January 10 samples used:

- Co-60
    - 1 Feb 09: 34.92 kBq = .9437 µCi
- Ba-133
    - 1 Feb 09: 35.59 kBq = .9619 µCi
- Cs-137
    - 1 Feb 09: 34.58 kBq = .9347 µCi

Current radioactivity of each sample

All same age: (2020-Jan-10) - (2009-Feb-01)

- 3995 days / (365 days per year)
    - = 10.945 years

General decay formula: $A = A_0 * e^{-t * \lambda}$

$\lambda = (\ln 2) / (T_{1/2})$
So the formula for each element's decay will be $A = A_0 * e^{-10.945 * \lambda}$

Co-60

- A_0 = .9437 µCi
- $T_{1/2}$ = 5.27 y
- $\lambda = (\ln 2) / (5.27\ y)$
    - $= 0.131527\ y^{-1}$
- $A = (.9437\ \mu Ci) * e^{-10.945 * 0.131527}$
    - = **0.2237 µCi**

Ba-133

- A_0 = .9619 µCi
- $T_{1/2}$ = 10.51 y
- $\lambda = (\ln 2) / (10.51\ y)$
    - $= 0.065951\ y^{-1}$
- $A = (.9619\ \mu Ci) * e^{-10.945 * 0.065951}$
    - = **0.4673 µCi**

Cs-137

- A_0 = .9347 µCi
- $T_{1/2}$ = 30.0 y
- $\lambda = (\ln 2) / (30.0\ y)$

- = .0231 y^{-1}
- A = (.9619 µCi) * $e^{-10.945 * .0231}$
  - = **0.747 µCi**

Efficiency Calibration

DE = D/N
DE = detector efficiency
D = number of photons counted in the detector
N = number of photons emitted by the source
$N = TB_{\text{Specific energy of isotope}} \times T_{\text{Detection}} \times A_{\text{Isotope}}$

Co-60

Total decays:

= 131.63 sec * 0.2237 µCi * ((3.7 * 10^4 decays per second)/(1 µCi))
= **1.089 * 10^6 decays**

a. 1173.23 KeV

N = 1 photon/decay * (1.089 * 10^6 decays)
= **1.089 * 10^6 photons**

b. 1332.49 KeV

N = 1 photon/decay * (1.089 * 10^6 decays)
= **1.089 * 10^6 photons**

Ba-133

Total decays:

= (131.63 sec) * (0.4673 µCi) * (3.7 * 10^4 decays per second)/(1 µCi)
= **2.276 * 10^6 decays**

a. 81 KeV

N = 0.34 * (total decays)
= **773,804 photons**

b. 276 KeV:

N = (.075 avg photons/decay) * (**2.276 * 10^6 decays**)

= **170,700 photons**

c. 303 KeV

N = .183 * (total decays)
= **417,171 photons**

D = 26965.9 counts
DE = 26965.9 / 773804.59
= .0348

d. 356 KeV

N = 0.62 * (total decays)
N = **1,411,055 photons**

D = 59841 counts

Cs-137

Total decays:

= (131.63 sec) * (0.747 μCi) * (3.7 * 10^4 decays per second)/1 (μCi)
= **3.638 * 10^6 decays**

a. 661.66 KeV

N = 0.85 avg photons/decay * (3.638 * 10^6 decays)
= **3,092,403 photons**
D = 97,575 photons

Energy Calibration

Gamma-ray energies and intensities:

- Co-60:
  - 1173.23 KeV, 99.85%
  - 1332.49 KeV, 99.98%
- Ba-133:
  - 81.00 KeV, 34.06%
  - 275.93 KeV, 7%
  - 302.85 KeV, 18.33%
  - 356.01 KeV, 62.05%
- Cs-137:

- 661.66 KeV, 85.1%

Results

Efficiency Calibration Results

We had trouble obtaining an equation that matched the existing calibration curve, above the knee. The below table has the energy levels with corresponding efficiency ratios (DE = D/N).

Area determined by GammaVision + calculated Detector Efficiency (DE)

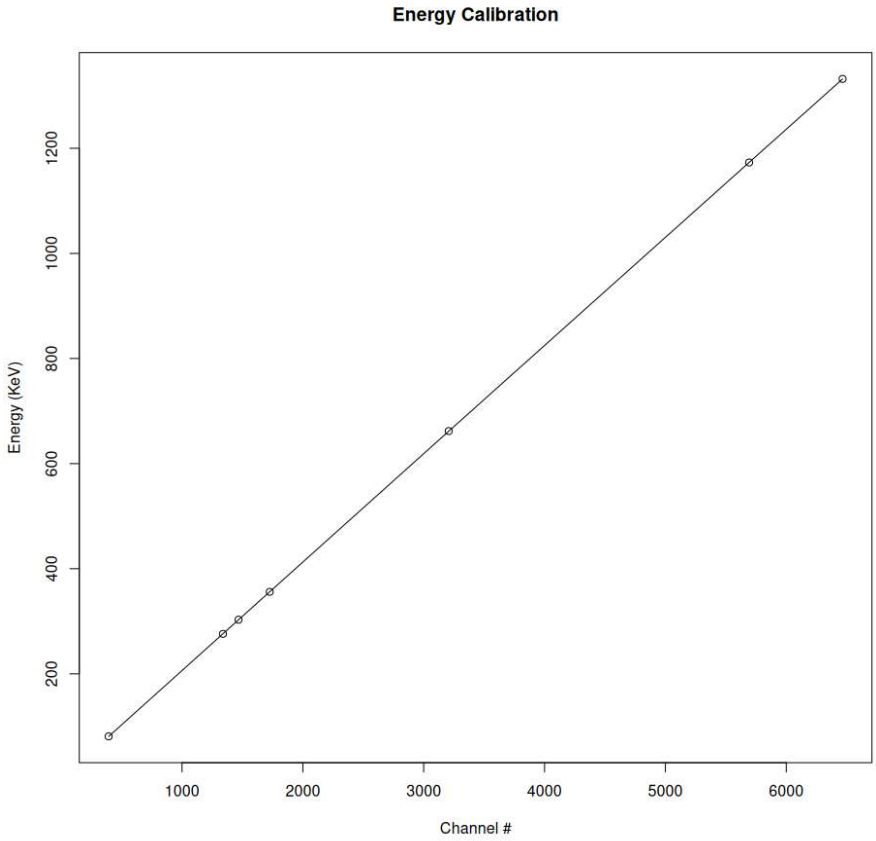
Isotope	Centroid channel #	Energy (KeV)	Gross area counts, GammaVision	Net area counts, GammaVision	Measured counts (D), using GammaVision net area	Total emitted counts (N)	**DE = D/N**
Co-60	5693	1173	9789	9053 +/- 119	9053	1,087,854	**0.00832**
	6463	1332	8576	8129 +/- 106	8129	1,089,270	**0.00746**
Ba-133	394	81	57934	38145 +/- 375	38145	775,170	**0.04921**
	1342	276	15623	6211 +/- 241	6211	170,700	**0.03639**
	1466	303	26175	17471 +/- 256	17471	417,172	**0.04188**
	1727	356	59841	50026 +/- 323	50026	1,411,055	**0.03545**
Cs-137	3187	662	97575	91505 +/- 359	91505	3,092,403	**0.02959**

Energy Calibration R results

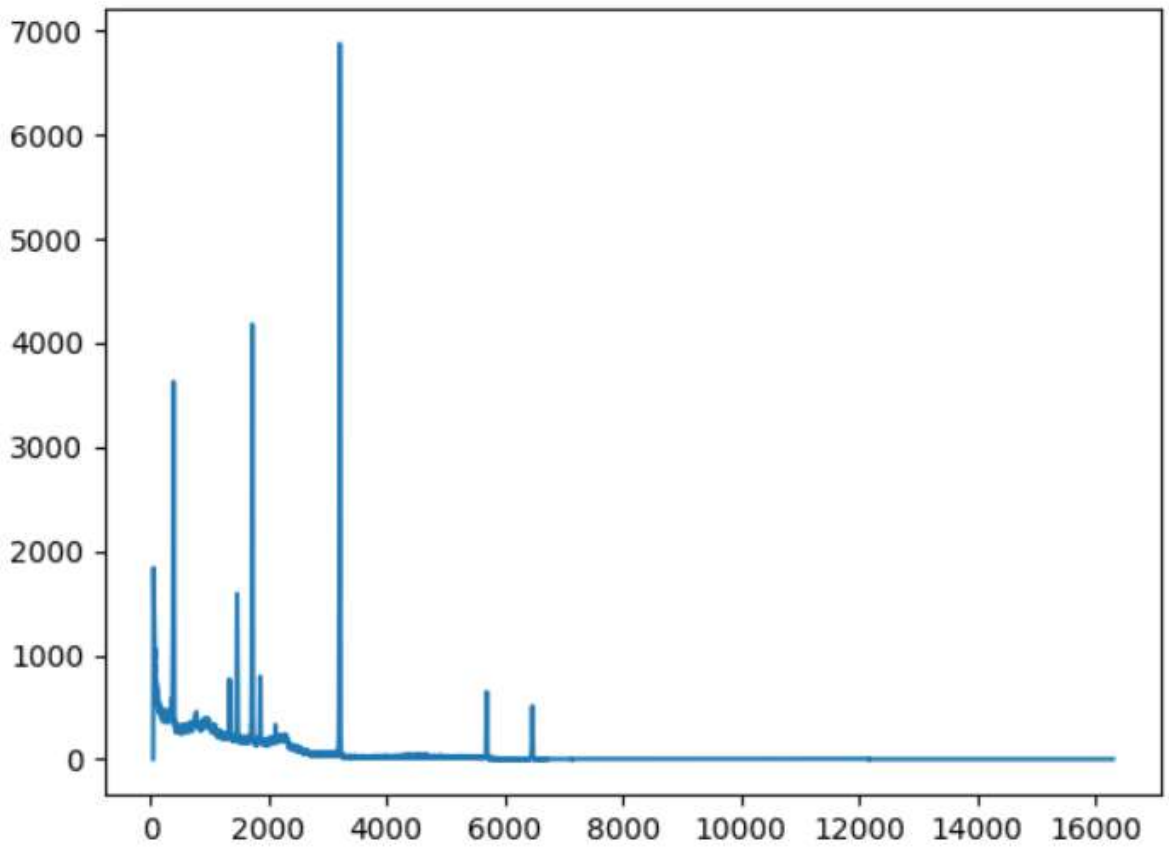
```
Residuals:
      1       2       3       4       5       6       7
 0.1950 -0.2944  0.0652 -0.2033  0.3382 -0.1804  0.0797

Coefficients:
                                    Estimate Std. Error t value Pr(>|t|)
(Intercept)                        -4.731e-01  3.226e-01  -1.467   0.2164
poly(data$channel, 2, raw = TRUE)1  2.069e-01  2.576e-04 803.181 1.44e-11 ***
poly(data$channel, 2, raw = TRUE)2 -1.240e-07  3.552e-08  -3.491   0.0251 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.2844 on 4 degrees of freedom
Multiple R-squared:      1,   Adjusted R-squared:      1
F-statistic: 8.593e+06 on 2 and 4 DF,  p-value: 5.417e-14
```

2nd order polynomial fit: $y = -0.473 + 0.207x - 1.240 \cdot 10^{-7}x^2$

Calibration report: $y = -0.125 + 0.207x - 7.297 \cdot 10^{-8}x^2$



Appendix



ListPRO binary output file of Co-60, Ba-133, Cs-137, plotted with Python's Matplotlib
Horizontal axis: channel
Vertical axis: counts