Effect of Lead Shielding on Gamma Ray Emission of K-40

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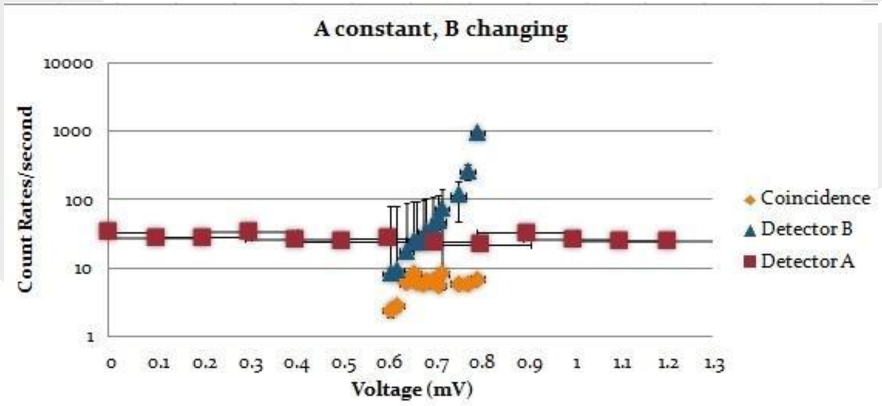
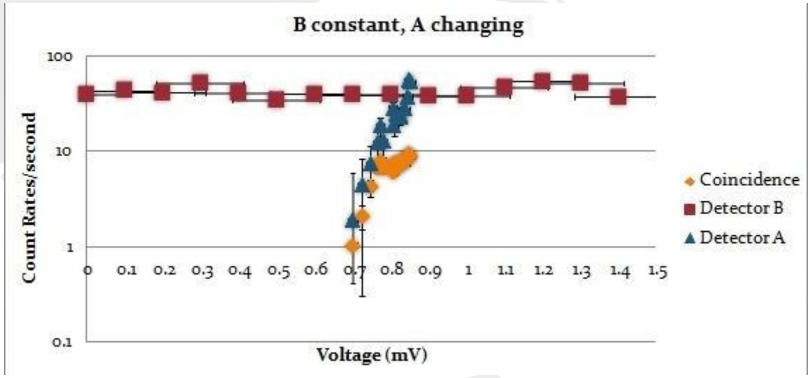
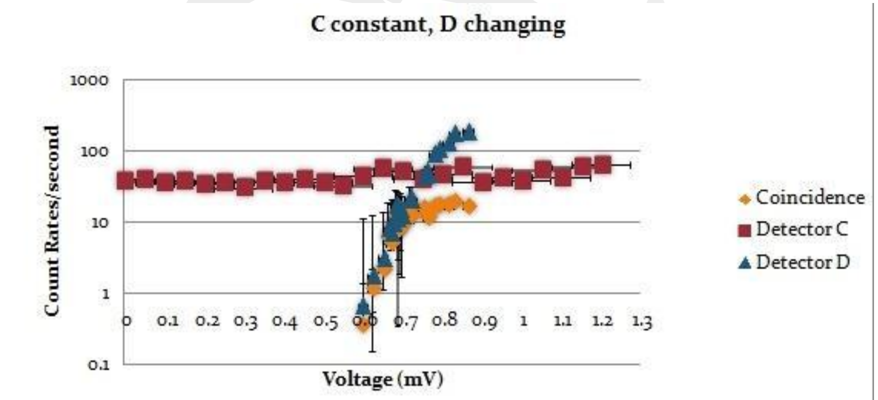
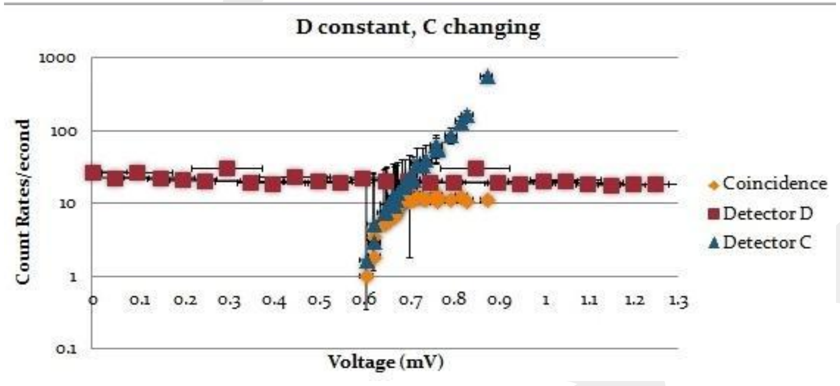
Muon Scintillator Calibration





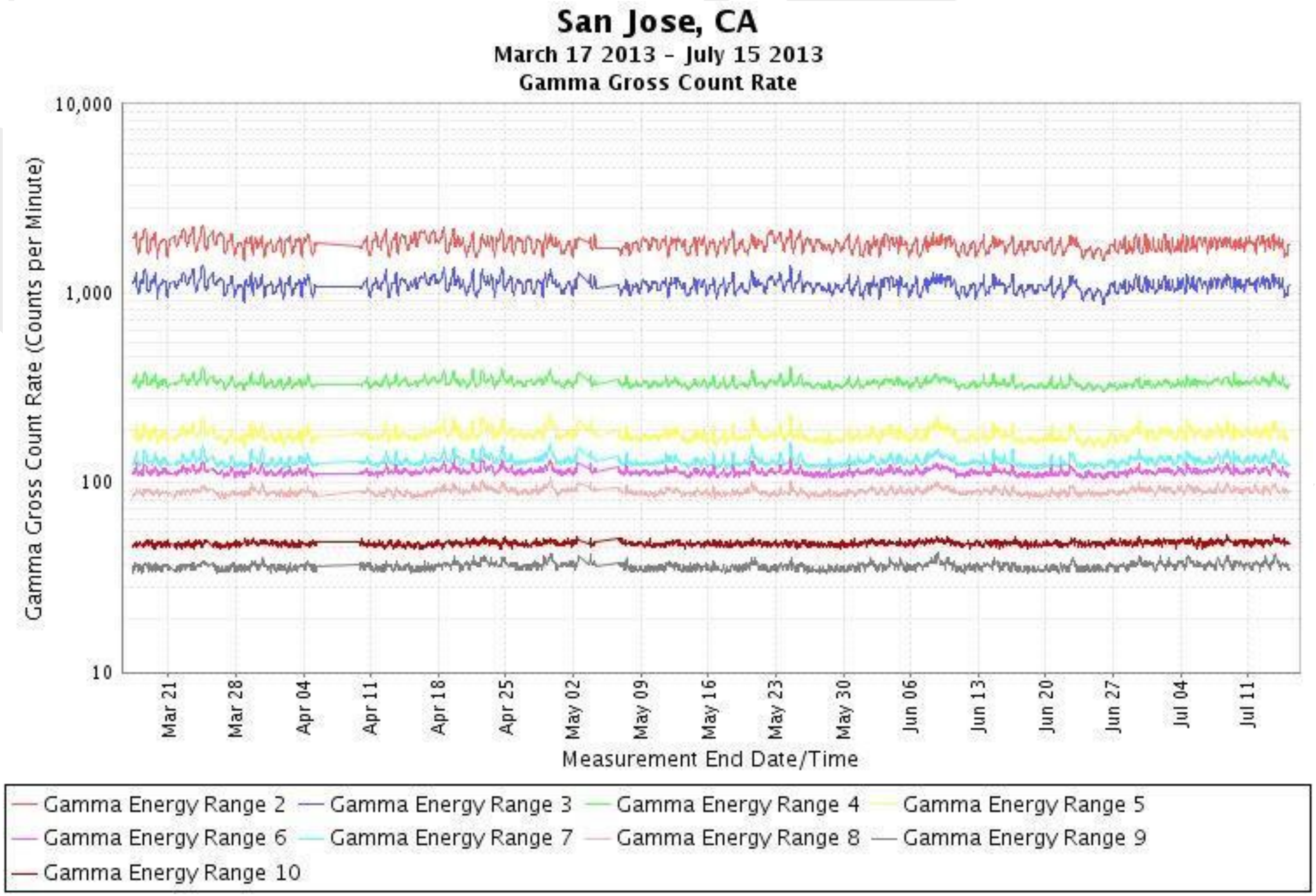




Gamma Radiation

- 1896: Henri Becquerel discovered gamma radiation
  - examined uranium
    - emitted "metallic phosphorescence"
- Gamma photons have 10,000 times the energy of photons in the visible spectrum
  - emitted from the nuclei of radioactive isotopes
  - present naturally in cosmic ray showers
  - high penetrating power of gamma rays
    - only materials with a high Z value (like lead) can shield gamma rays

Naturally Occurring Gammas:



Abstract

This experiment involves the lead shielding of the gamma ray flux of potassium-40. Potassium chloride is relatively rich in the radioactive isotope K-40, which releases gamma rays. Using a sodium iodide detector, first calibrated with cesium-137, gamma rays were counted and sorted by energy. The data was analyzed in the region between 1.1889 MeV and 1.5129 MeV, which encompassed the spectrum generally emitted by the source. Data was collected for at least an hour and a half each, and background checks were done overnight every few days. In each trial, different thicknesses of lead were stacked on top of the salt, effectively decreasing the count rate. After all the data was collected, the data points formed a decreasing exponential trend. We found the experimental absorption coefficient of lead to be 5.747, and the percent error was approximately 12.95%.

Objective

The purpose of this experiment was to determine the effect of lead shielding on the gamma ray flux of K-40. Different thicknesses of lead plates were placed on top of the K-40 source and data was collected.

Hypothesis

With an increased thickness of lead shielding, the amount of gamma rays detected by the NaI detector will decrease exponentially.

Materials

- Sodium Iodide Detector
  - detects all particles including gamma radiation
- Potassium Chloride (salt substitute)
  - contains K-40, radioactive isotope
  - 1.4627 kg
- Lead plates: 0.7 mm to 34.9 mm
  - varying thicknesses used to shield source
- Box for salt
  - used to compact source
- Black Box
  - increases proximity of source to detector

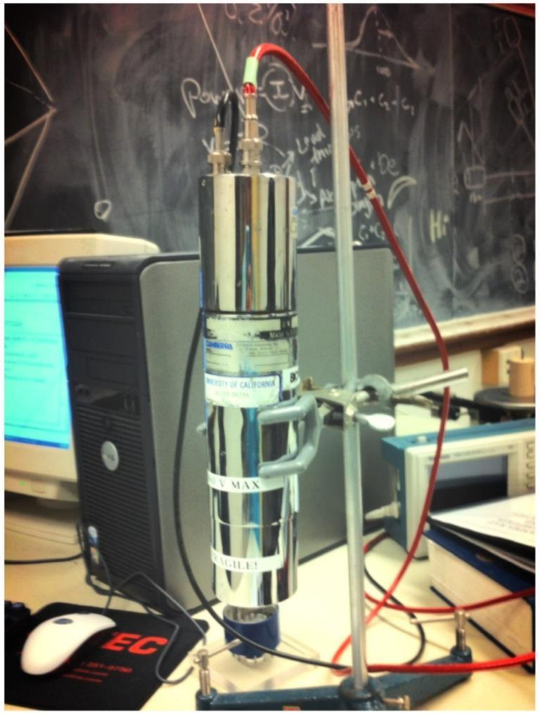
Materials (cont.)

- Computer w/ high voltage source (900 V)
  - used to power NaI detector
- Gamma Ray Acquisition and Analysis software
  - collects the count rate and energy levels of gamma rays and other particles

NaI Detector

- Gamma rays can be detected by a sodium iodide detector through:
  - Pair Production: gamma ray and nucleus
  - Photoelectric Absorption: gamma ray and a bond between nucleus and electron
  - Compton Effect: gamma ray and electron
- Particle detection
  - NaI crystal creates pulse of light proportional to energy of particle
- Energy of particles and count rate recorded by computer software in spectrum

NaI Detector (cont.)



Calibration of NaI Detector

- to calibrate NaI detector, cesium-137 placed under the detector
  - energy of the gamma radiation from the source:1.176 MeV
- With proportion of energy to channel number
  - Cs-137 source used to estimate the channel number of radiation from the K-40 source.

Potassium Chloride

- Potassium-40 is a radioactive isotope of K present at abundance of 1.2 x 10^-4
  - energy of gamma rays from K-40: 1.461 MeV
- count rate of K-40 is about 1.5 gamma rays per second higher than the count rate of the ambient spectrum.

$$N_{LEFT} = N_0 \cdot e^{-\left(\frac{cm^2}{g} \cdot \frac{g}{cm^2}\right)}$$

find value online

density $\left(\frac{g}{cm^3}\right)$ · thickness (cm)

Fraction of KCl w/ K-40 → 1.2×10^{-4}

Half Life → 1.248×10^{9} years → 3.94×10^{16} seconds

lifetime - τ

halflife - t

$$\tau = \frac{t}{\ln 2} = 5.684 \times 10^{16} \text{ seconds}$$

3 pounds ≈ 1463 grams

$$\frac{1463\,g}{74.55\,g/mol} \cdot 6.02 \times 10^{23} \frac{atoms}{mol} \cdot 1.2 \times 10^{-4}$$

$= 9.8 \times 10^{20}$ K-40 gamma emmitting particles

$$\frac{dN}{dt} = \frac{N_0}{\tau} = \frac{9.8 \times 10^{20}}{5.684 \times 10^{16}}$$

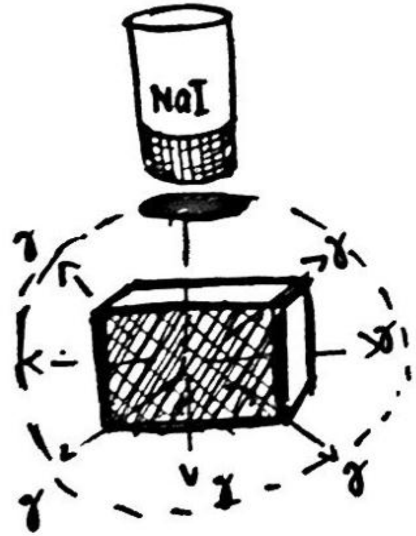
= 1724 counts/sec

only 1% reaches detector

= 17.24 counts/sec

& detector only counts 10%

$= \boxed{1.724 \text{ counts/sec}}$



Methods

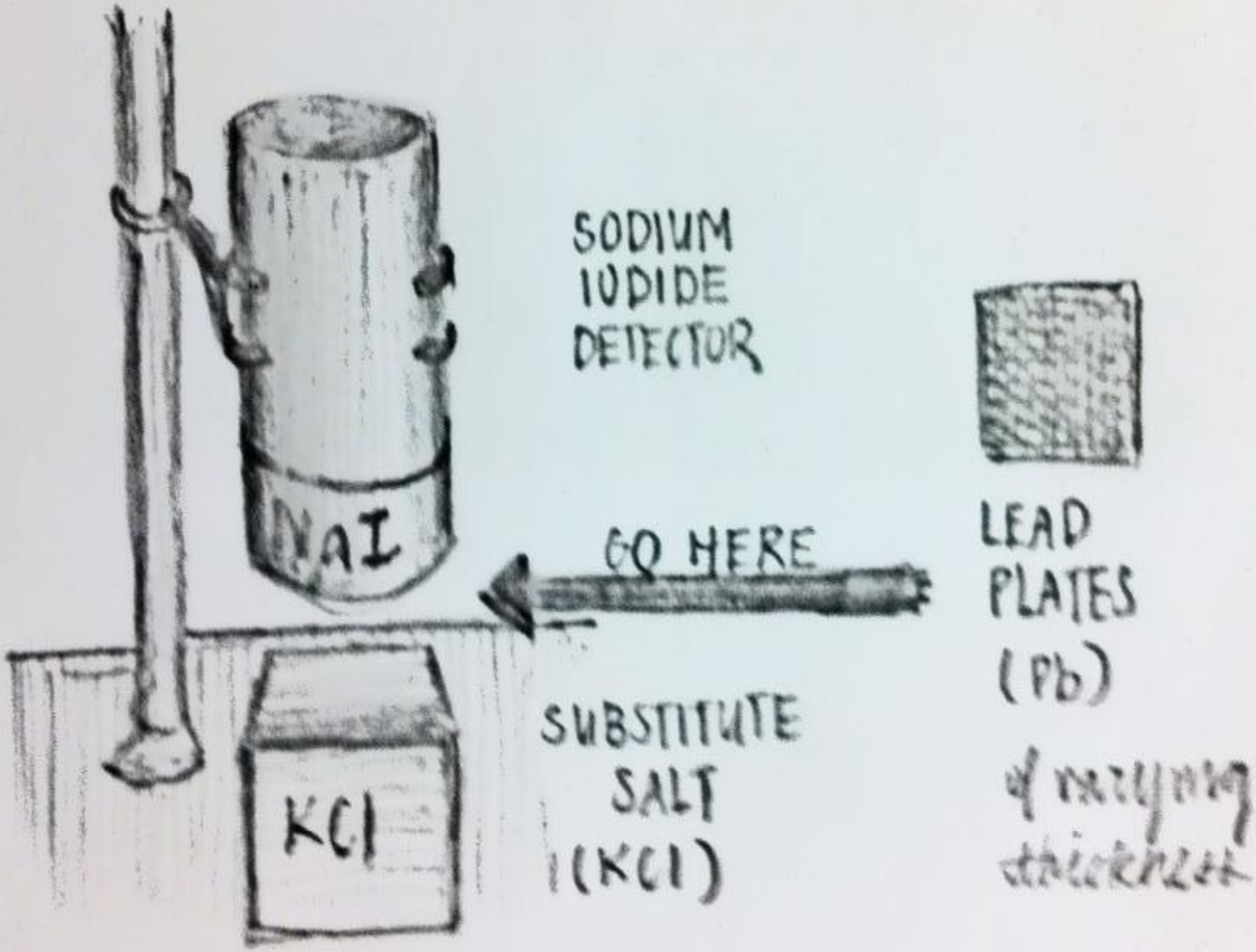
- NaI detector calibrated with Cs-137 source; background was run for three hours
- source placed 7.62 cm away from the detector
    - data from source was collected overnight
- background taken periodically (run overnight) and subtracted from count rate of the source
    - count rate of source taken periodically to account for natural flux.

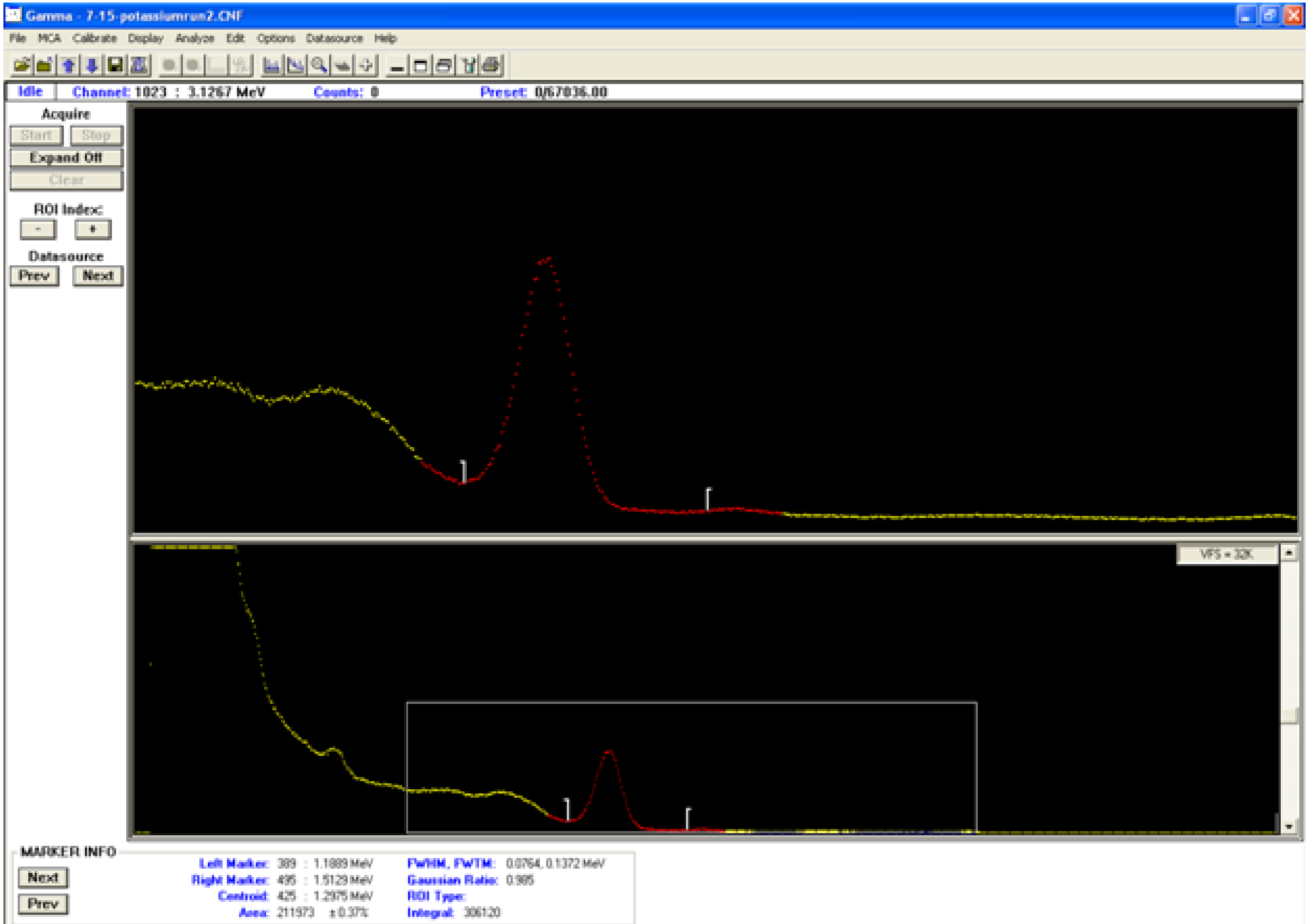
Methods (cont.)

- Different thicknesses of lead plates placed on top of source; data collected for one to two hours
  - 0.7 mm, 1.6 mm, 3.4 mm, 4.5 mm, 6.5 mm, 9.2 mm, 12.6 mm, 15.2 mm, 19.0 mm, 22.4 mm, 25.0 mm, 28.4 mm, 31.5 mm, and 34.9 mm were
- Optimal time period of data run calculated with following equation:

$$e^{p/d}$$

  - where p is lead thickness and d is absorption length

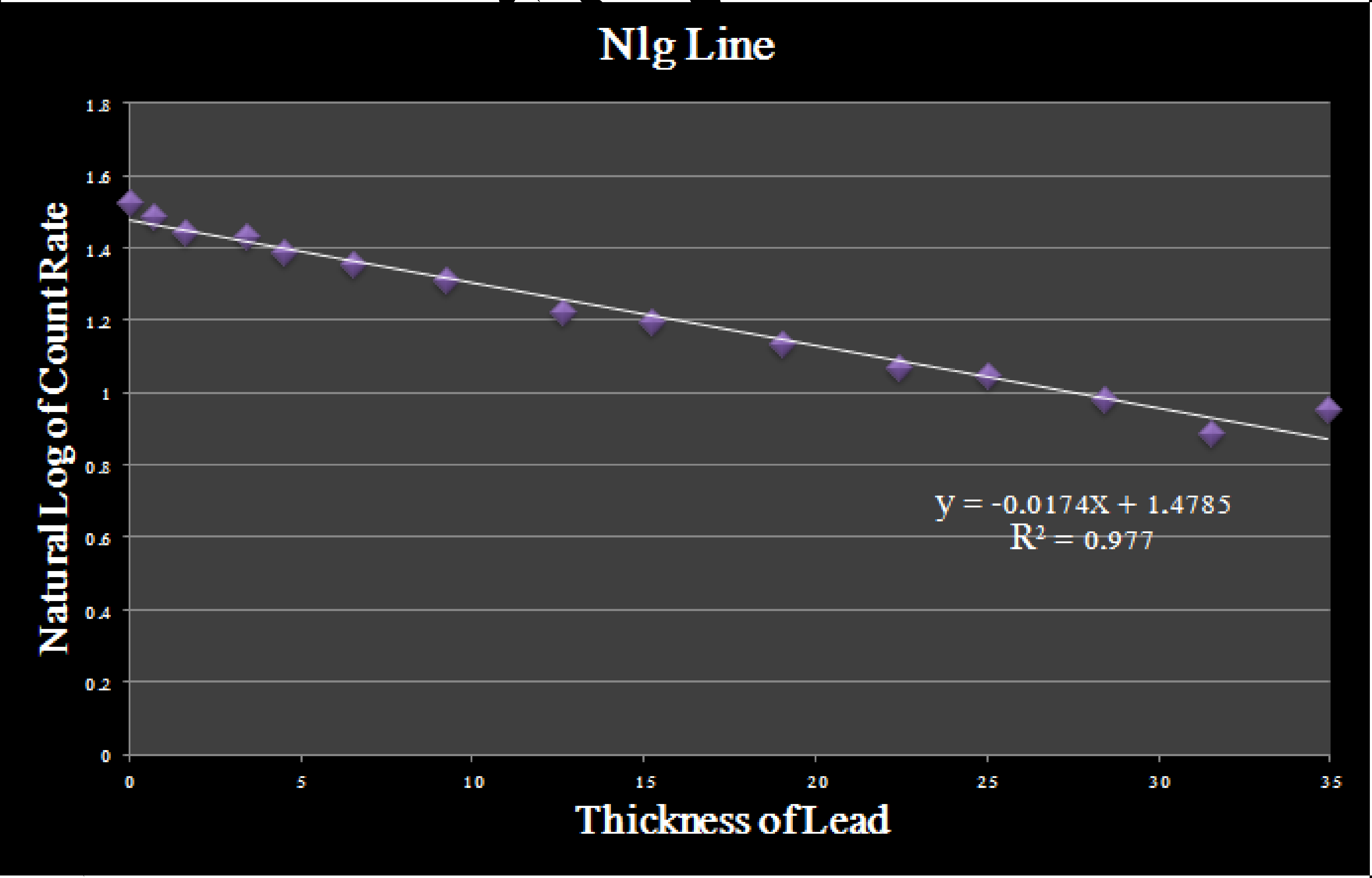

SODIUM IODIDE DETECTOR
NaI
GO HERE
LEAD PLATES (Pb)
of varying thickness
SUBSTITUTE SALT (KCl)
KCl



All data and count rates were analyzed in the region between 1.1889 MeV and 1.5129 MeV, which encompasses the peak of gamma radiation from K-40.

Results

- graph of count rate against the thickness of lead features a curve that decreases exponentially
- the natural log of this curve is linear
- one of the data points, 3.4 mm deviates from the line
    - the overlap of the lead pieces may have contributed to this
    - presence of other people in the room


Nlg Line
Natural Log of Count Rate
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
Thickness of Lead
y = -0.0174X + 1.4785
R² = 0.977

time to run each test:

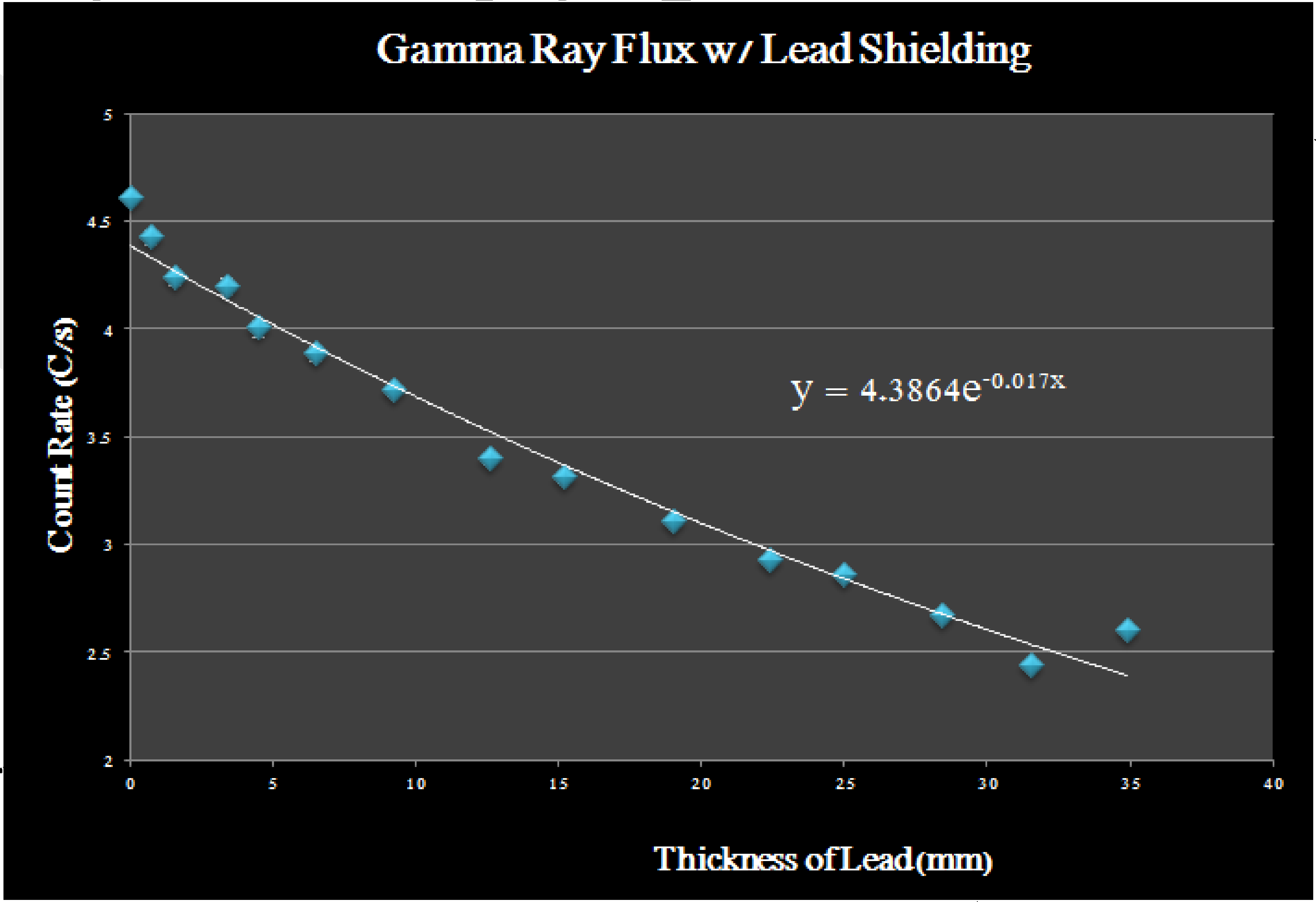
$e^{p/d}$ where p is lead thickness
and d is absorption length

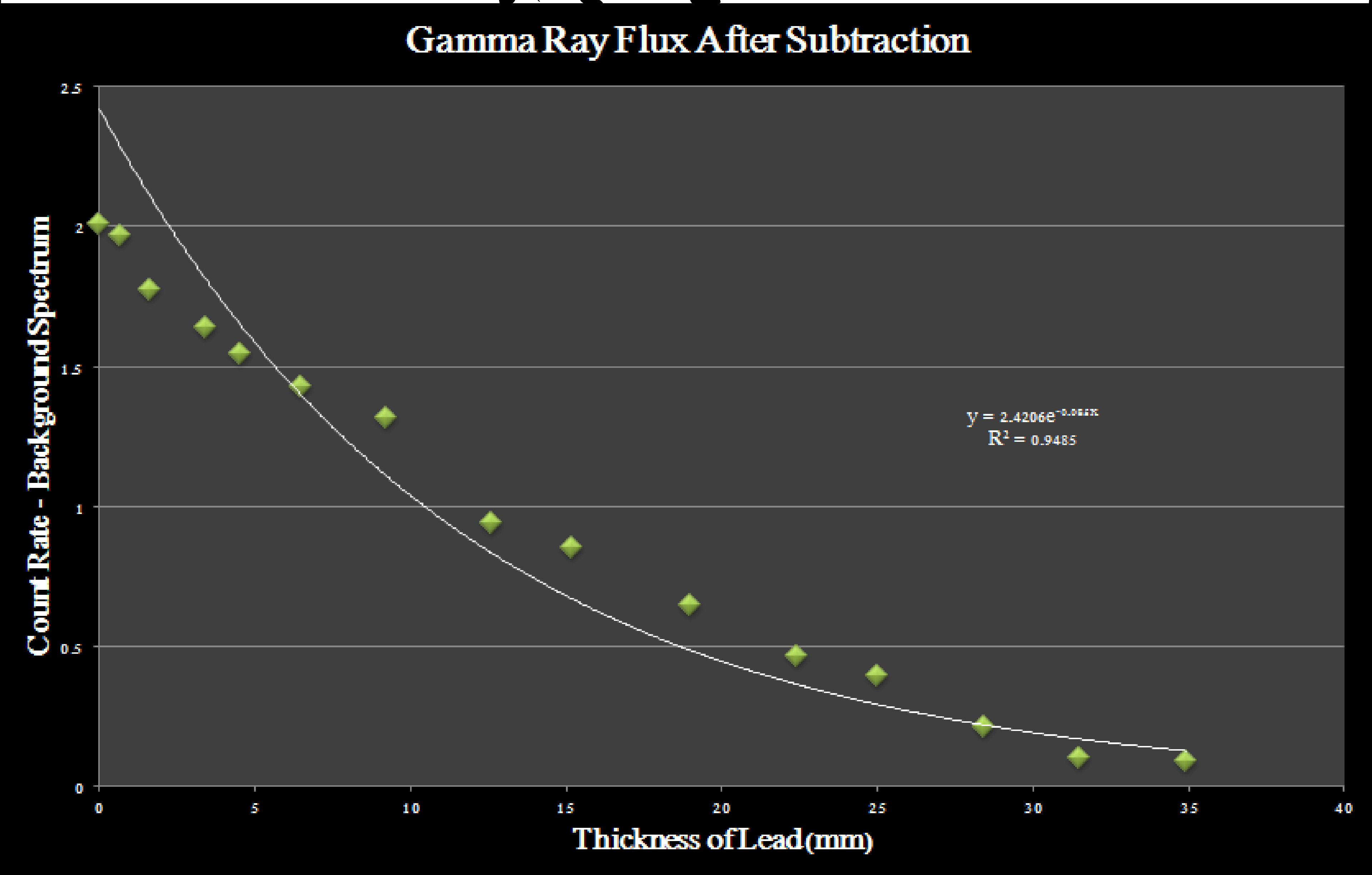
$$y = -0.0174x + 1.4785$$

$$\ln|N| = -0.0174x + 1.4785$$

$$e^{\ln|N|} = e^{-.0174x + 1.4785}$$

$$N = 4.3864\, e^{-.0174}$$


Gamma Ray Flux w/ Lead Shielding
Count Rate (C/s)
5
4.5
4
3.5
3
2.5
2
0
5
10
15
20
25
30
35
40
$y = 4.3864e^{-0.017x}$
Thickness of Lead (mm)



Gamma Ray Flux After Subtraction
Count Rate - Background Spectrum
Thickness of Lead (mm)
R² = 0.9485
0
0.5
1
1.5
2
2.5
5
10
15
20
25
30
35
40

Absorption Coefficient of Lead

- Experimental Value: 5.747
- Researched Value: 5.088
- Percent Error: 12.95%

Conclusion

With the increase of lead shielding, the count rate of K-40 decreased exponentially. With every additional millimeter of lead added, the natural log of the count rate of K-40 decreased by a factor of 0.0174. The experimental absorption coefficient of lead was found to be 5.747, and the percent error was approximately 12.95%. This data could have been affected by the presence of people and at times, other sources and metals in the room. Increasing the length of data runs, using lead plates that matched the dimensions of the container perfectly, and using a larger amount of the source could have reduced the experimental error. Running the experiment with smaller increments of lead could also decrease the error. The equation determined from this experiment, which relates the count rate of K-40 to the mm of lead shielding, could be used to eliminate the emission of gamma rays from the source in certain directions. This would allow for a study of gamma rays with reduced variables. In addition, this experimental setup could be used to study the effect of shielding on ionized radiation from various sources; with sufficient data, locations with abundant radioactive sources including nuclear power plants could be shielded to limit hazardous leakage.

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