Thickmess measurement using alpha spectroscopy and SRIM

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Abstract.
Thickness of a material can be calculated by measuring energy loss through the matter if the stopping power of the material is well known. This method is widely used to measure energy degrader, backing and target thickness for nuclear reaction experiments. However, the ions continuously lose their energy as they move through the matter, and also stopping power changes because of its energy dependent nature. For this reason, when calculating the thickness, one must take into account this effect, especially for a thick material. ThiMeT code takes into account stopping power changes through matter and calculates the accurate thickness by using SRIM. ThiMeT code also can be used for the determination of the required thickness for energy degraders. An experimental method for thickness measurement and calculation with ThiMeT code will be presented.

1. Introduction
The thin films and self-supported foils are used as energy degraders, backing and targets for the nuclear reactions. The thickness of the energy degraders and targets play important role for the nuclear physics experiments. For example, the energy degraders are needed for light ions to obtain lower energies quickly or to obtain energies which cannot be produced by accelerators [1–4]. The thickness and homogeneity information of the targets are also crucial for the reaction cross section measurement.

Thickness of a material can be calculated by measuring energy loss through matter if the stopping power of the material is well known [5]. The method is very simple and it is based on measurement of the energy loss of ions (charged particles) through the matter. This method is widely used to measure energy degrader, backing and target thicknesses for nuclear reaction experiments [1, 2, 6–8]. The energy loss of a charged particle after it traverses a material of thickness $t$ can be calculated by

$$\Delta E = \int_0^t \frac{dE}{dx} dx$$ (1)

Here, it is assumed that the particle range is greater than the material thickness ($R > t$) and $dE/dx$ is the total stopping power. If $t \ll R$, one may take the stopping power as a constant, and equation (1) is turned into,

$$\Delta E = \left( \frac{dE}{dx} \right)_{E_0} t$$ (2)
where \( (dE/dx)_{E_0} \) is the total stopping power for the initial energy of the particle. According to equation (2), if the energy loss \( \Delta E \) measured and the total stopping power is well known, thickness of material can be easily calculated [5, 9]. But, if the thickness of material is a considerable fraction of the range, stopping power cannot be considered to be a constant because the ions continuously loose their energy as they move through the matter, and also the stopping power changes with the energy (see Figure 1). In this case, in order to calculate an accurate thickness, one must take into account this effect, especially for a thick material. ThiMeT code [10] takes into account energy dependency of the stopping power, and it calculates the accurate thickness by using SRIM stopping power values [11–13].

2. ThiMeT Code
ThiMeT is a code that is a thickness calculation tool for SRIM [10]. SRIM is a group of programs that calculates stopping power and a range of ions into matter using a quantum mechanical treatment of ion-atom collisions [11–13]. SRIM code is based on theoretical formulations and semi-empirical models. There are lots of programs and tables for stopping power values, but for most cases, the SRIM is the best to describe stopping power for all ions at all energies in all targets [18]. Therefore, ThiMeT code uses the SRIM stopping power values. The reliability of the stopping power programs and the tables have been investigated in references [14–18] and references therein.

![Figure 1](image-url)

**Figure 1.** Stopping power changes through the Aluminum energy degrader for 5486 keV alphas emitted from \(^{241}\)Am. Stopping power values were obtained from SRIM-2013 [11]. Upper x-axis shows the alpha energy and lower x-axis shows the energy loss of the alphas. The thickness of the foil is 16.055 \( \mu \)m and indicated with shaded region in the plot. Right y-axis shows the stopping power difference in percent relative to the value at the incident energy.
ThiMeT code divides the total energy loss into segments, and it calculates the thickness of each segment using the stopping power value at the incident energy of the segment obtained from SRIM. After the first segment, it uses exit energy of the first segment as the incident energy of next segment, and so on. After the last segment, in order to find total thickness, sum of the calculated thicknesses of all segments are taken. Note that ThiMeT code actually uses SR Module in the SRIM, and the nuclear stopping powers of SR Module are slightly different from those in the full tables since these are improved values which will later be incorporated into SRIM [11].

ThiMeT code also can be used for the determination of the required thickness of energy degraders for the nuclear reaction experiments. This is often used for light ions, such as protons, to obtain lower energies quickly [1–4]. Because of the SRIM stopping power for light ions well described above 1 MeV, the accuracy of the calculation is also good. For example, stopping power for proton ions on Al above 1 MeV, the systematic difference between SRIM and experiment is 0.5%, and random error which contains some information about the experimental uncertainty is 0.7% [15].

### 3. Results and Conclusion

In order to determine the required thickness of a energy degrader, TRIM simulation can also be used according to the given method in the TRIM help menu and the user manual. This method can be summarized as follows;

1. estimate the thickness using mean stopping power values of incident and exit energy,
2. enter this thickness into TRIM and run it,
3. calculate mean transmission energy from the “Transmit.txt” file of the TRIM,
4. if the mean transmission energy equals desired exit energy, this energy corresponds to the required thickness,
5. but if the mean transmission energy dose not equal desired energy, change the thickness entered into TRIM and continue the steps from 2 through 5, and repeat this steps until the mean transmission energy gets a value as close as the desired exit energy.

This methods can be also used for thickness calculation of a material by measuring the energy loss with alpha spectroscopy. Table 1 shows the thickness results of the ThiMeT code and TRIM

| Ions | Material | Incident Energy (keV) | Exit Energy (keV) | TRIM Thickness (μm) | Calc. Thickness (μm) | Calc. Time (s) | Diff. (%) |
|------|----------|-----------------------|-------------------|--------------------|----------------------|----------------|----------|
| H    | Be       | 100000                | 52419             | 35000              | 7 m 34 s             | 34986.5        | 7 s      | 0.04     |
| H    | C        | 100000                | 24890             | 35000              | 14 m 10 s            | 35034.5        | 12 s     | 0.1      |
| H    | Al       | 100000                | 18644             | 35000              | 15 m 37 s            | 35050.4        | 13 s     | 0.14     |
| He   | Be       | 100000                | 17213             | 4000               | 21 m 21 s            | 3998.221       | 25 s     | 0.04     |
| He   | C        | 100000                | 18105             | 3000               | 29 m 16 s            | 2998.922       | 28 s     | 0.04     |
| He   | Al       | 100000                | 16866             | 3000               | 36 m 10 s            | 3000.003       | 25 s     | ≈0       |
| He   | Al       | 100000                | 8000              | 17.950             | 54 s                 | 17.899         | 1 s      | 0.28     |
| He   | Al       | 5486                  | 2486              | 16.125             | 1 m 34 s             | 16.055         | 1 s      | 0.44     |
| He   | Al       | 3183                  | 1184              | 7.86               | 47 s                 | 7.82           | 1 s      | 0.51     |
simulation. The results of ThiMeT code calculation is in agreement with TRIM simulation. But the calculation of the thickness with TRIM simulation takes much longer time, even if, for fastest calculation, “No graphical” and “No auto save” modes are set for TRIM and incident ion numbers are adjusted to 10000. In Table 1, calculation times of the thickness using both TRIM and ThiMeT codes are given, where the TRIM code was run just once with only one input value. For the precise determination of the thickness with TRIM, the TRIM simulation needs to be run more times to obtain desired exit energy. Therefore, determination of the thickness using this iteration method takes much longer time.

The main uncertainties of the thickness calculation depend on the uncertainty of the energy loss measurement and the uncertainty of the stopping power values of SRIM. Because, the energy calibration of the particle detector is crucial for the determination of the energy loss, one should check energy calibration of detector with a pulser and calibrated mix alpha source. Note that the SRIM stopping power and experimental one are not in a good agreement for all ions and targets at all energies. In order to estimate uncertainty of the thickness measurement, one must check the uncertainties of the stopping power values at the energy range of interest from the SRIM web site [11].

ThiMeT code is very useful tool for the calculation of thicknesses and the determination of the required thickness for energy degraders. ThiMeT code calculation is very quick and easy compared to the TRIM calculation. This is the first version of the ThiMeT code. The energy straggling and the uncertainty estimation for thickness calculation will be implemented to the forthcoming version of the ThiMeT code.

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