Analysis of Half-Value Layer on Multimeters and Manual Calculation Using Aluminum Filter

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Abstract: Limited number of qualified test laboratories leads to a long queue of calibration and conformity tests. X-Ray beam quality test that utilizes the half-value layer method might be used as an option for the internal test procedures to optimize the radiation protection program by the medical physicist. RADCAL and RAYSAFE were used as the multimeters for this experiment, with the exposure setting of 53 kV, 160 mA, and 50 ms. The best result is produced by the configuration where the Al plate is placed close to the source, right below the collimator, with a 2,5% mean deviation from the multimeter's HVL value. Meanwhile, when the Al plate is placed close to the multimeter sensor, the mean deviation can reach up to 13,5%. It can be concluded that the HVL method using an Al plate and detector can be used to measure the beam quality of the radiographic X-Ray machine. This research has no intention to replace the existing procedure but to add more insight for medical physicists' QA/QC program. As radiation safety and protection must also be considered, not only for certifications but also actualizations.

***Keywords**: Radiation Protection, Conformity Test, QA, QC*

1. Introduction

The pandemic had already taken a toll on everyone, especially those who were directly dealing with Covid-19, both patients and workers. If looked from a wider perspective, there are a lot of things that got affected by this situation. In this case, the radiology department has its own problems to be solved. Standard Operating Procedure (SOP) needed to be reviewed as soon as possible following new developments in the pandemic situation. This includes expanding the use of X-Rays modalities that have never been done before, such as including more mobile X-Ray units in the ICU, ER, and Isolation Chamber for Covid-19 patients. This results in an increasing number of patients that are exposed to radiation, including pregnant women. Therefore, medical physicists need to adapt to this situation regarding the safety of both patients and workers, hence quality control and assurance needed to be updated[1].

The need for mobile X-Ray also increased with clinics and hospitals in need of early screening before going into a further examination. Around 3000 Hospitals and 9000 combined of public health centers and private clinics are a huge potential market for X-Rays industries[2]. Therefore, the need for quality control and assurance will increase following the new equipment installed in the facilities. In medical and industrial environments where ionizing radiation is used to perform processes, the most important phase in the radiation protection operation is to provide the appropriate shielding materials between the radiation source and the biological tissue to prevent interaction[3]. According to Nuclear Energy Regulatory Agency (NERA), the number of Laboratories that are certified to perform conformity test and calibration on X-Ray modalities is far from sufficient to fulfill the needs of the market. There are only 43 laboratories nationwide that are eligible to do the task in contrast to thousands of facilities that already running and need to be regularly checked[4]. This leads to a decrease in the quality of the procedure itself and the output.

The regulation stated that the certificate of conformity is valid for 4 years, depending on the modality and conditions[5]. It means the test is done every 4 years, if not queued up because of the high demand. One of the parameters of the test is the beam quality test, which can be done by utilizing the half-value layer (HVL) method. It's basically substituting the output presented by the multimeter, by using the aluminum filter to reduce the initial dose to a half[6]. This experiment hopes to analyze the value of HVL that directly showed by the multimeter with the manual calculation using Al plate as a filter.

2. Materials and methods

In this experiment, a set of aluminum plates and two multimeters were used. The two multimeters, RADCAL and RAYSAFE, served as a detector that captured the dose exposed by the X-Ray machine, while the aluminum plate was used as a filter. Four different values of HVL will be presented, one is from the multimeter output, and the other three are from the manual calculation.

2.1. Aluminum plate

Aluminum is used as a benchmark and units for the half-value layer (HVL). This is because of its properties that fit very well. Al has a low atomic number, and an absorbing ability that is appropriate for X-Ray energy used for radiology. Its other properties such as easy to make, hard to be corroded, and flexibility are also part of why aluminum is the perfect choice for X-Ray filters[7]. In this experiment, we used a set of filter plates with various thicknesses from 0.25 mm to 2 mm thick 10 cm x 10 cm Al 99,5% plate.

2.2. X-Ray multimeter

2.2.1. RADCAL

RADCAL is a kV Multimeter that has a lot of configuration and selection of detectors. The one that was used for this experiment is the Accu Gold Touch Professional series, which is the top tier of the American-based diagnostic X-Ray measurement company. This includes all kinds of features that are offered like Dental Panoramic and Mammography measurement, but this time, General Purpose measurement was used. The sensor that was used is the AGMS (Accu-Gold Multi-Sensors) which is capable to detect many parameters with only one small sensor. It uses solid-state detectors which have many benefits for this type of measurement rather than other detectors. It's able to read low to high-energy X-Ray that is used for radiography[8].

2.2.2. RAYSAFE

RAYSAFE is a kV Multimeter that is more commonly used among Indonesian Laboratories than RADCAL, despite fewer options and features. Despite that, RAYSAFE can still serve many purposes, from mammography to CT-Scan. For this experiment, RAYSAFE X2 with R/F Sensor was used as the multimeter, and the sensor is also a solid-state detector, which is commonly used in many kV multimeters. The X2 system is a newer version that is faster, more robust, very easy to use, has a larger dynamic range, produces fewer errors, and stores 1000 exposures[9].

Some details that need to be considered are the threshold for dose parameters. RADCAL can read from 40 nGy – 100 Gy ±5% while RAYSAFE 1 nGy – 9999 Gy ±5%, this means RAYSAFE has higher sensitivity. However, RADCAL is much more sensitive when it comes to detecting energies, ranging from 20 – 160 kVp ±2%, while the latter can only read from 40 – 150 kVp ±2%. This can be explained since RADCAL uses AGMS, which is a multi-sensor that can be used for many modalities with only one sensor, whereas mammography energy level is only around 20 – 40 kVp, that is why RADCAL AGMS can also read a low X-Ray diagnostic energy. RAYSAFE on the other hand, with an X2 R/F sensor, only works for general-purpose radiography and Fluoroscopy. Both use medium-level energy X-Ray above 30 kVp. Despite the difference, both multimeters can perform the task very well for this experiment.

2.3. Half-value layer

Half-value layer (HVL) is commonly used as a benchmark for X-Ray beam quality. HVL itself is explained as a thickness of a material that is needed to reduce the initial dose to half of its value. The linear attenuation coefficient varies with photon energy, type of material, and physical density of the material. Since the dose is linear with intensity, the attenuation of photons is mathematically based on the following formula:

$$\frac{I}{I_0} = e^{-\mu x} \tag{1}$$

Where I_0 is the intensity of gamma-ray at zero absorber thickness, I is the intensity after passing an absorber or filter with x thickness and μ is the linear attenuation coefficient of the absorber. For HVL the equation becomes:

$$HVL = \frac{\ln(2)}{\mu} \tag{2}$$

2.4. Setup and parameter

There are a few setups and combinations for this experiment. There's a combination of the multimeters and also the placement of the filter. As planned, there will be two variations for filter placement, directly above the sensor and below the collimator. Then analyze the difference between the two variations. So, there will be a total of four sets of data from the variations of Al filter placement and multimeters. As for the direct values of HVL from the multimeters will only have two. The HVL itself has various ways to be calculated without the attenuation coefficient, the graph from the data set will then be used to make an equation to calculate the first variation of HVL. The raw data set can also be interpolated to find the second variation of HVL. Then the last variation will come from the equation that is used by the NERA to determine the value of HVL for the conformity test[5].

$$HVL = \frac{t_1 \ln\left(\frac{2D_2}{D_0}\right) - t_2 \ln\left(\frac{2D_1}{D_0}\right)}{\ln\left(\frac{D_2}{D_1}\right)} \tag{3}$$

Where,

D_0 = Dose measured without filtration; D_2 = Dose greater than ½D_0

D_1 = Dose smaller than ½D_0 t_1 = Width of filtration at D_1

t_2 = Width of filtration at D_2

Before the data is collected, the X-Ray tube is warmed up. Unfortunately, the battery pack for the generator was not at its optimum condition during our experiment. It is seen during the warm-up test that when the parameter was set to a certain value (high value), the generator immediately cut off and the system needs a reboot. According to the Radiation Protection Officer and the Head of the Radiology Department, it is still safe and usable, though it cannot be pushed to the limit. Since it is also still used for treatment, it's decided to change the parameters from 70 kVp to 50 kVp, following the instruction from the Radiation Protection Officer. The other parameter that needed to be altered is the current (mA) and time (ms), from 200 mA with 100 ms (20 mAs) to 160 mA with 50 ms (8 mAs) to avoid any cut-offs and reboots. After setting the parameter, the machine then warmed up again with the sensor in place, it was found that there was a slight error on the kV setting and output. Then it is decided to use the kVp setting at 53 to achieve the output of 50 kVp. This was also proved in previous research on HVL that showed good agreement for 59kV and 1.3 mm Al filter between measurements and simulations[6].

After the parameter is set, the data collection can begin. First, the sensor and multimeter are installed and connected to the laptop. SDD is set to 100 cm, with the collimator is set to achieve a 10 x 10 cm beam field. The beam field is aligned with the Al plate surface area to decrease scattering and unwanted exposure area, since HVL measurement needed to be performed in minimal scattering from surrounding objects and as narrow as possible to achieve good results[5,6]. After making sure the beam and sensor are well-aligned, the sensor was then exposed and the data went straight into the software.

The first setup was for the Al plate to be placed directly above the sensor. For this setup, it needed a couple of data to achieve the HVL value at a decent accuracy. First of all, we collect the data for D_0, exposed without filtration. This exposure also served as the HVL value from the multimeters. Then we add 1 mm of Al plate above the sensor, blocking the beam. The Al plate keeps on added until it reaches ± ½D_0, when closing into the value of ½D_0, the D_1; D_2; t_1; and t_2 were recorded for further calculations.
In the second setup, Al plates were put directly below the collimator, with the help of duct tape. The same step is followed, from finding the D_0 to the D_1; D_2; t_1; and t_2. All setups are done with both multimeters alternately so that it can be analyzed later. There were a lot of data output parameters from both multimeters, some data that are not relevant to this experiment can be ignored, while others such as kVp, time, dose, and HVL are important and needed to be noted. All the data is then put into Microsoft Excel to make the graph and make it easier to calculate.

3. Results and discussion

To make things easier, the combination and setups will be given a label. RADCAL (L); RAYSAFE (Y), as for the set-up, the above sensor will be given (A) for the **A**bove and (B) for the **B**elow collimator. There will be a total of six (6) data, L; Y; LA; LB; YA; YB, with L and Y both comes from the exposure of D_0. The data obtained was in a table, then turned into a graph to make it easier to be analyzed. RADCAL outputs will be discussed first and then followed by RAYSAFE. All the HVL values are in millimeters (mm).

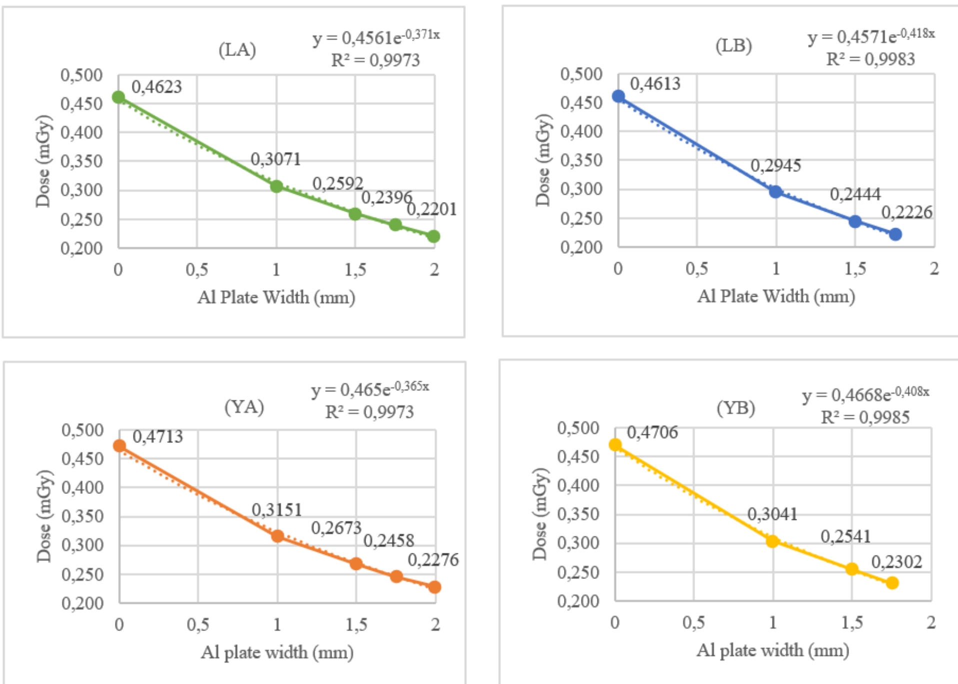

Figure 1. Dose graph for all four setups, LA; LB; YA; YB.

From the figure above, we can figure out the value of ½D_0, which leads to other data needed for the HVL Equation. The Graph Equation is also shown above, where **y** is ½D_0 and **x** is the HVL value. As for the HVL value from the multimeters is taken from the first exposure data, it's not shown on the graph, since it's a direct output from the multimeter. The interpolation HVL value can be obtained by forecasting the above data in hopes for the ½D0 value to appear using the Excel forecast formula. It can be seen that there are differences both between multimeters and setups. As for the multimeters, RAYSAFE's dose output is slightly higher than RADCAL, despite the same number of total exposures for each multimeter, which is seven. As for the setups, the notable difference can be seen in the number of exposures on each setup. The setup where the Al plate is put below the collimator has less exposure to achieve ½D_0 value, while the other setup needs one more exposure to achieve ½D_0 value.

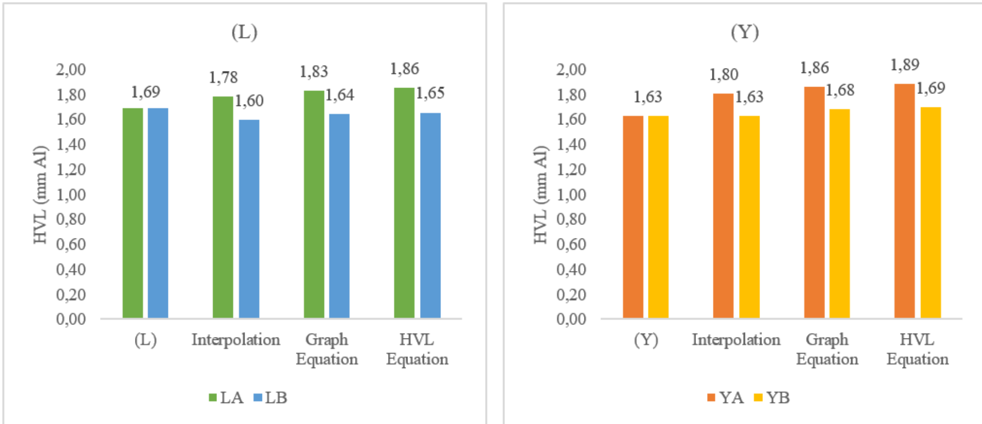

Figure 2. HVL value for RAYSAFE (Y) and RADCAL (L) in every setup.

The graph showed that there is only a slight discrepancy, while the multimeter HVL (L and Y) shows consistency between setups, the other values seem to have a slight disagreement. The deviation is analyzed by comparing the output from multimeters and other values of HVL with each setup and multimeter. For the LA and YA setups, the HVL equation value had the most deviation with 0,17 and 0,26 mm Al respectively. The least deviation for LA and YA comes from the interpolation value with 0,09 and 0,17 mm Al respectively. For the below collimator setup, HVL Equation from YB also has the highest deviation with 0,06 mm Al, while the lowest comes from interpolation with no deviation. For LB, the highest deviation comes from the interpolation value with 0,09 mm Al and the lowest comes from the HVL equation with 0,04 mm Al. The highest overall deviation comes from YA with a mean deviation of 0,22 mm Al or 13,5%. LA comes as the second highest overall deviation with a total of 0,13 mm Al or 7,7%. The least overall mean deviation comes from YB with only 0,04 mm Al or 2,5%, and LB comes second least with an overall mean deviation of 0,06 mm Al or 3,6%.

It can be seen that the closest agreement happened with the Al plate setup below the collimator with ≤ 4% for both multimeters, and also by combining three different values of HVL would give more perspective rather than just choosing one value over the other, since they are still on the same level of similarity. This also agreed with previous research that concludes filtration needs to shield the less penetrable radiation type first then proceed to shield the more penetrable type. The difference between multimeters is also in agreement both in kVp and HVL values with research involving several solid-state dosimeters with an overall deviation is less than 10%[10–13]. The slight discrepancy between the two setups might be caused by the inherent (permanent) filter that is embedded inside the tube[14, 15]. The degree of the anode also contributes slightly to the final output of the beam quality. So, when the plate is located closer to the source, the lower energy beam will be filtered, and the energy above that will pass through, while some are able to arrive at the sensor, some will lose its energy on the way[16, 17]. There are also contributions from backscatter and side scatter that happen with the other setups (Al plate above sensor) that caused the energy and dose to differ from other set up[17, 18].

4. Conclusion

It can be concluded that there is a high agreement between all methods and setup for HVL value variations and data collection, but the closest setup is when we put the Al plate closer to the source with ≤ 4% for both multimeters. As for the calculation methods, all are in a similar range with ±10%. It needs to be reminded that this experiment has no intention to replace the existing procedure for conformity and calibration test, nor the regulations regarding it. This experiment served as an optional method for testing the beam quality of the X-Ray modality that can be achieved using cheaper methods, and maybe faster. Though in the end it still needed the certified laboratory to do the test and publish the certificate, at least it can serve as a radiation protection method that includes the quality assurance and control program. Further research can be done by varying the kV and mAs parameters to analyze the HVL value and kV output. Further experiments are encouraged to analyze the HVL value between multimeter and surveymeter using Al plates filter.

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