KUBTEC® Tech Notes:

XCELL 180 half-value layer (HVL)

Introduction

The penetration of an x-ray beam into a given material depends largely on the energy of the beam. The half-value layer (HVL) is a parameter used to describe the quality of an x-ray beam. The HVL is dependent on the penetration of the beam and the inherent and additional filtration used. The HVL is defined as the amount of a given attenuator (usually aluminum for diagnostics beams and copper for therapy beams), measured in mm, that reduces the air kerma rate to one half of its original value (1). Experimentally, the HVL must be obtained in a narrow beam in order to reduce contributions from scattering. Even though the HVL yields no information regarding the amount or the energy spectrum of photons, it is common practice to describe the x-ray beam quality in terms of energy of the beam and its HVL.

In this paper, we describe the procedure used to obtain the HVL of KUBTEC's XCELL 180 irradiator x-ray source.

Definitions

1st HVL: The thickness, in mm, of a given attenuator that is needed to reduce the air kerma rate to one half of the original value (2,3).

2nd HVL: The additional thickness, in mm, of a given attenuator that is necessary to reduce the air kerma rate to one-half of the 1st HVL air kerma rate, or to one quarter of the original value.

Quarter-value layer: The thickness, in mm, of a given attenuator, that is necessary to reduce the air kerma rate to one fourth of the original value. The quarter-value layer is equal to the sum of the 1st and 2nd HVL.

Homogeneity Factor (HF): The quotient between 1st and 2nd HVL (2). It yields information on the quality of the beam. A larger HF means more beam homogeneity.

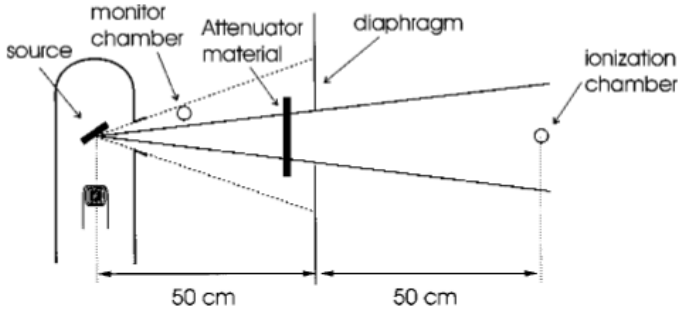
Measured Exposure Fraction: The air kerma fraction of the exposure when compared to the initial measure without attenuator.

Experiment Equipment and Materials

- XCELL 180 x-ray source, 180 kV, 990 W
- PTW farmer chamber, model TN30013, serial number 013470
- PTW Unidos Romeo electrometer, model TN10053
- Filters:
  - 0.15 mm Al,
  - 1.65 mm Al,
  - 0.15 mm Al + 0.25 mm Cu,
  - 0.15 mm Al + Thoreaus Filter (1.5 mm Al + 0.25 mm Cu + 0.75 mm Sn)
- Copper attenuators
- Lead diaphragm thick enough to attenuate X-ray beam to 0.1%.

Experimental Setup

The physical experiment setup followed the protocol published by the American Association of Physicists in Medicine, Task Group 61, entitled "Protocol for 40-300 kV x-ray beam dosimetry in radiotherapy and radiobiology", section III, subsection C "Determination of HVL." (1)



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The X-Ray source monoblock was set up to shoot x-rays vertically in a lead room. A lead diaphragm was installed at 50 cm (19.7 in) from the focal spot of the x-ray source. This lead diaphragm had an opening in the middle to allow for a beam diameter of 4 cm (1.57 in) or less at the location of the ionization chamber. This ensured a narrow beam for the purposes of this experiment. The ionization chamber was positioned in air, 50 cm (19.7 in) away from the lead diaphragm. Dosimetric and radiochromic film tests were performed to ensure that the sensitive area of the ionization chamber was accurately placed within the 4 cm diameter x-ray beam. The attenuator materials were placed just before the lead diaphragm, as indicated in Fig 1.

The beam filters were placed immediately adjacent to the exit window of the monoblock (not shown in Fig. 1), to ensure that the complete beam passed through the filter. The electrometer's corrections for temperature and air pressure were updated every hour.

Procedure

The HVL tests were performed at 180 kV, which is the maximum energy of the XCELL 180 irradiator.

1. After the source was warmed up, the initial dose was taken.
2. The initial dose measurement was divided by two to obtain the first Half Value Layer dose value, and by four to obtain the second Half Value Layer dose value.
3. A copper attenuator was placed immediately before the lead diaphragm, and the dose measurement was acquired.
4. This process (add attenuator, measure dose) was repeated until the dose was equal to or less than the second Half Value Layer dose value.
5. The complete process was repeated to find the first and second HVLs for beams with the filters indicated in the Experiment Equipment and Materials section of this paper.

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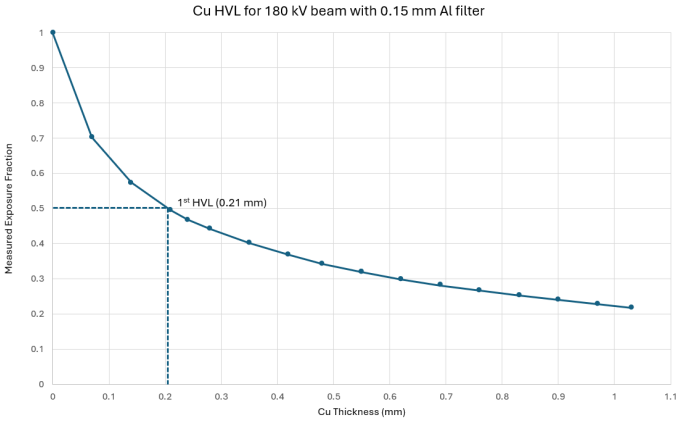
The complete process was repeated to find the first and second HVLs for beams with the filters indicated in the Experiment Equipment and Materials section of this paper.

Results

180 kV source, 0.15 mm Al Filter

Source: 180 kV
Filter: 0.15 mm Al
Attenuator material: Copper

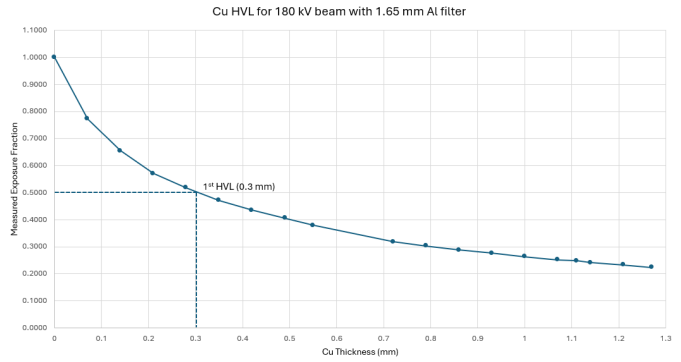
	Cu (mm)
1st HVL	0.21
2nd HVL	0.88
Quarter-value layer	1.09
Homogeneity Factor	24%



180 kV source, 0.15 mm Al Filter

Source: 180 kV
Filter: 1.65 mm Al
Attenuator material: Copper

	Cu (mm)
1st HVL	0.3
2nd HVL	0.79
Quarter-value layer	1.09
Homogeneity Factor	38%

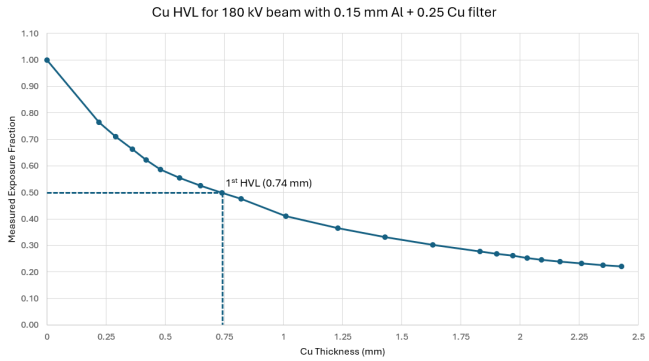


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180 kV source,
0.25 mm Cu + 0.15 mm Al Filter

Source: 180 kV
Filter: 0.25 mm Cu + 0.15 mm Al
Attenuator material: Copper

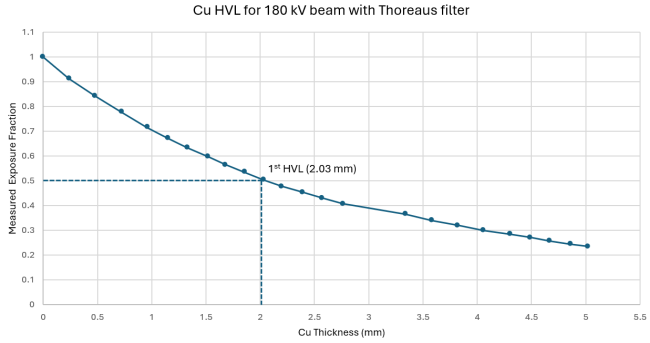
	Cu (mm)
1st HVL	0.74
2nd HVL	1.32
Quarter-value layer	2.06
Homogeneity Factor	56%



180 kV source, Thoreaus Filter

0.75 mm Sn + 0.25 mm Cu + 1.65 mm Al
Source: 180 kV
Filter: 0.75 mm Sn + 0.25 mm Cu + 1.65 mm Al
Attenuator material: Copper

	Cu (mm)
1st HVL	2.03
2nd HVL	2.83
Quarter-value layer	4.86
Homogeneity Factor	72%



Conclusions

Parameter	Filter Type: 0.15 Al	1.65 Al	0.15 Al + 0.25 Cu	Thoreaus 0.8 Sn + 0.25 Cu + 1.65 Al
1st HVL	0.21	0.3	0.74	2.03
2nd HVL	0.88	0.79	1.32	2.83
Quarter-value layer	1.09	1.09	2.06	4.86
Homogeneity Factor	24%	38%	56%	72%
Fluence with respect to 0.15 Al filter	100%	78%	47%	9%

From the table above, it can be observed that, as filtration increases, the Homogeneity Factor also increases. In irradiation, the goal of filtering the x-ray beam is to attenuate the lower energy photons, which in turn increases the mean energy of the beam. As the filters become thicker and of higher atomic number materials, the amount of lower energy photons that are attenuated increases, and the remaining photons are of a more uniform energy distribution.

It is also evident from the table that lower filtration yields a higher dose. If the x-ray beam is filtered through the 0.15 Al filter, and we determine that dose to be 100%, the same beam filtered through the Thoreaus filter will have an output that is ~9%. The 0.15 Al dose may be comprised of a wide range of energy—not all of it contributing to the expected biological effects, whereas the Thoreaus' filter dose may be more homogeneous. It is important to note, then, that a higher filtration yields a lower dose (but with better homogeneity). Irradiation performed while using thicker filters will yield better penetration and homogeneity but will require significantly longer exposure time. (4)

Bibliography

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