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Ministry of Education, Bangladesh

Final report

On

EXPERIMENTAL INVESTIGATION ON PRECISION OF X-RAY SPECTRUM GENERATION USING FAST READOUT CCD DETECTOR.

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Summary

X-ray is a common application in our daily life, specifically in the area of medical treatment. However, the most significant issue of doing X-ray is, how precise our X-rays in terms of image/spectrum. As physicians prescribe medicine for the patients, based on the X-ray diagnosis, therefore, precision of X-ray spectrum generation is very important in medical treatment. Otherwise, there is a high possibility of mistreatment for the patients.

In the current work, experiments were conducted to produce high precision of X-ray spectrum using special type of detector, so called Fast Readout CCD detector. Two phases were adopted during experiments.

a. **Phase-I:** Accelerated by different excitation voltages (5 keV-60 keV), high speed electrons strike anode materials in apparatus tube and identify precise X-ray spectra of tube itself.

b. Phase-II: Using the same excitation voltage (as phase I) and source (MnO_2), characterization of emitted X-ray spectra from the source. In addition, determination of background contribution from scattered radiation.

In case of **Phase-I**, number of elements from X-ray tube have been found in the generated X-ray spectrum. By doing energy calibration, they are explored.

In case of **Phase-II**, the source is covered by pure Al foil which acts as shielding material. That is why, clean Mn spectrum is detected and measured.

Keywords: X-radiation, CCD detector, Bremsstrahlung radiation, X-ray image.

Contents

1. Introduction & Motivation

Since the inception of X-ray invention, X-ray technique is being widely employed as excellent analytical tools for a variety of purposes, including material characterization, medical imaging, and basic research. In case of basic research, X-ray emission spectra shows information about the atomic shell structure of the materials **[1].**

It is experimentally proven that every element possesses a unique set of energy levels leading to unique spectrum emission. Therefore, the X-ray could be applied to identify unknown material composition since each element emits a distinct pattern of "characteristic X-rays".

A British scientist named Moseley first stated on characteristic X-rays in 1913. In his statement, he pointed out X-rays wavelength ranges from 0.01 to 10 nanometers and frequency ranges from 30 petaHertz to 30 exaHertz ($3x10^{16}$ to $3x10^{19}$ Hz).

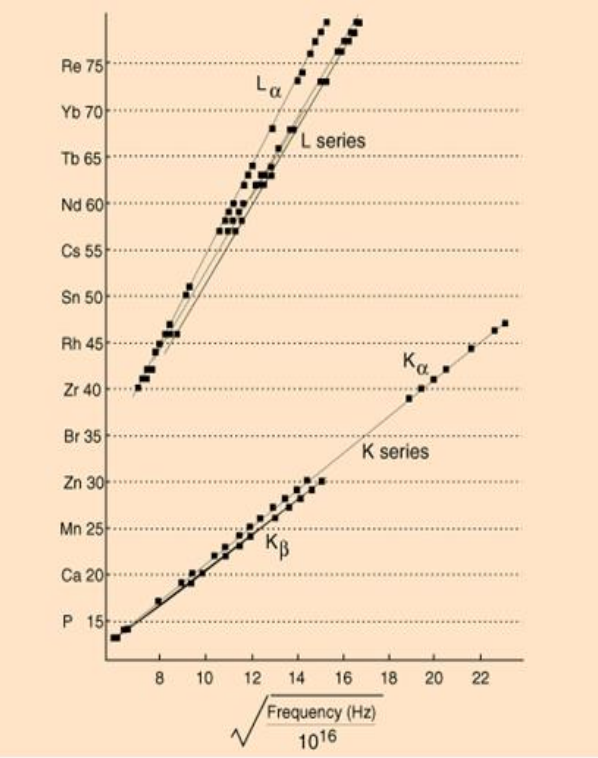


Fig. 1: Moseley plot of characteristic X-rays [2].

Moseley investigated the line spectra of thirty-nine elements and found that an element's atomic number has a linear relationship with the square root of the spectral line's frequency of its characteristic radiation **(Fig. 1) [2]**.

In the area of medical treatment, X-rays play a significant role undoubtedly. However, the most significant issue of doing X-ray is, how precise our X-ray image. Without good quality X-rays, it is almost impossible to do better medical treatment. As physicians prescribe medicine for the patients, based on the X-ray diagnosis, therefore precision of X-ray spectrum generation is very important in medical treatment. Otherwise, there is a high possibility of mistreatment for the patients.

In this current work, experimental analysis was conducted to produce high precision of X-ray spectrum using special type of detector, so called Fast Readout CCD detector **[3]**. Two phases were adopted during experiments.

a. **Phase-I:** Accelerated by different excitation voltages (5 keV-60 keV), high speed electrons strike anode materials in apparatus tube and identify precise X-ray spectra from the apparatus itself.

b. Phase-II: Using the same excitation voltage (as phase I) and radioactive source (MnO_2), characterization of emitted X-ray spectra from the source. In addition, determination of background contribution from scattered radiation.

The structure of the study is as follows:

- Summary of X-radiation and its interaction with matter, X-ray generation method and the working principles of several X-ray detectors, basic circuit of X-ray machine is presented in Section 2.
- Summary of the experimental approach like facility set up, testing and commissioning of high voltage generator, data acquisition system and CCD detector is presented in Sec. 3
- Section 4 discusses energy calibration technique of detector with a radioactive source.
- Section 5 summarizes the findings of the analysis.
- Finally, the experimental results are summarized and concluded in Section 6.

2. **Basic principles**

2.1 Nature of X-radiation

X-ray is one sort of electromagnetic radiation. Its wavelength ranges from 0.01 to 10 nanometers and frequency varies from 30 petaHertz to 30 exaHertz ($3x10^{16}$ to $3x10^{19}$ Hz) (**Figure 2**). The relation between energy (E), wavelength (λ) and frequency (ν) for a photon is represented by $E=h\nu = hc/\lambda$ where h is Planck's constant.

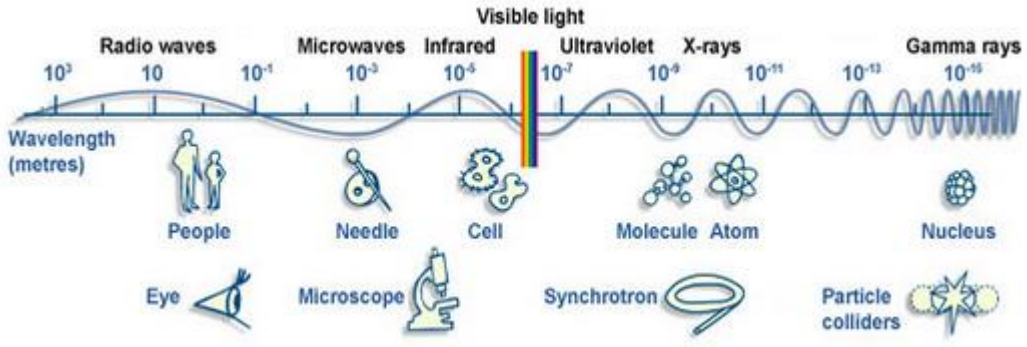


Figure 2: Comparative wavelength among different types of electromagnetic radiation **[4]**.

2.2 Generation of X-radiation

X-radiation can be generated by X-ray tube in two different ways:

- Characteristic radiation: In an inner electron shell, an incident electron can knock out an orbital electron if it (incident electron) has enough energy. In that situation, inner shell experiences a vacancy and then electrons fill the vacancy from higher energy levels **[5]**. As a result, characteristic X-radiation spectrum is formed.

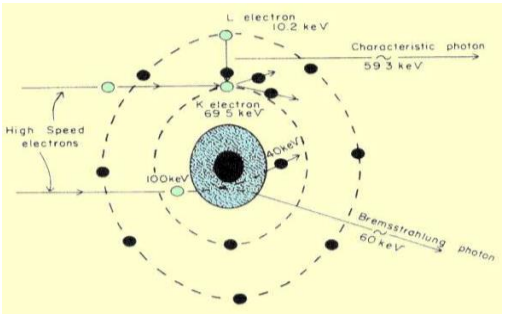


Figure 3: Diagram of electron-atom interaction of a tungsten atom **[6]**.

➢ Bremsstrahlung radiation:

Bremsstrahlung radiation is generated, when charged particles, like as electrons, are slowed down or decelerated by the electric field of an atomic nucleus or another charged particle. As a result of this process, photons having different energies are released into the atmosphere. Bremsstrahlung radiation is the main method by which X-rays are produced. The electrons are slowed down by the electric field of the target atoms when a high-energy electron beam is focused on a target material, such as tungsten or molybdenum, and this causes them to release X-ray photons through bremsstrahlung radiation.

2.3 X-ray interaction with material

X-ray energy range varies from 10 eV to 100 keV. But the energy ranges of bremsstrahlung may be up to many tens of MeV when decelerating electrons. With the energies considered here (up to 60 keV), only elastic scattering, inelastic scattering (Compton effect) process as well as photoelectric effect occurs **[7]**.

2.3.1 Elastic scattering

Elastic scattering occurs when two or more particles collide without any transformation of energy into internal excitations. In that case, may be the direction of the collided particles changed, but the total kinetic energy of the system remails same.

2.3.2 Compton scattering

Compton scattering can be imagined as a collision between an incoming photon and target electron in the outer shell. During the collision, a portion of photon energy is transferred to target electron. As a result, the electron is emitted. This emission phenomena is called the Compton Effect. The ejected electron is called Compton electron (**Figure 4**) **[7]**.

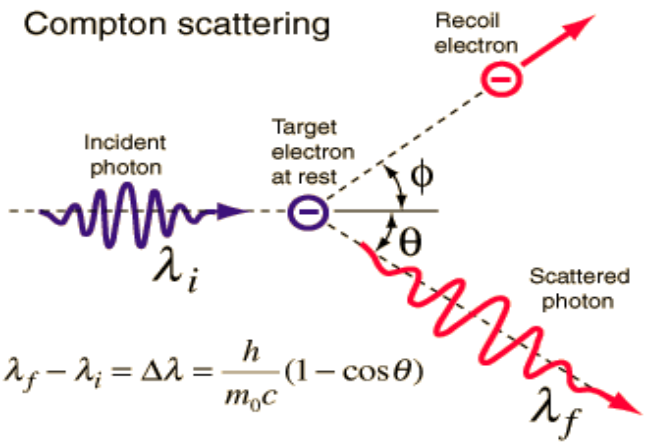


Figure 4: Compton scattering **[7]**.

Here Δλ denotes change of the wave length of the photon depending on the angle of scattering Θ, m_0 is electron mass at rest, Θ is the scattering angle and h is Planck's constant.

2.3.3 The photoelectric effect

In this process, an incoming photon collides with a target electron, where incoming photon becomes fully invisible and an energetic electron is emitted from the orbit of that atom (**Figure 5**).

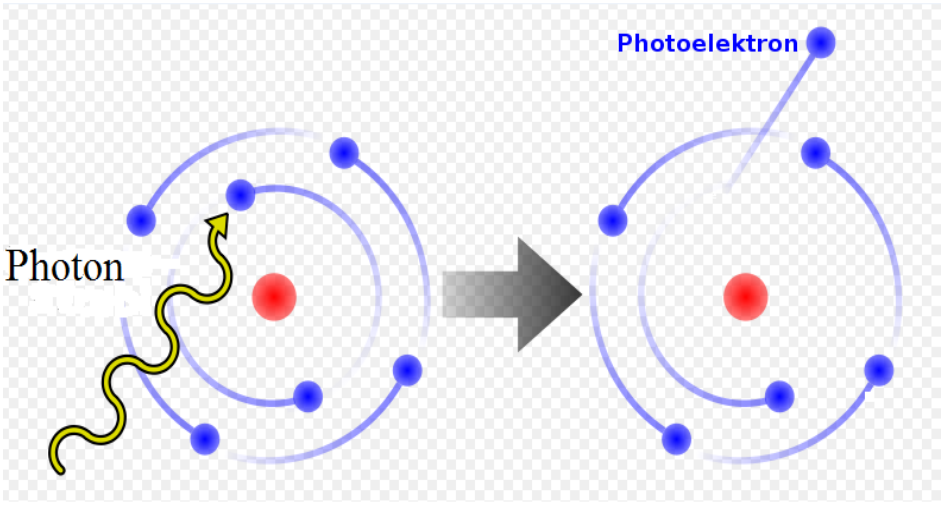


Figure 5: Photoelectric effect **[8]**.

The ejected electron is called photoelectron. Its energy is given by $E_{PE} = E_0 - E_{BE}$. In parallel to the emission of photo electron, an X-ray is emitted as well, which is called X-ray fluorescence.

2.4 The X-ray device

For laboratory use, X-rays may be produced by commercially available devices like X-ray tube which is an electron accelerator. It consists of a high voltage generator needed to accelerate electrons to high kinetic energies. Classically the electrons are accelerated within an evacuated glass tube and X-radiation is produced while impinging on the anode. However nowadays metallic tubes are used frequently instead of glass tubes.

2.4.1 Basic circuit of X-ray tube

The electric circuit provides energy to the apparatus tube for the generation of X-radiation. The circuit connects the accelerator tube to the high voltage generator **(Figure 6)**. The voltage generator gets electricity from electric distribution lines. Three major parameters of the high voltage generator can be adjusted by:

1. Tube high voltage
2. Tube current
3. Operation time

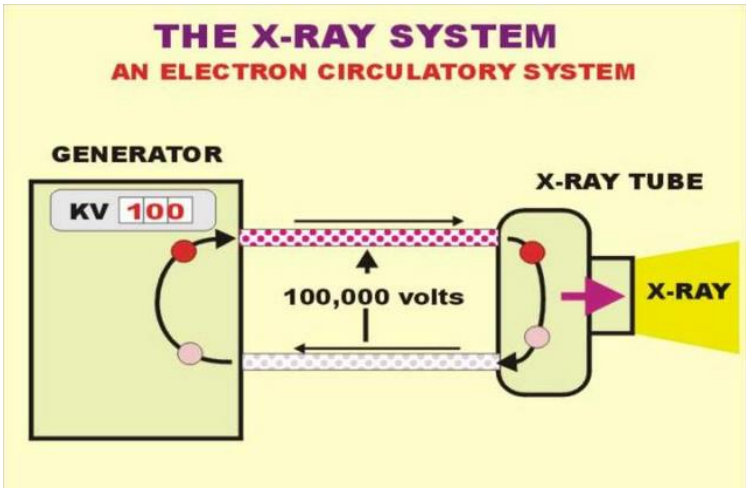


Figure 6: X –ray tube electrical circuit **[9]**.

The energy transferred to the X-ray tube is approximately given by the product of the current and voltage at cathode. For example, for an anode current of 3 mA at 30 kV gives the corresponding value of 90 Watt power consumption for the electron beam from which typically 1% is converted into X-radiation **[10]**.

2.4.2 Apparatus tube (X-ray tube)

An X-ray tube consists of 2 major elements: a cathode and an anode (an anode is the target material where the X-radiation is produced). When the flow of electrons occurs from cathode to anode through the tube, the cathode gets heated to a very high temperature where heat energy knock out electrons **(Figure 7)** **[11]**.

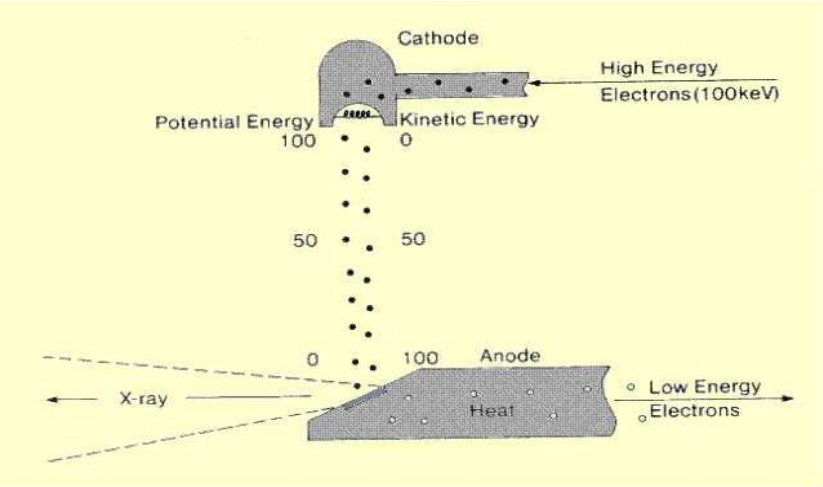


Figure 7: Energy exchange within an X-ray tube [**11**].

At the anode, electron's kinetic energy get converted to X-radiation but mainly into thermal energy. Therefore, most X-ray tubes use tungsten or molybdenum as they have a high melting point and in addition, are connected to the cooling circuit.

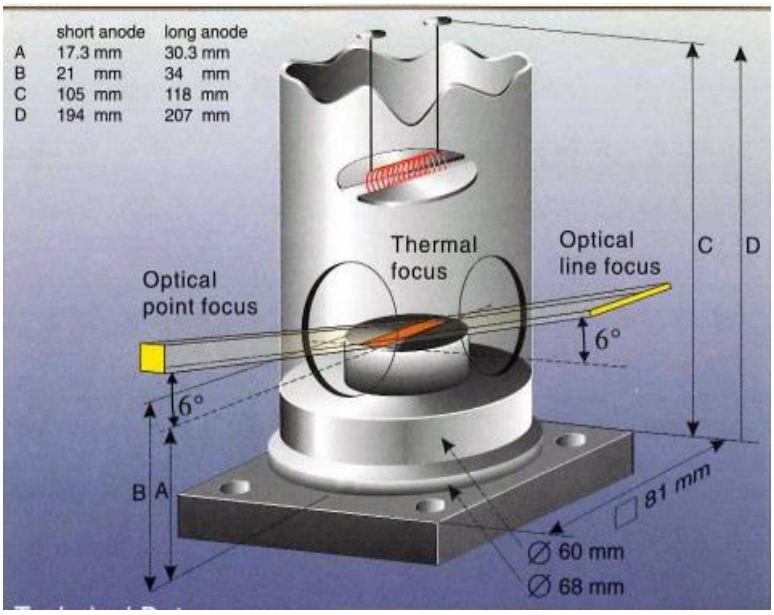


Figure 8: Geometric view of an X-ray tube **[12]**.

In this work (**Fig. 8**), spiral cathode emits electrons that finally strikes anode, located at the bottom. The basic parameters of the X-ray tube (for current case) is shown in Table 1.

Table 1: Key constraints.

Substance used in the anode	M_0
Applied potential difference in the tube	2-60 kV
Current used in Filament	2-50 amps
Be window thickness	0.25 mm
Maximum coolant pressure	101 PSI
Utilization of Power	3.5 kW

2.5 X-ray detectors

2.5.1 Detector types

In all commercially available X-ray detectors, X-rays are detected via the charge produced by ionization by photo or Compton electrons after interacting with the material of the detector **[13]**.

In a gas filled detector, there is a gas container filled with argon gas and a low absorption window that allows transmission of X-rays such as beryllium and one or more wires that serve as anode. Between cathode and anode, high voltage is applied.

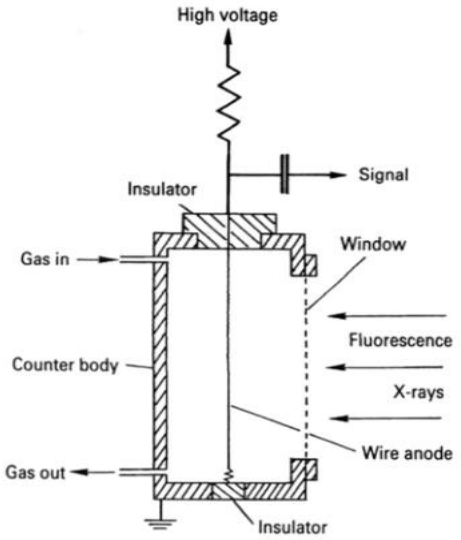


Figure 9: Schematic diagram of gas filled proportional counter **[14]**.

When accelerated, an electron ionizes more gas atoms. The released electrons are again accelerated thus producing by further ionization of an electron avalanche.

The ionizing radiation is measured by semiconductor detector, where ionizing particle generates the pair of electron-hole. In the depletion layer between the p- and n-doped materials, enlarged by the so called bias voltage. The accumulated charge generates a current pulse on the electrode **(Fig. 10)**.

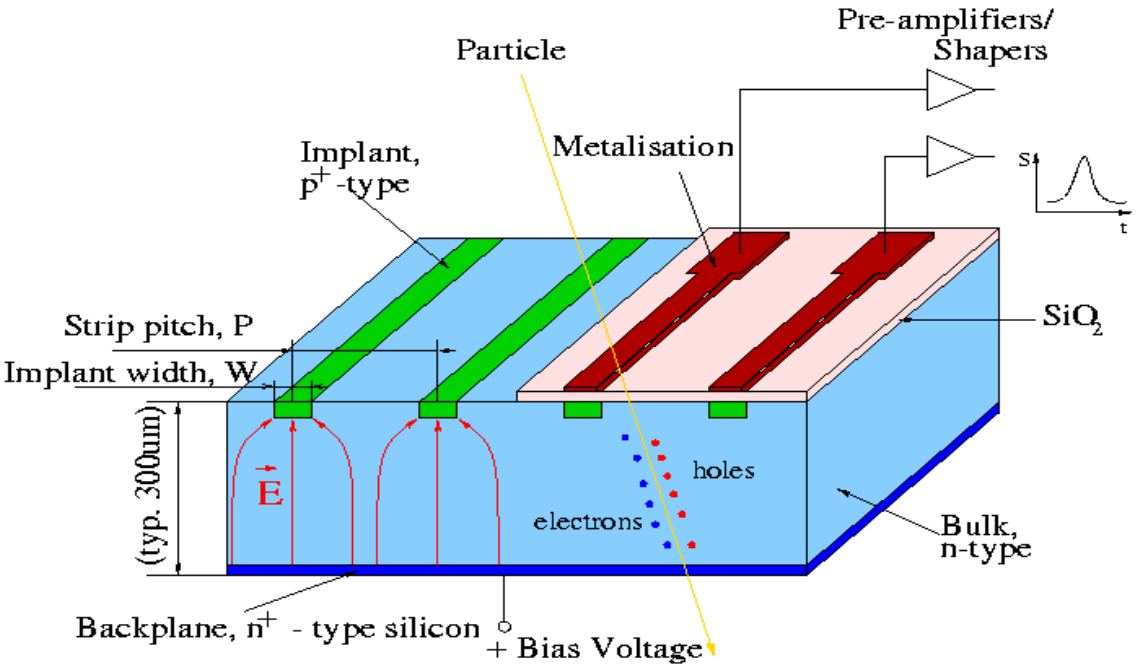


Figure 10: Working principle of semiconductor detector **[15]**.

In comparison to gas filled detectors, semiconductor detectors provide better energy resolution. In a scintillator, detection occurs typically via UV light which originates from de-excitation of atoms or molecules after impact of ionizing particles. As many of these photons as possible are collected on the photosensitive surface of a photo multiplier tube that releases itself photo-electrons. Electrons from the photocathode are focused and accelerated by the resulting electric field and driven into the surface of the first dynode. Each arriving electron possess enough energy to expel several secondary electrons. The secondary electrons are accelerated to the next dynodes where further multiplication takes place.

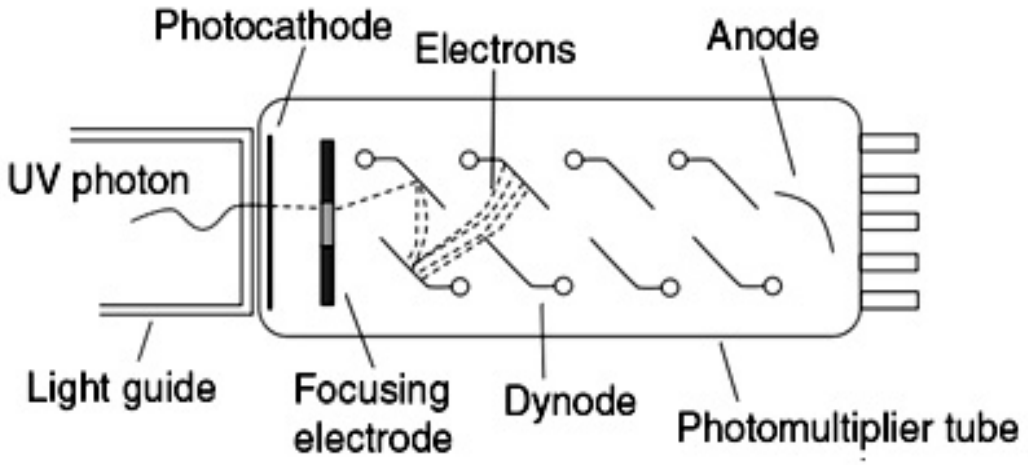


Figure 11: Detection mechanism of Scintillation detector **[16]**.

2.5.2 CCDs for X-rays

A special type of semiconductor detectors are so called charge-coupled devices (CCDs) based on storage of electrical charge **[17]**. They constitute an array of coupled capacitors generated by suitable surface structures on a silicon bulk material thus generating a pixel matrix. The radiation falling on a pixel is converted into charge and kept there, hence producing two- dimensional hit patterns. The charge is detected by shifting it pixel per pixel by electric pulse sequences through the whole CCD to a readout anode where the charge is converted into a voltage differences to be digitized by an analogue to digital converter (ADC).

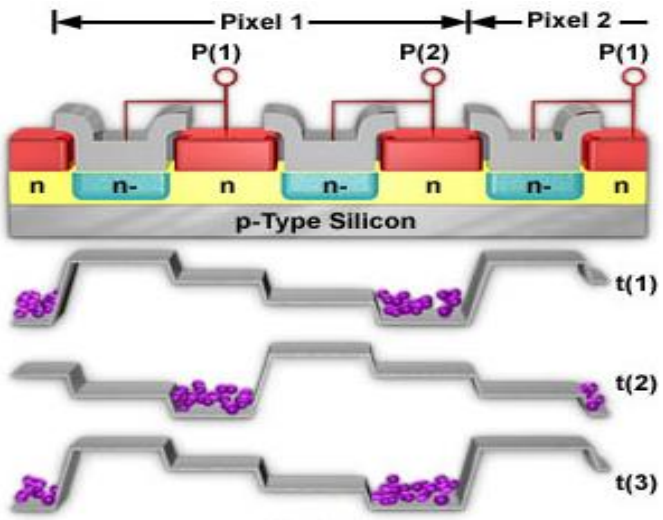


Figure 12: Typical charge collection mechanism of CCD **[17]**.

The more light falls on the pixel, the more charge will accumulate in the pixels. The amount of charge is a measure of the energy of radiation arriving at the pixel which is read out by the CCD electronics and converted to an image.

There are different types of X-ray CCD detectors like optical CCD, dedicated CCDs for X-ray detection. Optical CCD detectors have depletion layers of less than 5 µm, that's they are inefficient in X-ray detection above 2 keV. The depletion depth is the main difference between dedicated X-ray and commercial optical CCDs as used in digital cameras.

2.6 CCD detector

A CCD is a special type of charge-coupled device. It is used for X-ray imaging **[18]**. A very high frame rate (one complete readout cycle for all pixels) of up to 1000 images per second has been achieved.

CCD devices are fully depleted with a sensitive thickness of 450 µm (in our case 270 µm) and are illuminated from the back side which allow an ultra thin entrance window. The pixel matrix is again formed with p and n structures on the front side building up lines (p) and channels (n). Every channel ends at its own read out anode with an on- chip amplifier. The on-chip amplifiers are directly connected to a 64 channel silicon chip which enables the high transfer rates by parallel readout, amplifying and shaping of the signals.

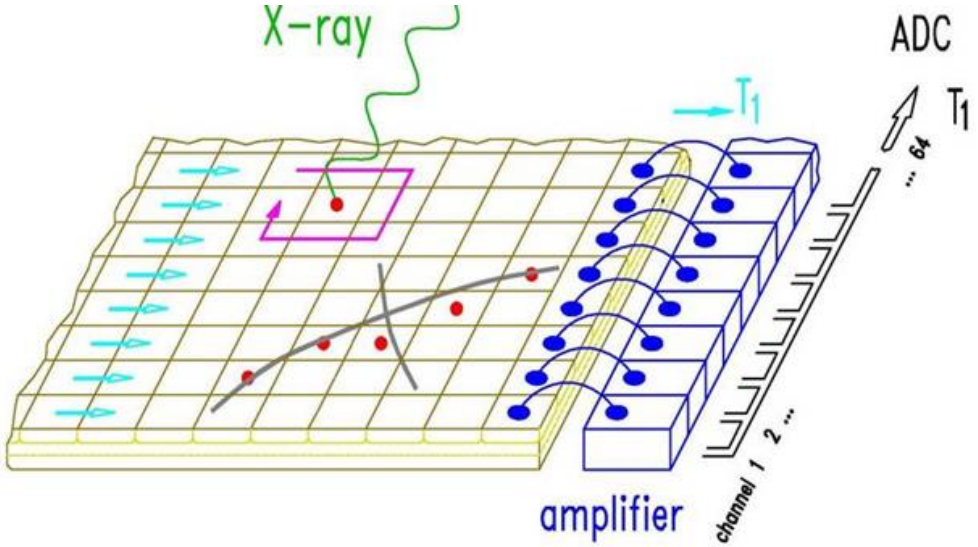


Figure 13: Scheme of the parallel read out of the CCD detector **[18]**.

3. Experimental approach

Two phases are considered for the experiment.

- **Phase-I:** Applying different excitation voltage (5 keV-60 keV) and identification of precise X-ray spectra from apparatus itself.

- **Phase-II:** Using the same excitation voltage (as phase I) and radioactive source (MnO_2), characterization of emitted X-ray spectra. In addition, determination of background contribution from scattered radiation.

3.1 Facility set up to measure X-radiation from tube itself.

The following figures **14-17** show the facility set up. The gap between X-ray tube & the detector was determined 151 ± 1 cm. There are 2 collimators, have been installed at inner side of the coupling tube. The function of the 1st one is to reduce the background radiation. In order to minimize the absorption loss, the tube is fully evacuated.

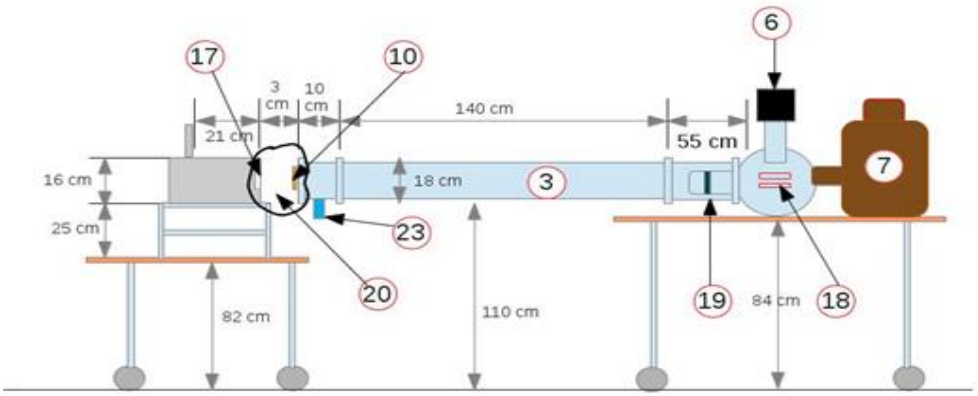


Figure 14: Set up diagram for phase-I: 17) open window in the X-ray tube chamber, 18) cabling port (outer electronics is not connected, (see Figure17), 20) air gap between X- ray tube & Kapton window, 19) detector location.

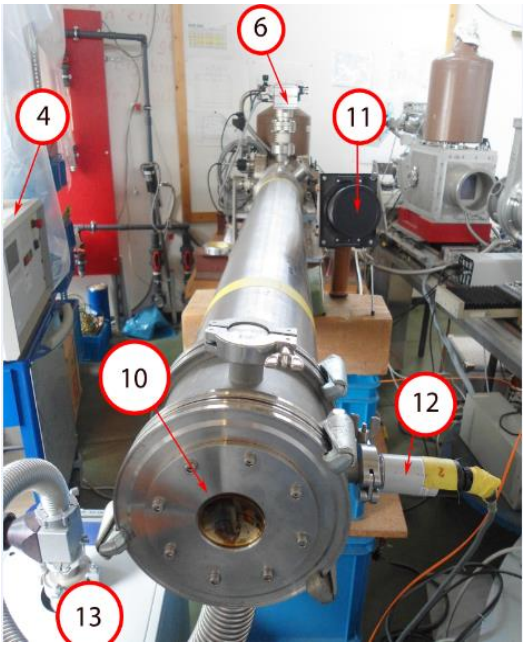


Figure 15: Vacuum tube. 4) high Voltage generator, 11) dosimeter for radiation measurement, 10) Capstan window.

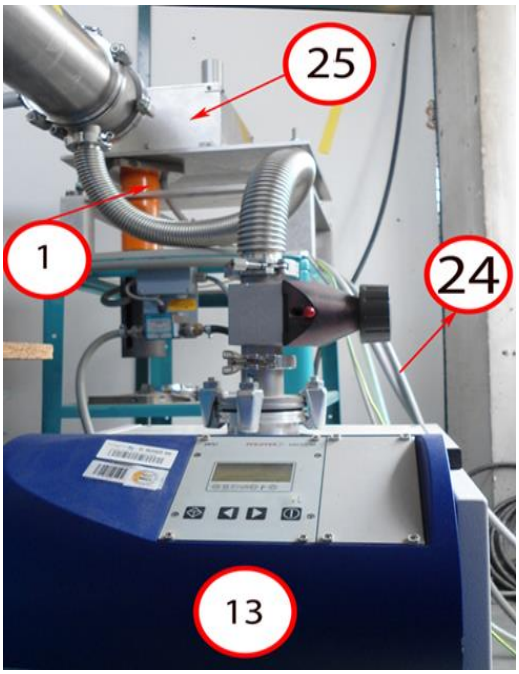


Figure 16: Mounting of the X-ray tube. 1) housing, 25) indication of source location, 13) turbo pump, 24) water cooling line.

Once the facility is ready, we go for voltage setting manually using set up button, shown in Figure 22. In our case, the maximum set up voltage is 60 kV. But it needs to be clear that the applied voltage must not exceed the set up voltage.

Figure 17: Operator panel of the high voltage generator **[19]**.

3.2 Detector setup

With the objective to reduce the absorption loss, the apparatus tube must be vacuum as shown in **Figure 14**. The detector coupling pipe (marked with 3, **Figure 14**) and vacuum chamber is connected with flexible shutter.

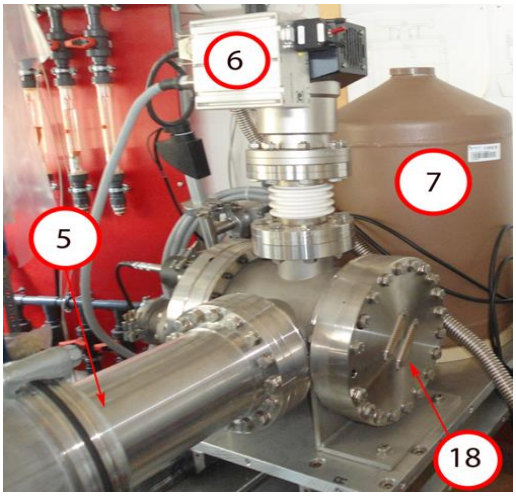


Figure 18: Location of the detector, 5) Be window location, 6) detector turbo molecular pump, 7) storage tank of liquid N2, 18) cabling port (outer electronics is not connected, see Figure 17)

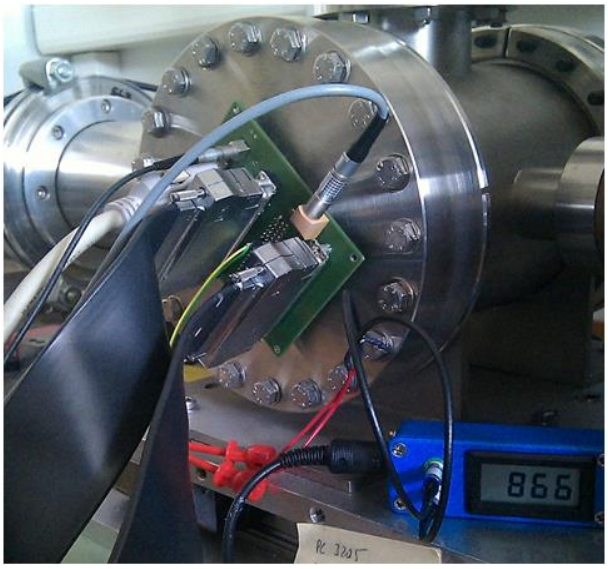


Figure 19: Connection between detector and outer electronics by cabling.

The inter connectivity among different components is shown in Figure 20.

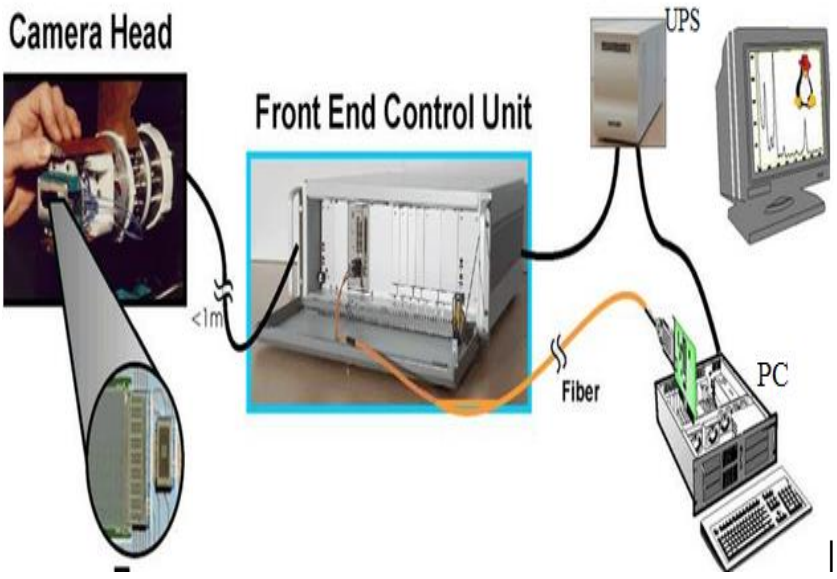


Figure 20: CCD system overview **[20]**.

3.3 Facility setup to measure emitted spectra from the source.

Figures **21-24** presents the facility set up for phase 2. The gap between the detector & the source was measured (184.5 ± 1) cm. Here, MnO_2 target acts as the source, which is covered by pure Al. That is why, we can see only Mn X-rays in the spectrum. In this case the full path from the tube to the detector is evacuated to reduce the absorption loss.

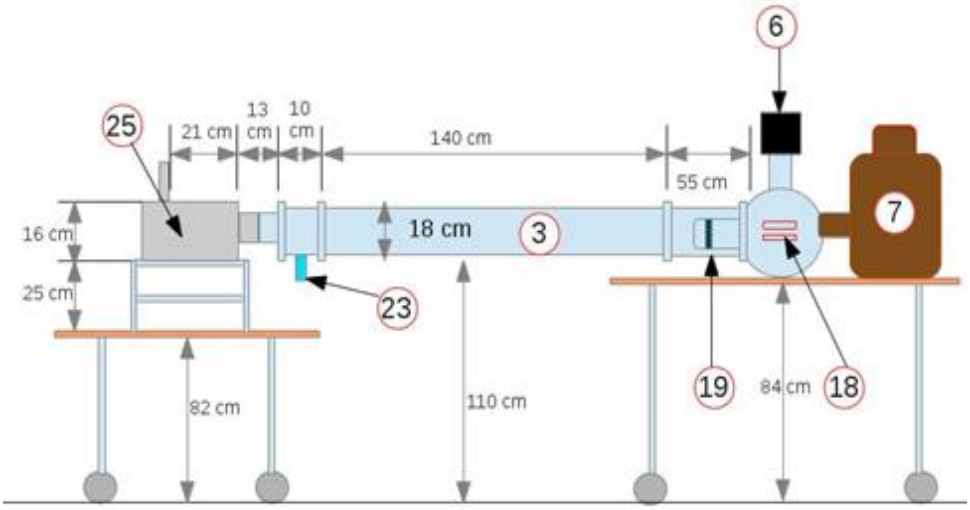


Figure 21: Setup diagram for phase-2**,** 25) source position, 23) pressure measurement device, 3) coupling tube, 18) port for cabling, 19) position of detector.

Figure 22: MnO_2 target acting as source.

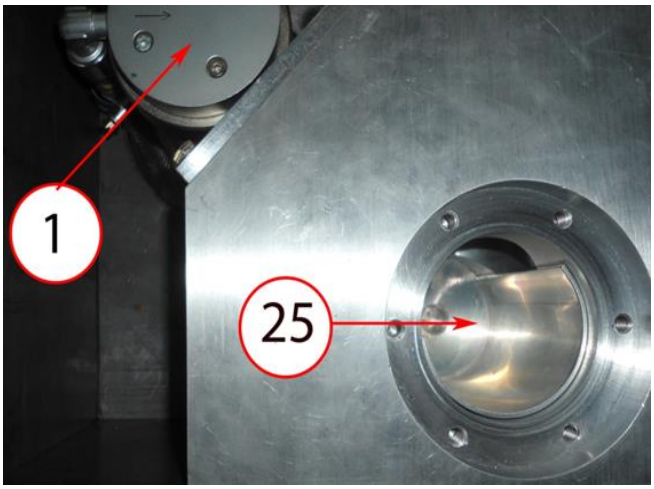


Figure 23: **Top view** 1) X- ray tube, 25) source position

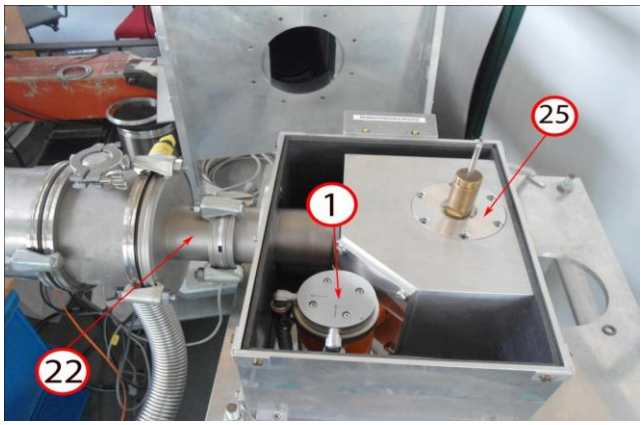


Figure 24: Top view of source position (25) and X-ray tube (1)

3.4 Data acquisition process

For the purpose of data readout & acquisition process, three programs (identified as controlling power, controlling CCD and controlling data display) work together. The main function of power control program is to supply power to drive the detector. The program works based on the components (sequencer, ADC units, preamplifier) functioning together as shown in **Figure 25** This program is loaded by typing **"./CCDcontrol"** in a terminal.

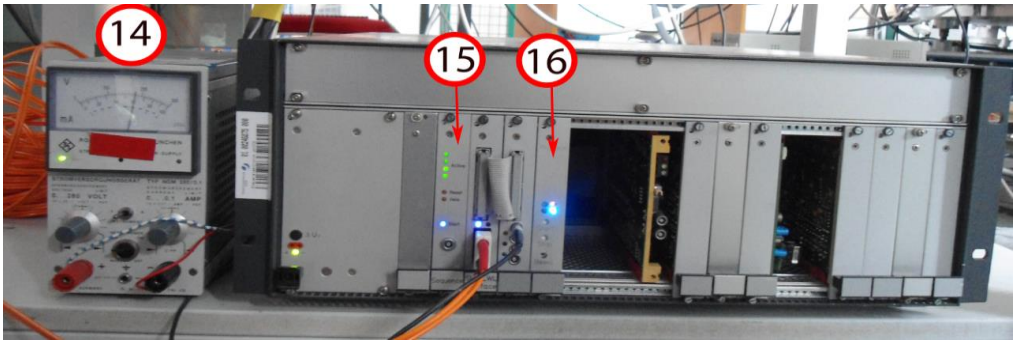


Figure 25: **Outer electronics crate including power supply.**

CCD controlling program is the principal software program that controls the detector by communicating with the PnCCD detector**.** This program is loaded by typing **"./CCDcontrol"** in a terminal.

pnDataDisplay is a program to produce spectra and store the data file in terms of text for upcoming analysis. It is loaded by typing **"./pnDataDisplay"**. To activate the CCD program, the following activities need to be considered.

A. Turn on outer electronics crate manually.

B. Load the **Power Control** program by writing ./**Controlling power.**

```
karotte@zel224 bin]$ ./PowerControl
 Found Suki-Controller-1.43 with DP-Ram history!


  Supply-Control Menu:
    Enables: Slot=0x0, U-Relay=0x0, I-Relay=0x0
  --------------------------
  1 Set Fix-Supply ON
  2 Set Fix-Supply OFF
  3 Set DAC-Value
  4 Enable Voltage-Measurement
  5 Disable Voltage-Measurement
  6 Set Voltage
  7 Set Current-Source [ON]
  8 Switch Current-Source
    ------------------------
  A Calibrate all Supplies
  C Calibrate Supplies
  S Save Calibration
  R Read Calibration
    ------------------------
  U Switch on form Config-File
  D Switch off form Config-File
    ------------------------
  0 Switch Amplifierer [OFF]
  --------------------------
  Q Finish is Program
  --------------------------
```

Figure 26: Screen display of the CCD power control menu.

C1. Press “1” to set the fix supply on, then in output choose 2 to select +5V.

C2. Press “4” to enable the voltage measurement. In output choose 1 to fix the supply, then 2 to select +5V

C3. Press “5” to disable the voltage measurement.

C4. Press “2” to fix the supply off and then again 2 to select +5V.

C5. Quit the program by typing “q” because only one program can run at a time.

C. Load the CCD control program using “./CCD Control” (Figure 27).

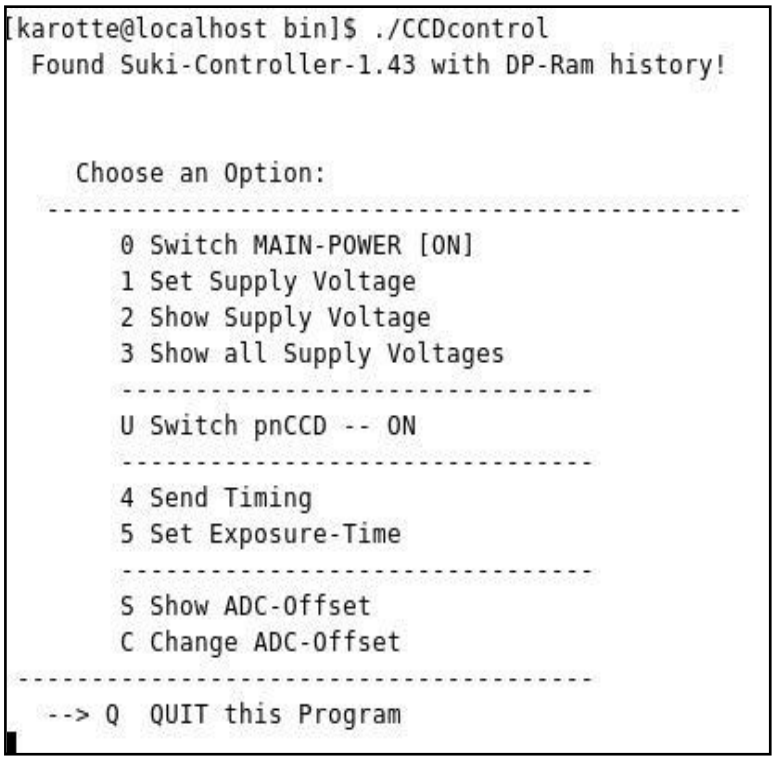


Figure 27: Screen display of the CCD control program menu.

E1. Press “U” to turn the CCD on.

E2. Press “4” to send the timing to detector via the sequencer. At this point blinking green LEDS can be seen on a sequencer board.

E3.Press “5” to enter/change the exposure time (Default is 5 micro sec.)

E4. Press “S” if you want to display the ADC offset

E5. Press “C” to enter ADC offset (0x0800)

E6. Quit the “./CCD” control” by typing “q” because only one program can run at a time.

D. Appearing online spectrum by typing “./spectrumdisplay”.

F1. Give a name for the measurement.

F2. What is a target? Enter the name.

F3. Say “no” to displayed question “found sigma offset file, should I use it?”

F4. Set the sigma limits for cut of the noise peak: Enter Yes (Lower =4, High limit=8), Sigma values, measuring time length, total number of recorded frames and other necessary values can be found on a computer screen during the measurement running.

F5. Answer “no” to displayed question, do you want to set sigma limits?”. Afterwards, the user can see a window on a screen plotting online data.

4. Energy calibration & analysis

With the aim of determining the corresponding energies of the peaks, the corresponding energies of each channel must be known. In the current case, detector calibration is done using Fe-55 source, emitting Mn-55 X-rays. It is to be noted that Fe-55 is a radioactive source that decays to manganese-55 through electron capture as shown in **Figure 28, [21]**.

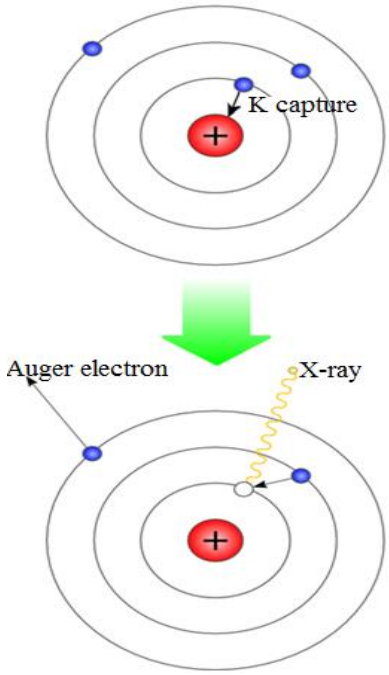


Figure 28: X-ray emission by Fe-55 electron capture process [21]

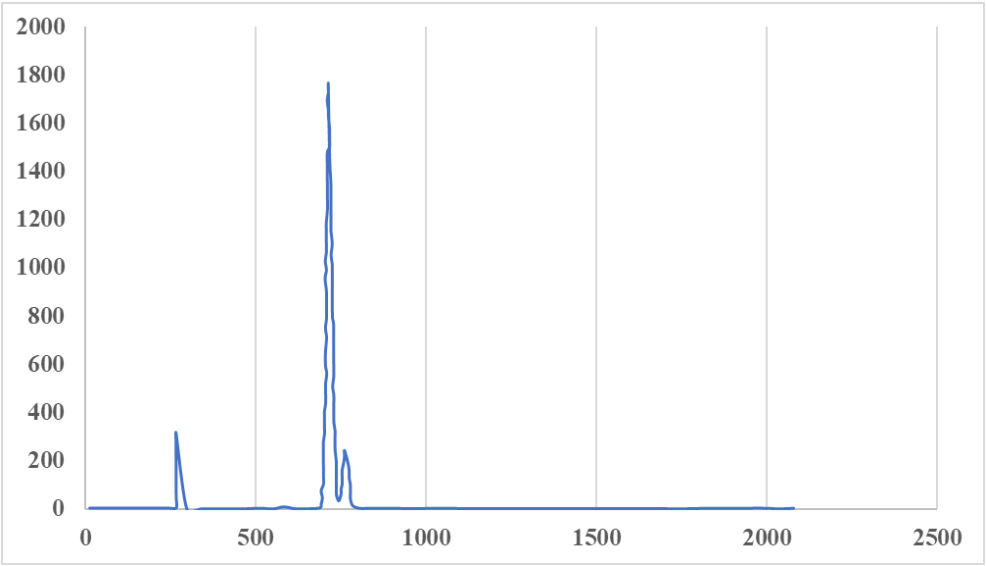


Figure 29: Generation of Mn X-ray spectrum by Fe-55 β –decay

In order to maintain small amount of data storage, almost all the noise peaks is excluded by special computer software. It is found from the graph **(Figure 29)**, the first peak appears in the left hand side, so called noise peak. For the sake of correct energy calibration, offset subtraction must be made. The most noticeable peak is found at channel 706, which is Kα line of Mn. After

subtracting the offset, the correct value of the channel is found 456. The literature shows the value of Kα for Mn is 5892 eV. Utilizing the value, the energy corresponding to each channel becomes 5892 eV/456 ch =12.921 eV/ch, which is known as energy calibration factor that remains same for the whole spectrum. With respect to the factor, each peak energy can be calculated.

4.2 Importance of detector illumination

In case of detector over illumination, the detector becomes unable to estimate the real count rate. Therefore, as a part of safety, the illumination degree should be kept 2% or less.

4.2.1 Determination of illumination degree

To determine the degree, it is needed to sum up all the counts of each channel from ADC and divide it by the product of frame number in each measurement and the pixel number in each frame. It is to be noted that the total number of pixel 4096). To make it understandable, we can take an example with respect to 25 keV X-ray energy (**Figure 36**), where total number of counts and frames are 992,169 and 110,000 respectively. So, the degree of illumination is 992,169/110,000*4096=0.22%.

4.2.2 Estimation of required thickness of filter

In case of phase I, the illumination is over 2%, accept 5 keV applied voltage. Therefore, it is required to use a filter (Table 1 for phase I). Prior to use Al filter with required thickness, we can use NIST calculator (Figure 30) **[22]**. It is to be noted that detector illumination is below 2% for phase II, (Table 2).

Table 1: Illumination degree for phase (i)

Executed Voltage (KV)	5.00	10.0	15.0	25.0	30.0	40.0	50.0	60.0
Degree of illumination (%)	.042	0.05	0.20	0.22	0.17	0.177	0.135	0.177
Al filter thickness (mm)	----	0.130	0.8	1.0	2	4	8	12

Table 2: Phase (ii) illumination degree

Voltage applied (kVA)	5.0	10.0	15.0	25.0	30.0	40.0	50.0	60.0
Degree of illumination (%)	0.012	0.026	0.16	0.17	0.23	0.36	0.475	0.58

If we consider the thickness of the Al filter is 50 μm, in that case more than 50% X-rays can penetrate the filter (**Figure 31**) **[22]** having less than 8 keV energy that makes the detector over illuminated.

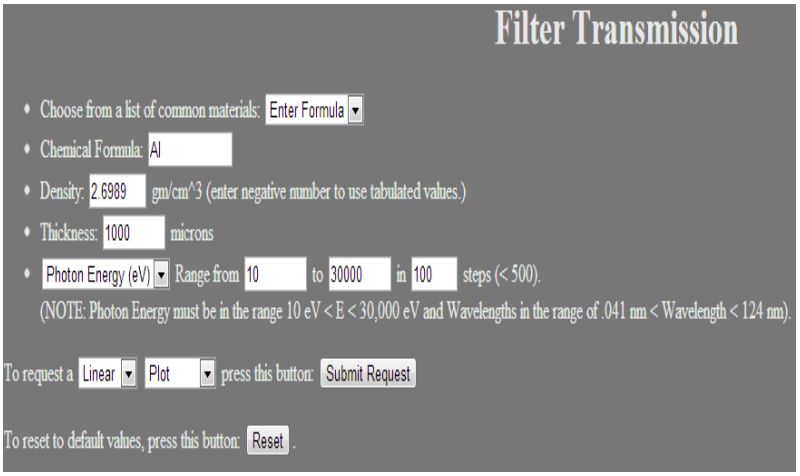


Figure 30: Setup panel for filter transmission **[22]**.

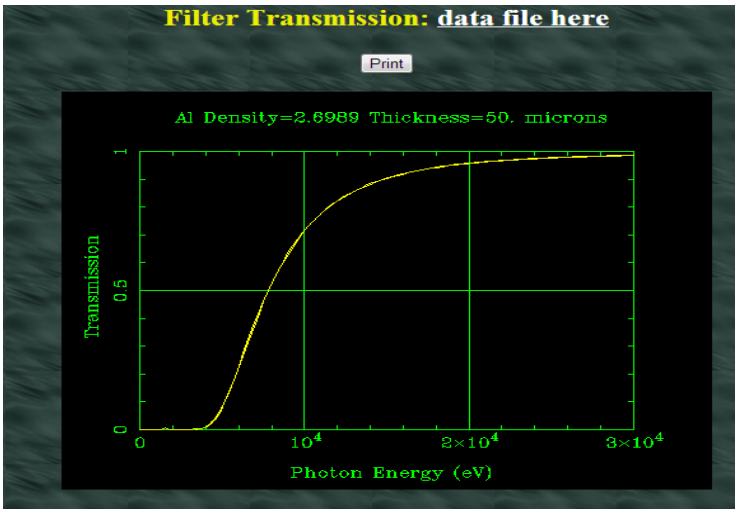


Figure 31: Filter transmission at 50 μm filter thickness **[22]**.

4.3 Results & discussion

In order to begin the analyzing part, spectra generated by 15 kV voltage is considered here.

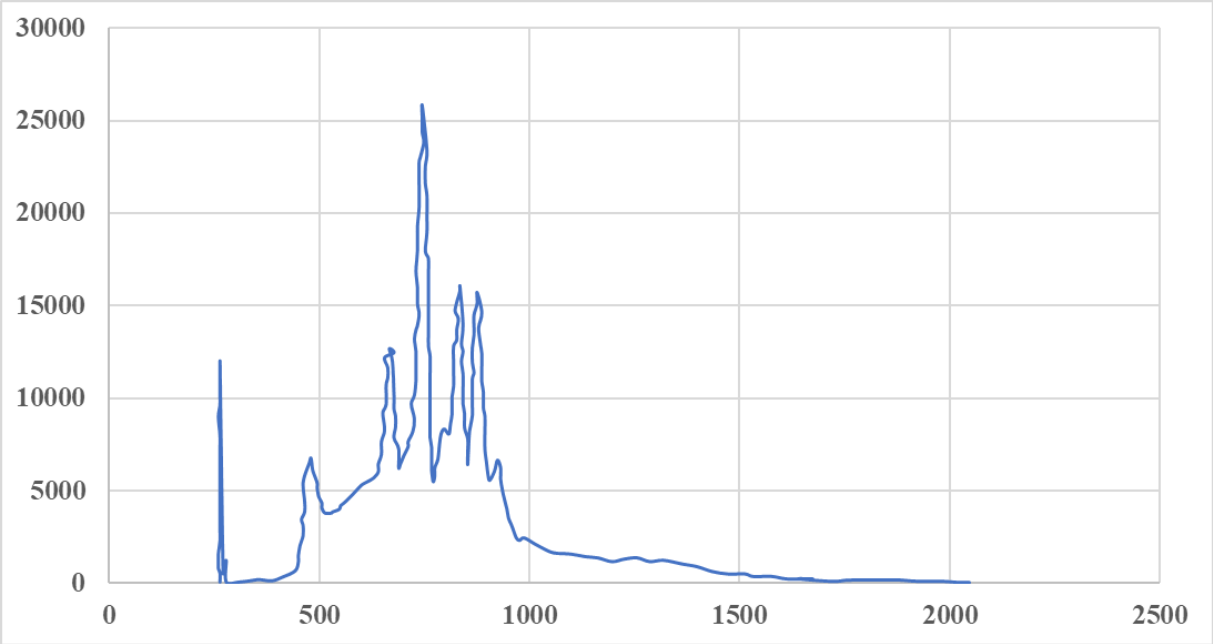


Figure 32: Generated X-rays by 15 kV applied voltage.

As can be seen that there is a narrow difference between adjacent peaks and some peaks are even superimposed to each other. As a result, they become invisible. In that case, we can use the fitting method so that the unseen peaks in the spectrum could be well analyzed. Under this technique, the peak position, their width and intensities can be properly identified.

Fitting method is applied by a special software, called FITOS **[23]**. Figure 33 shows the optimum fit to the spectra, generated by 15 kV. The associated values are presented in Figure 34.

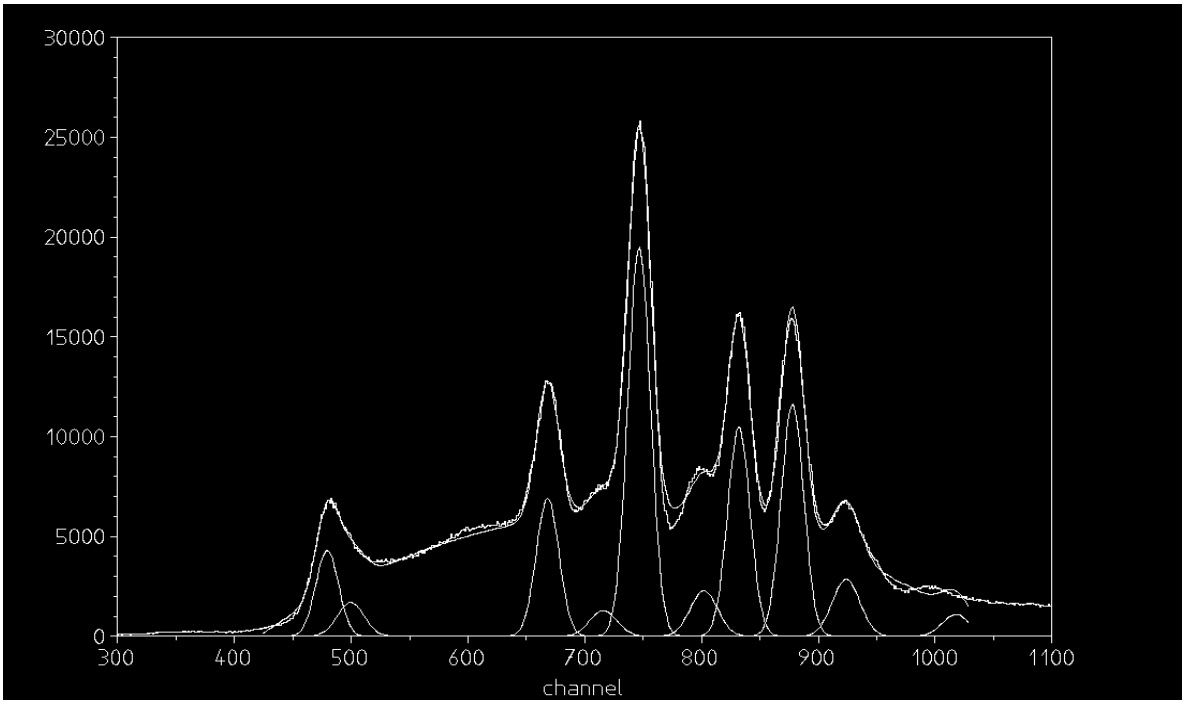
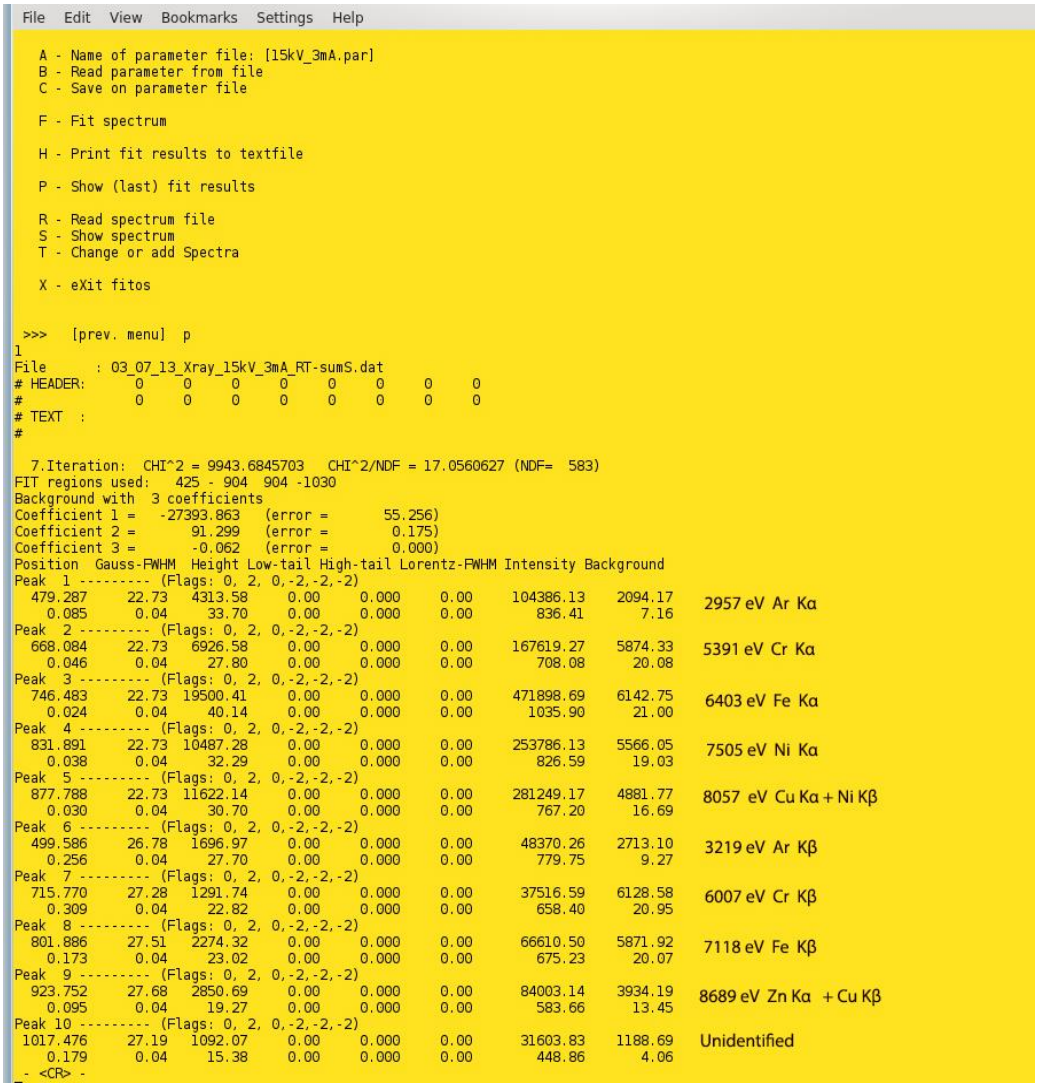


Figure 33: Fitting technique, applied for the case of 15keV applied voltage.



```
File   Edit   View   Bookmarks   Settings   Help

   A - Name of parameter file: [15kV_3mA.par]
   B - Read parameter from file
   C - Save on parameter file

   F - Fit spectrum

   H - Print fit results to textfile

   P - Show (last) fit results

   R - Read spectrum file
   S - Show spectrum
   T - Change or add Spectra

   X - eXit fitos


 >>>   [prev. menu]  p
1
File      : 03_07_13_Xray_15kV_3mA_RT-sumS.dat
# HEADER:      0     0     0     0     0     0     0     0
#              0     0     0     0     0     0     0     0
# TEXT  :
#

  7.Iteration:  CHI^2 = 9943.6845703   CHI^2/NDF = 17.0560627 (NDF=  583)
FIT regions used:   425 - 904  904 -1030
Background with  3 coefficients
Coefficient 1 =   -27393.863   (error =       55.256)
Coefficient 2 =       91.299   (error =        0.175)
Coefficient 3 =       -0.062   (error =        0.000)
Position  Gauss-FWHM  Height Low-tail High-tail Lorentz-FWHM Intensity Background
Peak  1 --------- (Flags: 0, 2, 0,-2,-2,-2)
  479.287     22.73   4313.58     0.00     0.000     0.00     104386.13    2094.17    2957 eV Ar Kα
    0.085      0.04     33.70     0.00     0.000     0.00        836.41       7.16
Peak  2 --------- (Flags: 0, 2, 0,-2,-2,-2)
  668.084     22.73   6926.58     0.00     0.000     0.00     167619.27    5874.33    5391 eV Cr Kα
    0.046      0.04     27.80     0.00     0.000     0.00        708.08      20.08
Peak  3 --------- (Flags: 0, 2, 0,-2,-2,-2)
  746.483     22.73  19500.41     0.00     0.000     0.00     471898.69    6142.75    6403 eV Fe Kα
    0.024      0.04     40.14     0.00     0.000     0.00       1035.90      21.00
Peak  4 --------- (Flags: 0, 2, 0,-2,-2,-2)
  831.891     22.73  10487.28     0.00     0.000     0.00     253786.13    5566.05    7505 eV Ni Kα
    0.038      0.04     32.29     0.00     0.000     0.00        826.59      19.03
Peak  5 --------- (Flags: 0, 2, 0,-2,-2,-2)
  877.788     22.73  11622.14     0.00     0.000     0.00     281249.17    4881.77    8057 eV Cu Kα + Ni Kβ
    0.030      0.04     30.70     0.00     0.000     0.00        767.20      16.69
Peak  6 --------- (Flags: 0, 2, 0,-2,-2,-2)
  499.586     26.78   1696.97     0.00     0.000     0.00      48370.26    2713.10    3219 eV Ar Kβ
    0.256      0.04     27.70     0.00     0.000     0.00        779.75       9.27
Peak  7 --------- (Flags: 0, 2, 0,-2,-2,-2)
  715.770     27.28   1291.74     0.00     0.000     0.00      37516.59    6128.58    6007 eV Cr Kβ
    0.309      0.04     22.82     0.00     0.000     0.00        658.40      20.95
Peak  8 --------- (Flags: 0, 2, 0,-2,-2,-2)
  801.886     27.51   2274.32     0.00     0.000     0.00      66610.50    5871.92    7118 eV Fe Kβ
    0.173      0.04     23.02     0.00     0.000     0.00        675.23      20.07
Peak  9 --------- (Flags: 0, 2, 0,-2,-2,-2)
  923.752     27.68   2850.69     0.00     0.000     0.00      84003.14    3934.19    8689 eV Zn Kα  + Cu Kβ
    0.095      0.04     19.27     0.00     0.000     0.00        583.66      13.45
Peak 10 --------- (Flags: 0, 2, 0,-2,-2,-2)
 1017.476     27.19   1092.07     0.00     0.000     0.00      31603.83    1188.69    Unidentified
    0.179      0.04     15.38     0.00     0.000     0.00        448.86       4.06
 - <CR> -
```

Figure 34: FIT presents the corresponding values to the spectrum.

If we sum up the total intensities of the peaks and all channels, it becomes 14,31520.0 & 20,32134.0 respectively. If, the summation of intensity of peak is subtracted from the channel summation, bremsstrahlung contribution can be found.

5. Analysis of results

5.1 Phase I measurement parameters are given in table 3.

Table 3: Phase 1 measurement parameters

Voltage, applied (kV)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0
Current, applied (mA)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Al filter thickness, mm	_	0.10	2.0	0.50	1.0	2.0	3.0	4.0	6.0	8.0	10.0	12.0

Figure 35 shows the emission of X-ray spectrum, applying 5 kV applied voltage. However, X-radiation with this applied voltage is not enough to ionize all the materials from anode, since their ionization energy is more than their excitation energy.

5.2 Emission of spectra from apparatus tube.

Reference values of the experimentally detected elements are presented in **Table 4**. Therefore, it is easy to recognize the elements by matching our experimental value with the reference value.

Table 4: Literature value of X-ray energies **[24].**

Elements	Atomic number (Z)	Energy/KV	Transition
Argon	18.0	2.956	Kα
		3.191	Kβ
Chromium	24.0	5.413	Kα
		5.945	Kβ
Ferus	26.0	6.401	Kα
		7.056	Kβ
Cobalt	27.0	6.938	Kα
		7.645	Kβ
Nickel	28.0	7.476	Kα
		8.261	Kβ
Cupper	29.0	8.042	Kα

		8.902	Kβ
Zink	30.0	8.635	Kα
		9.572	Kβ
Molybdenum	42.0	17.45	Kα
		19.62	Kβ

Figure 35 shows the final online spectra obtained with 5 kV excitation voltage. Roughly 4 peaks are detected, because the required ionization energy of the elements in anode and tube is greater than excitation energy.

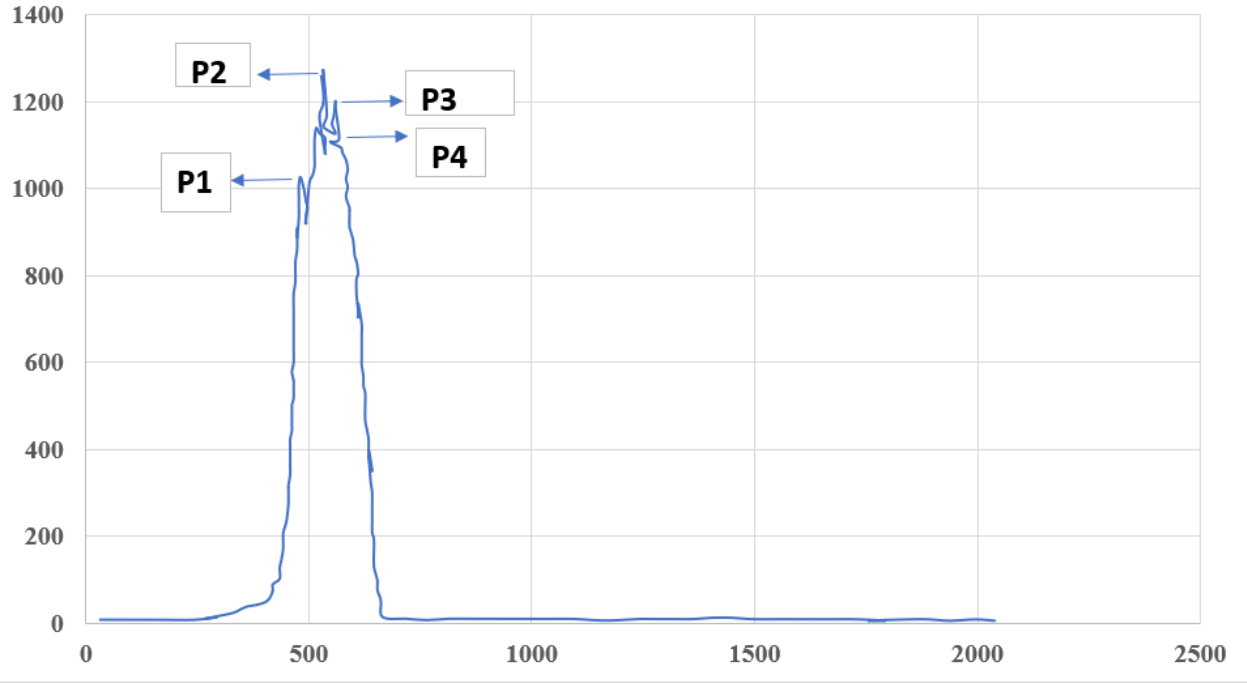


Figure 35: X-ray produced by 5 kV applied voltage: Peak1 (Ar-Kα1), Peak2(Ca-Kα1), Peak3 (Ti-Kα1), Peak4 (not recognized).

Using gain factor, elements are identified using corresponding peak energy. It is found that the first peak represents Ar element. However, we do not identify elements corresponding to peak 2-4. The reason may be due to bremsstrahlung effect.

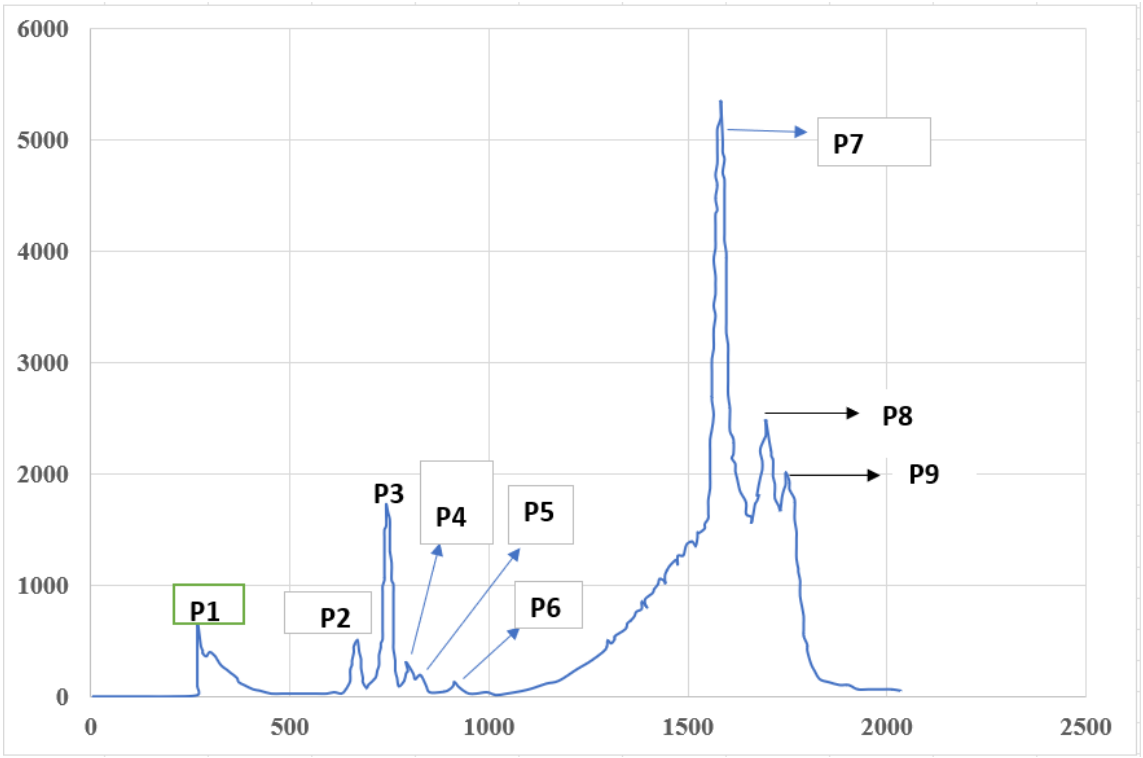


Figure 36: **Spectrum, generated by 25 kV applied voltage**: Peak1 (unidentified), Peak2 (Cr-Kα), Peak3 (Fe-Kα), Peak4 (Fe-Kβ), Peak5 (Fe-Kβ), Peak6 (Zn-Kα), Peak7 (Mo-Kα), Peak8 (Mo-Kβ backscattering), Peak9 (Mo-Kβ).

In case of 25 kV, we get a completely different scenario. All the anode elements have been clearly identified using energy calibration factor. These are known as Chromium, Ferrous, Nickel, Zinc and molybdenum. The remarkable phenomena is found at 7^{th} peak, X-radiation emitted from Mo element is detected.

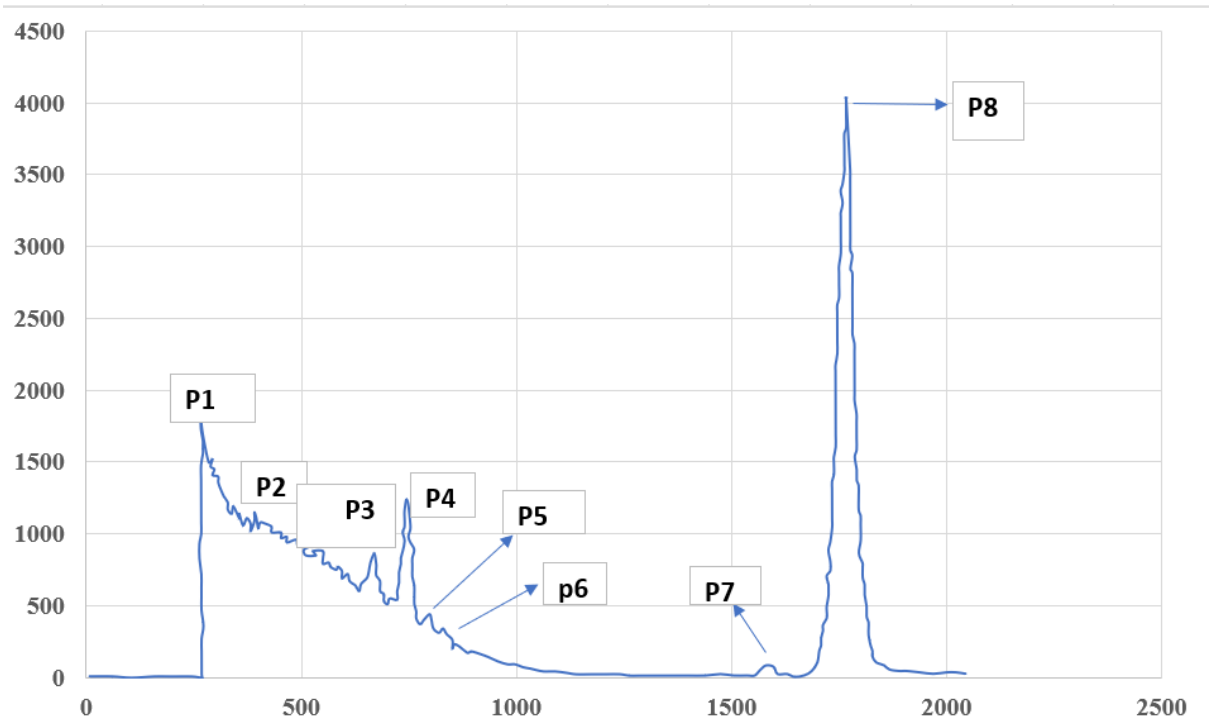


Figure 37: Emission of X-radiation, applying 60 kV applied voltage: Peak1 (unrecognized), Peak2 (P-Kα), Peak3 (Cr-Kα), Peak4 (Fe-Kα), Peak5 (Fe-Kβ), Peak6 (Ni-Kα), Peak7 (Mo-Kα), Peak8 (Mo-Kβ).

We experience data overflow in case of 60 kV **(Figure 37)**. That means, we can't find any peak when it is subjected to more than 20 keV x-ray excitation energy. This is the limitation of our experimental detector, meaning the detector, used in this case is unbale to detect X-ray spectrum over 20 keV.

5.3 Spectrum, generated by secondary radiation source MnO_2.

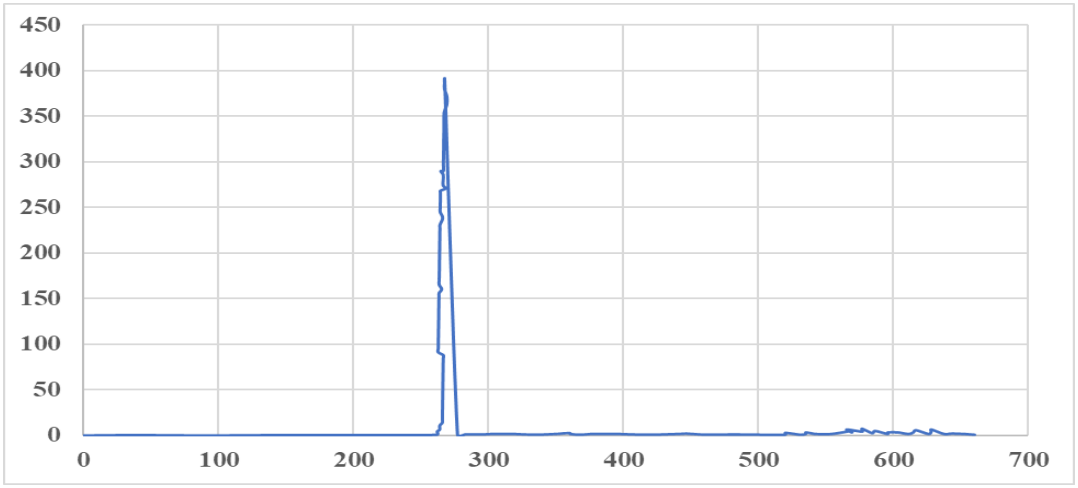


Figure 38: X-ray measurement at 5 kV applied voltage.

Since Mn ionization energy is 6 keV, therefore at this voltage level (5 kV), Mn will not be ionized and therefore we can't see Mn X-ray spectrum, shown in Fig. 38.

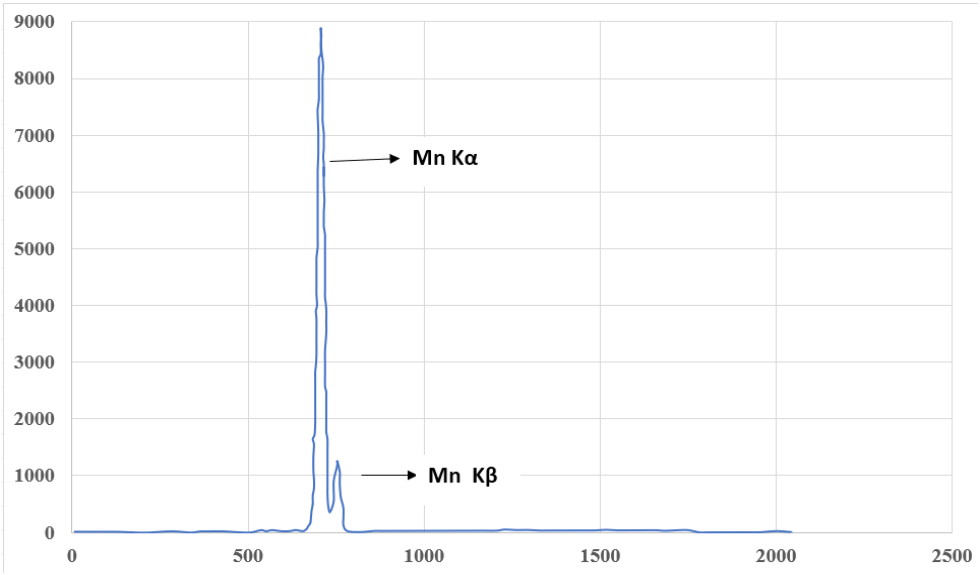


Figure 39: **X-ray emission spectra, applying 25 kV applied voltage.**

As can be seen from Fig. 39, Mo becomes ionized at19.87 keV. However, at this energy level, we don't see clear spectrum. But the spectrum becomes clearly visible at 60 kV as shown in Figure 40.

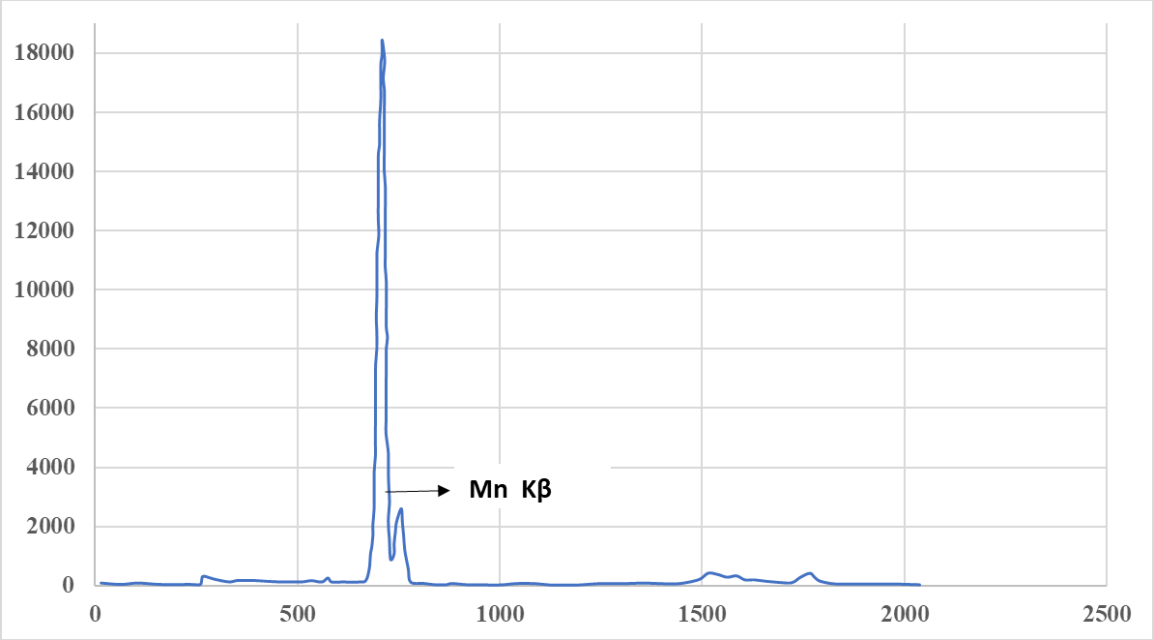


Figure 40: X-ray, generated at 60 kV applied voltage.

4. Summary & Conclusion

X-rays play a key role in our daily life, specifically in the area of medical treatment. However, without a quality X-ray report, there is a high probability of mistreatment for a patient. That is why, it is necessary to ensure precision of X-ray spectrum generation.

-In case **a**, high speed electrons, accelerated by high voltage strike anode materials in X-ray tube producing mainly a continuous Bremsstrahlung spectrum and as a result different elements from the tube, mainly Cr & Fe were detected and measured. Basically, the identification of Fe and Cr is the result of strong contribution from Bremsstrahlung radiation.

-In case of **b**, the source (MnO_2) is covered by pure Al foil which acts as shielding material and as a result Mn is no more disturbed by other elements. That is why, clean Mn spectrum is detected and measured.

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