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Research article

Determination of Elemental Filters used in medical X-rays diagnosis using the EGS5 code

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Abstract

For best use of X-rays in Computed Tomography, an elemental filter is placed between the X-rays source and the patient, which to optimize the radiation dose and prevent exposure to unnecessary radiation. However the filter can act as sources of secondary radiation due to angular scattering. The EGS5 code, which is a UNIX based software developed by Stanford Linear Accelerator Centre (SLAC) was used to simulate the transport of the radiation the filters. These filter materials include Al, Cu, Fe, Mg, Ni, Si, V, Y and Zn and of diameters from 1.5 to 6.0 mm. The quantity of X-rays transmitted depends on the atomic number of the filter material and Magnesium, Silicon and Aluminium having the highest transmitted photons with 96.02%, 94.20% and 93.86% at 120kV.

Keywords: X-rays filters, EGS5, filtration, radiation.

1. INTRODUCTION

X-ray radiation is used in the diagnosis of ailment and therapy. This is because of its ability to deliver dose to a specific area under consideration while sparing most normal tissues surrounding the organ(s) of interest. It is used in instruments like Computed Tomography (CT) scanner and others.

Computed Tomography is one of the most commonly used diagnostic procedures in modern medicine. It can contribute large percentage of radiation dose to the patients during medical procedure. Also, it is estimated that worldwide CT contributes 5% of the radiological examination but makes up 34% contribution to the collective dose (Poonam *et al, 2011*).

A radiation attenuating material is incorporated in the path of the radiation beam to absorb preferentially the less penetrating components of the useful beam. It may consist of a permanent filter, which is an integral part of the X-ray tube housing and which cannot be removed by the user, and/or an added filter that is intended to increase the total filter thickness.
The delivery of the required dose is minimized by the use of these filter materials between the source and the patient without affecting the image quality. The filter commonly used is aluminium, but other materials of atomic number between 12 and 39 can be used e.g. Copper, Iron, Magnesium, Nickel, Silicon, Vanadium, Yttrium and Zinc. These

filter materials are meant to reduce the dose to only allowed energy values and intensity without scattering the radiation. This is because the scattered radiation can cause unnecessary exposure to the patient and even staff in the radiation laboratory.

However, the use of such filters can act as a source of secondary radiation by angular distribution (Compton Scattering).

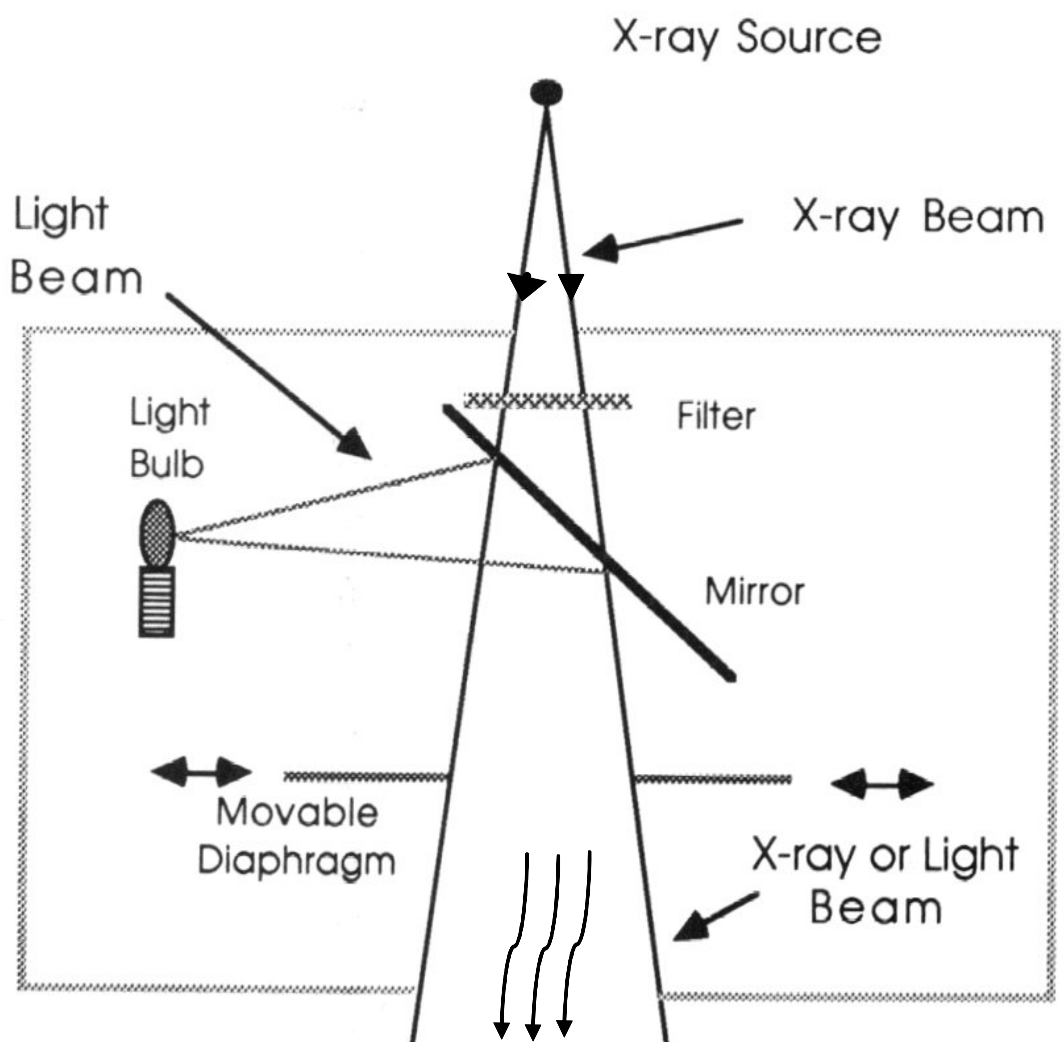

Figure 1: A Typical design of an X-ray source showing the filter (Jan Kybic, 2006)

Figure 1 above shows the sample of the process involved in the use of X-rays in medical diagnostic imaging. The filter is seen between the X-ray source and the mirror used to collimating the beam. The mirror together with the light source helps in illuminating the path and directs the beam. Numerical and computational models have been reported for scattered photons generated from some elemental filters commonly considered for use in medical radiology (Okunade, 2002). Some have considered the radiation from X-ray source in part or as a whole process of production, filter process, transmission and detection. Different computational methods based on empirical or semiempirical models and sophisticated Monte Carlo calculations have been proposed for prediction of x-ray spectra both in diagnostic radiology and mammography (Okunade, 2002)

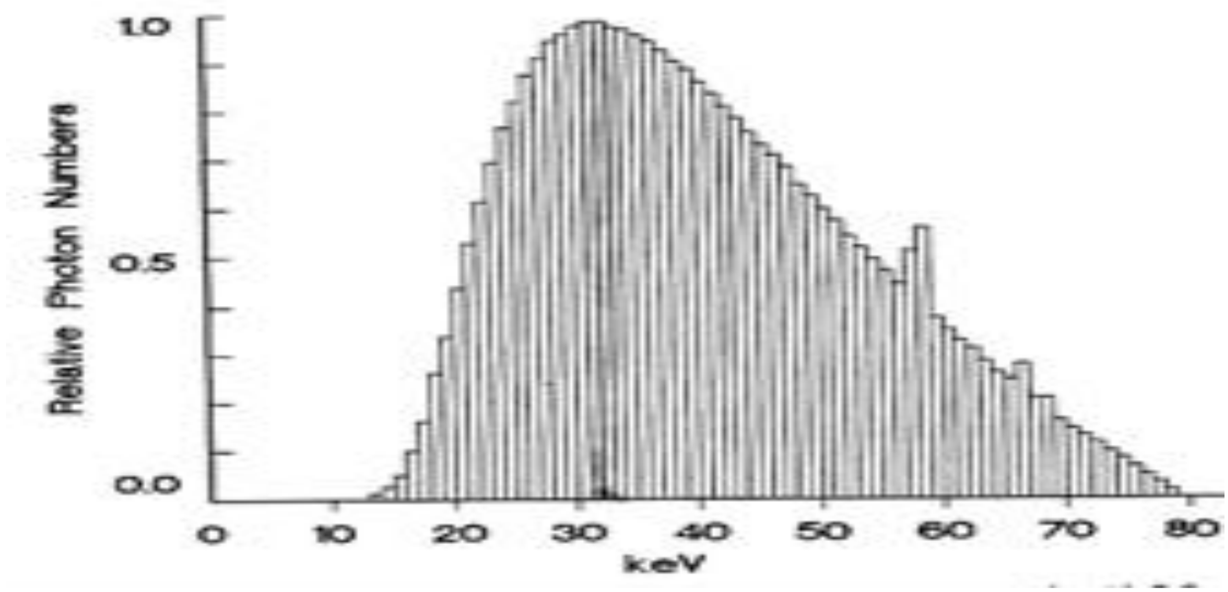

Figure 2: The emission spectrum for X-rays from tungsten target (Jan Kybic, 2006)

From the figure 2 above, it can be seen that the overall curve for the production of X-rays in tube using tungsten is smooth shaped. The X-ray production starts at approximately 15 keV and increases rapidly to 30-40 keV of maximum energy (peak of the curve). After the peak, there is a gradual downward slope to the x-axis (maximum energy).

From the analyzed information, the design of filters can be optimized to protect the patient and the staff from photons that may arise from the scattering of the filters and by limiting the radiation dose without affecting the image quality (Okunade, 2003).

However the X-ray filter which is between the source and the patient, acts as a source of extra focal radiation, which can degrade image contrast and contribute to unwanted radiation dose to the patient and laboratory staff. This was attributed to variations in half-value-thickness (HVT) of X-ray beam to scatter generated from filter materials (Trout *et al,* 1960). Ardam & Crooks (1962) reported that the scatter generated from filter invariably contribute to off-axis exposure. When this occurs within a cone of 15° or less (i.e. Rayleigh scattering) it will contribute to useful beam with comparable energy of primary source. But photons that undergo Compton interactions (wide-angle scattering) will contribute to other sensitive part of the patient/staff if not properly collimated.

The theoretical evaluation of imaging system requires the development of descriptive mathematical models for the successive steps involved. In this work, mathematical and computer models were used to perform a complete simulation of the process without resorting to rigorous experimental measurement. The Monte Carlo (MC) method has been widely used to simulate different processes that would have been nearly impossible experimentally.

Hence, EGS5 code, which is based on the Monte Carlo method, was used to simulate the transport of X-rays through different filters used in medical diagnostic radiology to evaluate the scattered photons.

2. METHODOLGY

The EGS5 code system obtained from SLAC- Stanford University was used to simulate the transport of photons in different media. The incident spectra data used for these calculations are those defined by Fawell *et al*, (1981). The spectra considered are at 80, 100 and 120 kV distributed at 2keV energy bins. The angular distributions were observed for Rayleigh and Compton interaction and compared with expected values of aluminium filter for 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 6.0 mm. Also, other elemental filters to be used are Magnesium, Silicon, Vanadium, Iron, Nickel, Copper, Zinc and Yttrium. This EGS5 code system runs only on Unix-based operating system but can also run on Windows operating systems with a Unix-platform. .

3. RESULTS AND DISCUSSION

3.1 Calculated photons for the Filters

The data for the transmitted photons, Rayleigh, Compton and Reflected photons are shown below in the figures 3, 4 and 5. It shows the percentage of the scattered photons for different filters for 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 6.0 millimeters.

For Aluminium at 80 kV, as the diameter of the filter increases from 1.5 to 6.0mm, less photon is transmitted but the Rayleigh, Compton and the reflected beam all increased. It also shows that at 100, and 120 kV, the percentage of transmitted beam reduces as the filter increases from 1.5mm to 6mm. The transmitted photons have the highest percentage at 120kV for 1.5mm and it has the lowest percentage at 6.0mm for 80kV. The Rayleigh photons increases as the diameter of the filter increase and it has its highest percentage of 3.47% at 6mm for 80 kV while the minimum is 0.45 % for 1.45mm and at 120 kV.

The Compton photon has maximum percentage of 17.86% at 120 kV, 17.61% at 100 kV and 17.15% for 80 kV all at 6.0mm while the minimum percentage of 5.24% is at 120 kV for 1.5mm.

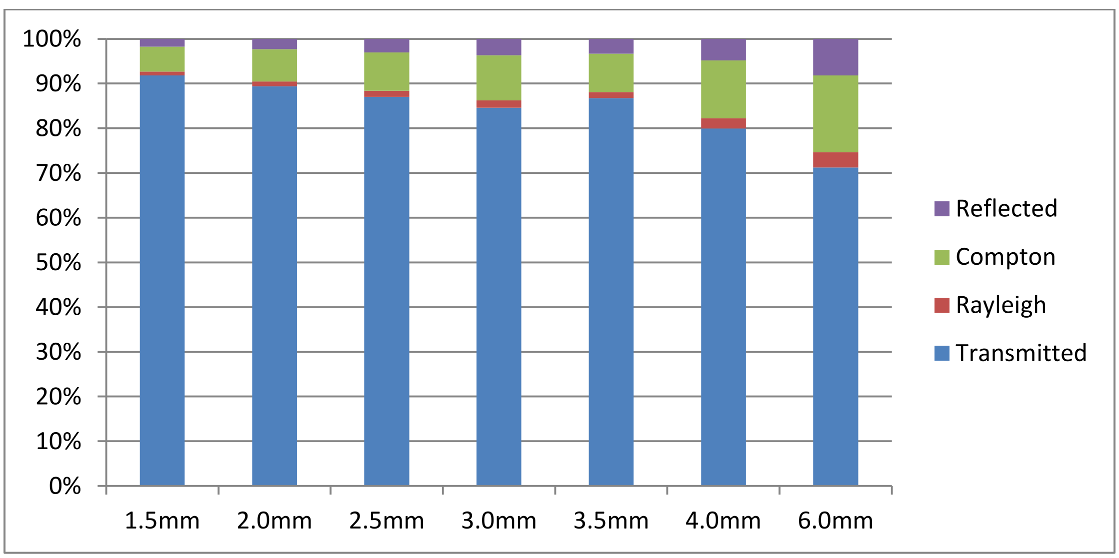

Figure 3: The scattered photons for Al at 80kV

As the diameter of the filters increase, the scattered transmitted photons reduces while the reflected, Compton and Rayleigh scattered photons all increases (Figures

3, 4 and 5.)

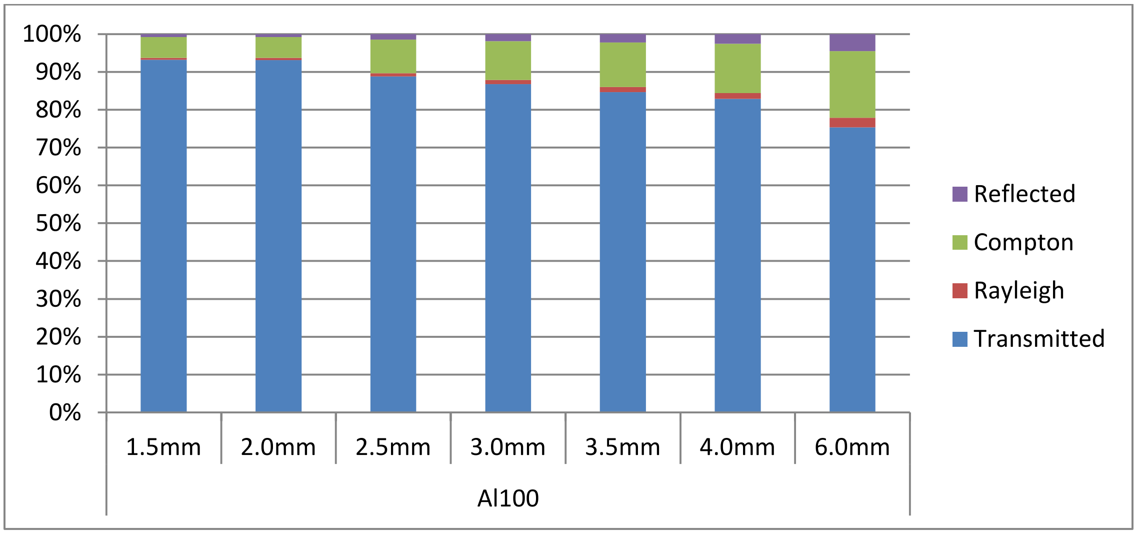

Figure 4: The scattered photons from Al at 100 kV

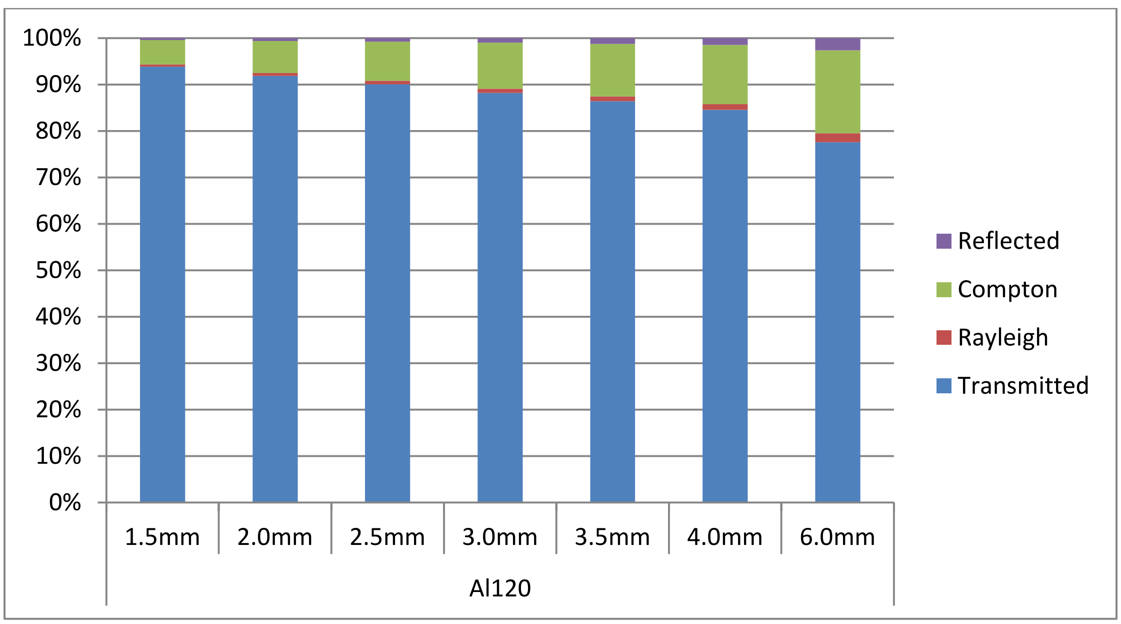

Figure 5: The scatter photons for Al at 120kV

3.1 Calculated Data of the Scattered Photons

The data calculated for the useful and non-useful photons is shown in figure 6 below. It was observed that the useful beam which include the transmitted photons and Rayleigh photons have the highest values for Magnesium, Silicon and Aluminium.

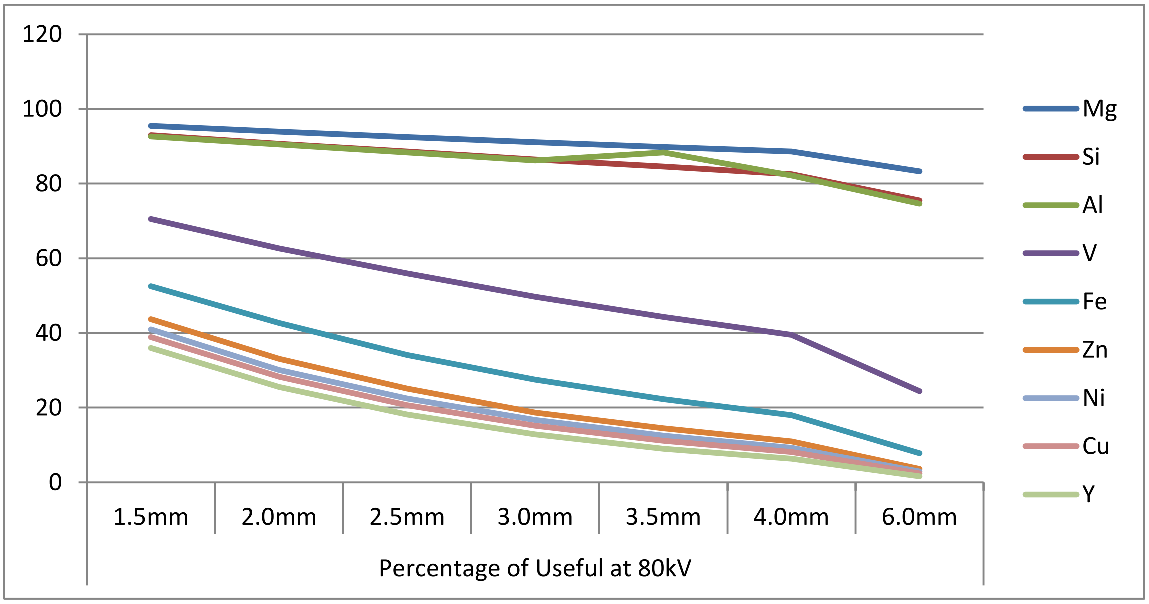

Figure 6: Calculated data for the useful photons for 80 kV

From figure 6, it can be seen that Magnesium with 95.42% has the highest percentage of useful photons at 80 kV while Yttrium with 1.65% has the lowest useful photons. As the diameter of the filtered material increased, the percentage of useful photons reduces. This reduction continued to reduce from Magnesium, Silicon, Aluminium, Vanadium, Iron, Zinc, Nickel, Copper and then Yttrium.

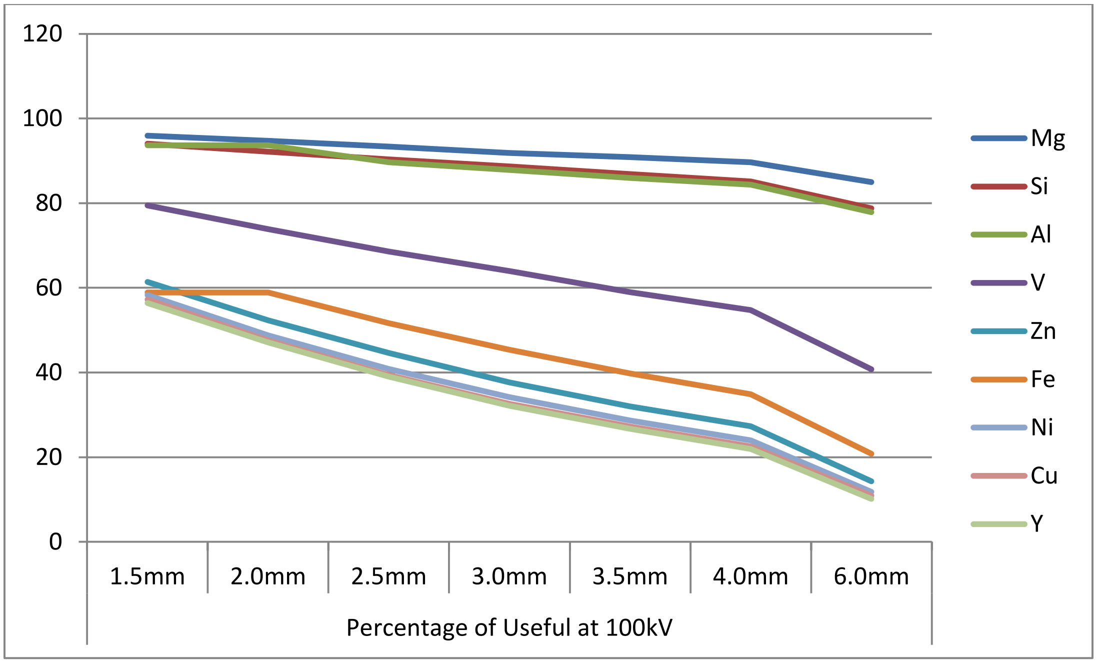

Figure 7: Calculated data for the useful photons for 100 kV

The calculated data above also shows that Magnesium with 95.93% has the highest percentage of useful photons at 100 kV while Yttrium 10.15% has the lowest useful photons as from figure 7. Similarly, the diameter of the filtered material increases as the percentage of useful photons reduced. The decrease is from Magnesium, Silicon, Aluminium, Vanadium, Iron, Zinc, Nickel, Copper and then Yttrium.

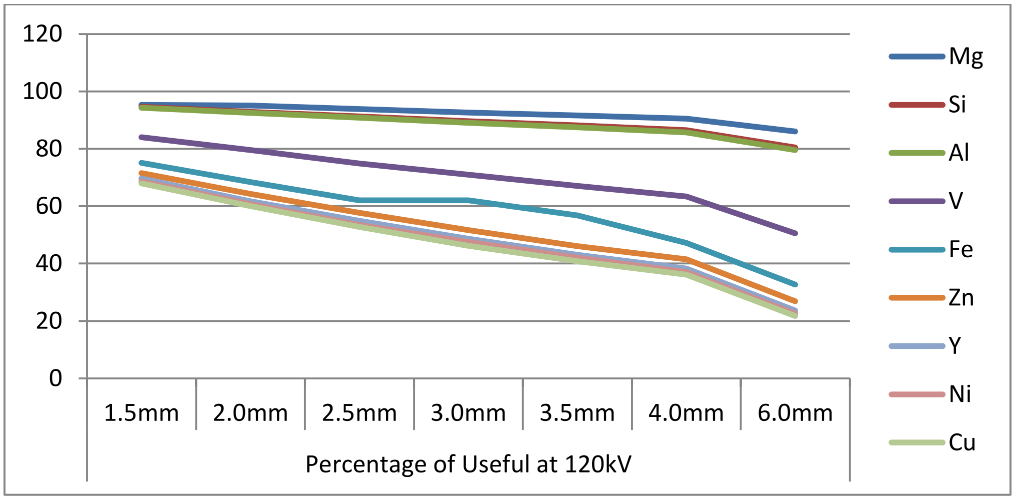

Figure 8: Calculated data for the useful photons for 120 kV

From figure 8 it can be seen that Magnesium with 95.27% has the highest percentage of useful photons at 120 kV while Copper (21.71%) has the lowest useful photons. It then reduced from Silicon, Aluminium, Vanadium, Iron, Zinc, Yttrium, Nickel and Copper. As the diameter of the filtered material increased, the percentage of useful photons reduces.

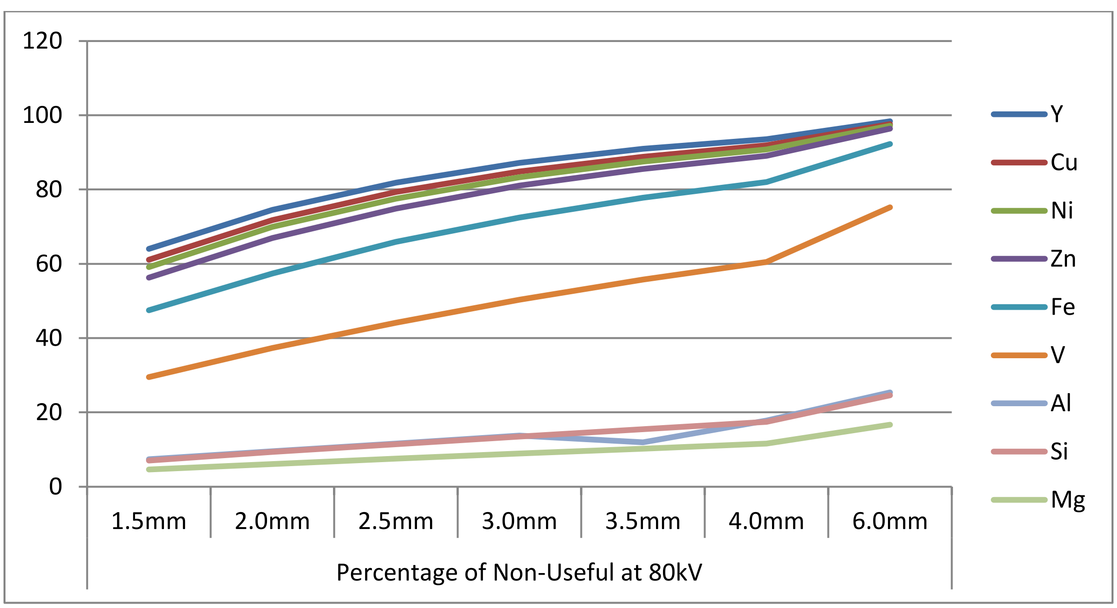

Figure 9: Calculated data for the Non-useful photons for 80 kV

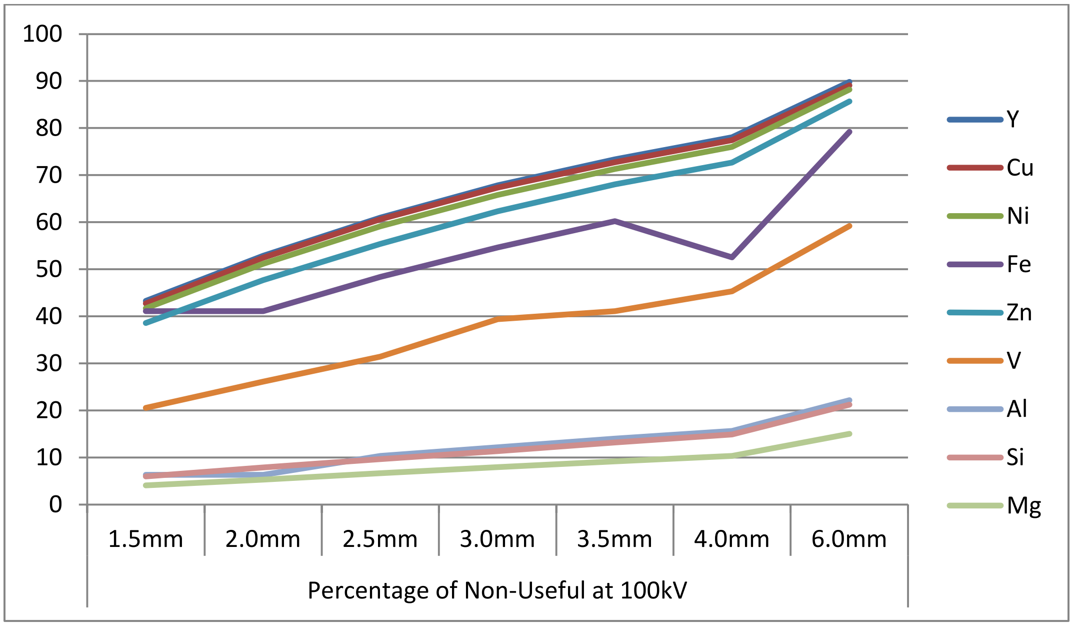

Figure 10: Calculated data for the Non-useful photons for 100 kV

The non useful photons which include the reflected and Compton beam has its highest value is Yttrium and as the diameter of the filter increases, more photons are scattered. It can also be seen that Magnesium has the lowest non-useful photons.

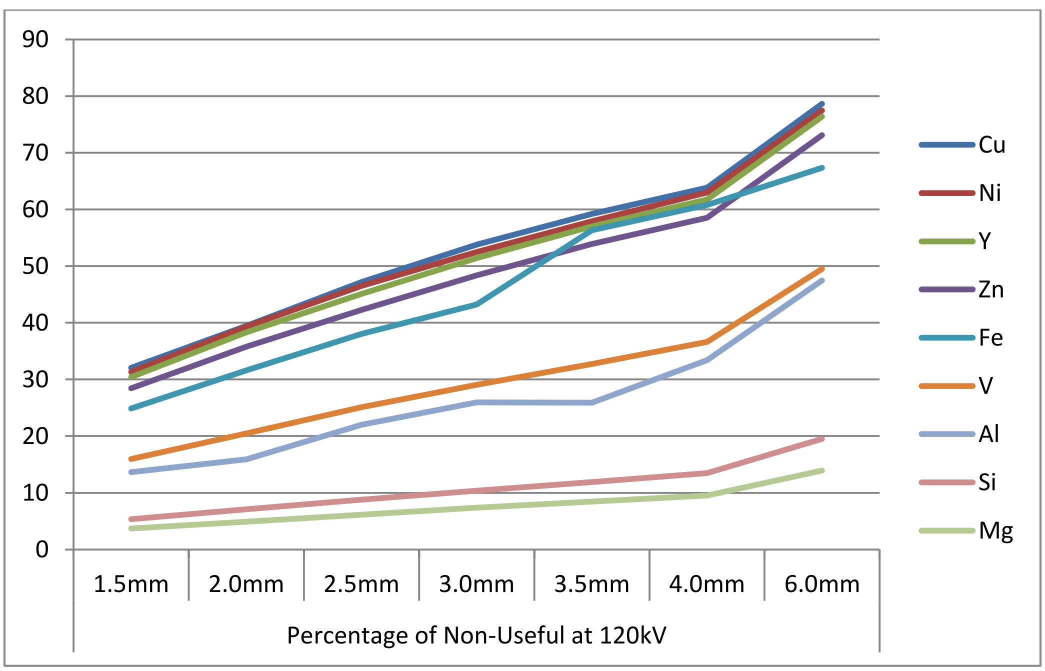

Figure 11: The percentage of Non-useful photons at 120kV

4. CONCLUSION

Data obtained at 80kV for Al, Si and Mg show that increasing the diameter of the filter can also increase the scattered photons despite the reduction in the transmitted photons. However, the Compton scattered photons reduced steadily for Fe, Ni, Zn and relatively steady for V and Y although Vanadium has a higher scatter than the Yttrium. It is observed that at 80 kV, the highest Rayleigh scattering for 1.5mm is Nickel at 3.56%, for 2.0mm it is Iron at 3.91%, for 2.5, 3.0, 3.5, 4.0 and 6.0mm, the highest Rayleigh scattered photon is Vanadium at 4.01%, 4.27%, 4.52% and 4.36% respectively. The lowest is Magnesium at 0.52% for 1.5mm. For 2.0, 2.5, and 3.0 mm it is Magnesium at 0.70%, 0.87%, and 1.03% respectively. For 3.5, 4.0 and 6.0mm, the lowest is Yttrium at 1.33%, 1.02% and 6.0mm respectively.

At 100 kV, the data show that the highest Compton scattered photons is Al, which increases steadily as the diameter of the filter increased. A lower increase was observed in Silicon, Vanadium and Magnesium. The others filters reduced as the diameter of the filter also increased from 1.5mm to 6.0mm. At 100 kV in Table 12.0, the highest Rayleigh scattering for 1.5mm is Nickel at 3.69%. For 2.0mm it is Nickel at 4.09%. For 2.5, 3.0, 3.5, and 4.0mm, the highest Rayleigh scattered photon is Iron at 4.32%, 4.61%, 4.75% and 4.75% and for 6.0mm the highest is Vanadium at 5.33%.

The lowest is Magnesium with 0.35%, 0.48%, 0.60%, 0.71%, 0.83%, 0.95% and 1.46% for 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 6.0 mm respectively

The increase in the Compton scatter was observed in Al, Si, V and Mg, while it decreased in Ni, Cu, Zn and Y at 120 kV. This showed that as the diameter of the filter increased, less photon are scattered by Yttrium, Zinc, Copper and Nickel.

Rayleigh scattered photons which can contribute to useful beam always have a steady increase in Aluminium, Silicon, Magnesium and Vanadium while it decreased for the other materials as the diameter of the material increased. At 120kV in Table 13.0, the highest Rayleigh scattering for 1.5 and 2.0mm is Nickel at 3.33% and 3.94% respectively. For 2.0mm it is Iron at 3.91%, for 2.5, 3.0, 3.5, 4.0 and 6.0mm, the highest Rayleigh scattered photon is Vanadium at 4.01%, 4.27%, 4.52% and 4.36% respectively. The lowest is Magnesium at 0.52% for 1.5mm. For 2.0, 2.5, and 3.0 mm it is Magnesium at 0.70%, 0.87%, and 1.03% respectively. For 3.5, 4.0 and 6.0mm, the lowest is Yttrium at 1.33%, 1.02% and 6.0mm respectively.

The Rayleigh scattered photons which has the highest value is Vanadium at 100kV with 5.33% and 120kV with 5.13%. The next highest value is Iron at 120kV with 4.95%. But the lowest is Magnesium at 120kV with 0.25 and 0.35%.

The choice of a filter which can be based on the highest transmitted photons, the Rayleigh scattered photons and the least Compton scattered photons is to be considered. Compton scattered photons which have its highest value at 120kV for Aluminum with 17.86% and at 100kV with 17.61% and at 80kV with 17.15%. Magnesium and Silicon have the lowest contribution to Compton scattered photons. The transmitted photons have their highest values for Magnesium, Silicon and Aluminium at 96.02%, 94.20% and 93.86% all at 120kV. This is because the observed Compton scattered photons is small enough and cannot contribute much to the unwanted exposure. This is also because the Rayleigh scattered will still be within the 15 degrees and increase the useful beam from the transmitted photons. This implies that an ideal material made of only Magnesium, Silicon or Aluminum can be used cautiously since the unnecessary beam due to scattering is still possible. The work considered the use of materials with atomic number between 12 and 39 only and with a range of tube power of energy 80, 100, 120 kV. However further research can design a filter material that combines two or more elements to form a better material and further measurement of the actual transmitted photons can be done with the appropriate detectors. This can be used to optimized the radiation from the X-ray during medical imaging and reduce the unwanted exposure to other patient organs and staff.

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