)

International Standard IEC 61578: Radiation Protection Instrumentation – Calibration and verification of the effectiveness of radon compensation for alpha and/or beta aerosol measuring instruments – Test methods

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Beta Compensation

- Static or Dynamic Gamma Background Compensation
  - User defined fixed background rates (iCAM/S) and/or active gamma subtraction from second diode (iCAM/D)
- Radon/Thoron beta background is compensated out by deduction from the alpha background
- In low gamma areas (< 1 mR/hr, 10 µSv/hr), the radon/thoron betas dominate the background
- High speed counters for beta - up to 640 kBq on filter

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i CAM - Beta Detection Efficiency

i-CAM. Detection Efficiency (for max temp 50°C)			**4π Detection Efficiency**	
Nuclide	**Maximum Beta Energy**	**Mean Beta Energy**	**Standard Test Source (19 mm active diameter)**	**Filter (25 mm diameter)**
$^{90}Sr/^{90}Y$	546 keV (^{90}Sr) 2284 keV (^{90}Y)	196 keV (^{90}Sr) 935 keV (^{90}Y)	27.5%	24%
^{36}Cl	710 keV	251 keV	27%	23.5 %
^{137}Cs	514 keV	174 keV	25.5%	22%
^{99}Tc	294 keV	85 keV	18.5%	16 %
^{60}Co	318 keV	96 keV	18 %	15.5 %
^{147}Pm	225 keV	62 keV	14%	12%
^{14}C	156 keV	49 keV	10.5 %	9 %

- NB Higher efficiencies can be achieved if a reduced upper temperature limit is acceptable

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Beta Measurement Uncertainties vs Gamma Background

Integrated Airborne Beta Activity Concentration in DAC.hours (Beta DAC= 100 Bq/m3)

	UNCOMPENSATED			Gamma Compensated Case 1				Gamma Compensated Case 2				Gamma Compensated Case 3				Gamma Compensated Case 4			
Gamma Dose Rate uGy/h	Mean	St.Dev	Minim Alarm Level	Mean	St.Dev.	Syst. Error	Minim. Alarm Level	Mean	St.Dev.	Syst. Error	Minim. Alarm Level	Mean	St.Dev.	Syst. Error	Minim. Alarm Level	Mean	St.Dev.	Syst. Error	Minim. Alarm Level
0	0.0	0.00	0.0	0.0	0.00	0	0.0	0.0	0.00	0.00	0.0	0.0	0.00	0.00	0.0	0.0	0.00	0.00	0.0
0.05	0.0	0.00	0.0	0.0	0.00	0	0.0	0.0	0.01	0.00	0.0	0.0	0.01	0.00	0.1	0.0	0.01	0.00	0.1
0.1	0.0	0.00	0.0	0.0	0.00	0	0.0	0.0	0.02	0.00	0.1	0.0	0.02	0.00	0.1	0.0	0.02	0.00	0.1
0.2	0.0	0.00	0.0	0.0	0.00	0	0.0	0.0	0.02	0.00	0.1	0.0	0.02	0.00	0.1	0.0	0.02	0.01	0.1
0.5	0.0	0.00	0.0	0.0	0.00	0	0.0	0.0	0.04	0.00	0.2	0.0	0.04	0.01	0.2	0.0	0.04	0.02	0.2
1	0.0	0.00	0.1	0.0	0.01	0	0.0	0.0	0.05	0.01	0.2	0.0	0.05	0.02	0.3	0.0	0.05	0.04	0.3
2	0.1	0.01	0.1	0.0	0.01	0	0.0	0.0	0.08	0.02	0.3	0.0	0.08	0.05	0.4	0.0	0.08	0.08	0.5
5	0.2	0.01	0.3	0.0	0.01	0	0.0	0.0	0.12	0.05	0.6	0.0	0.12	0.12	0.7	0.0	0.12	0.19	0.9
10	0.5	0.01	0.5	0.0	0.02	0	0.1	0.0	0.17	0.09	0.9	0.0	0.17	0.24	1.2	0.0	0.17	0.38	1.4
20	0.9	0.02	1.0	0.0	0.02	0	0.1	0.0	0.24	0.19	1.4	0.0	0.24	0.47	1.9	0.0	0.24	0.76	2.5
50	2.3	0.03	2.4	0.0	0.04	0	0.1	0.0	0.39	0.47	2.5	0.0	0.39	1.18	3.9	0.0	0.39	1.89	5.3
100	4.5	0.04	4.7	0.0	0.05	0	0.2	0.0	0.55	0.95	4.1	0.0	0.55	2.36	6.9	0.0	0.55	3.78	9.7
200	9.1	0.05	9.3	0.0	0.07	0	0.3	0.0	0.77	1.89	6.9	0.0	0.77	4.73	12.5	0.0	0.77	7.56	18.2
500	22.6	0.08	23.0	0.0	0.12	0	0.5	0.0	1.22	4.73	14.3	0.0	1.22	11.81	28.5	0.0	1.22	18.90	42.7
1000	45.3	0.12	45.8	0.0	0.17	0	0.7	0.0	1.73	9.45	25.8	0.0	1.73	23.63	54.2	0.0	1.73	37.81	82.5

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Notes on Beta Measurement Uncertainties

The values given in these tables are based on test results that are described in “Type Test Report for iCAM Activity in Air Monitor”.

Notes for Tables

GBF= Gamma Balance Factor = Assumed ratio of gamma response 1st/2nd Detector Default GBF=1. User can set the value of GBF for local conditions

St.Dev. = the expected Standard Deviation due to random statistical variations

Var Gam Resp = Range of variation in the relative response to ambient gamma radiation of the two detector diodes

Syst. Error = the estimated systematic error caused by differences in the response to gamma radiation of the 1^{st} and 2^{nd} detector diodes

Minimum Alarm Level = Lowest Activity Alarm Level that can be set (= 2x Systematic Error + 4x Standard Deviation)

Compensation for ambient gamma radiation

Measurement uncertainties are tabulated for ambient gamma dose rates in the range 0 to 1000 µGy/h
under the following conditions

Uncompensated: Either (i) a Single-diode detector is fitted or (ii) Gamma Compensation is NOT SELECTED

Gamma Compensated Case 1: GBF set for local conditions. Gamma omnidirectional or from a fixed direction. (Systematic compensation error = 0%)

Gamma Compensated Cases 2 to 4: GBF not set for local conditions. (GBF = 1)

Case 2: Typical systematic errors (+/-2%) when the gamma radiation is omnidirectional.

Case 3: High systematic errors (+/- 5%) can occur with gamma radiation from a fixed direction

Case 4: Worst-case systematic errors (+/- 5%) can occur when the direction of the gamma radiation is highly directional and the direction varies

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NRPB Type Testing to IEC1172

- IEC1172 covers:
- Linearity/accuracy
- Energy dependence
- Cross response: beta to alpha & alpha to beta, & gamma
- Flow measurement
- Leakage
- Statistical fluctuations
- stability/warm up
- Power supply variations
- Temperature/humidity

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IEC1172 Test Results

- Linearity:
- ± 5% to > 640 kBq on filter
- Energy dependence - see tables
- Cross response:
- Alpha channel beta rejection ratio 0.013
- Beta channel alpha rejection ratio $<4 \times 10^{-6}$
- gamma compensation better that ± 8%
- Flow Measurement:
- ±7% from 6 to 60 l/min
- Leakage:
- between 65 & 130 cc/min ie ~ 0.3%

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IEC1172 Test Results

- Statistical Fluctuations:
- Coefficient of variation < 2% above 300 dpm
- Stability/Warm Up
- Negligible variations due to warm up. Long term stability < 2% of reading
- Power Supply Variations
- Negligible
- Temperature/Humidity
- alpha: ± 11%, beta: ± 5%, flow rate: ± 6%, all from -10 ^{o}C to +50 ^{o}C
- ± 9% 40% to 95% Rh

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