Electron range after titanium foil window from low energy electron accelerator

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Abstract. Currently, the low energy electron accelerator machine in Malaysian Nuclear Agency is at the commissioning stage. Various parameters are tested and studied. One of the parameters is the electron range in the air through titanium foil window. This parameter is important for the process of sample irradiation. There are two methods to determine this parameter. The first is through manual calculations and second is through Monte Carlo code simulations using PHITS. This paper describes the results of both methods and attempts to make comparisons between them.

1. Introduction
Malaysian Nuclear Agency has successfully developed a low-energy electron accelerator with the maximum energy of 250 keV and beam current output of 30 mA. For this device to work properly, it needs to go into the commissioning process to ensure the reliability of the resulting radiation dose. There are several parameters to be tested and studied and one of them is the range of the electrons in the air after passing through a titanium foil.

The electron range in the matter is the maximum penetration distance of an electron in the matter (air) measured in a straight line [5]. The unit of electron range is g/cm². The range depends on its initial energy and on the material through which it passes [3]. By knowing the density of a substance, the electron range within a material can be calculated.

In this paper, two methods have been used and shown. The first is a well-known method to estimate electron range as shown by Katz and Penhold (1952) for electron energy less than 2.5 MeV. It is a method where the electron range is manually calculated. The second method is a simulation of the electron transport using PHITS.

PHITS, which stands for Particle and Heavy Ion Transport Code System, has been developed by JAEA. It is a general purpose Monte Carlo particle transport simulation code and is used in many studies and one of them is on accelerator technology studies [4].

This study is important because by calculating the electron range in the air after the titanium foil window, the positioning of the sample for irradiation purposes can be determined. The sample for irradiation purpose will be positioned in between the range of electron in the air.
2. Methodology

2.1. Study case
For both calculation and simulation, the consideration is when an electron is accelerated in an
accelerating tube (vacuum) through a 25 µm thick titanium window before it goes out into the air
(diagram 1). The distance traveled electrons in a straight line through the air will be calculated by manual
calculation and by simulation via PHITS 3.10 for the initial electron energies of 100 keV, 150 keV, 200
keV and 250 keV.

Diagram 1. The event for calculation and simulation of electron range in air after passing through a
titanium foil.

2.2. Calculation of Electron Range Through Air After Passing a Titanium Foil
The maximum range, \( R_{\text{max}} \), of an electron at energy less than 2.5 MeV can be computed from an
empirical formula given by Katz and Penfold [2]:

\[
R_{\text{max}} \left[ \text{g/cm}^2 \right] = 0.412 E_{\beta}^{1.265 - 0.0954 \ln(E_{\beta})} 
\]

(1)

where \( E_{\beta} \) is the maximum electron energy in MeV.

The range can also be expressed as density thickness \( (\text{g/cm}^2) \) of the material given by [1], as follows:

\[
R_{\text{material}} \left[ \text{g/cm}^2 \right] = \rho_{\text{material}} \left[ \text{g/cm}^3 \right] \times t_{\text{material}} \left( \text{cm} \right)
\]

(2)

2.3. PHITS Simulation
PHITS ver. 3.10 was used for this study. In this simulation, the source in the form of a pencil-shaped
electron beam was used. A total of 100,000 particles per batch (5 batches) was simulated at 10 cm from
window inside vacuum cylinder while the outside cylinder is consisting of air. Simulation error is set to
5% and any values above this limit was ignored. Initial electron energies of 100 keV, 150 keV, 200 keV
and 250 keV were used in this simulation.
3. Results and Discussion

From the calculations, we found that the values of the electron range increases along with the electron energy. The same goes for PHITS simulations (Figure 1). This shows that the PHITS simulation results adheres to the equations provided by Katz and Penfold.

(a) Electron track with initial energy of 100 keV

(b) Electron track with initial energy of 150 keV
Figure 1: PHITS simulation results for the electron track of (a) 100 keV, (b) 150 keV, (c) 200 keV and (d) 250 keV.
Electron *track* means the value of electron fluence in any specific region. From the PHITS simulation results, it is found that the electron *track* length through the air increases with the increase of initial electron energy. The value of the electron flux ((1/cm²/source) decreases at larger electron distance in the air for each initial energy considered. This indicates that if the initial electron energy is high then the penetration distance is far. Its flux value decreases as more electrons are absorbed by air.

![Figure 2: Plot of electron ranges in air vs energy values from manual calculation and PHITS simulation](image)

From Figure 2, it is found that there is a difference in the values of electron range between manual calculation and PHITS simulation. This difference may be due to the parameters used in the calculation and simulation by PHITS. From diagram 1, the electron range can be expressed as:

\[ R_{\text{max}} = R_{\text{Ti foil}} + R_{\text{air}} \]  
\[ R_{\text{Ti foil}} = \rho_{\text{Ti foil}} \times t_{\text{Ti foil}} \]  
\[ R_{\text{air}} = \rho_{\text{air}} \times t_{\text{air}} \]

where,

- \( R_{\text{Ti foil}} \) is range of electron in Ti foil,
- \( \rho_{\text{Ti foil}} \) is density of Titanium foil,
- \( t_{\text{Ti foil}} \) is thickness of titanium foil,
- \( R_{\text{air}} \) is range of electron in air,
- \( \rho_{\text{air}} \) is density of air and,
- \( t_{\text{air}} \) is thickness of air.

Hence, the actual thickness (distance), \( t_{\text{air}} \) electron in air can be computed:

\[ t_{\text{air}} = \frac{R_{\text{max}} - R_{\text{Ti foil}}}{\rho_{\text{air}}} \]
From equations (3) to (6), the linear electron distance ($t_{\text{air}}$) in the air after the titanium window can be estimated for the initial electron energy values of 100 keV, 150 keV, 200 keV and 250 keV. Similarly, in the PHITS simulation, the electron distances in the air can be obtained by taking a flux value of less than 0.05 (tolerance error). From these values (Fig. 3), it is possible to determine the optimal position of the sample for the purpose of irradiation for specific electron energy. The sample will be placed in between the electron range. Exceeding the electron range value means the absence of electron.

![Plot of the electron distance in the air vs energy after titanium window from manual calculation and simulation of PHITS.](image)

**Figure 3:** Plot of the electron distance in the air vs energy after titanium window from manual calculation and simulation of PHITS.

4. **Conclusions**
In comparison between the manual calculations and PHITS simulations, the patterns as shown in Figure 3 are similar despite the differences in values. This indicates that the PHITS simulation results is acceptable.

5. **References**
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