Study on Material Discrimination by Atomic Number Using Dual Energy γ-Rays

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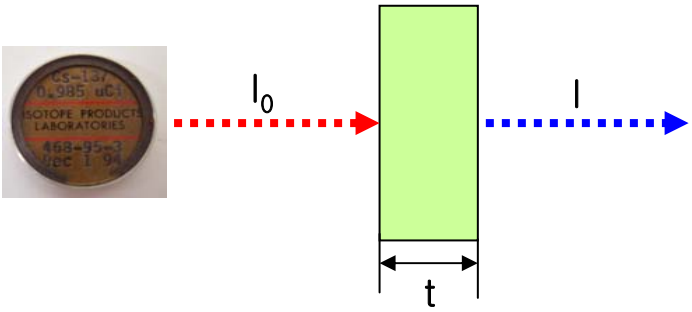
Abstract

The aim of this study is to demonstrate the practical value of radioscopic differentiation materials. The proposed method for achieving singling out and identifying four basic groups of materials according to an atomic number is complex. Atomic numbers are identified using high- and low-energy profiles obtained through the irradiation of materials. The experiment is done using gamma-ray beams with 1.25 MeV/0.662 MeV dual energies and by using NaI(Tl) scintillation detector. In addition to simulation under the same condition for the experiment, the MCNP simulation is done using bremsstrahlung X-rays from 9 MeV/4 MeV dual electron beam.

Discrimination Method



$$I = I_0\, e^{-\mu t}$$

$$\mu\, t = \ln (I_0 / I)$$

$$\downarrow$$

$$\mu\, t = \mu'\, t'$$

Discrimination is not possible !

t : thickness of material [cm]

μ : total linear attenuation coefficient [cm^{-1}]

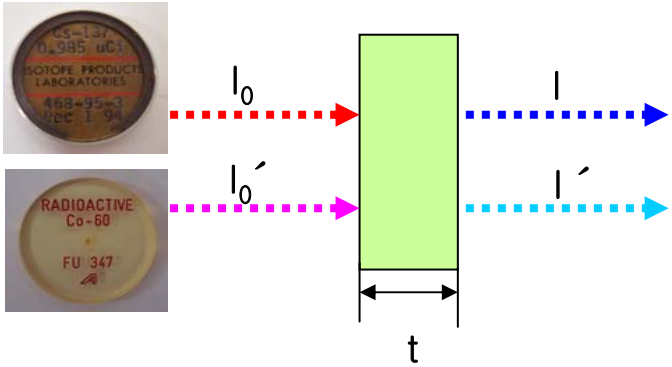
$$\mu = \tau + \sigma + \kappa$$

τ : contribution of photoelectric effect

σ : contribution of compton effect

κ : contribution of pair production

Total Attenuation = $f\,(Z_m,\ \rho_m,\ t_m,\ E_{\gamma\text{-ray}})$

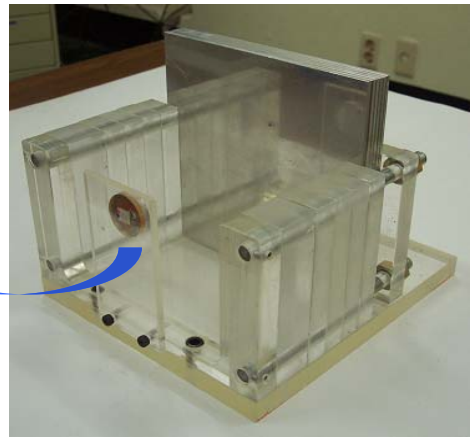


$$I = I_0\, e^{-\mu t}$$

$$I' = I_0'\, e^{-\mu' t}$$

$$\Rightarrow \frac{\mu}{\mu'} = \frac{\ln (I_0 / I)}{\ln (I_0'/I')} = R\,(E_1,\ E_2,\ t,\ Z)$$

Experimental Setup



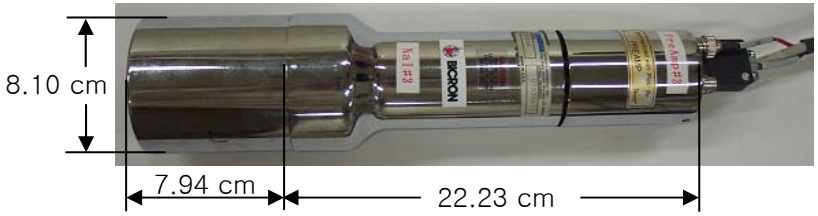
Gamma-ray Source

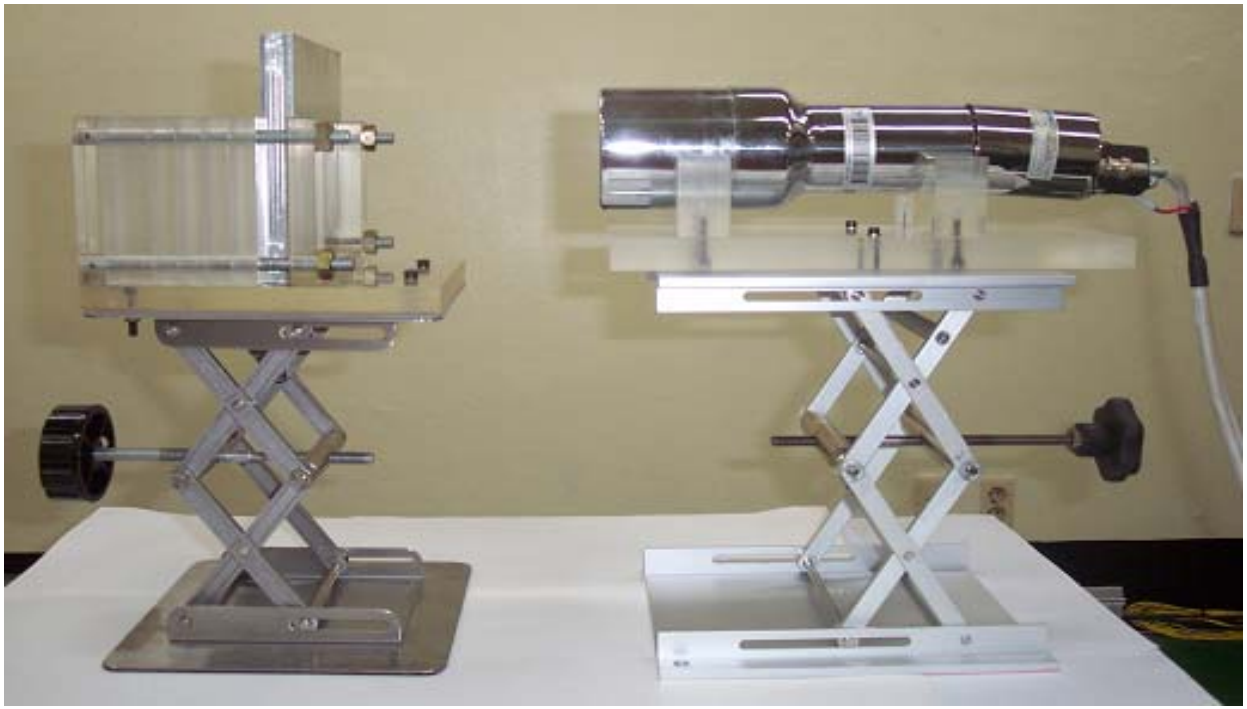
Nuclide	Activity	Photon energy(keV)
Cs-137	36.445 kBq (Dec.1.1994)	662 (85%)
Co-60	34.2 kBq (Dec.1.1997)	1173.2(99.9%) 1332.5(99.9%)

NaI(Tl) Scintillation Detector

Model	Crystal Size mm (in.)	Resolution*
802-3×3	76×76(3×3)	7.5%

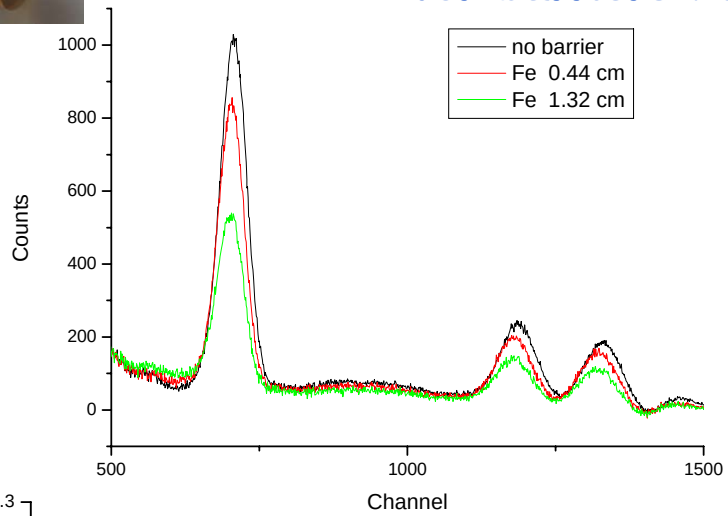
*Resolution is specified at the 662 keV peak of ^{137}Cs.





Ratio of Attenuation Coefficient, $\frac{\mu_{Cs\text{-}137}}{\mu_{Co\text{-}60}}$

for barriers : Polyethylene, Al, Fe, and Pb

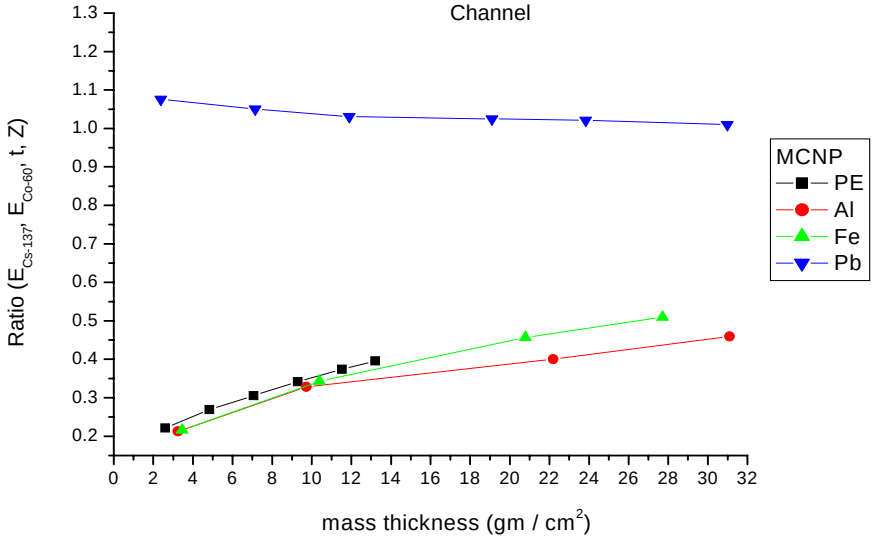


I_0 : Area of channel 615~1000 of "no barrier"

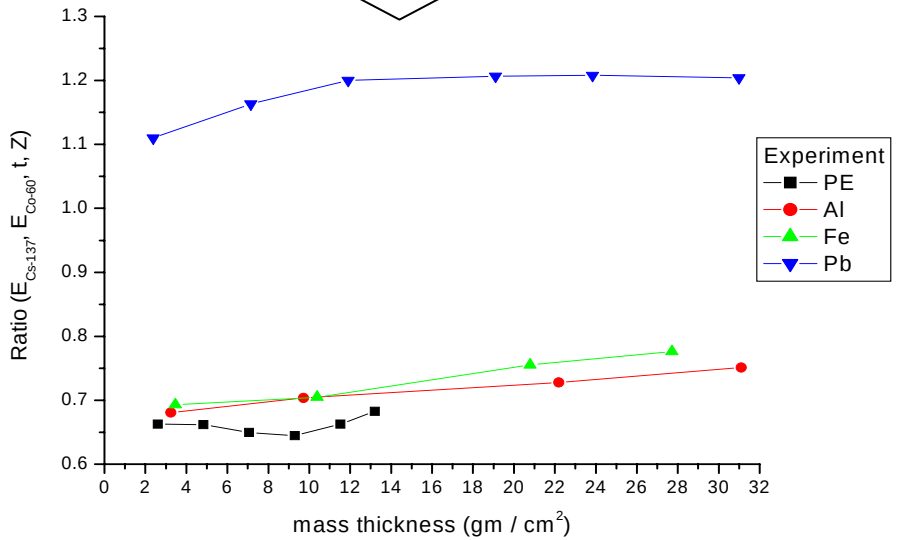
I : Area of channel 615~1000 of each barrier

I_0' : Area of channel 1001~1500 of "no barrier"

I' : Area of channel 1001~1500 of each barrier



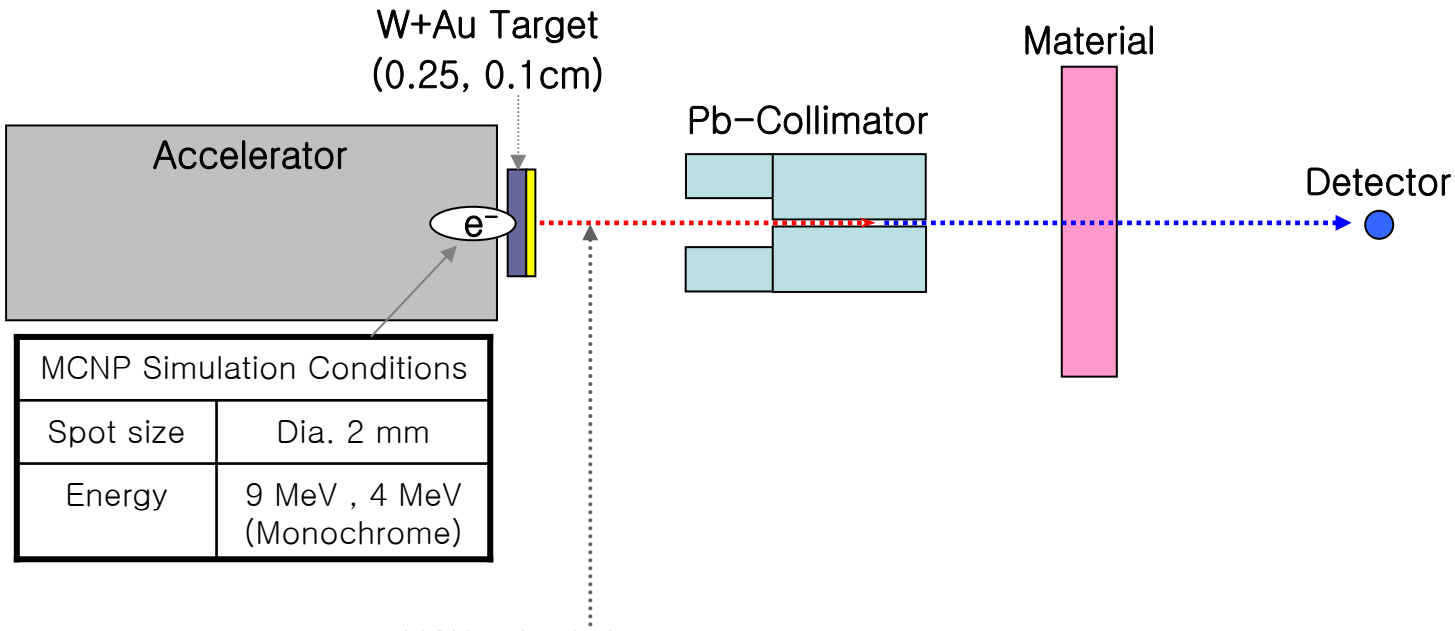
compare



MCNP simulation for monochromatic beam geometry

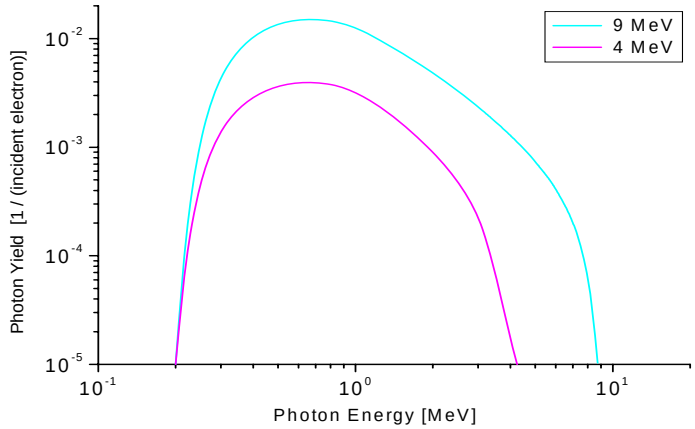
Experimental data using dual source

Simulation for Dual Energy Using 9 / 4 MeV X-ray

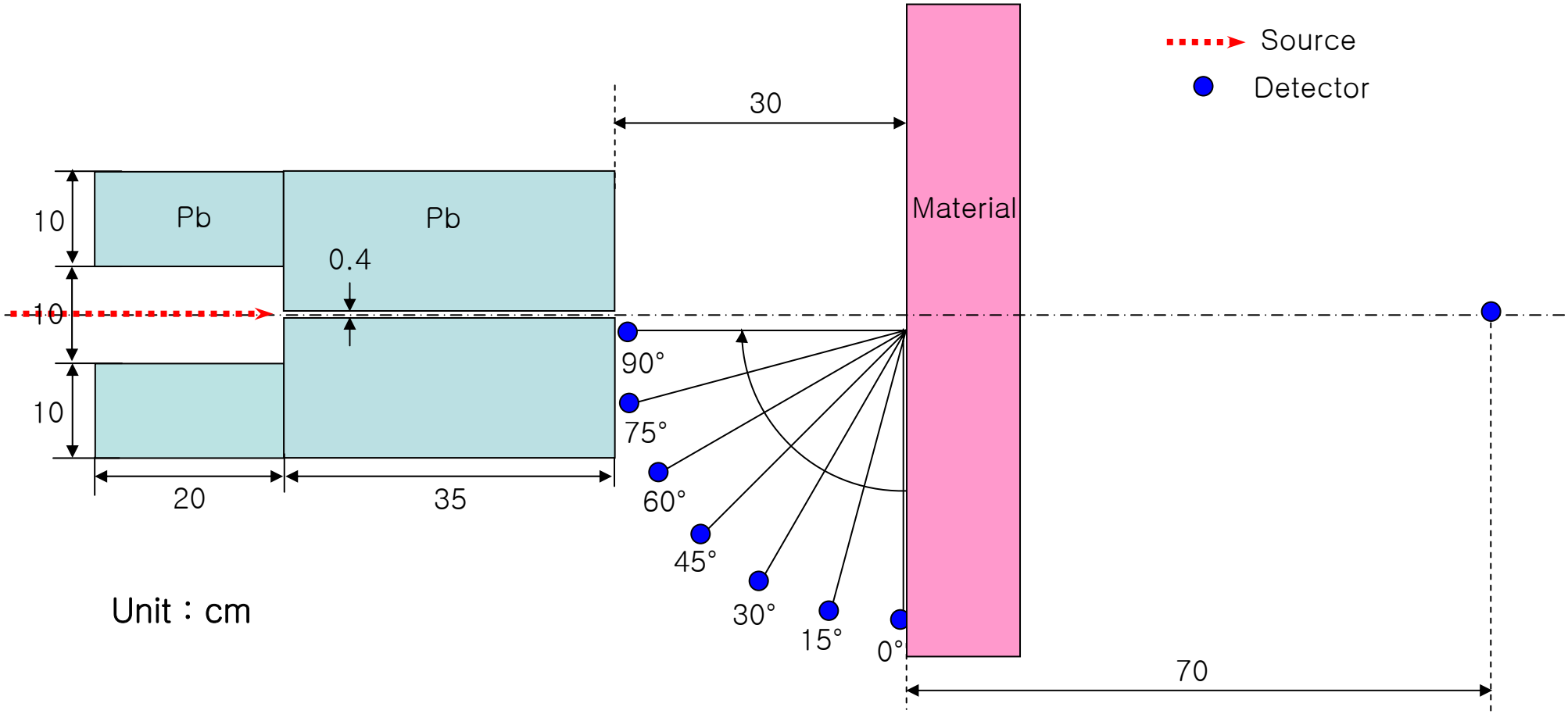


MCNP Simulation Conditions	
Spot size	Dia. 2 mm
Energy	9 MeV , 4 MeV (Monochrome)

Result of *MCNP simulation* of Bremsstrahlung Spectrum after electron beam passes through target

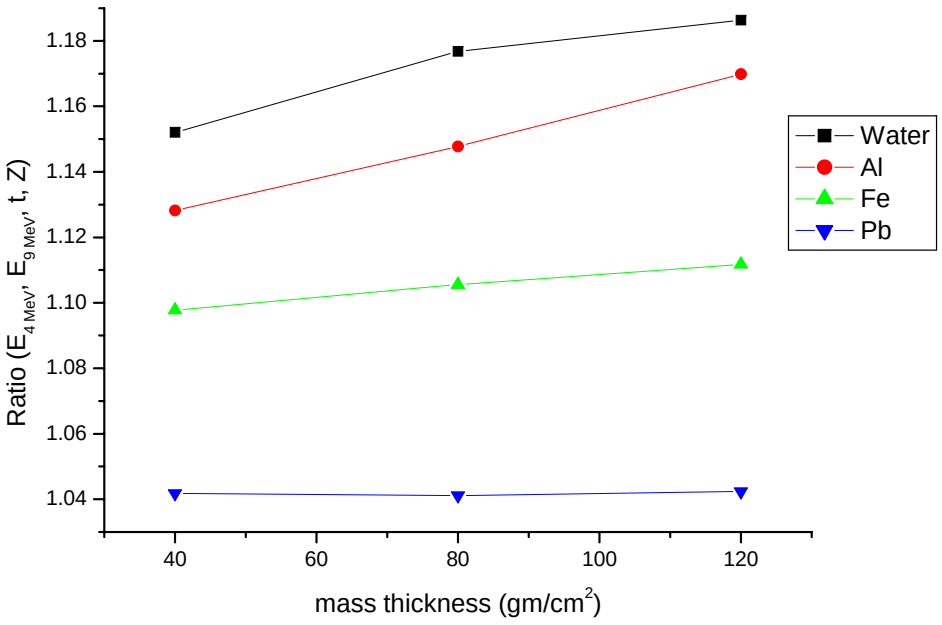


Simulation of Dual Energy Method & Back Scattering

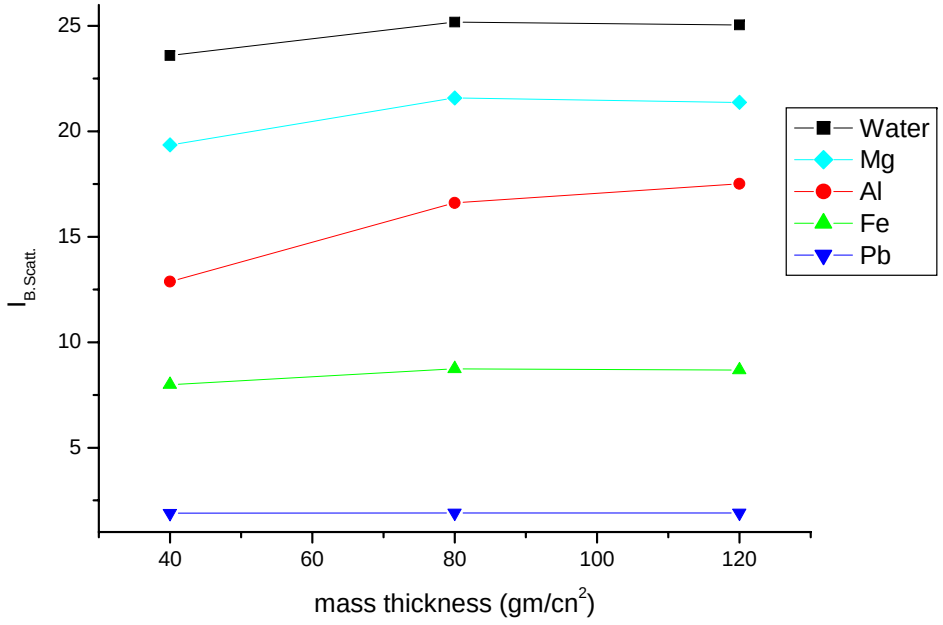


Results of Dual Energy Method & Back Scattering

Dual Energy Method



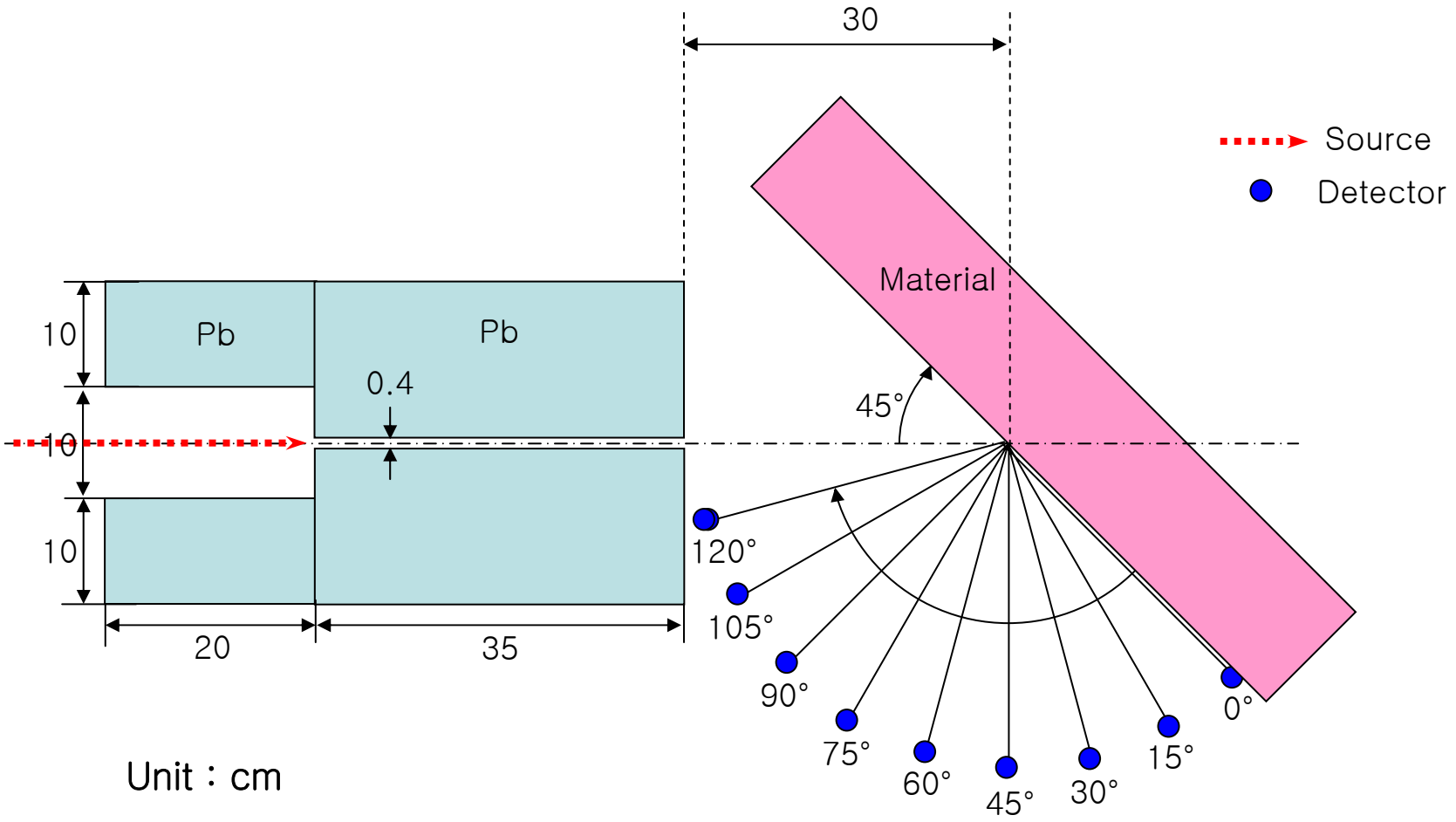
Back Scattering Method



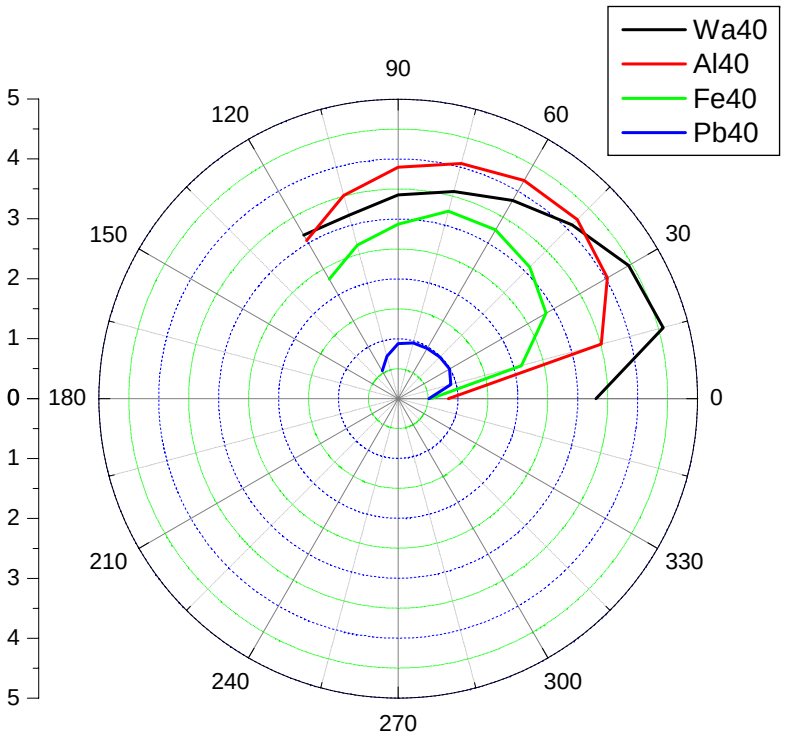
- More effective for the discrimination of materials compared to the Single Energy Method
- Especially effective for the discrimination of Low Z materials

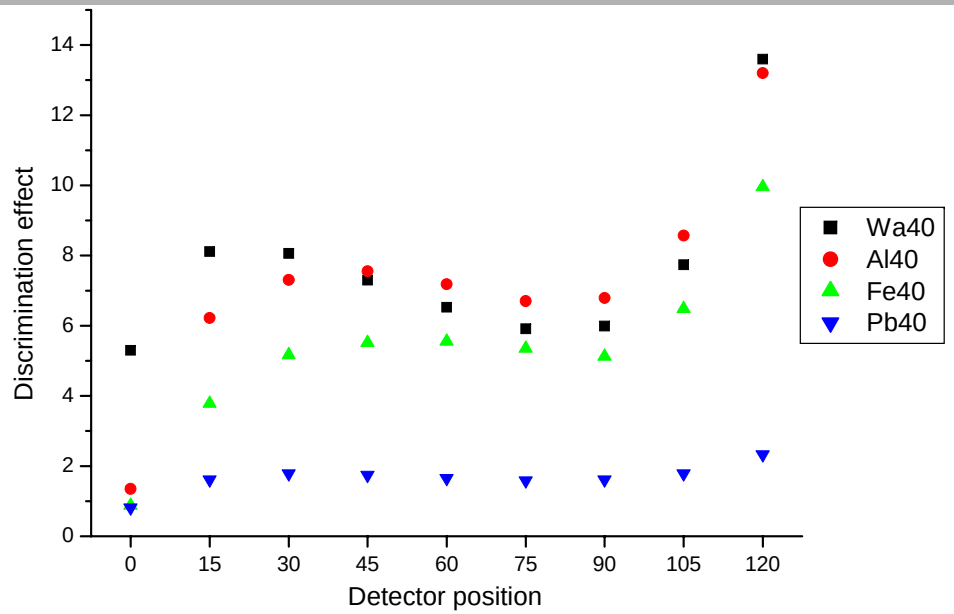
Combine Dual Energy Method & Back Scattering Method

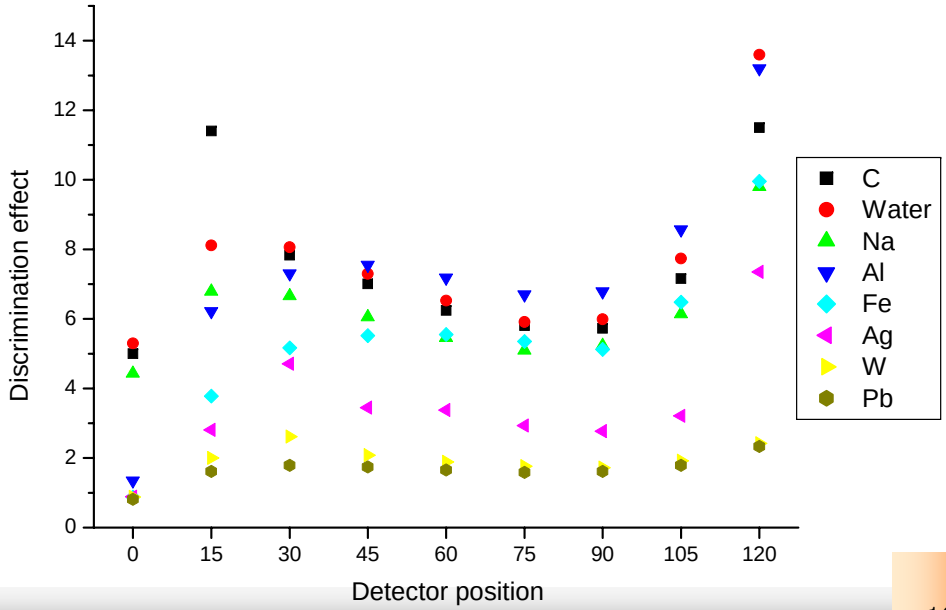
Geometry for Polar Plot of Back Scattering Effect



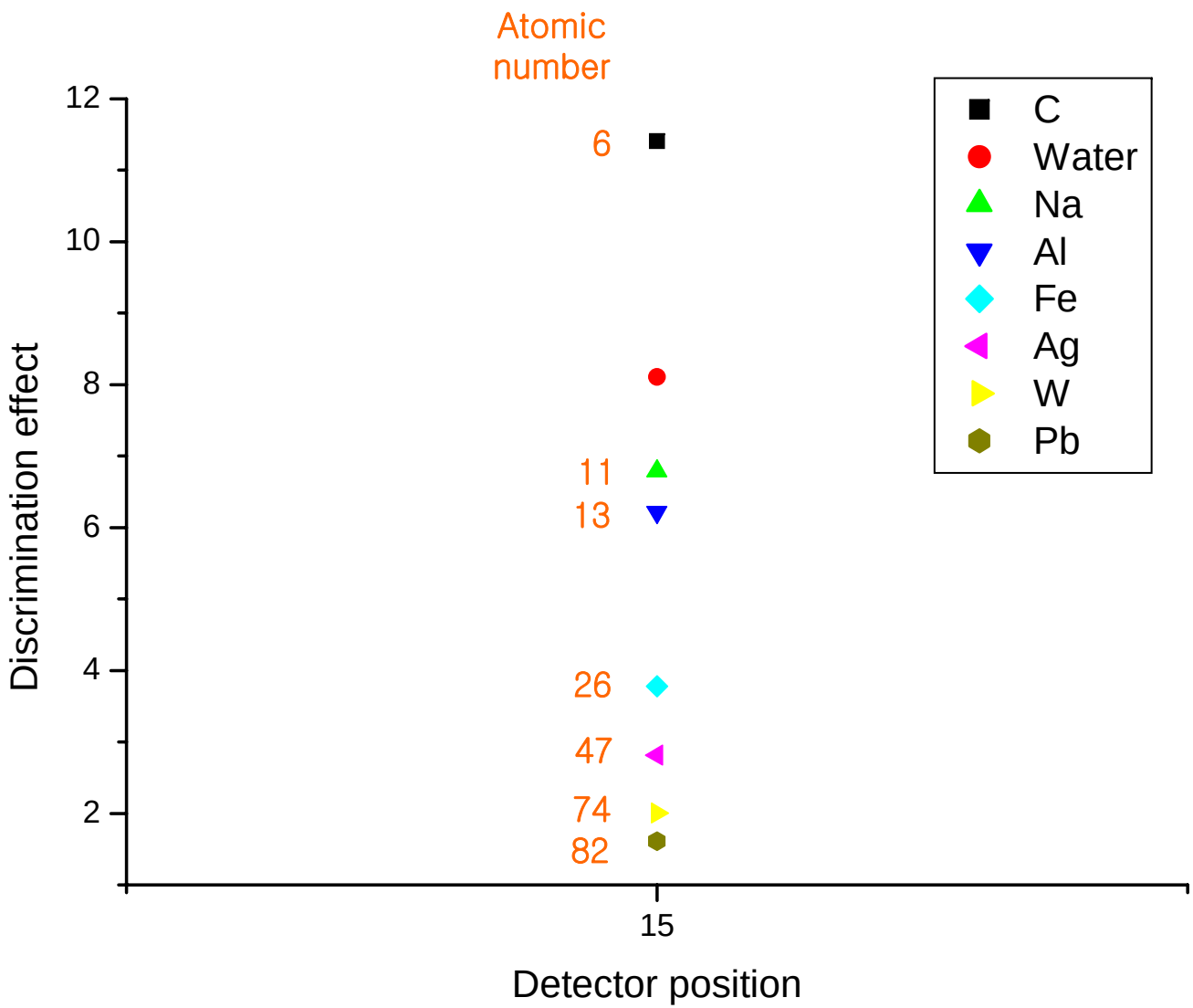
Polar Plot of Discrimination Effect of Back Scattering







Discrimination Effect of Back Scattering



Conclusion

- The aim of this research is to demonstrate the practical value of radioscopic differentiation materials.
- We have measured with the Dual Energy (Cs-137 : 0.662 MeV, Co-60 : 1.173, 1.332 MeV) to estimate the ratio of attenuation coefficients for the materials.
- The measured data in this study are in good agreement with the MCNP simulation.
- We have extended the energy level to 9 MeV / 4 MeV Bremsstrahlung in order to discover the optimal energy for Dual Energy Method.
- The Dual Energy Method with 9 MeV/ 4 MeV is more effective for the discrimination of materials according to their atomic number compared to the Single Energy Method.
- Back Scattering Method is especially effective for the discrimination of low Z material.
- It is more effective for the discrimination of materials to combine the Dual Energy Method and Back Scattering Method.