Determination of an Effective Linear Attenuation Coefficient without a Collimator or Chemical Composition

Jong In Byun, Ju Yong Yun

Korea Institute of Nuclear Safety

62 Gwahak-ro, Yuseong, Daejeon, Korea

1. Introduction

Background and purpose

❖ In gamma spectrometry for voluminous environmental samples, the self-absorption effects can lead underestimation or overestimation of the radioactivity, especially for the samples emitting low energy gamma rays. For this reason, the correction for the effects should be performed for more accurate analysis. One of the most important factors for the correction is a linear attenuation coefficient of the samples.

❖ The linear attenuation coefficient can be determined using the ratio (I_m/I_0) of transmitted and incident gamma ray intensities. If there is information for the chemical compositions of the samples, the linear attenuation coefficient can be calculated using the nuclear data. It can be also determined experimentally using a beam collimator system or analytical method. However, those methods may be time and cost consuming. This study was conducted to find the simple and effective method to determine the linear attenuation coefficient for the environmental samples with complicated matrix.

2. Method

Theoretical approach

❖ Mathematical approach of the correlation between a linear attenuation coefficient and I_m/I_0

$$\frac{I_m}{I_0} = \left(\int_0^{\theta_1} e^{-\mu_m M(\theta)}\left(1 - e^{-\mu_{E\_Ge} G(\theta)}\right) d\theta + \int_{\theta_1}^{\theta_2} e^{-\mu_m M(\theta)}\left(1 - e^{-\mu_{E\_Ge} G(\theta)}\right) d\theta\right) / \left(\int_0^{\theta_1} \left(1 - e^{-\mu_{E_{Ge}} G(\theta)}\right) d\theta + \int_{\theta_1}^{\theta_2} \left(1 - e^{-\mu_{E\_Ge} G(\theta)}\right) d\theta\right)$$

$$\mu_m = \mu_{ph.} + \mu_{comp.} + \mu_{Pair.}$$

$$\mu_{E\_Ge} = \mu_{ph.} + \alpha\mu_{comp.} + \beta\mu_{Pair.}$$

$$M(\theta) = \frac{t_m}{cos\theta}$$

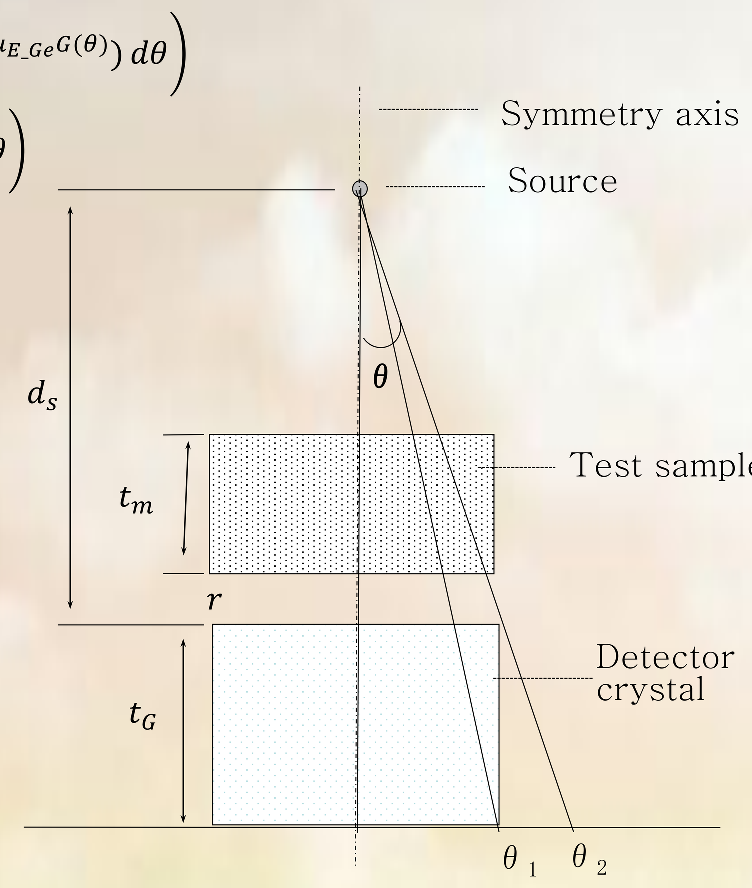
$$G(\theta) = \frac{t_G}{cos\theta}(0 < \theta < \theta_1),\ G(\theta) = \frac{r - d_s\,tan\theta}{sin\theta}(\theta_1 < \theta < \theta_2)$$

$$\boldsymbol{\theta_1 = arctan(\frac{r}{d_s + t_G})}$$

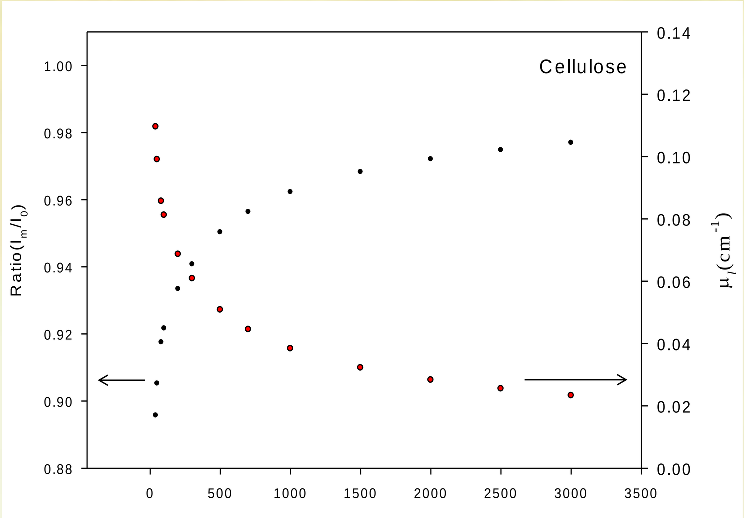
$$\boldsymbol{\theta_2 = arctan(\frac{r}{d_s})}$$

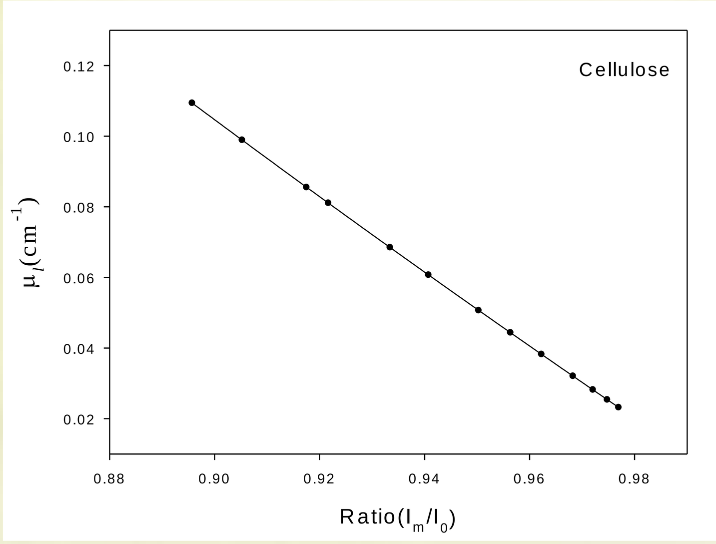
The correlation can be assumed using μ_{Ge} instead of μ_{E_Ge} where,

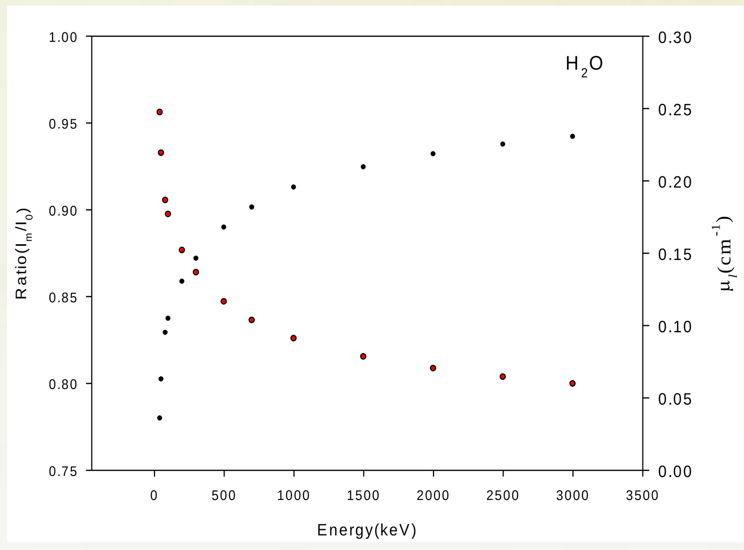
$$\boldsymbol{\mu_{Ge} = \mu_{ph.} + \mu_{comp.} + \mu_{Pair.}}$$

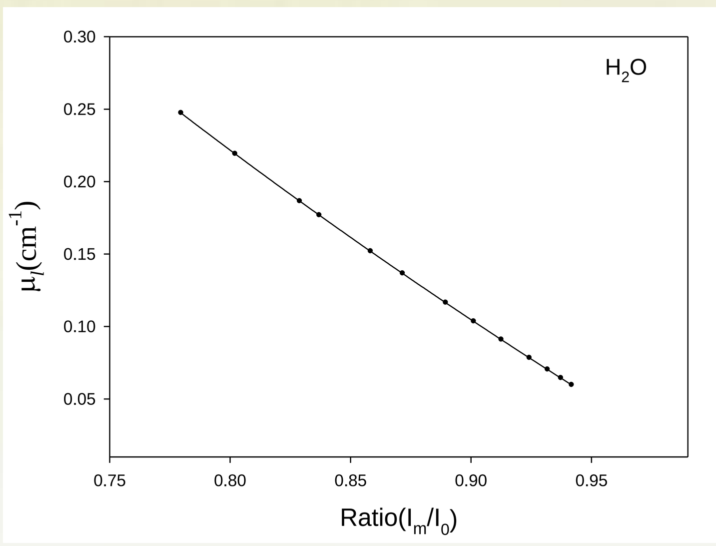


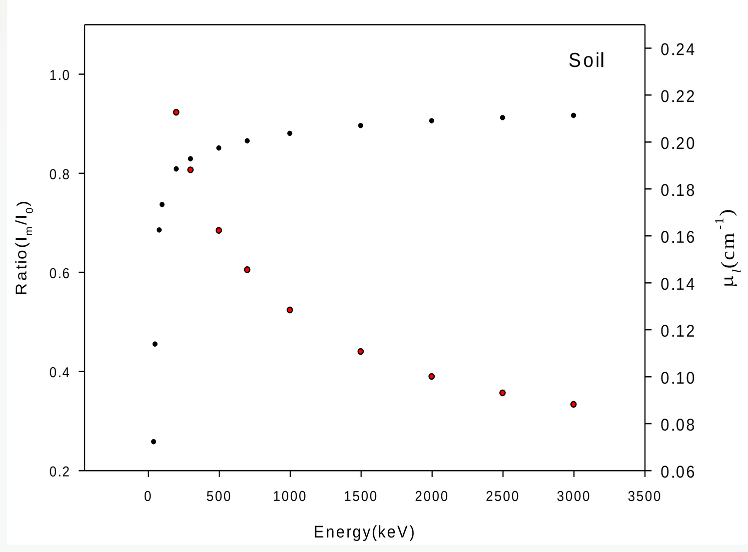
Schematic diagram of whole geometry

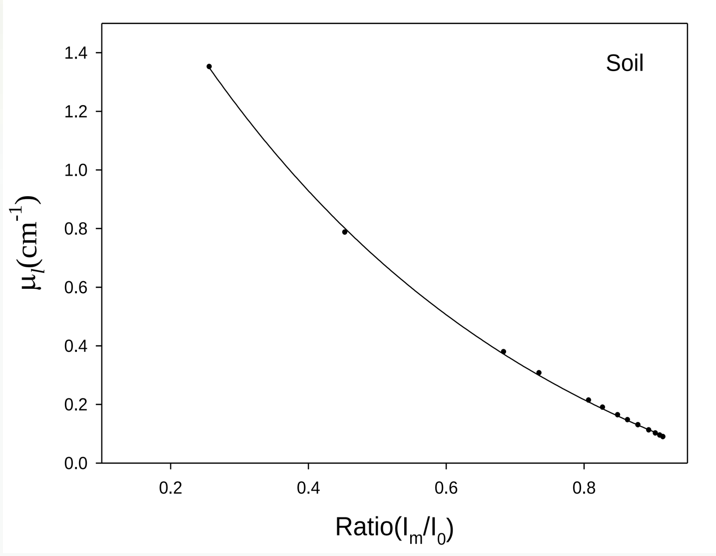


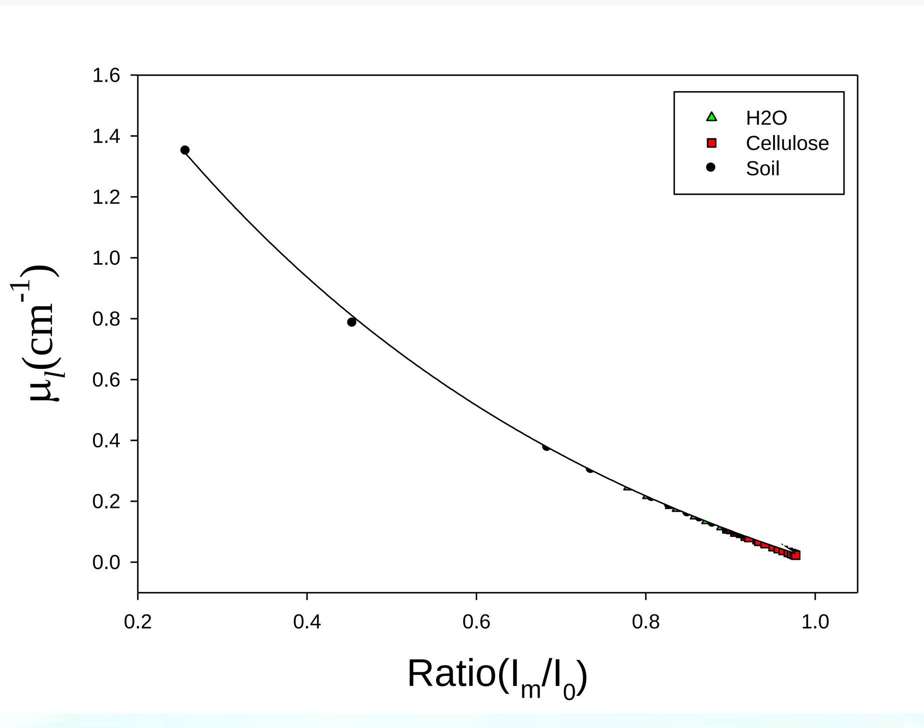






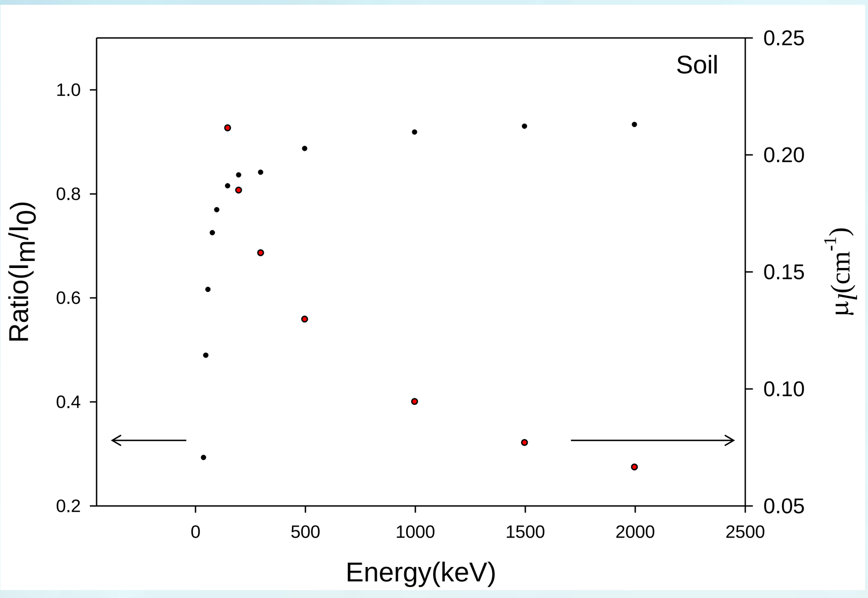


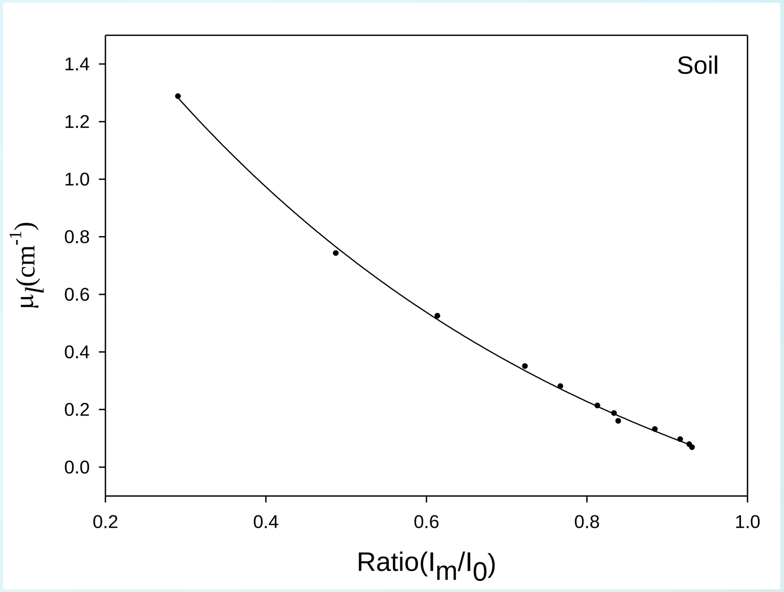




The ratio vs. linear attenuation coefficients by mathematical modeling :

- d_s : 20 cm
- t_m : 1 cm
- t_G : 3 cm
- r : 4 cm



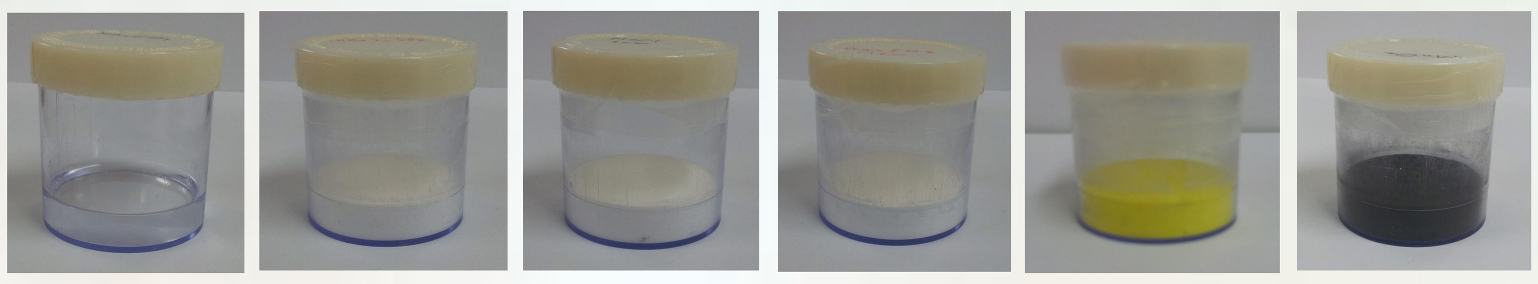


The ratio vs. linear attenuation coefficients by the MCNP modeling :

- d_s : 20 cm, t_m : 1 cm, t_G : 3 cm, r : 4 cm

Materials

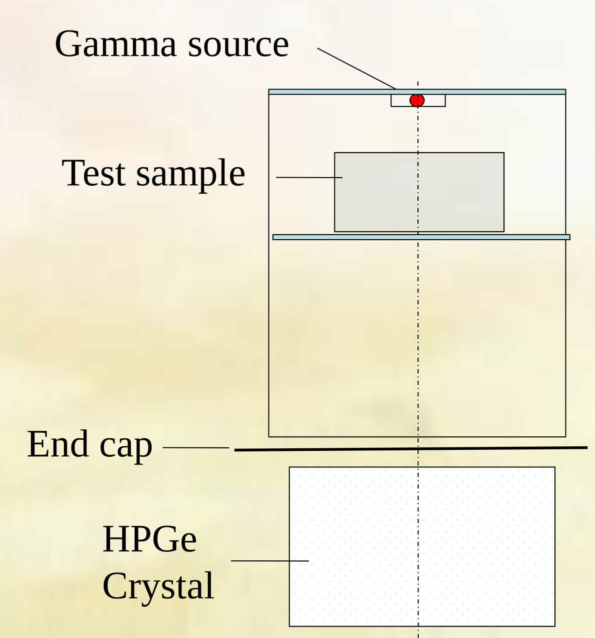
❖ Test samples(density) used in this study



H_2O	$(NH_4)_2SO_4$	NaCl	Na_2CO_3	K_2CrO_4	MnO_2
(1 g/cm^3)	(1.16 g/cm^3)	(1.43 g/cm^3)	(1.45 g/cm^3)	(1.84 g/cm^3)	(2.77 g/cm^3)

❖ Gamma ray emitting radionuclides used in this study : ^{241}Am, ^{60}Co, ^{137}Cs, ^{152}Eu

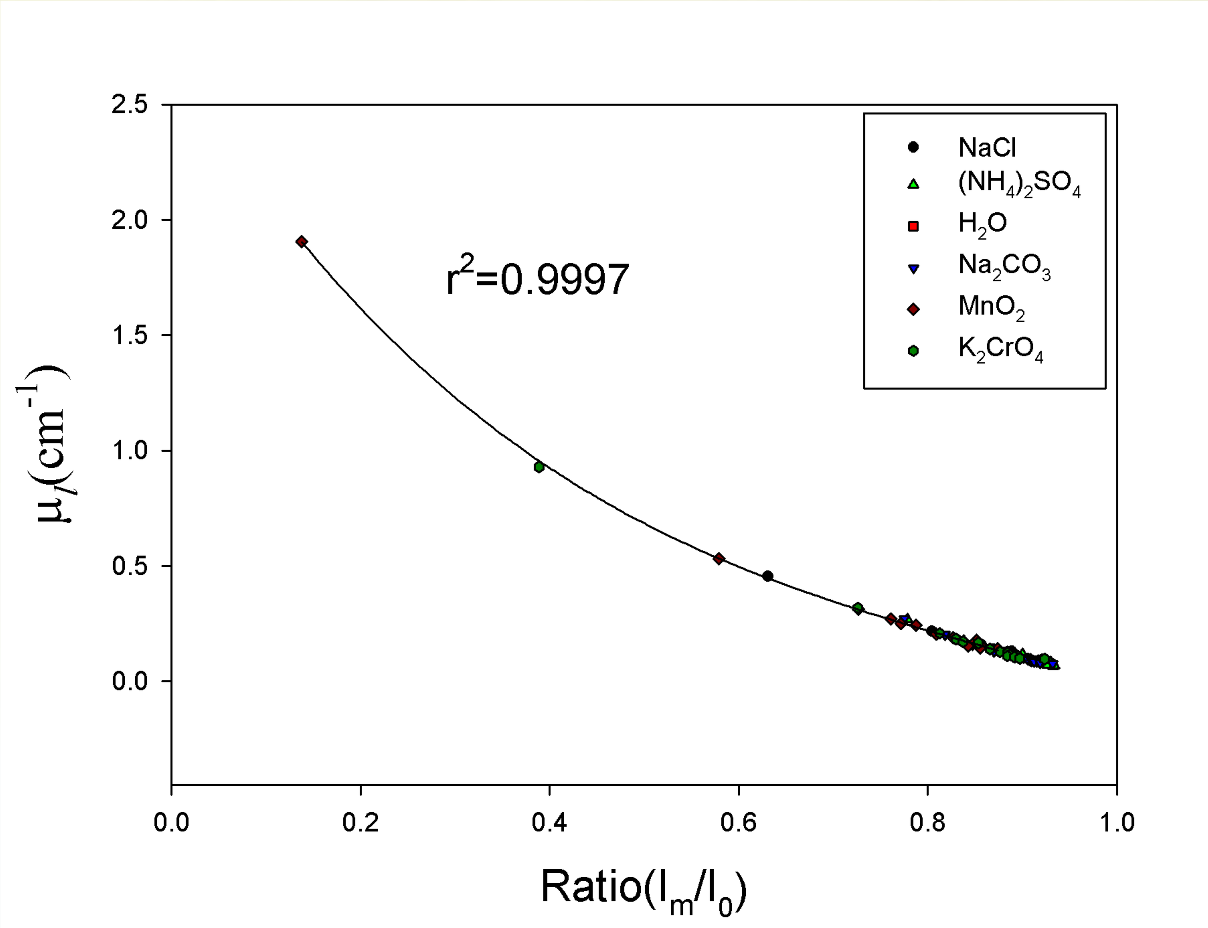
Measurement



Schematic diagram of whole geometry for the measurement

BEGe(Broad Energy Germanium, relative efficiency : 38%) detector system with the test sample

3. Results



The ratio(I_m/I_0) vs. linear attenuation coefficients with H_2O, $(NH_4)_2SO_4$, NaCl, Na_2CO_3, K_2CrO_4 and, MnO_2 ; μ_l was calculated using by XCOM

❖ $\mu_l = y_0 + aR(E) + bR(E)^2 + cR(E)^3 + dR(E)^4 + eR(E)^5$

, where $R(E) = I_m/I_0$

4. Conclusion

❖ In this study, a new semi-empirical method to calculate linear attenuation coefficients without collimator or chemical composition was fully developed

❖ This method can be useful for self-attenuation correction in gamma spectrometry for the environmental radioactivity analysis of unknown chemical composition.