Effects of tube potential and filtration thickness towards beam quality and x-ray spectra

Jason Carl Martin A. Tupas,*[1] Reymond R. Mesuga,[1] and Lian Angelo B. Ramos[1]

[1] *Department of Physical Sciences, Polytechnic University of the Philippines-Sta.Mesa, Philippines*
*Corresponding author: jason.tupas0506@gmail.com

Abstract

The effects of peak tube potential and filtration thickness towards the generated x-ray spectra and beam quality are investigated. The peak tube potential used in this paper varies from 80-100 kV while the Aluminum filtration thickness used are 1, 3, 5 and 7 mm. The resulting spectra and beam quality parameters such as HVL, E_{mean}, E_{eff} and radiation output are calculated using the SpekCalc program. It is found out that an increase in peak tube potential within the range of 80-100 kV with constant take-off angle and filtration thickness produced linear increase on the beam quality parameters. Increasing the filtration thickness for constant tube potential of 90 kV produced a linear increase in both effective and mean energy of the spectra, linear decrease in characteristic output while exponential decrease for bremsstrahlung output.

Keywords: beam quality, HVL, Spekcalc

1 Introduction

X-rays are produced by bombarding highly energetic electrons into a metal target and converting their kinetic energy into electromagnetic radiation. The radiation produced is comprised of photons with differing energy. Low-energy x-rays are generated in greater abundance compared to high-energy x-rays since the probability of an electron's directly impacting a nucleus is extremely low since the nuclear cross-section of an atom is very small [1]. The distribution of photons as function of the varying photon energy makes the x-ray spectrum. The maximum x-ray energy (in keV) of the x-ray spectrum is equal to the peak electrical voltage of the x-ray tube (in kV). In this situation, the kinetic energy of an accelerated electron is converted totally into photon energy. The minimum x-ray energy is primarily limited by the filtration material in the x-ray beam [2].

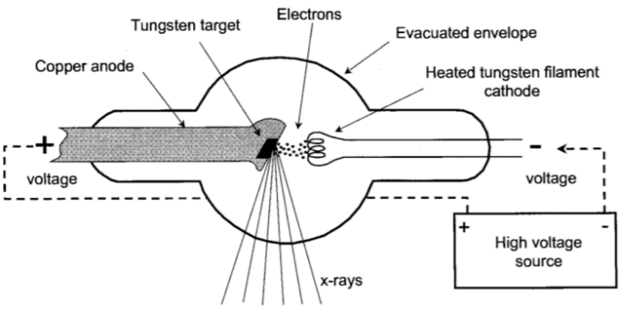

Figure 1: An X-ray equipment system

X-ray spectrum is mostly composed of the bremsstrahlung spectrum, with limited number of x-rays produced in characteristic spectrum. In bremsstrahlung spectrum, x-rays have a broad energy distribution produced by the decelerating the electron due to Coulombic forces, causing a significant loss of energy equal to the resulting photon energy. For characteristic x-rays (shown in Figure 2), it involves the transitions of electrons between various orbital shells produced from ionizing the target atom (usually tungsten) if the energy of the incident electron exceeds the binding energy of an electron of a target atom. Characteristic x-rays appear as discrete lines at certain fixed energies in the x-ray spectrum [1,2].

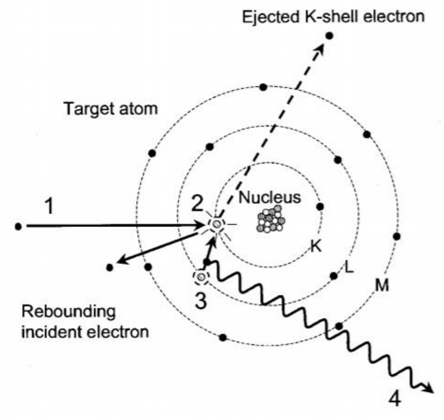

Figure 2: Generation of characteristic x-ray

X-rays serve an important role in medical industry and research. The X-ray spectrum and beam quality are the significant parameters for studying the dosimetric properties of X-ray beams in diagnostic radiology. It involves the determination of the half-value layer (HVL) of a beam, which is the thickness of material required to reduce the energy of an x-ray beam to one half its initial value [1]. Another parameter involved is the effective energy (E_{eff}) of an x-ray spectrum which is used to describe the penetration of a polyenergetic beam. The effective energy of a polyenergetic beam is equal to the energy of a monoenergetic X-ray beam that is attenuated (HVL) at the same rate as the polyenergetic beam [3]. Another parameter is the mean energy of the spectrum (E_{mean}) which is defined as the mean beam energy averaged over the fluence spectrum [4]. The bremsstrahlung and characteristic output (in uGy/mAs @ 1m) are also calculated.

In this paper, the different factors affecting the x-ray spectra and beam quality are examined. These factors involved the peak tube potential (kVp) and the filtration thickness used in the x-ray tube. The resulting spectra and beam quality parameters such as HVL, E_{mean}, E_{eff} and radiation output are obtained using the SpekCalc program, a free-to download program used for simulating x-ray spectra emitted from thick-target tungsten anode x-ray tubes [4].

2 Methodology

The x-ray spectra for various conditions are calculated using the SpekCalc software. The spectra are simulated from tungsten anode x-ray tubes, in which the user can customize the electron energy in keV, the x-ray take-off angle and the amount of filtration used. The SpekCalc graphical user interface (GUI) is shown in Figure 3.

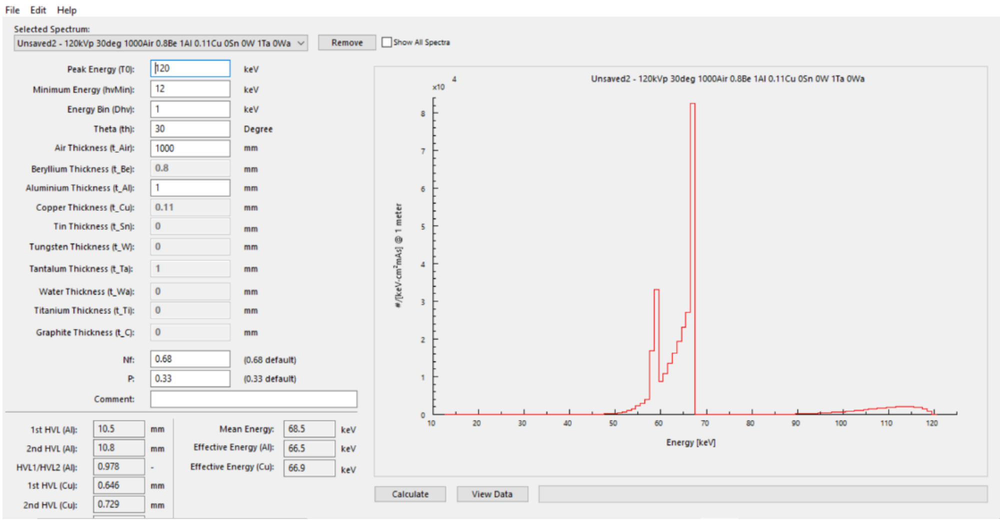

Figure 3: Screenshot of SpekCalc GUI

For overall spectra distribution analysis, three different peak tube potential were considered; 80, 90 and 100 kV, with constant x-ray take of angle of 30˚, air thickness of 1000 mm and filtration thickness of 1 mm of Aluminum. The resulting spectra distribution were graphed and directly compared. For the beam quality parameters, the radiation output, HVL, E_{mean} and E_{eff} were evaluated from 80 to 100 kVp with a constant increment of 2 kV in peak potential.

Four different Aluminum (Al) filtration thickness were evaluated; 1, 3, 5 and 7 mm. The spectra were determined at a constant 90 kVp potential for all filtration thickness. The mean and effective energy were also plotted and analyzed.

3 Results and Discussion

3.1 Effect of peak tube potential

The peak tube potential exhibited an effect on the x-ray spectra. It is shown in Figure 4 that as the peak tube potential increased, the number of photons for every individual photon energy also increased. As expected, the resulting maximum photon energy of a spectrum is equal to the peak tube potential. The number of characteristic x-ray produced also increased as the peak tube potential increased. These characteristic x-rays are produced at specific photon energies which are the same for all tube potentials since the anode material used in simulation is tungsten for all trials.

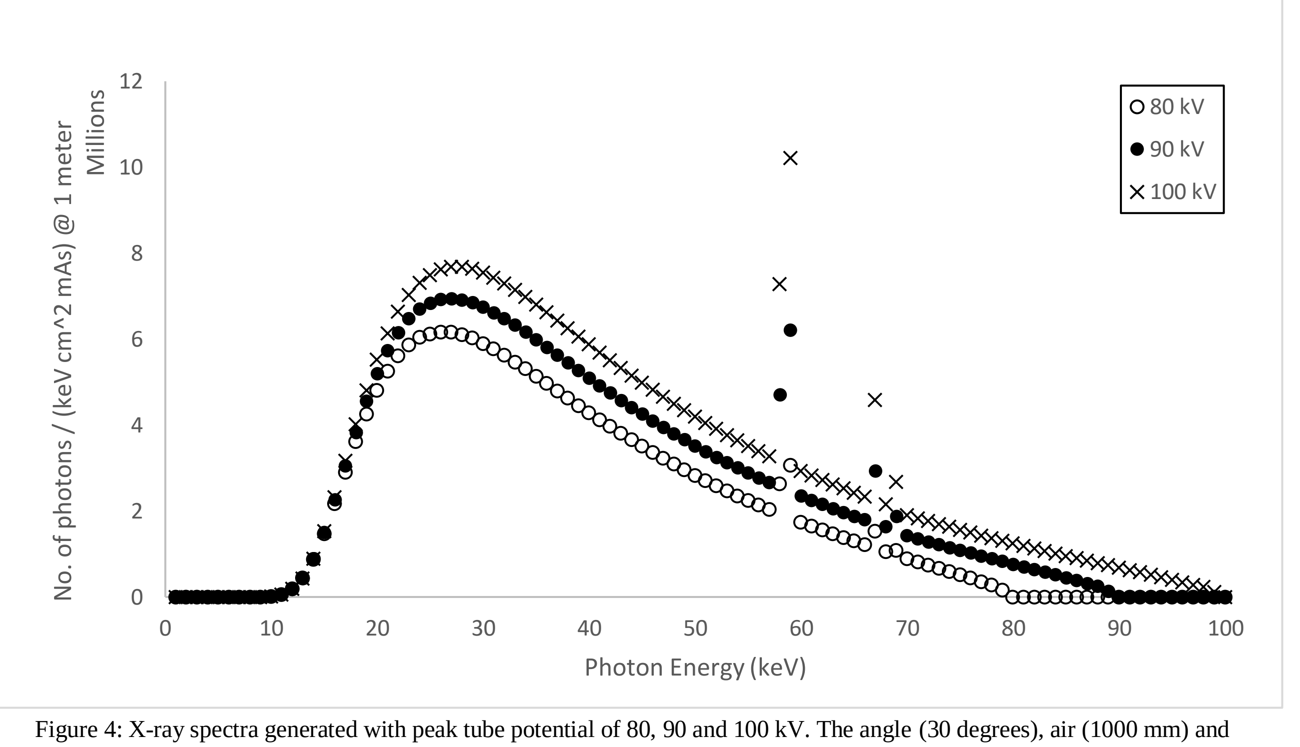

Figure 4: X-ray spectra generated with peak tube potential of 80, 90 and 100 kV. The angle (30 degrees), air (1000 mm) and filtration (1 mm Al) thickness are kept at constant value for all trials.

The x-ray output for both bremsstrahlung and characteristic x-ray are also affected by the peak tube potential. Based on Figure 5, the x-ray output of the two types of x-rays also increased as the peak tube potential increased. The bremsstrahlung output increased more rapidly compared to characteristic x-ray, with the total increase in radiation output of 47.44 and 3.47, respectively.

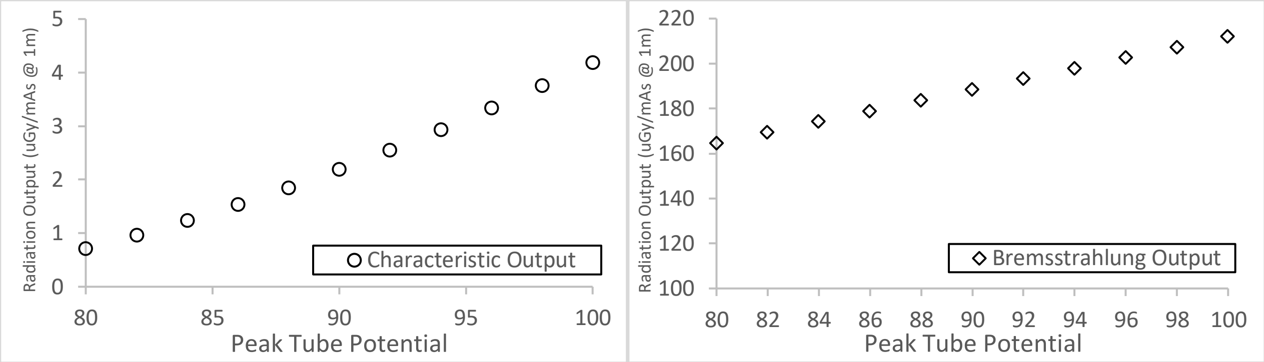

Figure 5: Radiation output vs. peak tube potential

For the beam quality, it is shown that the HVL increased as the peak tube potential increased. The trend is almost linear as seen in Figure 6(a) in which the linear approximation closely fits in the calculated data. The HVL had an increase of 0.03 mm for every 2 kV increase in potential. The increase in effective energy and mean energy is also approximately linear as shown in Figure 6(b), with the effective energy increasing rapidly compared to the mean energy. For an increase of 2 kV in potential, the effective energy and mean energy had an increase of 0.5-0.6 keV and 0.1-0.2 keV, respectively. In general, the effect of peak tube potential within the range of 80-100 kV at the beam quality is basically linear.

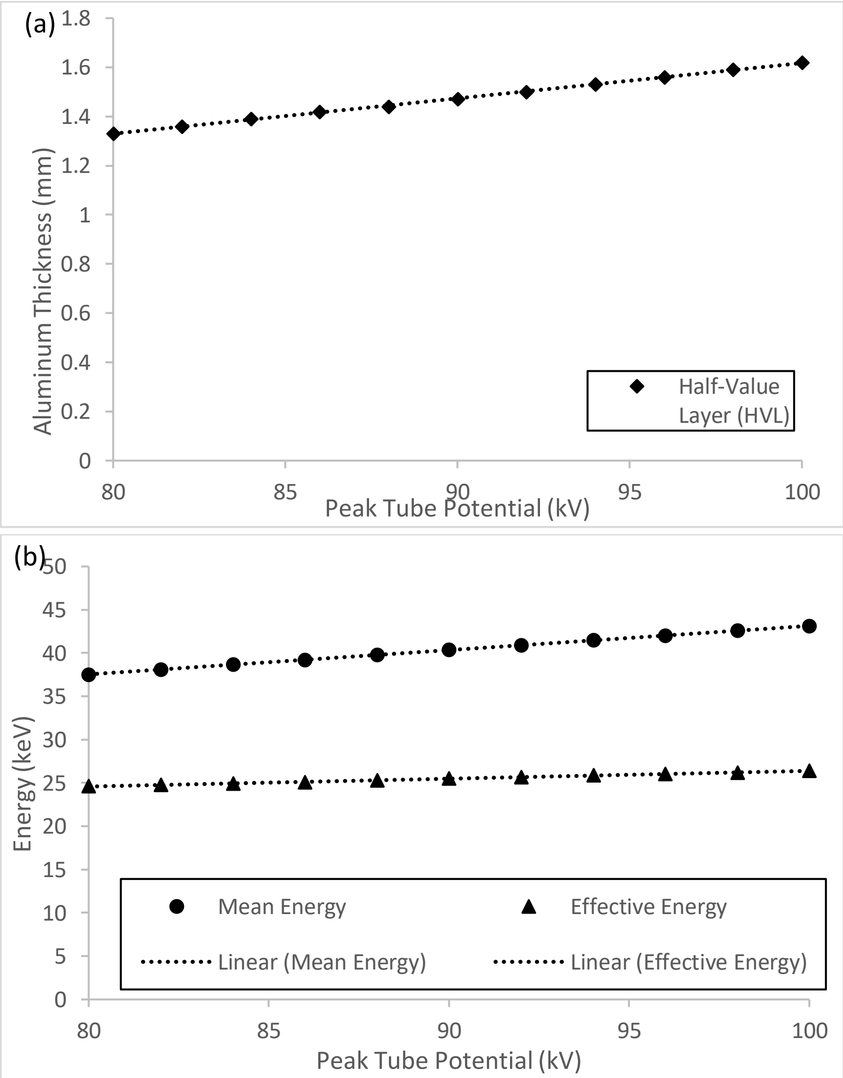

Figure 6: (a) HVL of Aluminum vs. peak tube potential (b) E_{mean} and E_{eff} vs. peak tube potential. The angle (30 degrees), air (1000 mm) and filtration (1 mm Al) thickness are kept at constant value for all trials.

3.2 Effects of filtration thickness

The thickness of filtration material has a relatively large effect on the x-ray spectra. As shown in Figure 7, the number of photons produced for every specific photon energy decreased as the thickness of Aluminum filter increased. The distribution graph also become less skewed to the left as the thickness increased; indicating that fewer low-energy x-ray are produced. It is because more low-energy photons are filtered by the Aluminum as its thickness increased with the highly energetic photons only being able to fully penetrate the material.

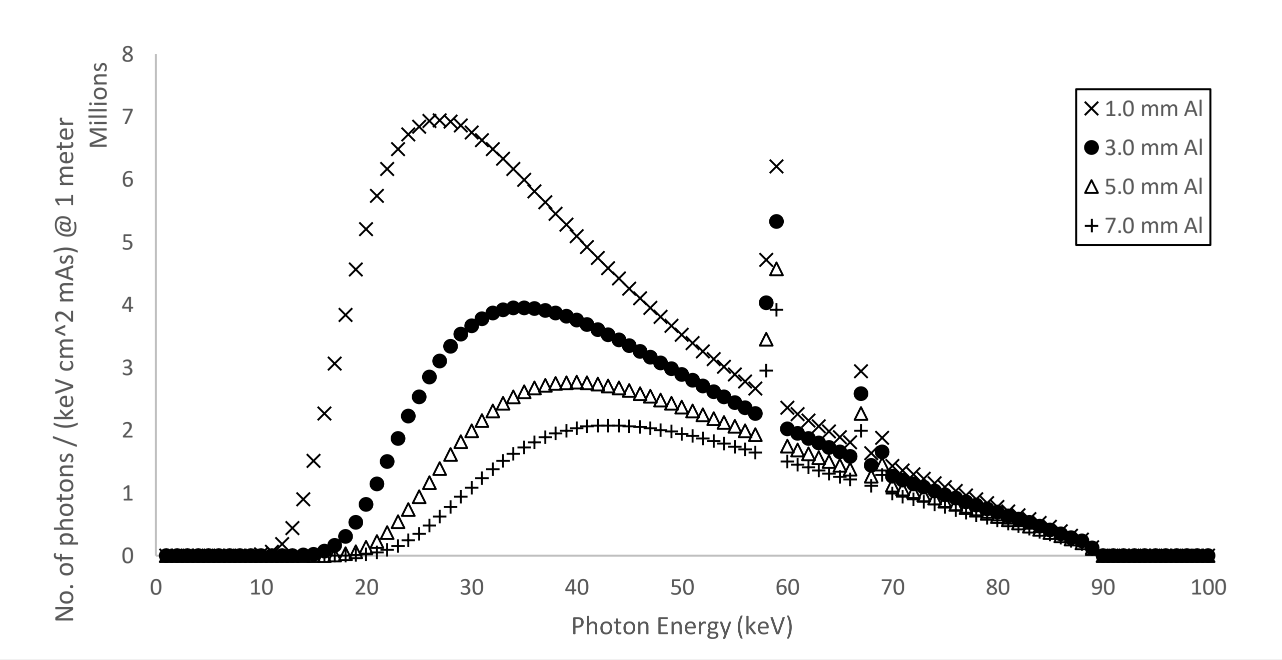

Figure 7: X-ray spectra generated with filtration thickness of 1, 3, 5 and 7 mm of Aluminum. The angle (30 degrees), air (1000 mm) and peak tube potential (90 kVp) are kept at constant value for all trials.

The x-ray output for both bremsstrahlung and characteristic x-ray are also affected by the thickness of filtration material. Based on Figure 8, the x-ray output of the two types of x-rays decreased as the Aluminum thickness increased. The bremsstrahlung output decreased more rapidly compared to characteristic x-ray, exhibiting an approximately exponential decrease in output while the decrease in characteristic output is almost linear.

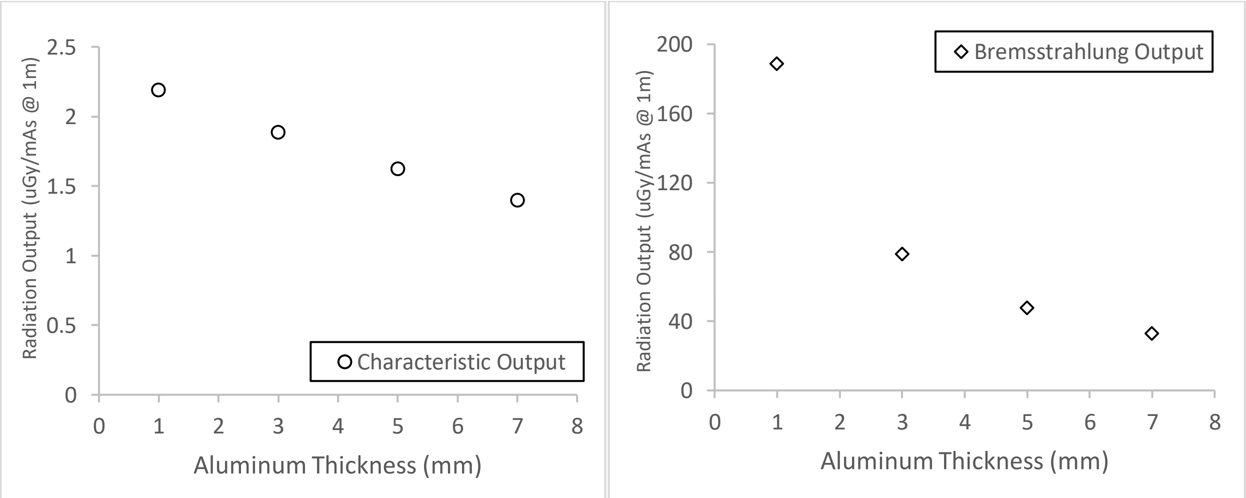

Figure 8: Radiation output with varying filtration thickness of 1, 3, 5 and 7 mm of Aluminum. The angle (30 degrees), air (1000 mm) and peak tube potential (90 kVp) are kept at constant value for all trials.

For the beam quality, it is shown that the mean energy and effective energy increased as the thickness of Al increased. This increase in mean energy indicates that more high-energy photons are produced compared to low-energy photons, which agrees with the analysis of spectra above. The increase in effective energy means that higher energy of photon is required for these x-rays to penetrate the filter material with the same intensity of penetration as the HVL.

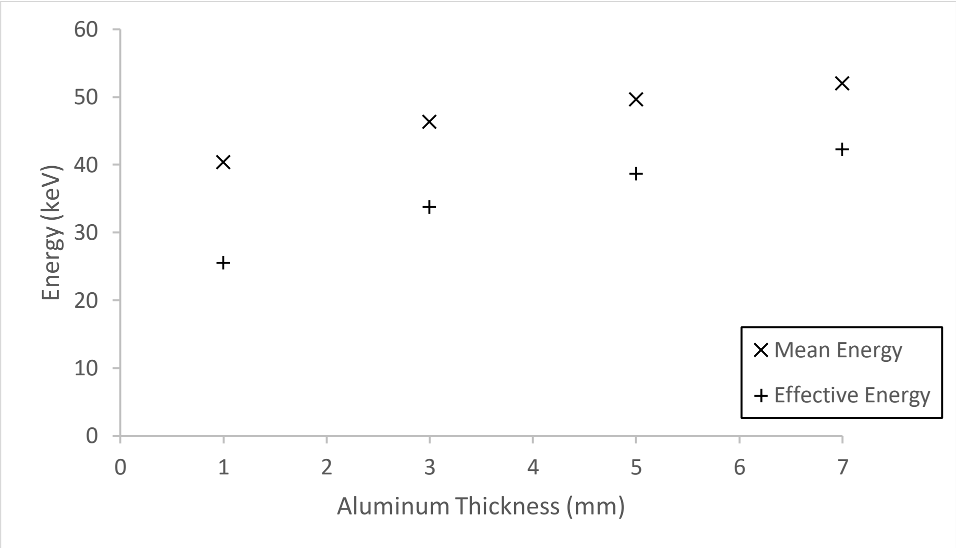

Figure 9: Mean and Effective energy with varying filtration thickness of 1, 3, 5 and 7 mm of Aluminum. The angle (30 degrees), air (1000 mm) and peak tube potential (90 kVp) are kept at constant value for all trials.

4 Conclusions

This paper has yielded important results regarding the effect of peak tube potential and filtration thickness to the x-ray spectra and quality of beam. It is shown that the increase in peak tube potential produced an increase in the radiation output of both bremsstrahlung and characteristic x-rays, with the increase in bremsstrahlung occurring more rapidly compared to characteristic output. The increase in tube potential also produced a linear increase in the HVL, mean energy and effective energy of the spectra. For the thickness of filtration material, an increase in Aluminum thickness yielded a relatively exponential decrease for bremsstrahlung output while linear decrease for characteristic output. The increase in Aluminum thickness also produced an increase in mean and effective energy of x-ray spectra after filtering out more low-energy photons generated by the x-ray production.

References

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