

# **Study of CdTe Detector Efficiency and Energy Resolution using different radioactive sources**

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## **1. Abstract:**

This experiment deals with the observation of X-ray radiation spectra of radioactive metals - 55Fe, 109Cd & 241Am - using a CdTe semiconductor detector. The spectra were analysed for the energies at which the peaks were observed and consequently a comparison was made between observed and expected values from theory. The Gaussian fitting of each peak was done to determine the FWHM & Energy Resolution of the peaks. The photopeak detection efficiency of CdTe detector was theoretically determined for energy range 1-1000 keV. The decay process of each metal and the cause for each observed peak has also been explained.

## **2. CdTe Detector:**

CdTe is a solid X-ray detector of very small size. It is mounted on a two-stage thermoelectric cooler. The internal components of the detector are kept at a temperature of approximately -30°C. The X-rays and the gamma rays interact with the CdTe semiconductor to create an average of one electron/hole pair for every 4.43 eV lost in the lattice structure. Depending on the energy of the incoming radiation, the energy loss is either dominated by photoelectric effect or Compton scattering<sup>1</sup>. The primary advantage of CdTe is its much greater efficiency, due to its higher atomic number, Z.(For Si, Z=14 while for CdTe , Z=50). Since photoelectric cross-section scales as  $Z^5$ , the efficiency of Amptek's 500μm thick Si detector begins to fall above 10 keV, while for 1mm CdTe, efficiency is high till around 100 keV.<sup>1,2,3</sup>

The principle of operation of a semiconductor detector is based on the collection of the charges, created by the primary photon interactions, and their drift through the lattice by application of an external electric field. The energy range of interest mainly influences the choice of the proper semiconductor material for a radiation detector. Among the various interaction mechanisms of x-rays and gamma rays with the detector, three effects play the most important roles in radiation measurements: photoelectric absorption, Compton scattering, and pair production. In photoelectric absorption the photon transfers all its energy to an atomic electron, while a photon interacting through Compton process transfers only a fraction of its energy to a free electron, producing a hot electron and a degraded photon. In pair production, a photon with energy above threshold energy of 1.02 MeV interacts within the Coulomb field of the nucleus producing an electron and positron pair. Neglecting the escape of characteristic x-rays from the detector volume (the fluorescent lines), photoelectric effect results in the total absorption of the incident energy and thus gives useful information about the primary photon energy. The interaction cross sections are highly dependent on the atomic number. In photoelectric absorption, interaction cross-section varies as  $Z^4$  or  $Z^5$ . Compton scattering, it changes as  $Z$  or  $Z^2$  for pair production. An optimum spectroscopic detector must favour photoelectric interactions, and hence, semiconductor materials with a high atomic number are preferred.<sup>4,5</sup>

### 3. Peaks:

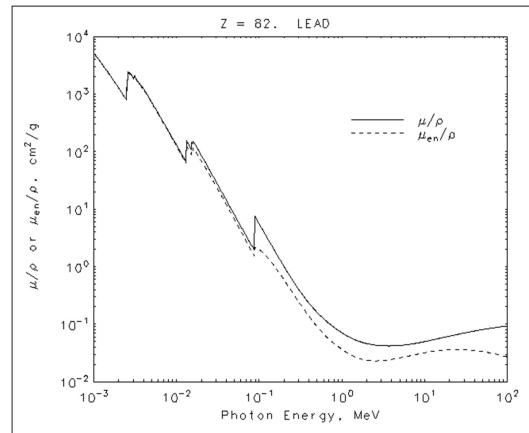
There are two kinds of peaks which will be observed in the spectra:

- Photo peaks:

These are observed because of photoelectric effect.  $K\alpha$ ,  $K\beta$ ,  $L\alpha$  &  $L\beta$  lines will be observed in this way. In many cases the  $\alpha$  &  $\beta$  lines will be close enough for the detector to be not able to resolve them. In Iron spectra, one single cumulative peak was observed for  $K\alpha$  &  $K\beta$  lines. By using Gaussian modelling, one could fit the cumulative peak with 2 Gaussian functions to reveal the individual components.

- Escape peaks:

When a radiation is incident on the detector, the probability of absorption directly depends on the linear attenuation coefficient. The attenuation coefficient drops just before the Kedge, Ledge etc. energy by almost a factor of 10. The attenuation coefficient decreases with energy as  $E^3$ . Hence an incident photon of energy just below Kedge will have lesser probability of getting absorbed by the detector. Therefore the  $K\alpha$ ,  $K\beta$  photons released by the detector atoms(on photoelectric absorption) will have a chance to 'escape' the detector lattice without being detected, the rest of incident gamma energy will only be detected. Hence peaks with energy of  $\gamma$ - $K\alpha$ ,  $\gamma$ - $K\beta$  called escape peaks will also be observed.



### 4. Energy Resolution:

Energy resolution is a measure of the width (full width half max) of a single energy peak at a specific energy, either expressed in absolute keV (as with Germanium Detectors), or as a percentage of the energy at that point (CdTe Detector)<sup>6</sup>. The energy resolution of a detector is given through the full width at half maximum (FWHM) of an energy peak. The FWHM is defined as the width of the distribution at a level that is just half the maximum ordinate of the peak<sup>6,7</sup>. The energy resolution of CdTe detector measures its ability to distinguish gamma-rays with close energies. The better the energy resolution, the better it can separate two adjacent energy peaks, which allow identifying different decays or radionuclides in the spectrum<sup>8</sup>.

$$Energy\ Resolution(\%) = \frac{FWHM\ of\ the\ Peak}{Energy\ of\ the\ Peak} \times 100$$

$$Energy\ Resolution \propto \frac{1}{\sqrt{Energy}}$$

## 5. Detection Efficiency:

The detection efficiency of a detector is defined by the probability of interaction of particles with the detector lattice. Each of the possible interaction processes can be characterised by a probability of occurrence per unit path length in the absorber. The sum of the probabilities for the individual processes is the total probability per unit length that the photon is removed from the beam, termed the linear attenuation coefficient, and is denoted  $\mu(\text{cm}^{-1})$ .

The number of primary photons transmitted through a thickness  $t$  is - <sup>9,10</sup>

$$I = I_o e^{-\mu t}$$

Where  $I_0$  is the flux of incident photons,  $t$  is the thickness of the attenuator,  $\mu$  is the linear attenuation coefficient and  $I$  is the flux of transmitted primary photons. The number of primary photons interacting in a thickness  $t$  is:

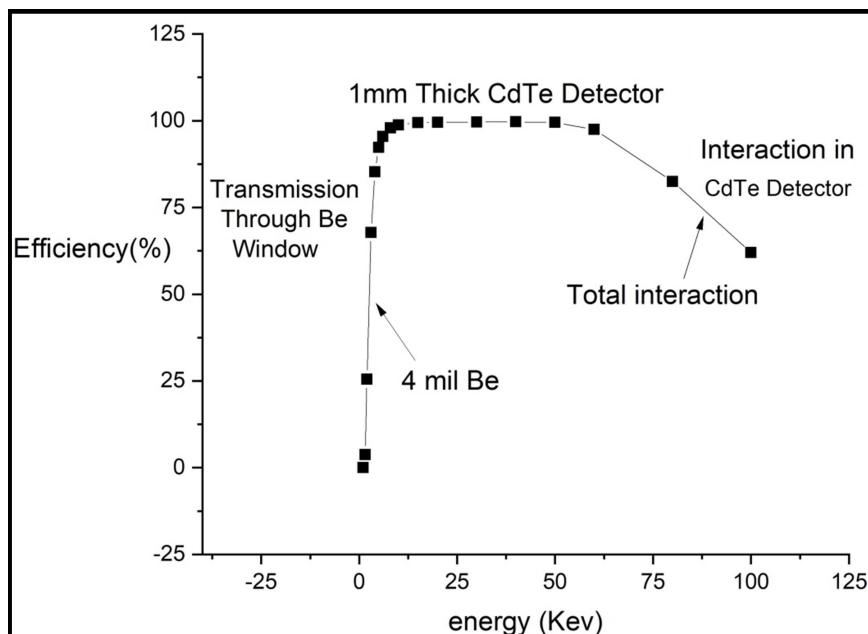
$$I = I_o (1 - e^{-\mu t})$$

Amptek's standard XR-100T-CdTe consists of a 1 mm thick CdTe located behind a 4 mil (100  $\mu\text{m}$ ) Be window. The probability of a photon interaction somewhere in the thickness is the product of:

- the probability of transmission through Be
- the probability of interaction in the material <sup>9</sup>

$$I' = I_o \times e^{-\mu t} \times (1 - e^{-\mu t})$$

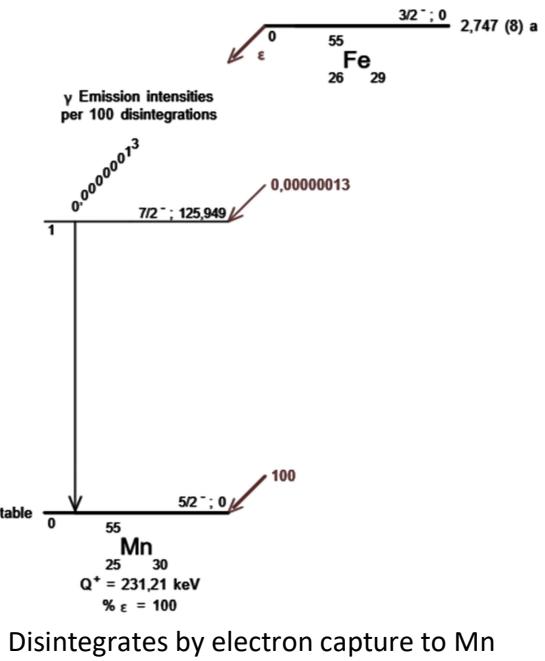
The Detection efficiency of CdTe detector for Energy(in range of 1-100 keV) is calculated and plotted below.



## 6. Decay Schemes:



	Energy keV	Photons per 100 disint.	
<b>X-Ray Emissions</b>			
XL (Mn)	0,556 — 0,721	0,524 (21)	
XK $\alpha_2$ (Mn)	5,88765	8,45 (14)	} K $\alpha$
XK $\alpha_1$ (Mn)	5,89875	16,57 (27)	}
XK $\beta_3$ (Mn)	6,49045	}	
XK $\beta_1$ (Mn)		}	K' $\beta_1$
XK $\beta_5''$ (Mn)	6,5352	}	
XK $\beta_4$ (Mn)		}	K' $\beta_2$
<b>Gamma Emissions</b>			
$\gamma_{1,0}$ (Mn)	125,949 (10)	0,00000013 (1)	
<b>Auger Electrons</b>			
Auger K			
KLL	4,953 — 5,210	100	Relative probability
KLX	5,671 — 5,895	27,2	
KXY	6,370 — 6,532	1,85	
Auger L	0,47 — 0,67		



- Container was made up of Brass
- Emission will be observed from Mn

Photo peaks from Mn:      K $\alpha$  [5.90keV]      &      K $\beta$  [6.49 keV]



	Energy (keV)	Electrons (per 100 disint.)
<b>Electron Emissions</b>		
e <sub>AL</sub>	(Ag) 1,8 - 3,8	167,3 (8)
e <sub>AK</sub>	KLL 17,79 - 18,69	
	KLX 20,945 - 22,160	
	KXY 24,079 - 25,507	20,8 (6)
ec <sub>1,0</sub> K	(Ag) 62,520 (1)	41,8 (8)
ec <sub>1,0</sub> L	(Ag) 84,2279 - 84,6826	44,1 (9)
ec <sub>1,0</sub> M	(Ag) 87,3162 - 87,6670	9,04 (19)
ec <sub>1,0</sub> N	(Ag) 87,9385 - 88,0304	1,413 (29)
<b>X Radiations</b>		
X <sub>K</sub>	K $\alpha_2$ 21,9906	53,05
	K $\alpha_1$ 22,16317	100
	K $\beta_3$ 24,9118	
	K $\beta_1$ 24,9427	
	K $\beta''_5$ 25,146	27,7
	K $\beta_2$ 25,4567	
X <sub>L</sub>	K $\beta_4$ 25,512	4,82
	L $\ell$ 2,634	
	L $\alpha$ 2,977 - 2,985	
	L $\eta$ 2,807	
	L $\beta$ 3,151 - 3,438	
<b>Gamma Emissions</b>		
$\gamma_{1,0}(\text{Ag})$	88,0336 (10)	3,66 (5)

(Emissions below 88 keV)

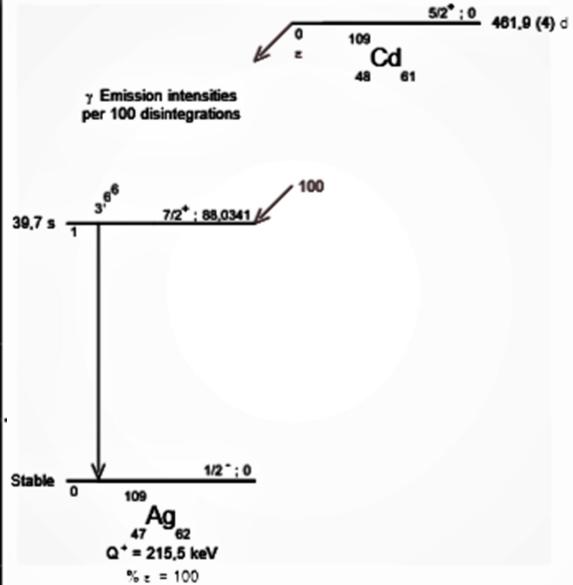
- Container was made up of Brass
- Emissions will be observed from Cd, Zn & Cu from Brass, Cd & Te from CdTe Detector and Ag.

➤ Photopeaks:

Ag:	K $\alpha$ [22.16 keV]	;	K $\beta$ [24.94 keV]	;	$\gamma$ [88.03 keV]
Cd:	K $\alpha$ [23.17 keV]	;	K $\beta$ [26.09 keV]		
Te:	K $\alpha$ [27.47 keV]	;	K $\beta$ [30.99 keV]		
Zn:	K $\alpha$ [ 8.64 keV]	;	K $\beta$ [ 9.57 keV]		
Cu:	K $\alpha$ [ 8.05 keV]	;	K $\beta$ [ 8.09 keV]		

➤ Escape peaks:

Cd:	$\gamma$ -K $\alpha$ [64.86keV]	;	$\gamma$ -K $\beta$ [61.94keV]		
Te:	$\gamma$ -K $\alpha$ [60.53keV]	;	$\gamma$ -K $\beta$ [57.01keV]		



Decays by electron capture to Ag-109

$^{241}_{\text{95}} \text{Am}^{146}$

		Energy keV	Relative probability
<b>X<sub>L</sub> X-Ray Emissions</b>			
L $\ell$		11,89	
L $\alpha$		13,76 – 13,944	
L $\eta$		15,876	
L $\beta$		16,13 – 17,79	
L $\gamma$		20,12 – 22,2	
<b>Electron Emissions</b>			
e <sub>AL</sub>	(Np)	6,04 – 13,52	33,4 (17)
ec <sub>2,1</sub> L	(Np)	3,92 – 8,73	14 (5)
ec <sub>1,0</sub> L	(Np)	10,769 – 15,590	15,9 (21)
ec <sub>3,1</sub> L	(Np)	20,28 – 25,09	0,31 (7)
ec <sub>2,1</sub> M	(Np)	20,606 – 22,681	3,7 (5)
ec <sub>4,2</sub> L	(Np)	20,99 – 25,81	8,8 (12)
ec <sub>1,0</sub> M	(Np)	27,46 – 29,53	4,0 (6)
ec <sub>1,0</sub> N	(Np)	31,70 – 32,79	1,08 (16)
ec <sub>6,4</sub> L	(Np)	33,13 – 37,95	0,87 (11)
ec <sub>3,1</sub> M	(Np)	36,97 – 39,04	0,076 (17)
ec <sub>2,0</sub> L	(Np)	37,114 – 41,930	30,2 (22)
ec <sub>4,2</sub> M	(Np)	37,68 – 39,76	2,3 (4)
ec <sub>4,2</sub> N	(Np)	41,92 – 43,02	0,65 (9)
ec <sub>6,4</sub> M	(Np)	49,82 – 51,90	0,228 (30)
ec <sub>2,0</sub> M	(Np)	53,802 – 55,877	8,12 (25)
ec <sub>6,4</sub> N	(Np)	54,06 – 55,16	0,062 (8)
<b>Gamma Emissions</b>			
$\gamma_{2,1}$	(Np)	26,3446 (2)	2,31 (8)
$\gamma_{(-1,1)}$	(Np)	32,183	0,0174 (4)
$\gamma_{1,0}$	(Np)	33,1963 (3)	0,1215 (28)
$\gamma_{3,1}$	(Np)	42,704 (5)	0,0055 (11)
$\gamma_{4,2}$	(Np)	43,420 (3)	0,0669 (29)
$\gamma_{14,10}$	(Np)	51,01 (3)	0,000026 (12)
$\gamma_{6,4}$	(Np)	55,56 (2)	0,0181 (18)
$\gamma_{(-1,2)}$	(Np)	57,85 (5)	0,0052 (15)
$\gamma_{2,0}$	(Np)	59,5409 (1)	35,92 (17)

(Emissions below 59.54 keV)

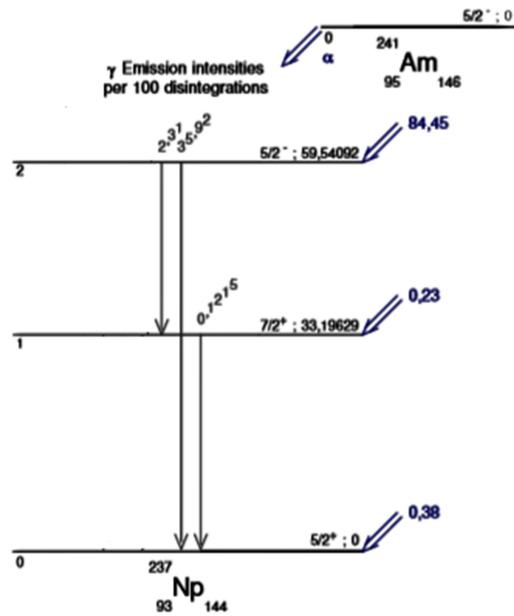
- Emissions will be observed from Am,Np, Cd & Te from CdTe Detector.

➤ Photopeaks:

Np:	L $\alpha$ [20.77 keV]	;	K $\beta$ [17.74 keV]	;	$\gamma$ [59.54 keV]
Am:	L $\alpha$ [22.04 keV]	;	K $\beta$ [18.83 keV]		
Cd:	K $\alpha$ [23.17 keV]	;	K $\beta$ [26.09 keV]		
Te:	K $\alpha$ [27.47 keV]	;	K $\beta$ [30.99 keV]		

➤ Escape peaks:

Cd:	$\gamma$ -K $\alpha$ [36.37 keV]	;	$\gamma$ -K $\beta$ [33.45 keV]
Te:	$\gamma$ -K $\alpha$ [32.07 keV]	;	$\gamma$ -K $\beta$ [28.55 keV]



Decays by alpha transition to Np-237

## **7. Configuration of Device:**

Connect the USB cable from DP5 to USB 3.0 port of the laptop. Open Amptek DPPMCA software. A ‘Select DPP Communications Port’ window pops up. Select USB mode and click on connect. Check the status bar at the bottom of the main window. If the communication is set, a green icon named ‘WinUSB’ is seen. Next click on the MCA tab menu and select ‘Acquisition Setup’ or press F9. In the pop-up window, select ‘CdTe Default PX5’, click apply and then Ok.

## **8. Data Collection:**

The default gain in the right column is 11.996X, and the Gain delta (step size to vary the gain) is 1.00. We first put the Fe-55 source in front of the detector at some optimum distance (roughly 5 cm). Start the acquisition from the MCA tab menu and observe the peak. Adjust the gain using increment/decrement option in the DPP tab menu such that 5.9 keV peak is adjusted at around channel 100. The fine adjustment of the gain can be done, by changing the step size of the Gain delta by multiples of 10. Gain delta changes the step size by which gain can be changed. The actual changes in the gain are obtained by using the Increment/Decrement option in the DPP tab menu only. Remove the Fe-55 source and then without changing the gain, record the background data for 500 to 1000 seconds. Then replace the Fe-55 source to the same position in front of the detector and record the data for the same time duration as the background data. Then stop the Acquisition and Save the spectrum. Repeat the same for 109Cd and 241Am source.

## **9. Data Analysis:**

The data obtained from the spectrum was copied to a text file(count vs channel values). A python program was made to fit the individual peaks with Gaussian plots. The program is capable of fitting a peak with any number of Gaussian functions (max. 11) using least-sq. fitting method. The program plots the Gaussian curves and displays the Gaussian fit parameters, Energy, channel and Energy Resolution values with fitting errors(from the fitting covariance matrix). A graph of Energy Resolution (keV) vs X-ray peak energy was plotted. An allometric fitting reveals the dependence between Energy resolution and peak energy. A log-log graph of ER vs E was also plotted with a linear fit. Data values of only photopeaks were taken.

## 10. Program:

```
#This is the program used for fitting the Cadmium spectra, the other two
programs for Iron & Americium are almost similar
import numpy as np
import matplotlib.pyplot as plt
import scipy.optimize
from math import sqrt
f=open("finalcd.txt",'w+')
''' '_1gaussian' is function for a gaussian curve(parameters-amplitude,
mean, std. deviation; 'master' is the function for multiple gaussian
curves added together with a background noise 'd'; 'plot1g' function
helps in plotting the individual gaussian curves from the fitting
parameters obtained from 'master' '''
def master
(x_ar,d=0,a1=0,c1=0,s1=1,a2=0,c2=0,s2=1,a3=0,c3=0,s3=1,a4=0,c4=0,s4=1,a5=
0,c5=0,s5=1,a6=0,c6=0,s6=1,a7=0,c7=0,s7=1,a8=0,c8=0,s8=1,a9=0,c9=0,s9=1,a
10=0,c10=0,s10=1,a11=0,c11=0,s11=1):
    return[_1gaussian(i,a1,c1,s1)+_1gaussian(i,a2,c2,s2)+_1gaussian(i,a
3,c3,s3)+_1gaussian(i,a4,c4,s4)+_1gaussian(i,a5,c5,s5)+_1gaussian(i,a6,c6
,s6)+_1gaussian(i,a7,c7,s7)+_1gaussian(i,a8,c8,s8)+_1gaussian(i,a9,c9,s9)
+_1gaussian(i,a10,c10,s10)+_1gaussian(i,a11,c11,s11)+d for i in x_ar]
def _1gaussian(x, a1, c1, s1):
    return (a1*(1/((s1)*(np.sqrt(2*np.pi)))))*(np.exp(-((x-
c1)**2/((2*(s1))**2))))
def energy(x):
    return calfac*(x)
def fwhm(x):
    return 2*sqrt(2*np.log(2))*(x)
def straightline(x,m,c):
    return x*m+c
def plot1g(x, var):
    for i in range(int(len(var)/3)):
        r=[*list(var[i*3+j+1] for j in range(3)),var[0]]; print(r)
        f.write(str(str(r)+'\n'))
        plt.plot(x, var[0]+_1gaussian(x, *list(var[i*3+j+1] for j in
range(3))), '--',lw=0.6)
a=np.loadtxt('cd1.txt')
b=np.loadtxt('background.txt')
a[:,1]=a[:,1]-b[:,1]
for i in range(90):
    a[i,1]=0 #there's too much noise till channel 90; hence those
values were deleted
plt.plot(a[:,0],a[:,1],'g')
x_ar,y_ar=a[:,0],a[:,1]
```

```

#two peaks were identified from the plots with a known definite energy,
and their means were used to compute the calibration factor
calfac=(24.9427-22.16317)/(437.9999999999994-388.50434028228256)
intercept=88.04-calfac*1536.877934920594 # if intercept is not equal to
zero then it means 0th channel does not correspond to 0keV energy
print("calibration factor-",calfac,"intercept-",intercept)
#specify the channel region which you want to fit(from x1[i] to x2[i])
x1=[131,378,427,1000,1124,1154,1534]
x2=[183,398,450,1052,1148,1187,1550]
'''for every x1[i] to x2[i] region, C[i] array should contain the(exact)
channel(s) where you think there must be a peak, use 0 to specify an
unknown peak; len(C[i]) will be the number of gaussian functions the
program is going to fit the region with
for eg. use C=[[0],[0],[0],[0],[0],[0]] to fit every region with
1 gaussian function without specifying where the peak might be '''
C=[[147,175],[389],[437],[1013,1038],[1135],[1174],[0]]
channel,E,ER,FWHM,channelerr,FWHMerr,ERerr,Eerr=[],[],[],[],[],[],[]
for i in range(len(x1)):
    print("peak ",i+1)
    x_ar=a[int(x1[i]):int(x2[i]),0]
    y_ar=a[int(x1[i]):int(x2[i]),1]
    p0=[0]
    b=[0],[min(a[int(x1[i])-20:int(x2[i])+20,1])+2]
    for k in range(len(C[i])):
        p0.append(max(y_ar))
        if C[i][k]!=0 : p0.append(C[i][k])
        else : p0.append(sum(x_ar)/len(x_ar))
    p0.append(0.2)
    b[0].append(0)
    b[1].append(1000000)
    if C[i][k]!=0 :
        b[0].append(C[i][k]-1)
        b[1].append(C[i][k]+1)
    else :
        b[0].append(x_ar[0])
        b[1].append(x_ar[-1])
    b[0].append(0)
    b[1].append(10)
    print(p0,b)
    #fitvars contains the fitting parameters; fiterr contains the
covariance matrix
    fitvars,fiterr=scipy.optimize.curve_fit(master,x_ar,y_ar,p0,bounds=b)
    plot1g(x_ar,fitvars)
    plt.plot(x_ar,master(x_ar,*fitvars))
    for j in range(len(C[i])):
        E.append(energy(fitvars[3*j+2]))

```

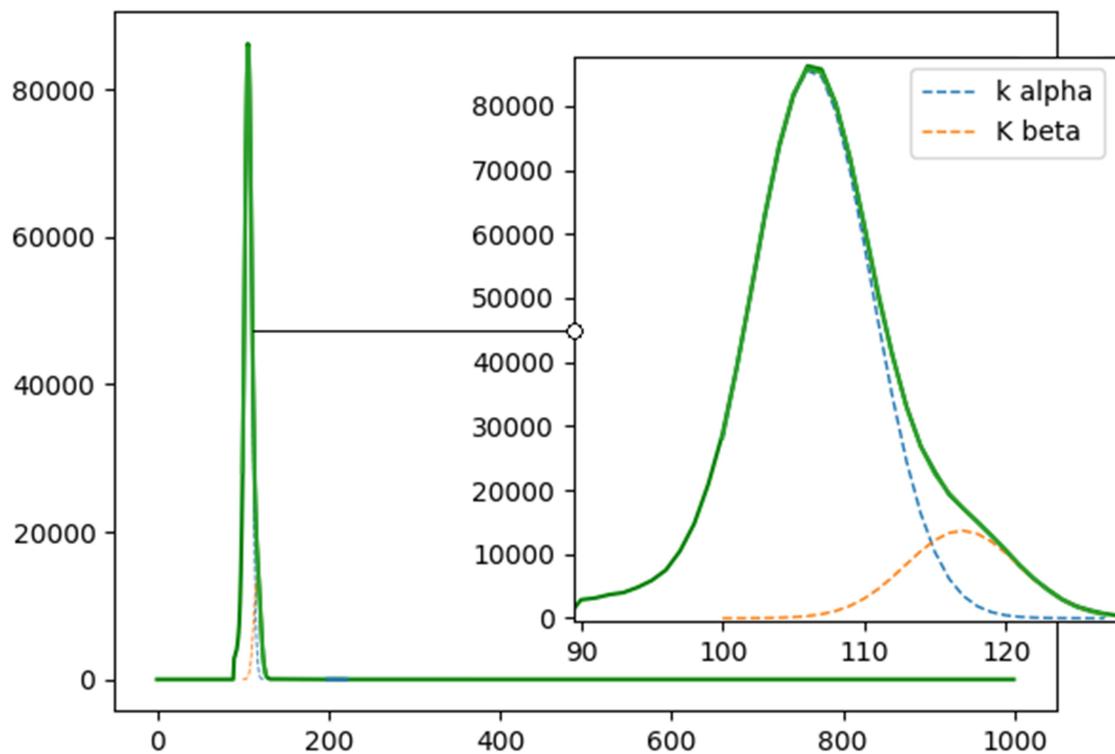
```

channel.append(fitvars[3*j+2])
channelerr.append(fiterr[3*j+2,3*j+2]**0.5)
Eerr.append(energy(fiterr[3*j+2,3*j+2]**0.5))
FWHM.append(fwhm(fitvars[3*j+3]))
FWHMerr.append(fwhm(fiterr[3*j+3,3*j+3]**0.5))
ER.append((fwhm(fitvars[3*j+3])/(fitvars[3*j+2]))*100)
ERerr.append(ER[-1]*(sqrt((FWHMerr[-1]/FWHM[-1])**2+(Eerr[-1]/E[-1])**2)))
print("FWHM",j+1,"-",FWHM[-1],"(+/-)",FWHMerr[-1],"nEnergy",j+1,"-",E[-1],"(+/-)",Eerr[-1],"nEnergy resolution",j+1,"-",ER[-1],"(+/-)",ERerr[-1],'%')
plt.show()

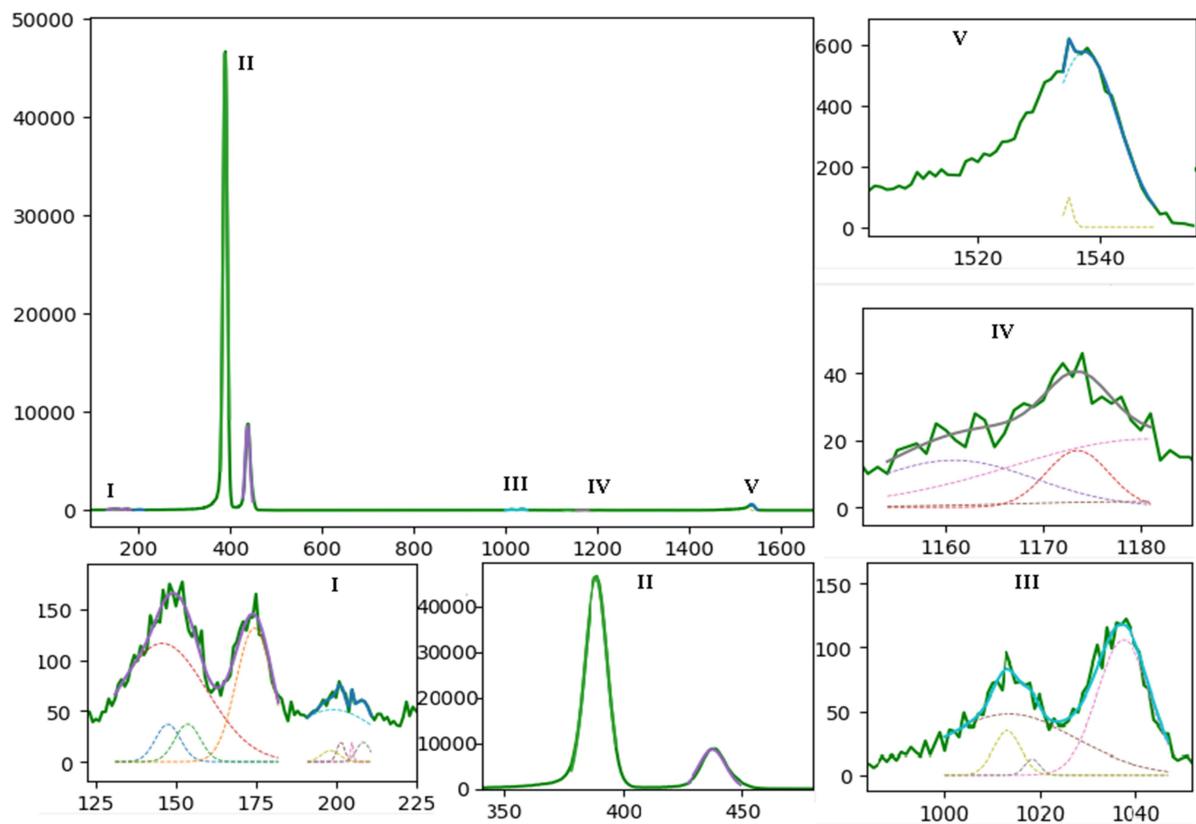
```

## 11. Outputs:

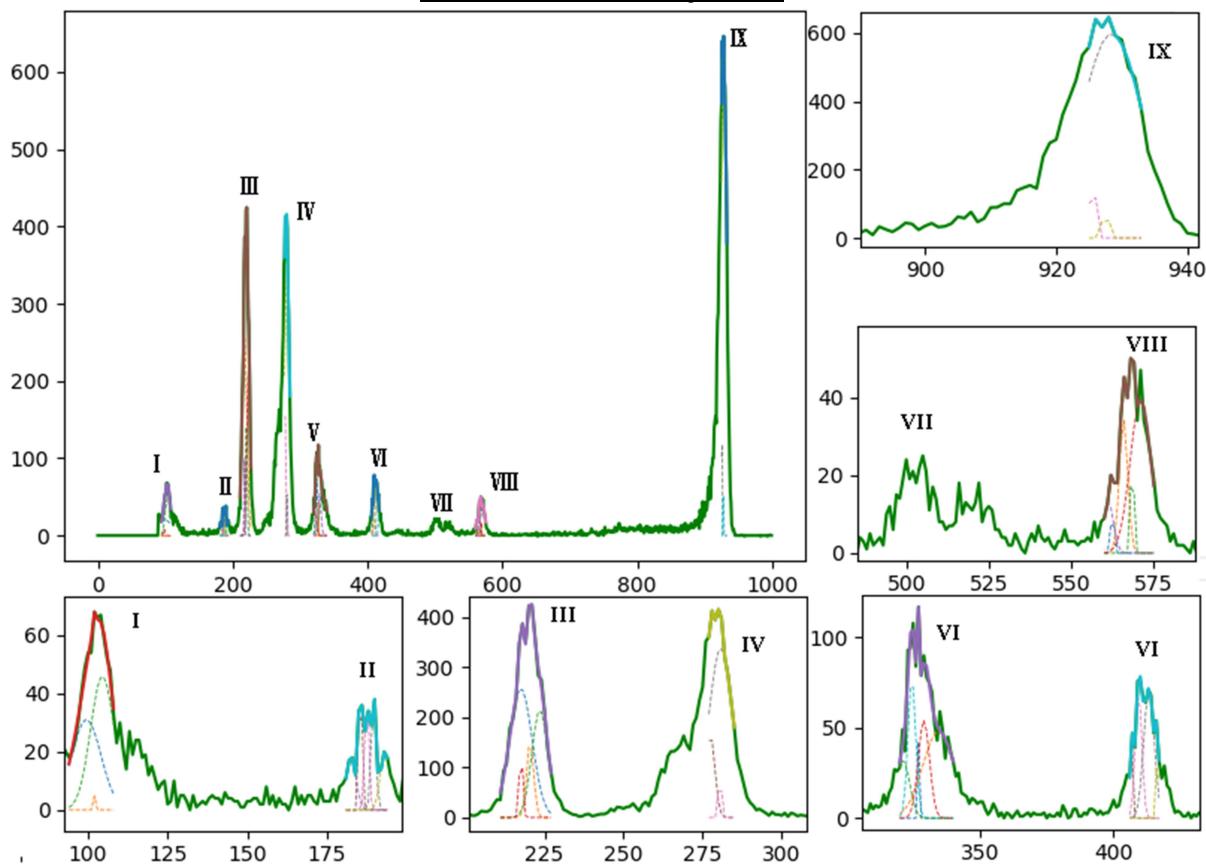
Iron-55 spectra



### Cadmium-109 spectra



### Americium-241 spectra



## 12. Data:

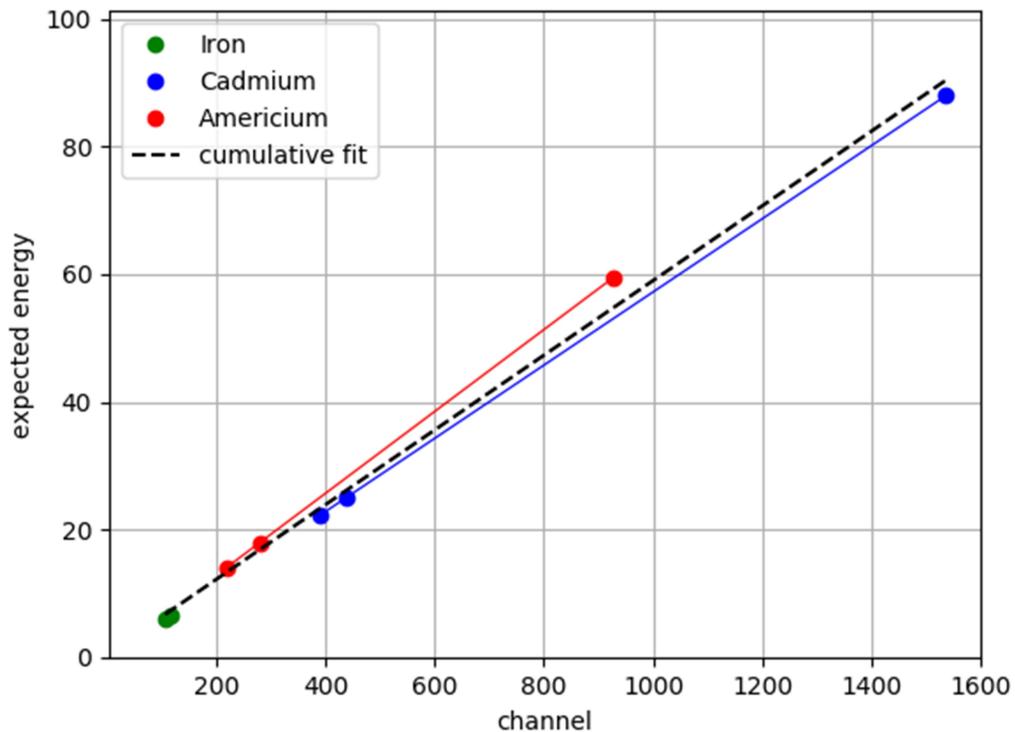
	Peak type		Channel	Counts	Observed energy	fitting error	Expected energy	FWHM	fitting error	Energy Resolution	fitting error
Fe-55											
1*	Photopeak	Mn K $\alpha$	106.4	86958	5.90	0.00	5.90	6.06	0.00	6.91%	0.11%
2*	Photo peak	Mn K $\beta$	117.7	17151	6.49	0.03	6.49	5.89	0.64	5.01%	0.55%
Cd-109											
1	Escape peak	Zn K $\alpha$	148.0	179.1	8.66	0.02	8.64	15.39	1.98	10.40%	1.34%
2	Escape peak	Zn K $\beta$	174.0	147.9	10.12	0.02	9.57	8.07	0.93	4.64%	0.53%
3*	Photo peak	Ag K $\alpha$	388.5	47126	22.16	0.00	22.16	7.84	0.15	2.02%	0.04%
4*	Photo peak	Ag K $\beta$	437.9	9496.6	24.94	0.00	24.94	8.89	0.46	2.03%	0.10%
5	Escape peak	Te $\gamma$ -K $\beta$	1013.7	95.7	56.92	0.02	57.01	13.49	1.11	1.33%	0.11%
6	Escape peak	Te $\gamma$ -K $\alpha$	1037.0	133.2	58.23	0.01	60.53	9.38	0.57	0.90%	0.05%
7	Escape peak	Cd $\gamma$ -K $\beta$	1135.3	51.5	63.75	0.02	61.94	12.42	3.95	1.09%	0.35%
8	Escape peak	Cd $\gamma$ -K $\alpha$	1173.0	51.5	65.87	0.04	64.86	14.74	3.52	1.26%	0.30%
9	Photo peak	Ag $\gamma$ line	1536.9	597.9	86.31	0.01	88.00	9.98	0.91	0.65%	0.06%
Am-241											
1	Escape peak	**	102.8	65.7	6.58	0.01		8.22	0.31	7.99%	0.30%
2	Escape peak	**	187.7	42.1	12.03	0.04		7.49	1.18	3.99%	0.63%
3*	Photopeak	Am Ly	219.9	425.7	14.09	0.01	13.90	7.10	0.25	3.23%	0.11%
4	Photopeak	Am L $\beta$	279.2	417.2	17.90	0.01	17.70	7.41	0.42	2.66%	0.15%
5	Photopeak	Am L $\alpha$	327.7	92.04	21.01	0.04	20.70	11.26	1.20	3.43%	0.37%
6	Escapepeak	Te $\gamma$ -K $\beta$	411.7	73.8	26.39	0.02	28.55	7.16	0.79	1.74%	0.19%
7	Escapepeak	Te $\gamma$ -K $\alpha$	502.1	22.5	32.19	0.04	32.07	8.35	0.97	1.66%	0.19%
8	Escapepeak	Cd $\gamma$ -K $\beta$	519.5	13.4	33.31	0.06	33.45	10.01	2.65	1.93%	0.51%
9	Escapepeak	Cd $\gamma$ -K $\alpha$	568.7	46.6	36.47	0.02	36.37	7.67	0.55	1.35%	0.10%
10*	Photopeak	Np $\gamma$ line	927.5	632.8	59.48	0.01	59.54	9.10	0.61	0.98%	0.07%

\*other peaks(energy) were calibrated using these peaks

\*\* - These peaks might be from L $\ell$  X-Ray of Np [11.89keV] or from Auger L electrons [6.04-13.52keV] or due to impurities in sample or container

## 13. Plots:

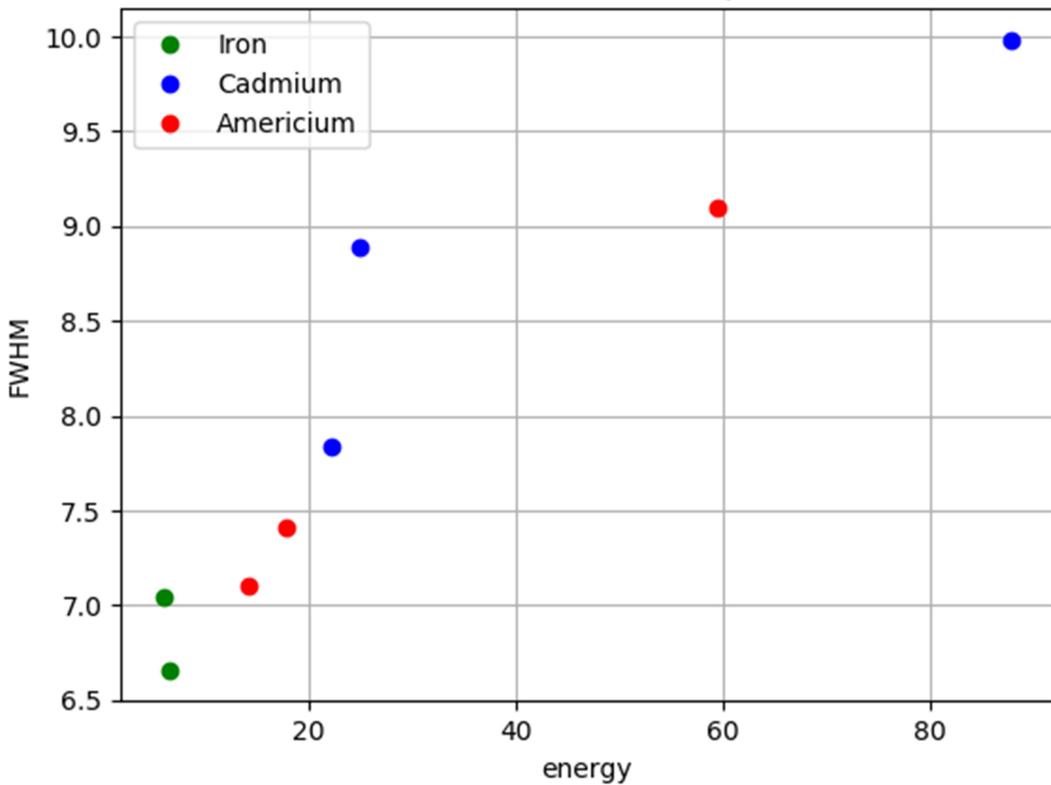
Expected energy vs peak position:



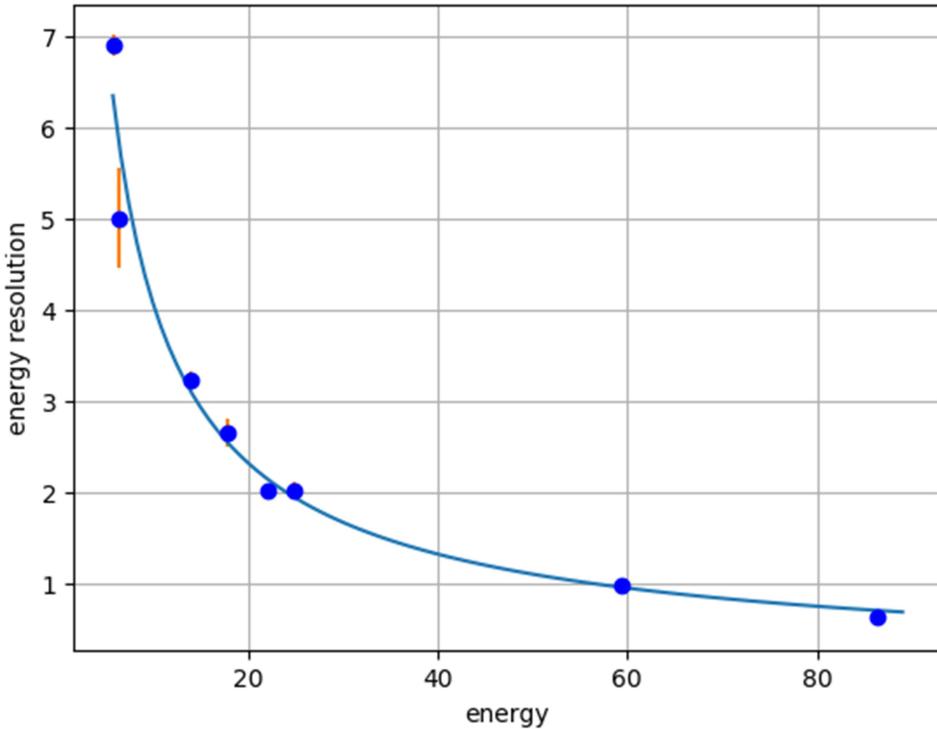
Plot was fit using the equation:  $y = m \times x + c$

Fitting parameters:  $m=0.05853772$  &  $c=0.45744848$

FWHM vs energy:



### Energy Resolution vs. Energy plot(photopeaks):



Plot was fit with the equation:  $y = a \times x^b + c$   
Fitting parameters:  $a=2.63e+01$  ;  $b=-8.08e-01$  &  $c=-3.1e-03$

## 14. Results:

- 2 Photo peaks were identified in Iron-55 Sample.(Fe K $\alpha$  & K $\beta$  lines)
- 3 Photo peaks were identified in Cadmium Sample.(Cd K $\alpha$ ,K $\beta$  & Ag  $\gamma$  lines)  
Escape peaks of Copper & Zinc(from brass container) were also observed.
- 4 Photo peaks were identified in Americium Sample.(Am L $\gamma$ ,L $\beta$ ,L $\alpha$  & Np  $\gamma$  line)
- 4 Escape peaks of Cd & Te were observed in Cd & Am spectra.(K $\alpha$  & K $\beta$ )
- Theory expects that Energy Resolution should depend on energy as  $E^{-0.5}$ .  
Experiment predicts  $E^{-0.8}$ . This deviation is mainly because the FWHM did not vary with energy as expected which is because the peaks with similar energy couldn't be resolved enough to be fit with gaussian curves.
- FWHM was observed to increase with the energy of peak, as expected by theory.
- The plot of efficiency of CdTe detector shows that the detection efficiency is almost 100% in the range of 10-50keV. The efficiency decreased on further increasing the energy. At 100keV it was almost 60%.