Log Book: Experiment 1.02 - Range and energy loss of α particles in air.

Monday, 7 September 2020 9:03 PM

Risk Assessment

Risk Factors	Risk Level	Existing Control	Proposed Control
Radiation -Sealed source Am-241. Radiation exposure from Am-241	Low	Am-241 is in a sealed brass vacuum chamber, with perspex guard. Maximum exposure will be less than 0.1uSv/hr	Students using the apparatus will be informed to avoid opening chamber. Students will wear dosimeter if fears of radiation are present.
Vacuum system can be hazardous if operated incorrectly	Low	Vacuum system is positioned behind perspex glass so that students cannot easily adjust it.	Ensure that lab procedure is correctly followed.

The Range and Energy of α-particles in air.

Aim: The aim of the experiment is to determine how air effects the energy of α-particles from an Americium-241 source, and to determine the mean energy of the particles.

Theory:
When unstable elements decay, one of the forms of matter produced is an alpha-particle, essentially a helium nucleus. When Americium-241 undergoes alpha article decay, it produces an α-particle and becomes Neptunium-237. The most probably decay path produces α-particles with an energy of 5.4857 MeV and a gamma ray at 59.6 keV.
As they contain protons but no electrons, these alpha particles are positively charged. Due to this, they interact with matter, and lose their kinetic energy, causing them to have very low penetrating power. The energy can be given by

$$-\frac{dE}{dx} = B\rho E^{-0.73}, \qquad (1)$$

B = 2.58 MeV (cm kg m^{-3})$^{-1}$, E_0 is the initial energy in MeV, ρ is the density of air (ρ = 1.204 kg m^{-3} at 20°C and 101.325 kPa), and x is the distance in cm. The range can then be found by integrating this over distance:

$$R = \int_0^R dx = \int_{E_0}^0 \frac{dE}{\left(\frac{dE}{dx}\right)} = \frac{E_0^{1.73}}{1.73B\rho} \qquad (2)$$

This leads to the theoretical range of particles in dry air at 20°C and 101.325 kPa is
$R_{atm} = 0.186E_0^{1.73}$

As this range is also proportional to the pressure, the range at a pressure p can be related to the range at atmospheric pressure through $R = R_{atm} * p_{atm}/p$

Using the assumption that air acts as an ideal gas, this relation becomes:

$$R = 64.31\frac{T}{p}E_0^{1.73} \qquad (3)$$

For finding the range and

$$p_0 = 64.31\frac{T}{x_0}E_0^{1.73} \qquad (4)$$

By integrating equation 2, we can find the energy of the alpha particles after passing through a distance of air to be

$$E = \left(E_0^{1.73} - 0.0156\frac{p\Delta x}{T}\right)^{0.578} \qquad (5)$$

In an effect known as "range straggling", air's particle nature causes random variations in the path length of each particle, despite all particles from a given transition having essentially the same energy, causing a range of results for alpha particles. The number of particles dn from the same transition that have a range between x and dx is given by a normal distribution following

$$\frac{dn}{dx} = n_0\frac{1}{\alpha\sqrt{\pi}}e^{-\left(\frac{x-R}{\alpha}\right)^2} \qquad (6)$$

Were α is the straggling parameter, which is proportional to the initial energy of the particles, and thus their range. For air at atmospheric pressure, this parameter is approximately equal to 0.015 times the range. As in this instance, the air is not the medium that the alpha particles have to pass through, as the surface of the source has been coated in gold, there is additional dispersion. This can be modelled by defining

$$\alpha^2 = \alpha_{air}^2 + \alpha_{source}^2 \qquad (7)$$

By integrating equation (5), we can find the number of alpha particles that remain at a distance x.

$$n(x) = n_0 - \int_0^x dn \qquad (8)$$

Ultimately giving us

$$n(x) = n_0\left\{1 - \int_0^x \frac{1}{\alpha\sqrt{\pi}}e^{\left(\frac{x-R}{\alpha}\right)^2}dx\right\} \qquad (9)$$

In this experiment, the number of particles remaining will be measured as the pressure in the chamber is varied. Using equations 3 and 4, we can substitute air pressure for propagation distance, giving

$$n(p) = n_0\left\{1 - \int_0^p \frac{1}{\alpha\sqrt{\pi}}e^{\left(\frac{p-p_0}{\alpha}\right)^2}dp\right\} \qquad (10)$$

As α is proportional to p_0, we can use the Error Function $\operatorname{erf}(y) = \frac{2}{\sqrt{\pi}}\int_0^y e^{-t^2}\,dt$ to rewrite equation 10 as

$$n(p) = \frac{n_0}{2}\left(1 - \operatorname{erf}\left(\frac{p-p_0}{\alpha}\right)\right) \qquad (11)$$

The degree to which a material is capable of stopping an alpha particle is inversely proportional to the square root of the atomic mass of the material, and directly proportional to its density. This relation is described by the Bragg-Kleeman rule:

$$\frac{R_1}{R_0} = \frac{\rho_0}{\rho_1}\frac{\sqrt{A_1}}{\sqrt{A_0}} \qquad (12)$$

Where R is the range, ρ is the density, and A is the atomic mass. For air, the atomic mass is $\sqrt{A_{air}} = 3.82$. This rule can be used in conjunction with equation 5, in order to predict the energy of alpha particles after passing through a thickness Δx of a material of air:

$$E = \left(E_0^{1.73} - 4.464\rho_1\frac{\sqrt{A_{air}}}{\sqrt{A_1}}\Delta x\right)^{0.578} \qquad (13)$$

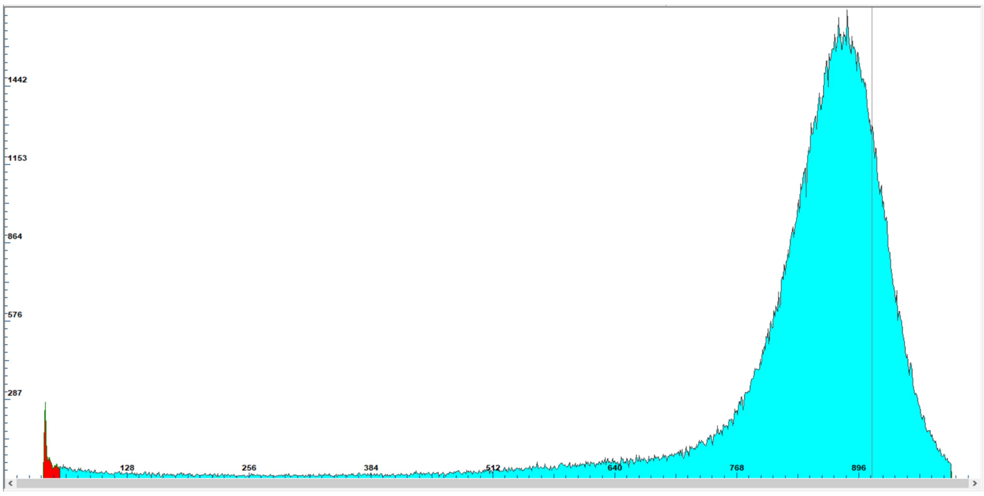
Method:

The "air admittance" valve was closed, and the vacuum gauge was turned on, in order to remove as much air as possible. The pump was then turned on, and the "vacuum pump line" valve was opened. Once the pressure fell below the range measurable by the gauge, a minute was taken to allow the pressure to drop further, and then the pump line valve was closed, and the pump was turned off.
Once the pressure was adjusted, the ORTEC modules, MCA unit, DSO, and amplifier units were turned on, and the chamber was fully evacuated. It was ensured that the output of the amplifier was connected to the DSO, and that the output of the amplifier was connected to the MCA unit. The ADMCA software was set up so that the "preset time" was set to 30 seconds and the "Threshold" was set to 10. It was double checked to make sure that "Preset time" was set to seconds, "Timer" was set to "live time", and "ADC Channels" was set to "1024". The MCA acquisition of data was then started for a brief period of time. The data collected was examined to determine the bins that contained large amounts of noise data around 0V. This data was then

used to determine what the threshold should be set to in order to eliminate the noise from the final data collection. This is done in order to ensure that the apparatus does not use time reading the noise data, and records as many decay events as possible.
Once the threshold was set to the determined value, the data stored in the MCA memory was cleared, and new sets of data were collected for a further 15 pressure values. Great care was taken around the pressure where the data from the alpha particle events was interacting with the noise floor being detected. 10 measurements were taken in this region.

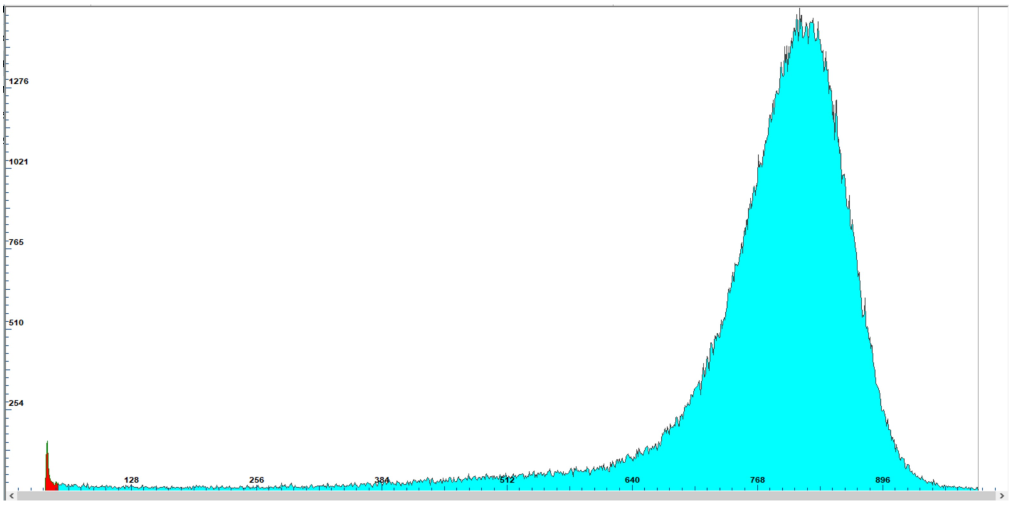
Results:

0.00mbar



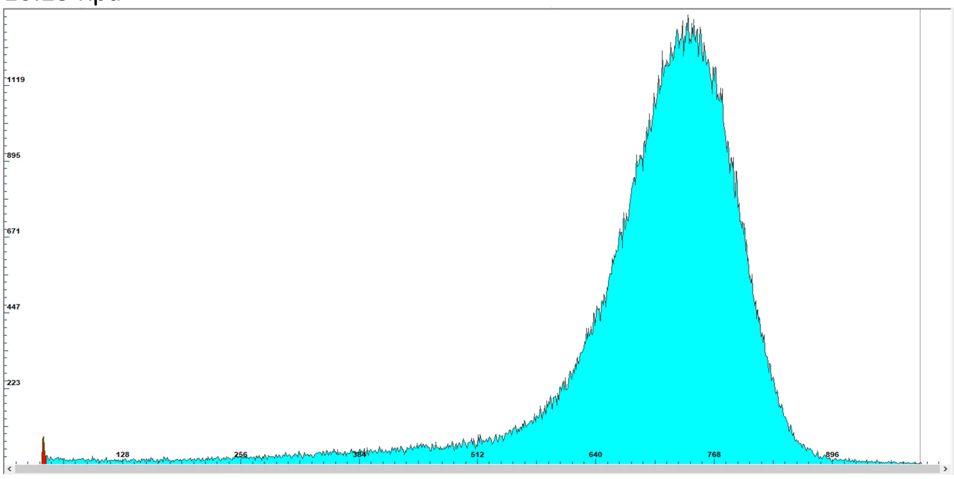
Centroid: 912.02
Peak Estimate: 890
FWHM: 98.3823
Net Area: 1685.41
Uncertainty: 0.30
Net Rate: 1685.14
Gross Area: 213250

5.17 KPa



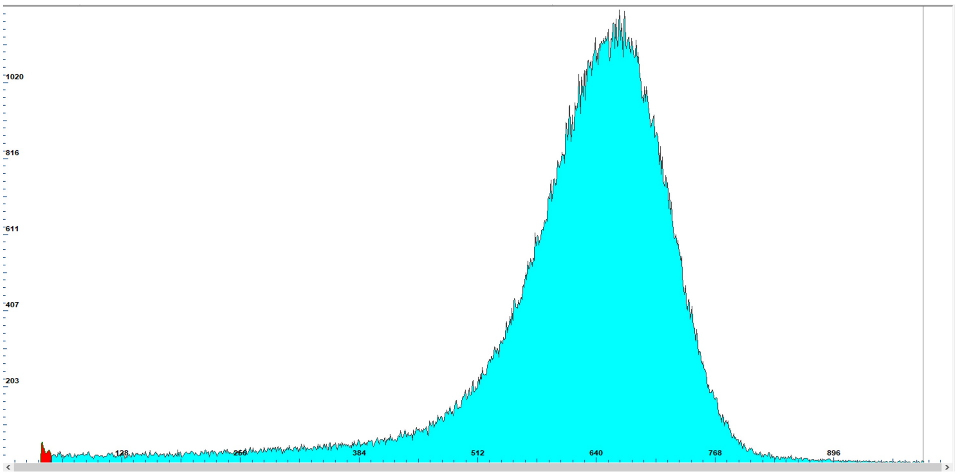
Centroid: 788.94
FWHM: 115.1423
Net Area: 203904
Uncertainty: 0.23
Net Rate: 2039.04
Gross Area: 212346

10.23 Kpa



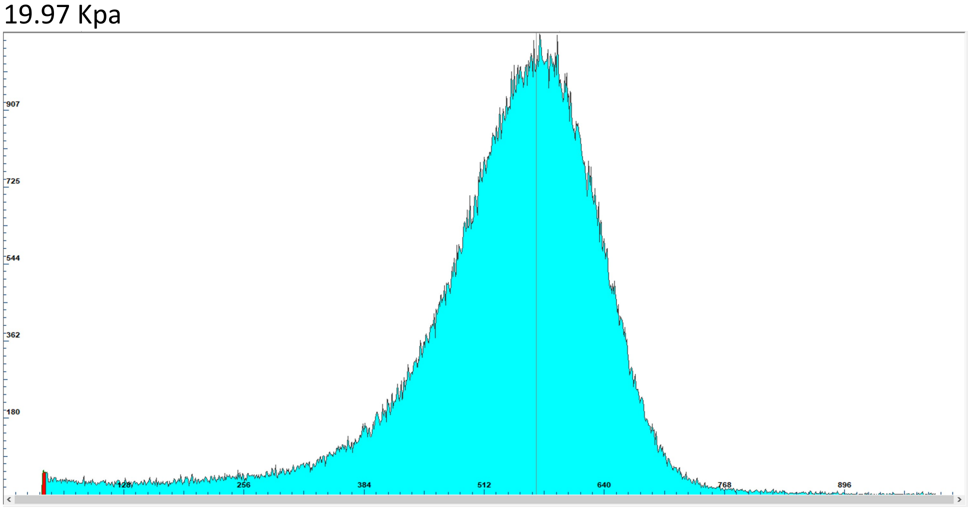
Centroid: 720.98
FWHM: 132.1429
Net Area: 1947447
Uncertainty: 0.24
Net Rate: 1944.47
Gross Area: 209535

15.14 KPa



Centroid: 629.80
FWHM: 142.825
Net Area: 198720
Uncertainty: 0.23
Net Rate: 1987.20
Gross Area: 207162

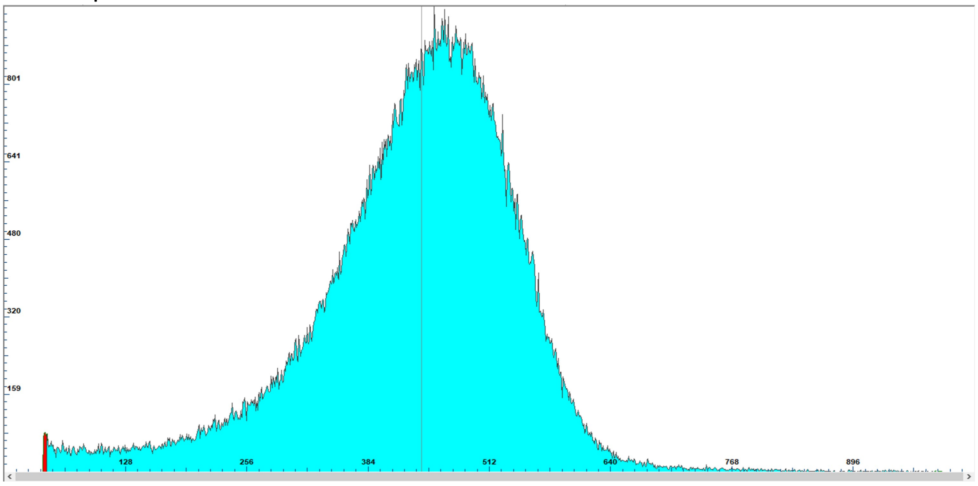
19.97 Kpa



Centroid: 554.52

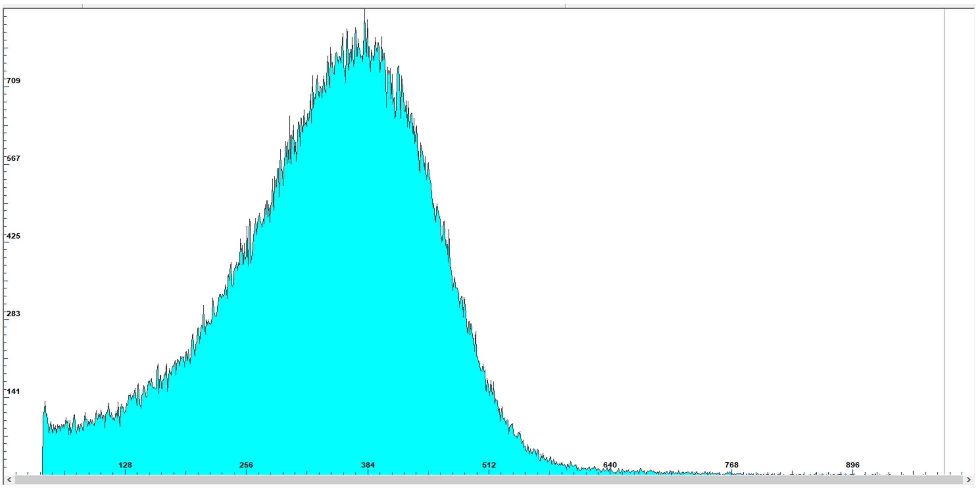
FWHM: 159.2947
Net Area: 179958
Uncertainty: 0.27
Gross Area: 204008

25.01 Kpa



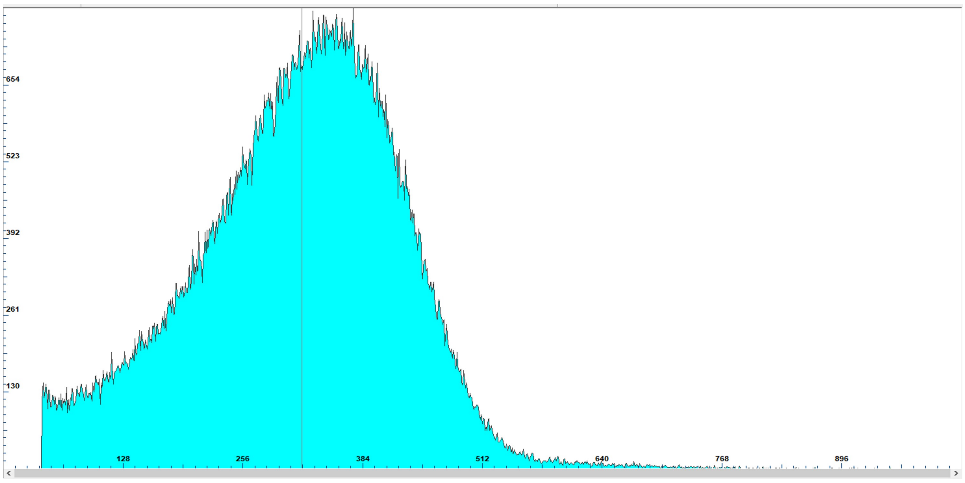
Centroid: 448.47
FWHM: 171.0231
Net Area: 162359
Uncertainty: 0.30
Gross Area: 199252

29.06 KPa



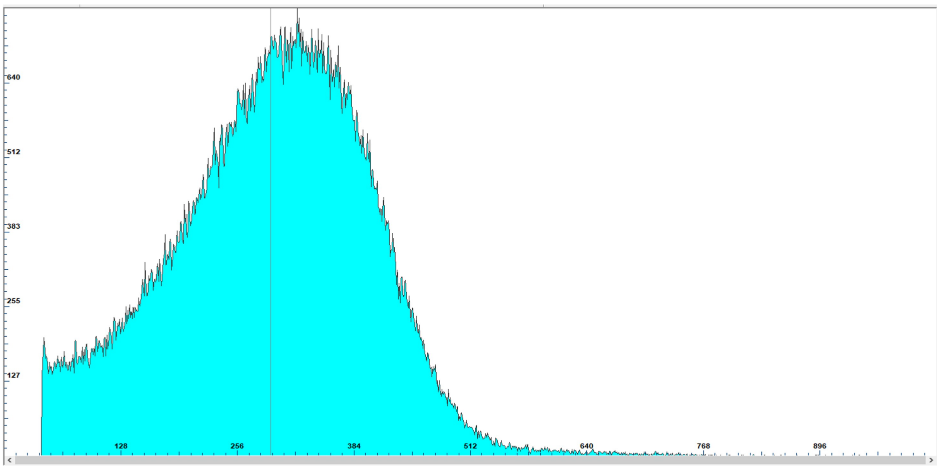
Centroid: 340.33
FWHM: 198.5675
Net Area: 193537
Uncertainty: 0.23
Gross Area: 193537

30.07 KPa



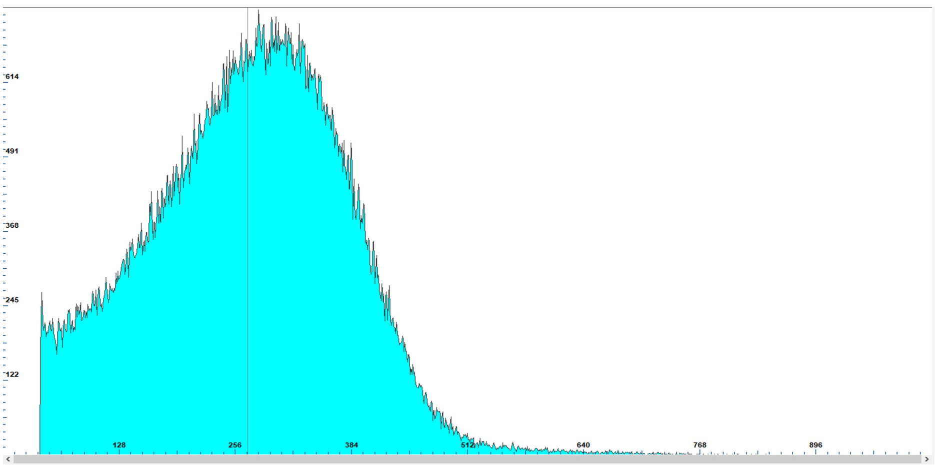
Centroid: 313.86
FWHM: 215.5595
Net Area: 190924
Uncertainty: 0.23
Gross Area: 190924

31.04



Centroid: 291.89
FWHM: 221.5390
Net Area: 187928
Uncertainty: 0.23
Gross Area: 187928

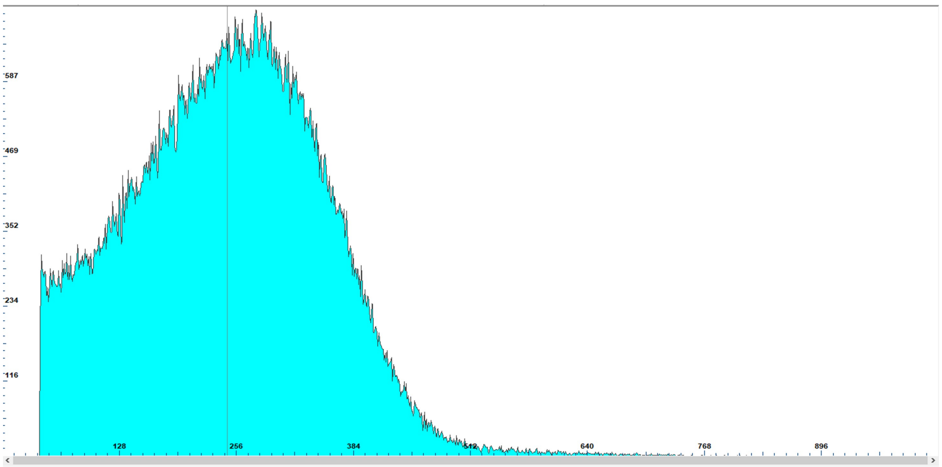
32.00 KPa



Centroid: 268.95
FWHM: 230.9703
Net Area: 187129
Uncertainty: 0.23

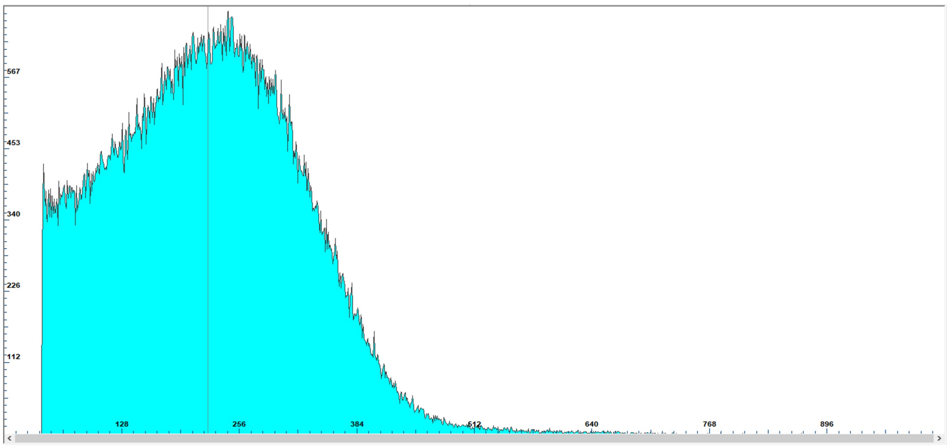
Gross Area: 184129

33.00 KPa



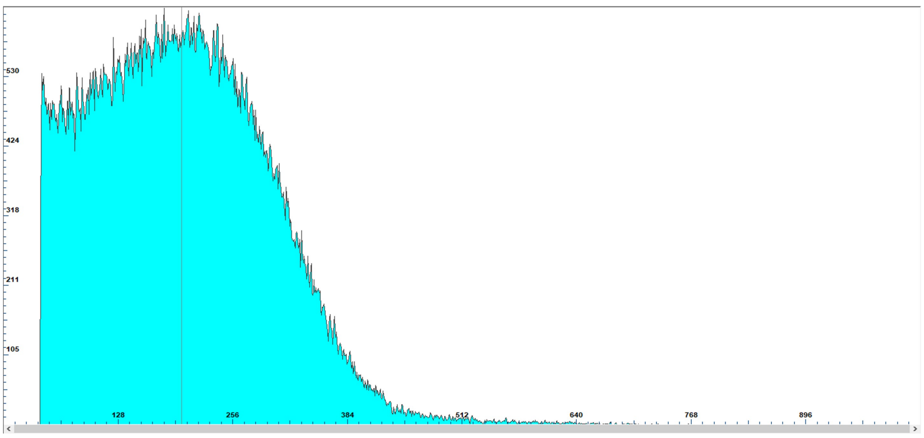
Centroid: 245.05
FWHM: 243.3879
Net Area: 178909
Uncertainty: 0.24
Gross Area: 178909

34.05 KPa



Centroid: 220.89
FWHM: 264.9823
Net Area: 171507
Uncertainty: 0.24
Gross Area: 171507

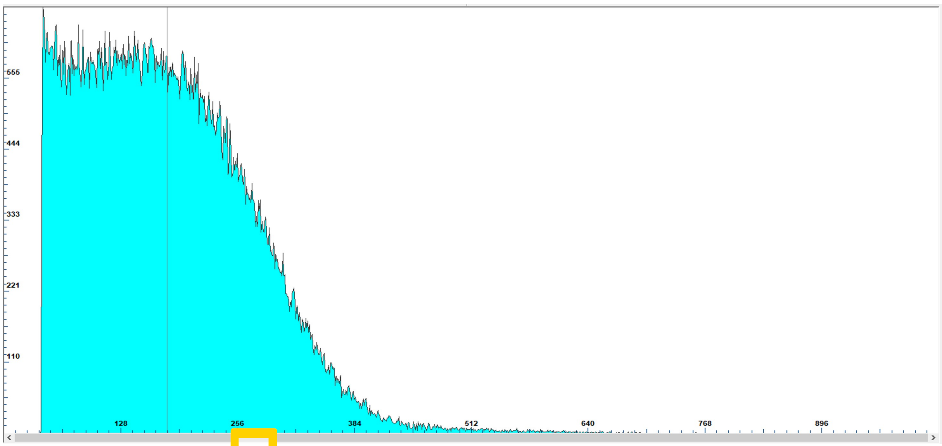
35.05 KPa



Centroid: 198.24
FWHM: 272.7831
Net Area: 161946

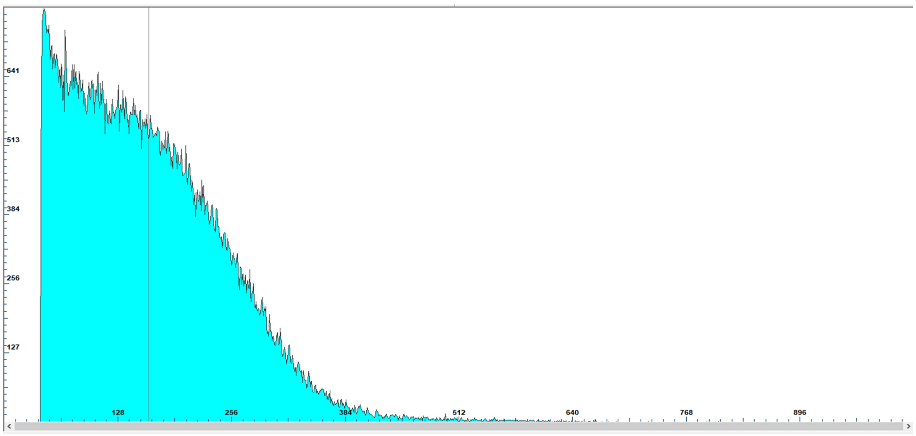
Uncertainty: 0.25
Gross Area: 161946

36.06 KPa



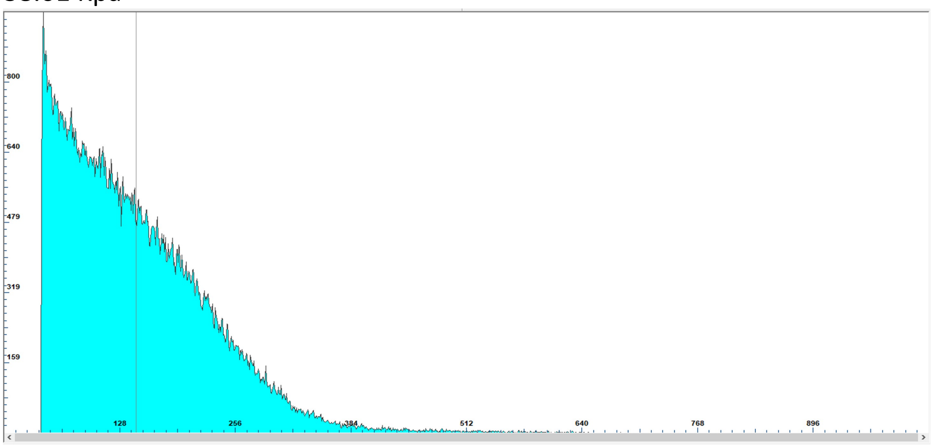
Centroid: 177.73
FWHM: 233.9162
Net Area: 150083
Uncertainty: 0.26
Gross Area: 150083

36.99 KPa



Centroid: 161.72
Peak Estimate: 155
FWHM: 174.1986
Net Area: 135672
Uncertainty: 0.27
Gross Area: 135672

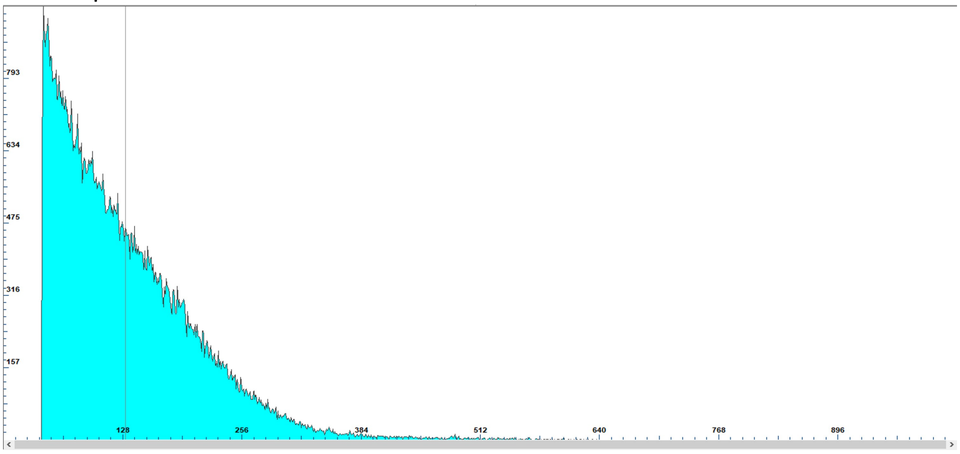
38.01 Kpa



"Centroid": 144.78

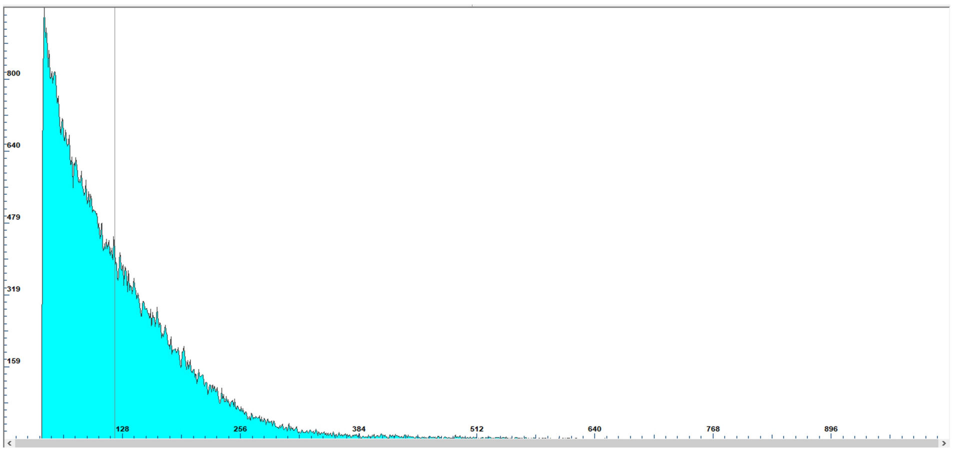
Peak Estimate: 130
Net Area: 119182
Uncertainty: 0.29
Gross Area: 119182

39.02 Kpa



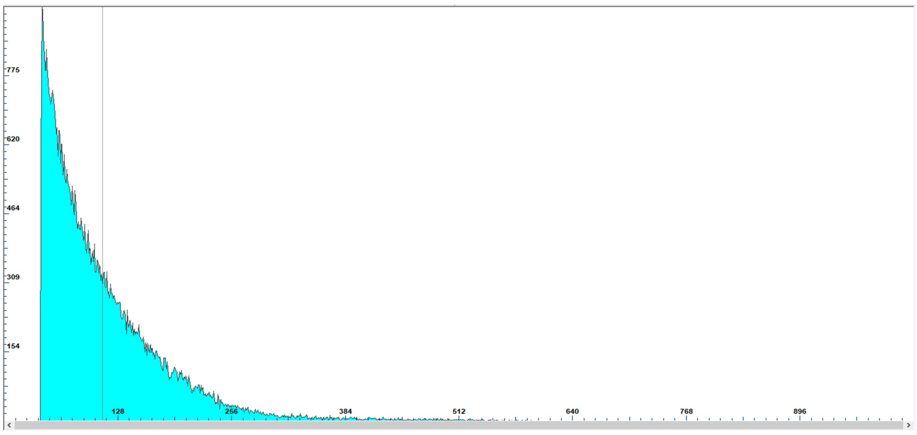
"Centroid" :130.75
Peak Estimate: 100
FWHM: 82.3529
Net Area: 99058
Uncertainty: 0.32
Gross Area: 99058

39.99 KPa

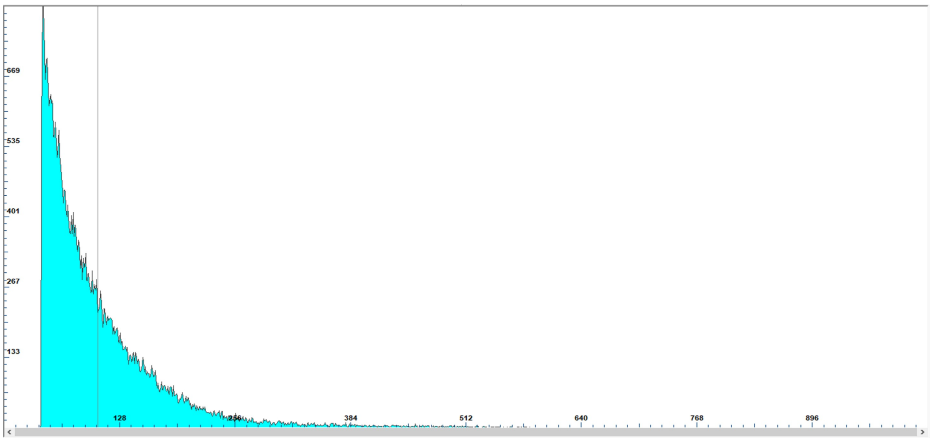


"Centroid": 119.38
Peak Estimate: 60
FWHM: 59.9590
Net Area: 80044
Uncertainty: 0.35
Gross Area: 80044

41.04 KPa



"Centroid": 109.62
Peak Estimate: 25
FHWM: 37.0736
Net Area: 60233
Uncertainty: 0.41
Gross Area: 60233

42.00 KPa


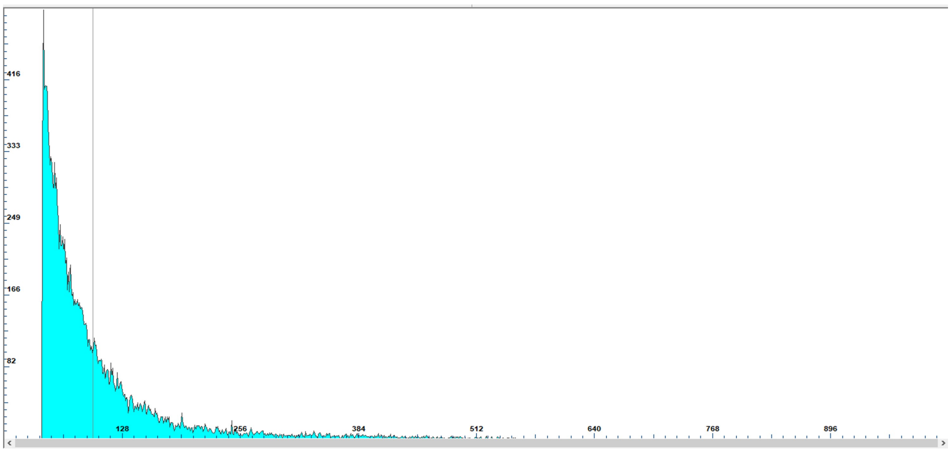
Centroid: 102.55
Peak Estimate: 15
FWHM: 28.2501
Net Area: 43157
Uncertainty: 0.48
Gross Area: 43157

43.00 KPa


Centroid: 97.62
Peak Estimate: 10
FWHM: 23.6987
Net Area: 28788
Uncertainty: 0.59

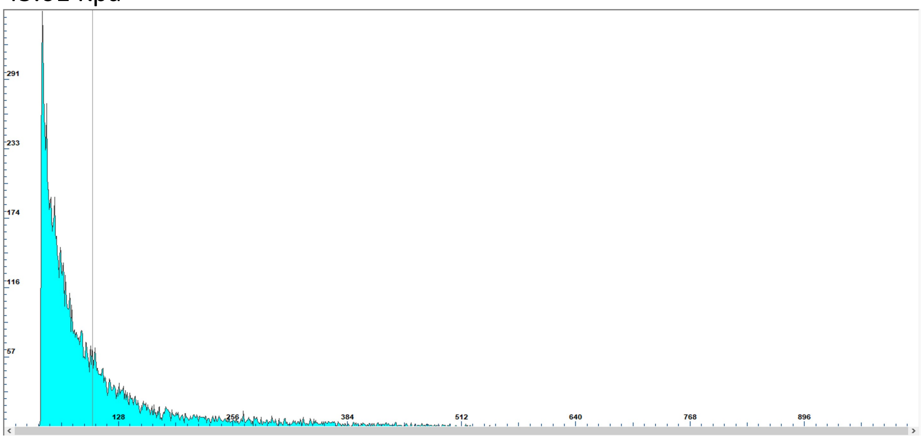
Gross Area: 28788

44.00 KPa



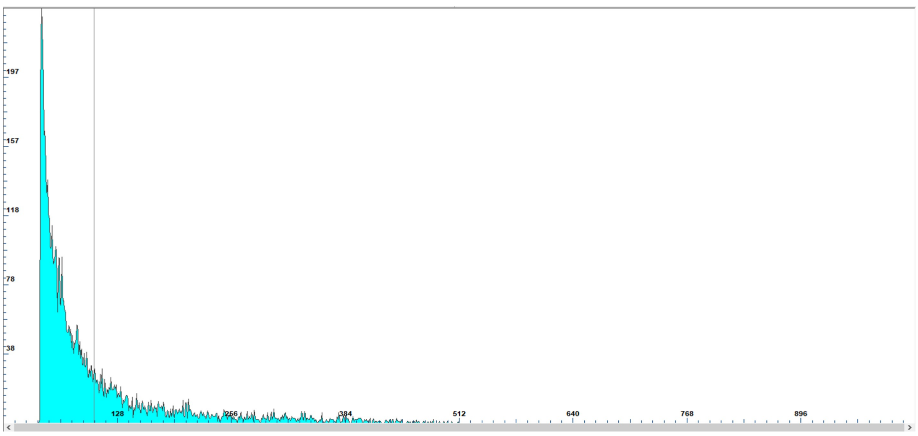
Centroid: 95.80
Peak Estimate: 7
FWHM: 17.4347
Net Area: 18240

45.01 Kpa



Centroid: 97.67
Peak Estimate: 7
FWHM: 11.9130
Net Area: 10840
Uncertainty: 0.96
Gross Area: 10840

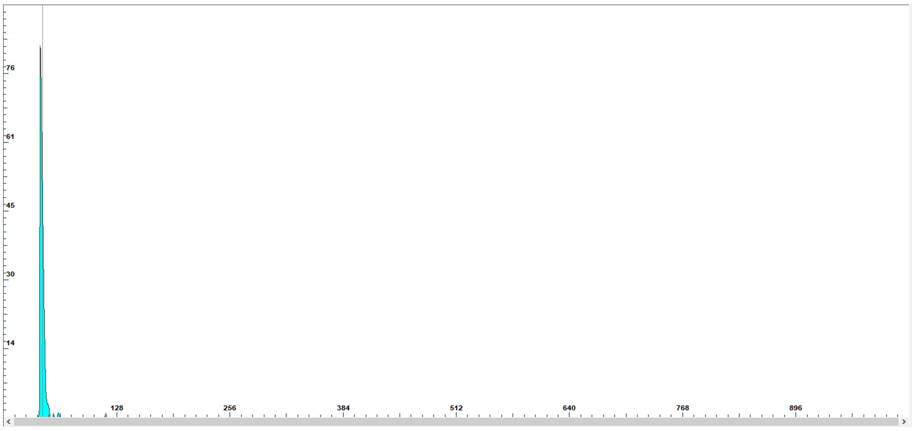
45.99 KPa



Centroid: 100.48
Peak Estimate: 2
FWHM: 9.4023

Area: 6636
Uncertainty: 6636

101.39 KPa



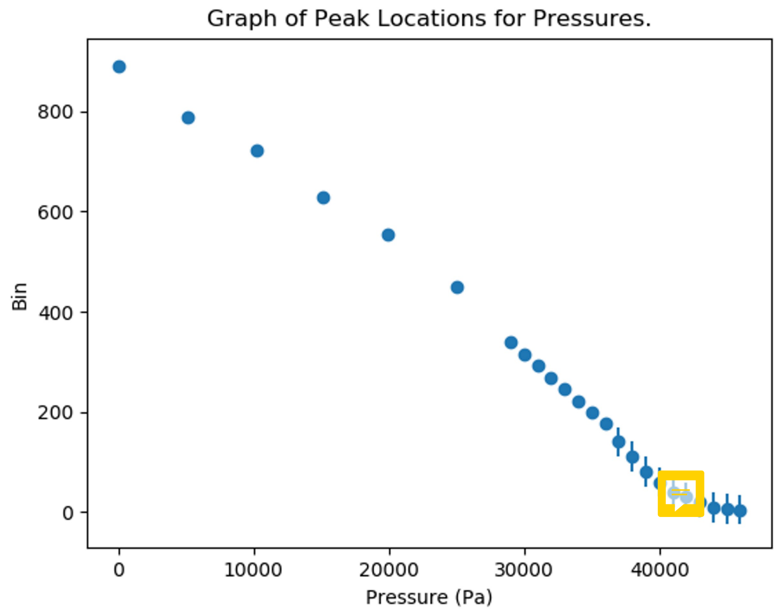
Centroid: 43.34
Peak Estimate: 0 (no alpha decay events detected)
FWHM: 3.1778
Net Area: 330
Uncertainty: 5.50
Gross Area: 330

Pressure	Peak	U(peak)	Width	Gross Area
0.00	890	+/- 20	98.38	213250
5.17	788.94	+/-0.05	115.1423	212346
10.23	720.98	+/-0.05	132.1429	209535
15.14	629.80	+/-.05	142.825	207162
19.97	554.52	+/-0.05	159.2947	204008
25.01	448.47	+/-0.05	171.0231	199252
29.06	340.33	+/-0.05	198.5675	193537
30.07	313.86	+/-0.05	215.5595	190924
31.04	291.89	+/-0.05	221.5390	187928
32.00	268.95	+/-0.05	230.9703	184129
33.00	245.05	+/-0.0	243.3879	178909
34.05	220.89	+/-0.05	264.9823	171507
35.05	198.24	+/-0.05	272.7831	161946
36.06	177.73	+/-0.05	233.9162	150083
36.99	155	+/-30	-	-
38.01	130	+/-30	-	-
39.02	100	+/-30	-	-
39.99	70	+/-30	-	-
41.04	40	+/-30	-	-
42.00	30	+/-30	-	-
43.00	20	+/-30	-	-
44.0	10	+/-30	-	-
45.01	7	+/-30	-	-

45.99	5	+/-30	-	-
101.39	0	+/-30	-	-

Analysis/Discussion

The pressure was likely varied instead of the distance to the detector as at atmospheric pressure the range of the alpha particles is relatively small at only roughly 3 cm, so either the range of distances would have to be small, or the apparatus would have to be operating at lower than average pressure anyway. Varying the pressure while keeping the range constant allows the experiment to use a wider range of values for variation.

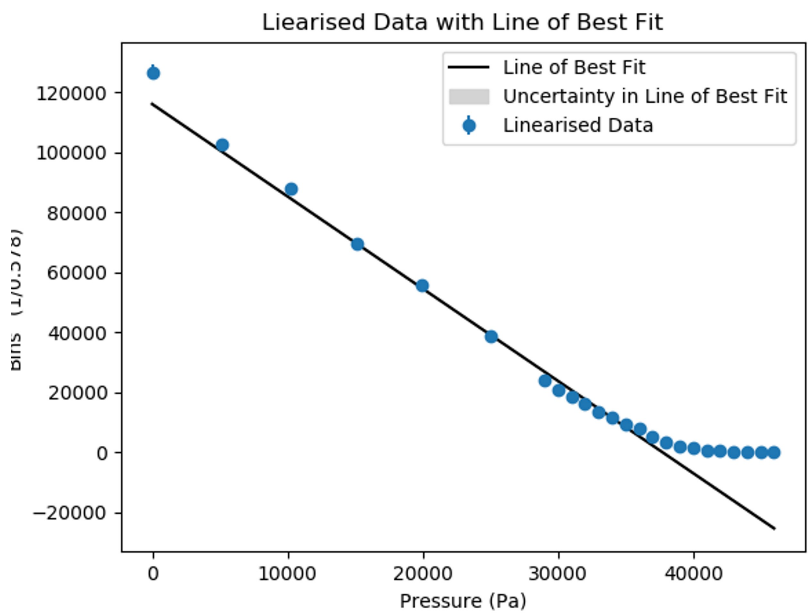


Linearize the data by using equation (5).

$E^{1/0.578} = E_0^{1.73} - 0.0156(p\Delta x/T)$

$(\text{Peaks})^{(1/0.578)} = \lambda * \text{pressure}$

U_lin_peaks = (u_peaks/peaks)x(1/0.578)*lin_peaks



Gradient = -3.0777 +/- 0.0002

Intercept = 116092 +/- 8

$0 = 116092 - 3.0777*p$
$P = 37720$ +/- 8 (Due to adding in quadrature, uncertainty from gradient becomes negligible relative to uncertainty in intercept)

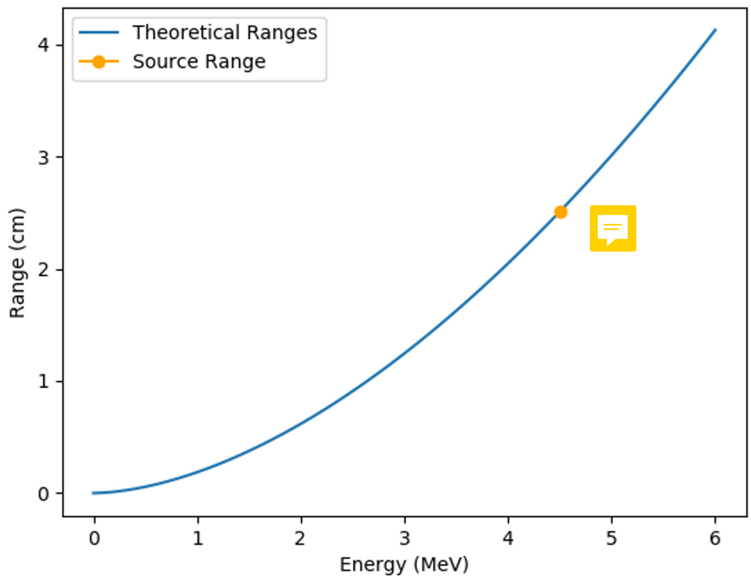
Therefore $p_0 = 37.720$ +/- 0.008 KPa

$P_0 = 64.31(T/x_0)E_0^{1.73}$
$X_0 = 6.77$ +/- 0.1 cm
$T = 294$ +/- 0.5 K

$E_0 = 4.50$ MeV
$E_0 = (p_0*(x_0/T))^{1/1.73}$
$U\_E_0/E_0 = [(8/37720)^2 + (.1/6.77)^2 + (.5/294)^2)^{1/2}$
$U\_E_0 = 0.07$

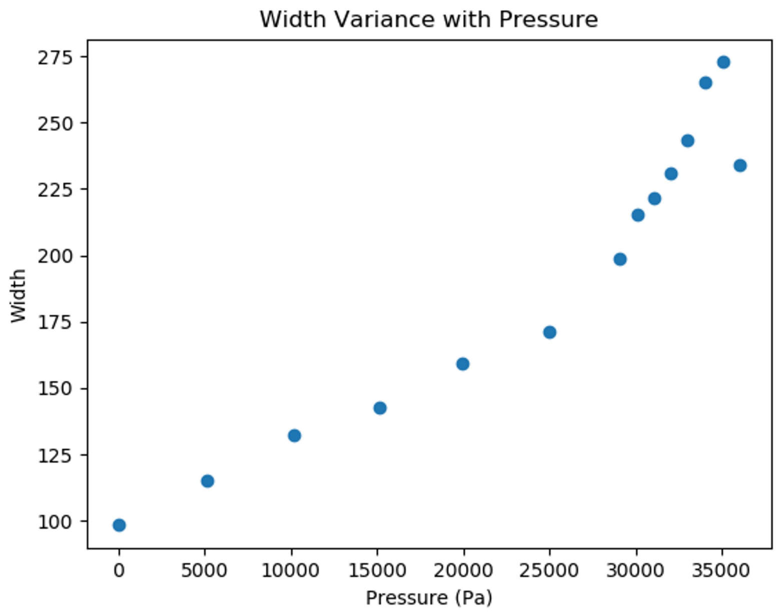
This is on the same order as the literature value of 5.48 MeV, however, it is outside of 3 uncertainties. This difference is likely due to the presence of the gold shell.

$4.50 = (E_0^{1.73} - 4.464\rho_{gold}((A_{air})^{1/2}/(A_{gold})^{1/2})\Delta x)^{0.578}$
$E^0 = 4.5029$ MeV
$A_{gold} = 197$
$\rho_{gold} = 19.3\ g/cm^3$
Therefore $\Delta x = 0.235$ cm. This is significantly greater than the 0.0003 cm manufacturer spec.

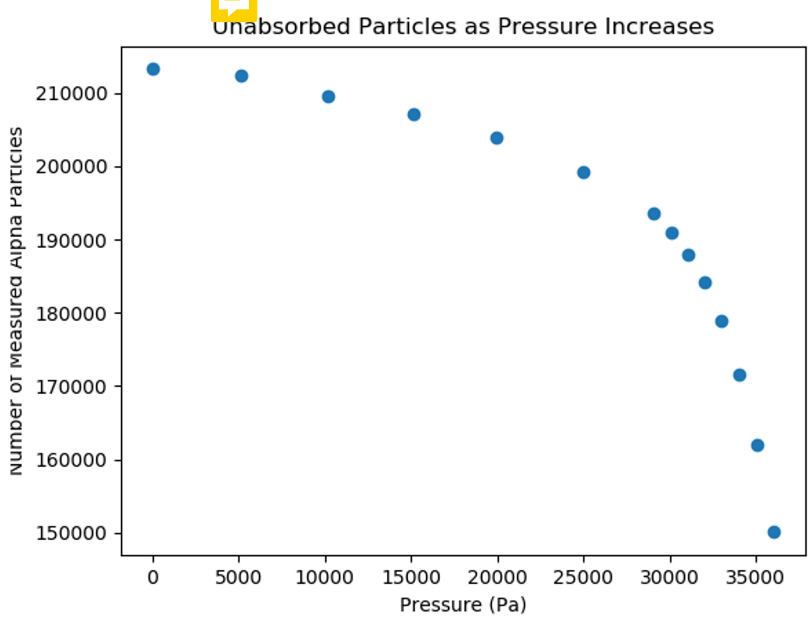


Plot of theoretical ranges at atmospheric pressure.

For values of width when peak passed below threshold, ADMCA did not accurately measure width, and it is impossible to measure.



The width of the distribution increases as the pressure does, until the peak of the distribution nears the point of the measurement threshold, causing the software to incorrectly estimate the width, basing it off of information that it does not have. A similar effect occurs in the measurement of the Gross Area of the graphs, as the software (much like a student who procrastinated too much) is not able to extrapolate from the data present into the threshold.



Conclusion:

By linearizing the data collected by the detector and MCA, p_0 was found to be 37.720 +/- 0.0008 kPa, while the base energy of the alpha particles being emitted by the source was found to be 4.5 +/- 0.07 MeV, indicating a gold shell 0.235 cm thick. All of these values were significantly far from the expected values. This was likely due to the poor estimations and extrapolations of the peak locations at high pressures, where the noise interfered with the data spectrum, and it was cut off by the measurement threshold of the MCA. These values likely caused the intercept and gradient of the linear fit applied to the linearized data to be incorrect, propagating that error throughout the following results. In order to correct this, more care would be taken to more carefully consider how the points would extrapolate from the previous data, and to try and better account for the noise data in the region, and attempt to subtract that from the desired data.

References:

Monas University School of Physics and Astronomy (2020) 1.2: Range and Energy Loss of α-particles in Air. Retrieved From https://d3cgwrxphz0fqu.cloudfront.net/02/e3/02e34691201103c65605bea35a145a9e4d538114?response-content-disposition=inline%3Bfilename%3D%22Exp%201.2%20-%20Range%20and%20loss%20of%20alpha%20particles%20v6.6.pdf%22&response-content-type=application%2Fpdf&Expires=1599765003

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