Spectral Filtering for Improving Quality of Material Discrimination Using Dual Energy X-rays

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POSTECH, [1]PAL

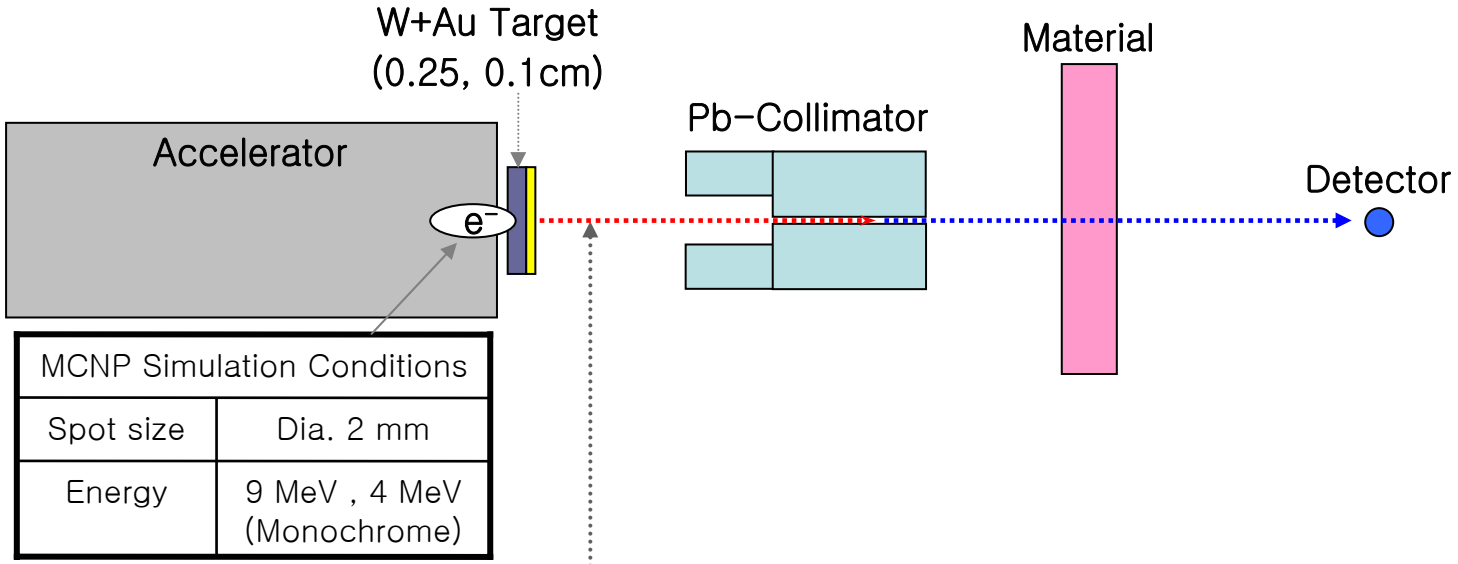
Abstract

The well-known dual energy method of material discrimination can be used in x-ray inspection systems for customs and other security purposes. The major advantage is capable of differentiating between materials according to their atomic numbers. Even though the dual energy method is more effective than the single energy, it is insufficient for discrimination purpose. In order to make up for this insufficiency, a spectral filtering method of photons transmitted through a object is needed.

In this study, MCNP simulation is done in order to demonstrate the practical value of radioscopic differentiation of materials using the bremsstrahlung beams with 9 MeV/4 MeV dual boundary energies. And the signals produced by the x-rays transmitted through the objects are compared in two spectral profiles: one without a filter and with a filter.

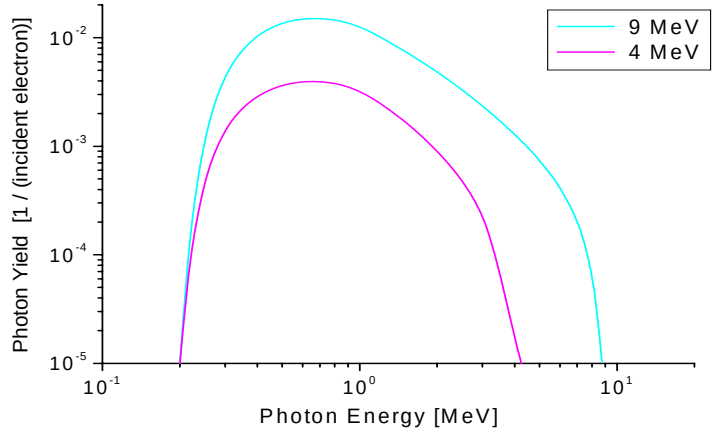
The results from this study are expected to make a contribution to develop the filtering methods or detecting systems for improving the quality of the material discrimination.

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

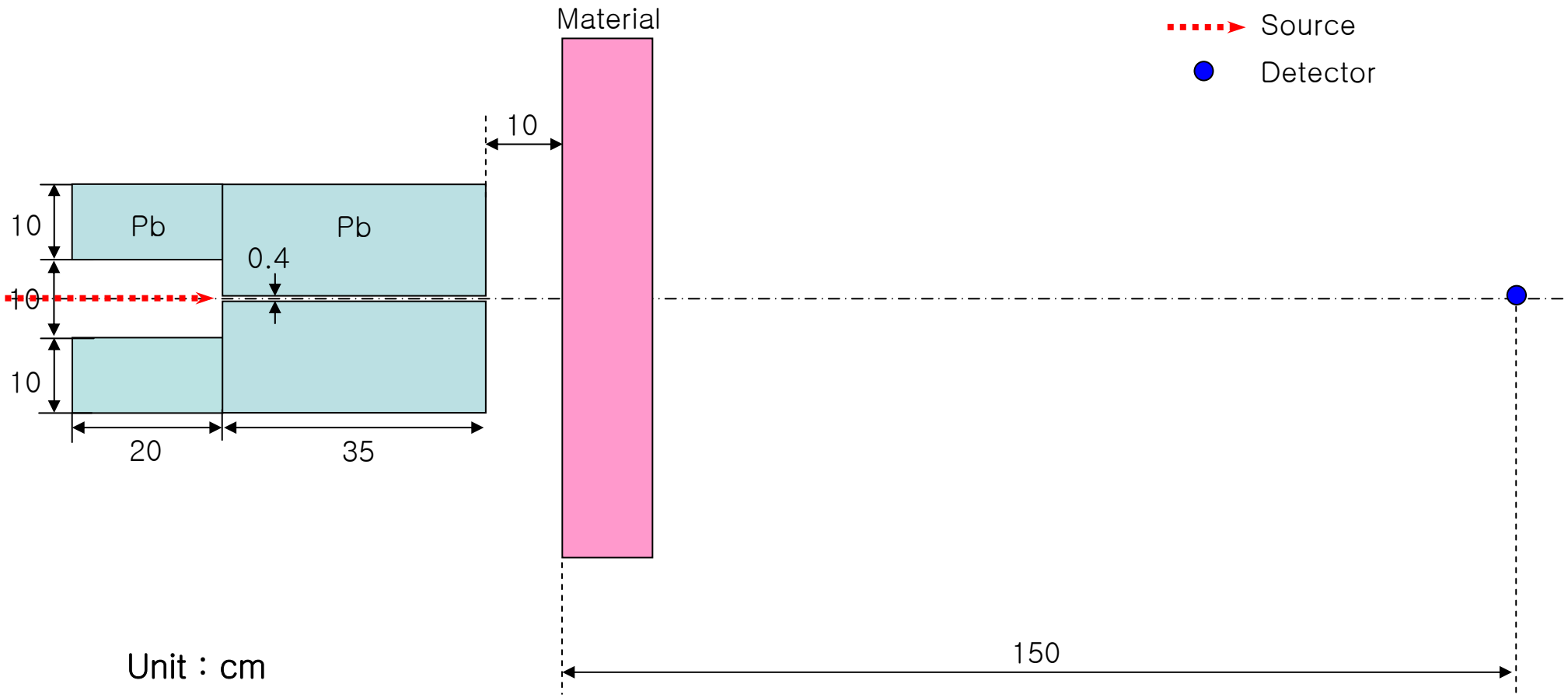


MCNP Simulation Conditions	
Spot size	Dia. 2 mm
Energy	9 MeV , 4 MeV (Monochrome)

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

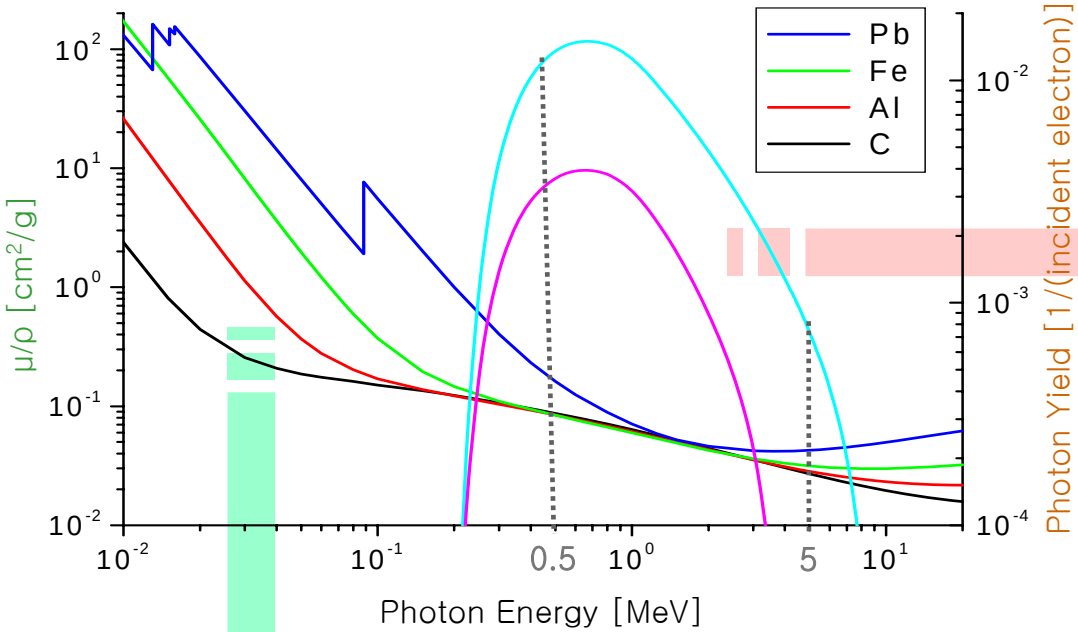


Geometry for MCNP Simulation



Searching High & Low Energy Pairs

(Data of X-ray Mass Attenuation Coefficient is obtained from NIST* database.)



Analysis of Bremsstrahlung Spectra

9 MeV		4 MeV	
Energy Range [MeV]	Fraction [%]	Energy range [MeV]	Fraction [%]
~0.5	17.6	~ 0.5	21.9
5~9	3.5	–	–
total	21.1	total	21.9

X-ray Mass Attenuation Coefficient

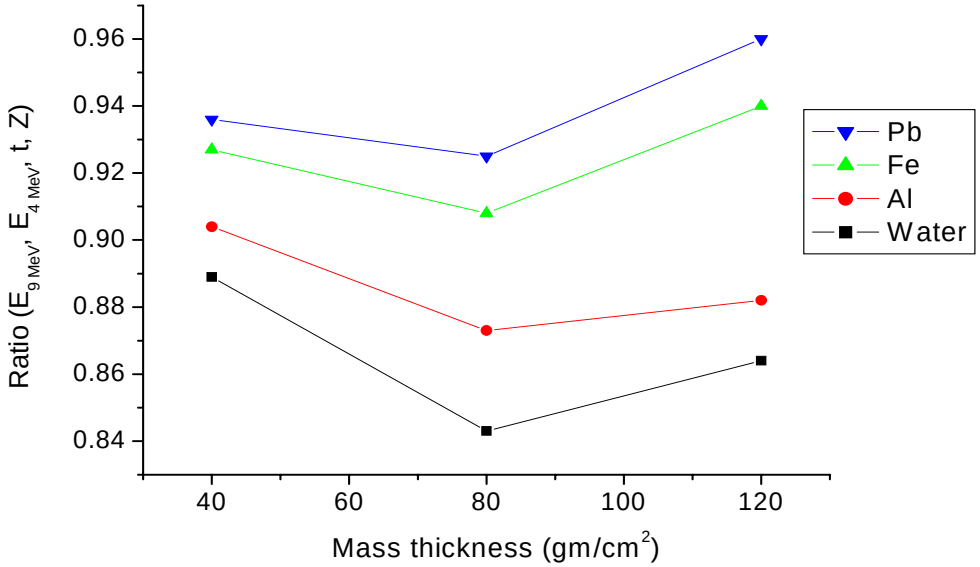
Interaction type	Energy dependence	Energy range [MeV]	Atomic number dependence
Photoelectric effect	$E^{-3.5}$	~ 0.5	Z^5
Compton effect	E^{-1}	0.5 ~ 5, 1 Max	Z/A
Pair production	E−1.02	1.02~	$Z^2/A \sim Z$

- It seems that due to region of Compton scattering the error is increased and material discrimination is difficult.
- Assuming that the region of Compton scattering is filtered, more effective for the discrimination of materials.

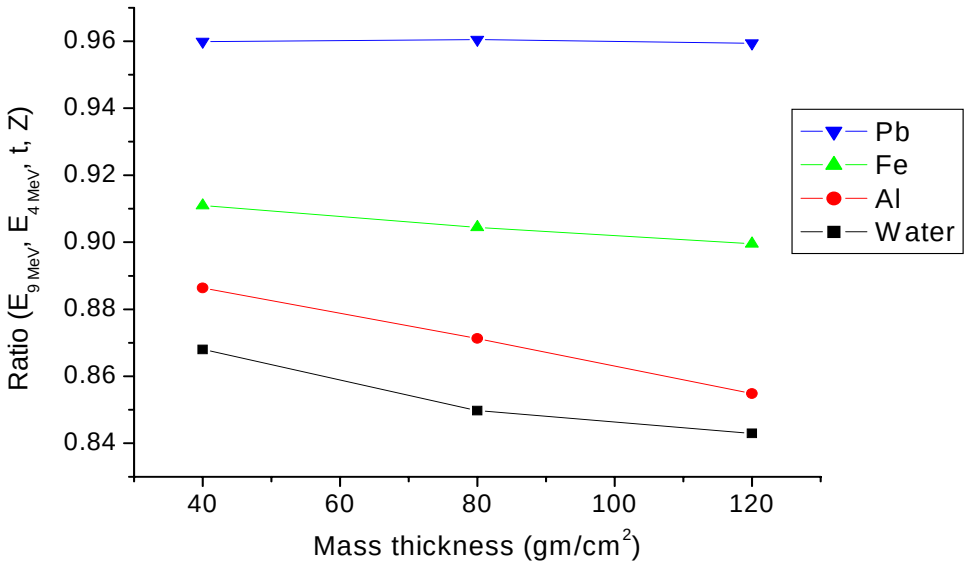
* NIST : National Institute of Standards and Technology

Filtering Spectra of Bremsstrahlung

Filtering the Region of Compton Scattering
(filtering 1 ~ 5 MeV)

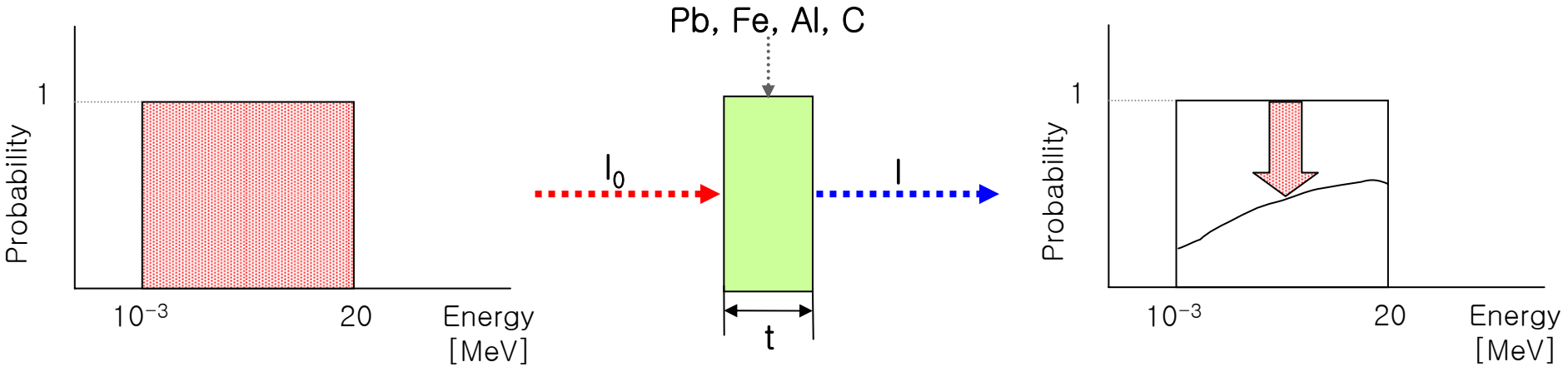


Filtering the Region of Photoelectric Effect
(filtering below 1 MeV)

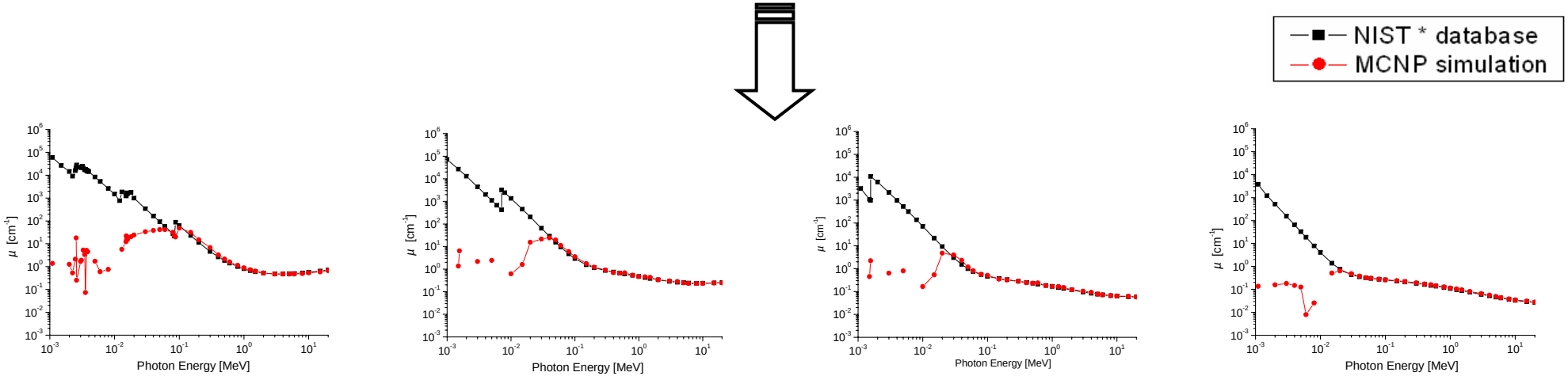


- Filtering the region of photoelectric effect is more effective for the material discrimination than filtering the region of Compton scattering.
- It is considered that low energy region corresponding to photoelectric effect region is not necessary for the material discrimination.

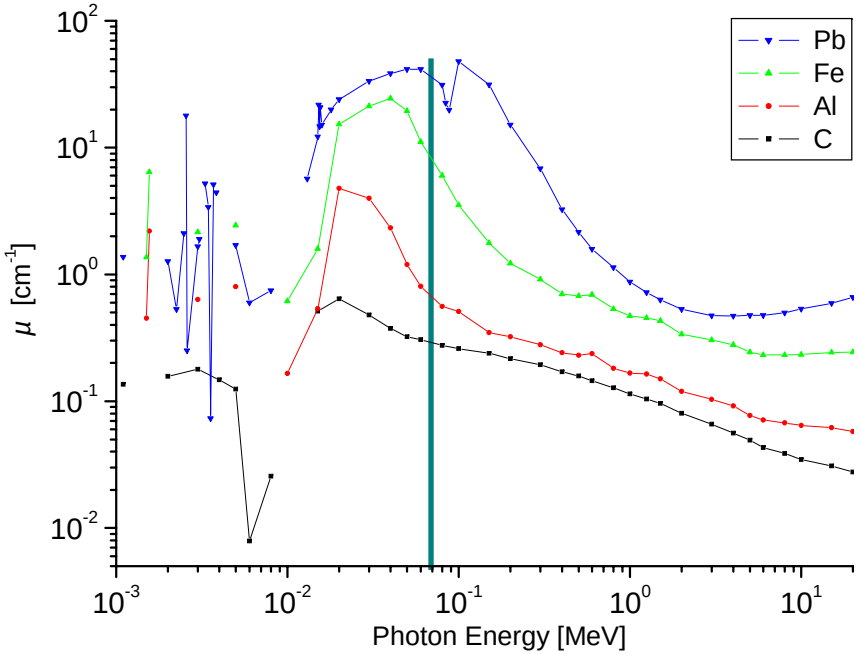
Calculating μ with *MCNP simulation*



$$\mu = \frac{1}{t} \ln (I_0 / I)$$



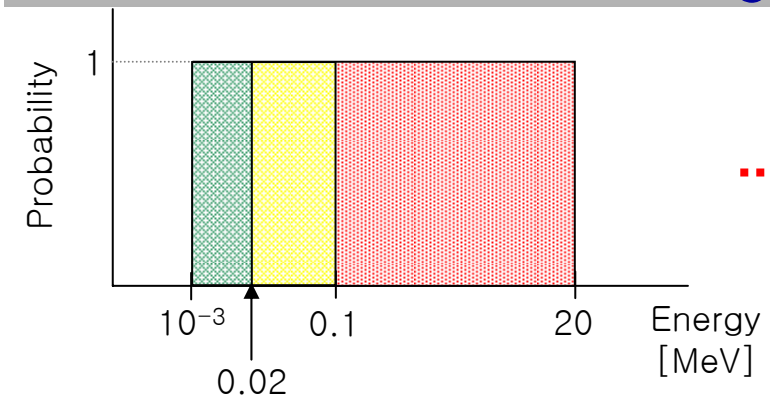
X-ray Linear Attenuation Coefficient

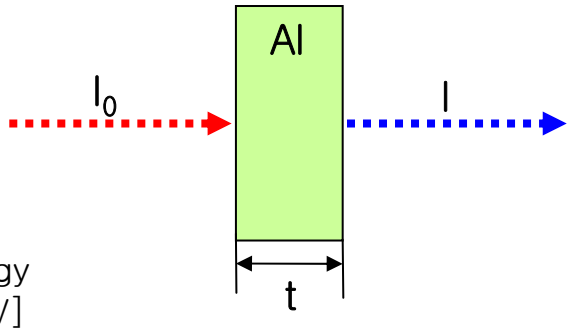


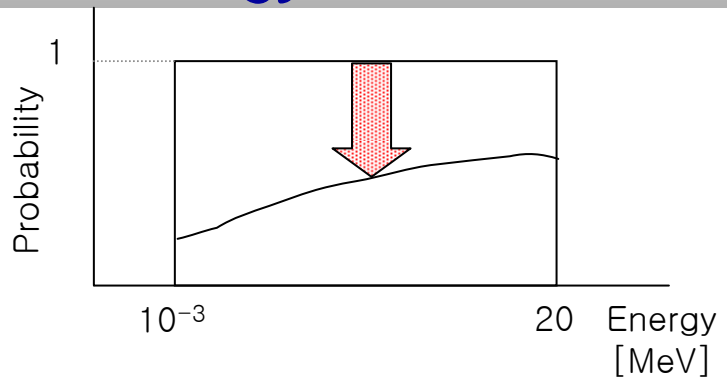
Results of *MCNP simulation* of calculating μ for Pb, Fe, Al and C

Results of ***MCNP simulation*** are correspond to the data of NIST above 60 keV.

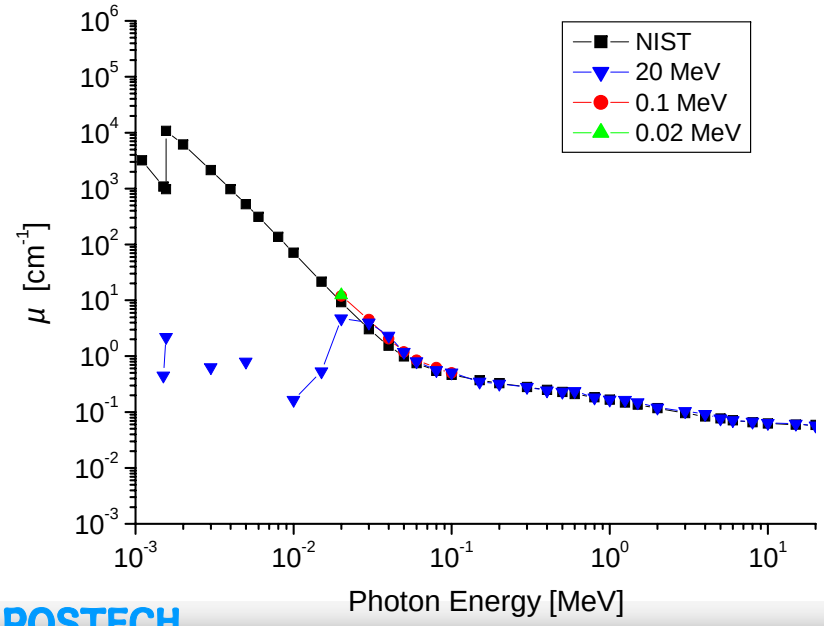
Calculating μ in Range of Low Energy

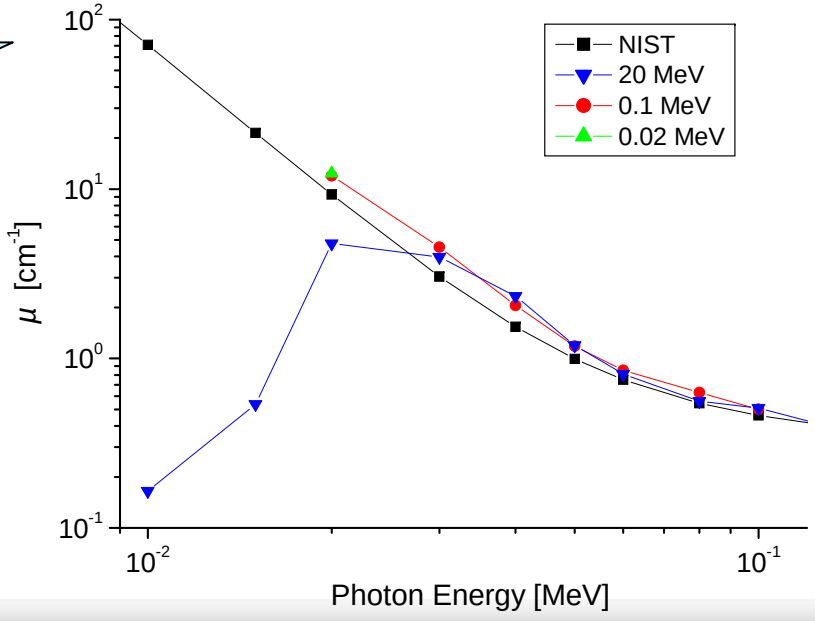




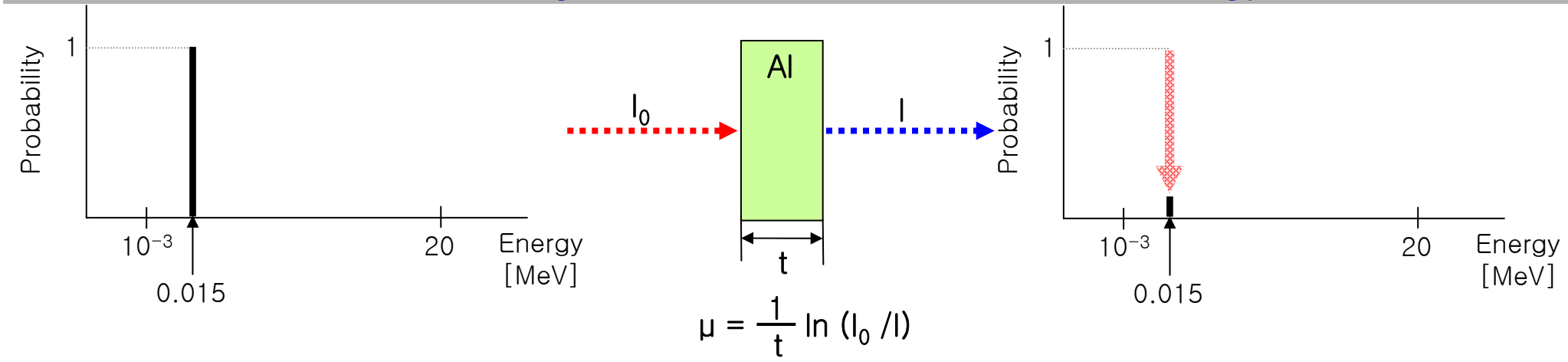


$$\mu = \frac{1}{t} \ln (I_0 / I)$$

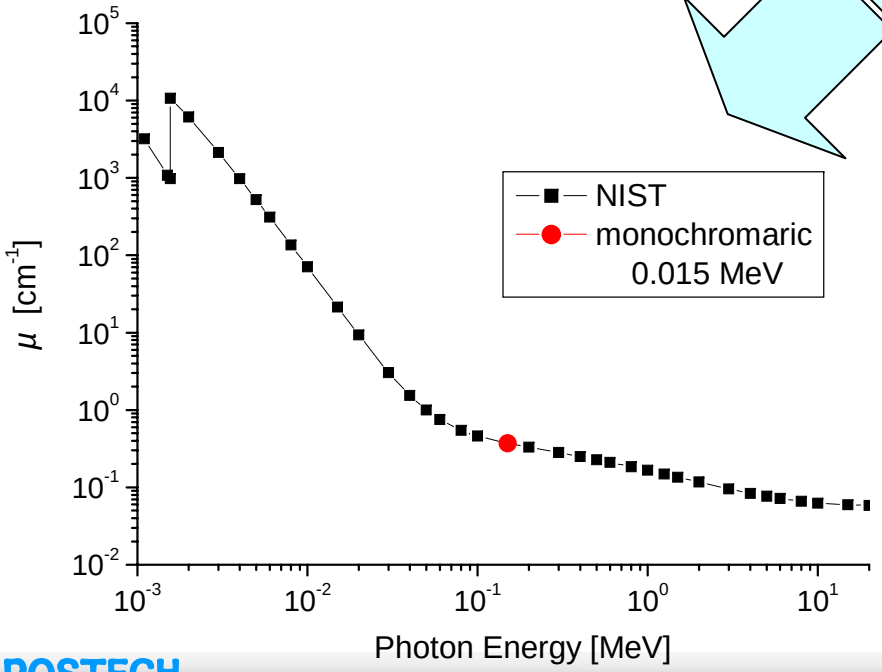




Calculating μ in Monochromatic Energy



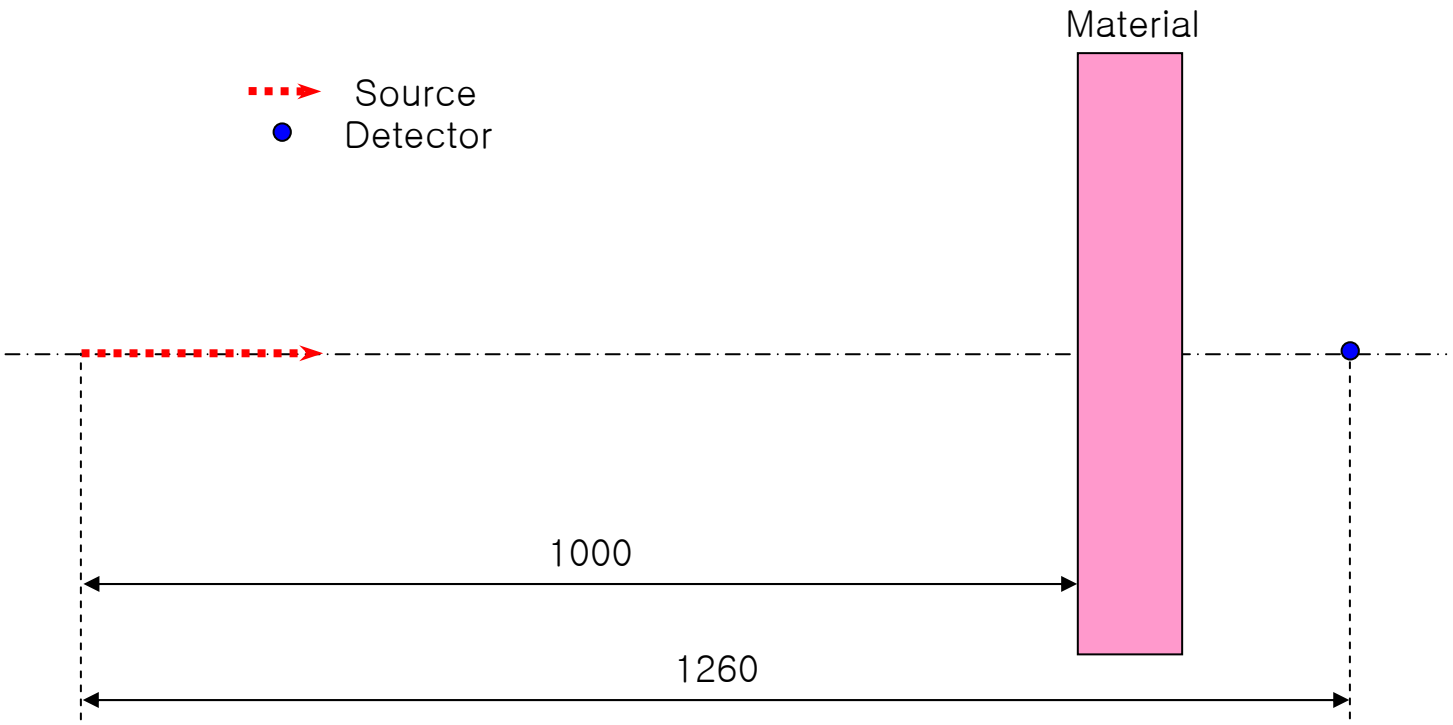
$$\mu = \frac{1}{t} \ln (I_0 / I)$$



They only accord when the source is monochromatic?

But in results of additional simulation, below 0.015 MeV, in spite of the monochromatic source, they do not accord. If so, why?

Simulation Geometry



Unit : cm

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

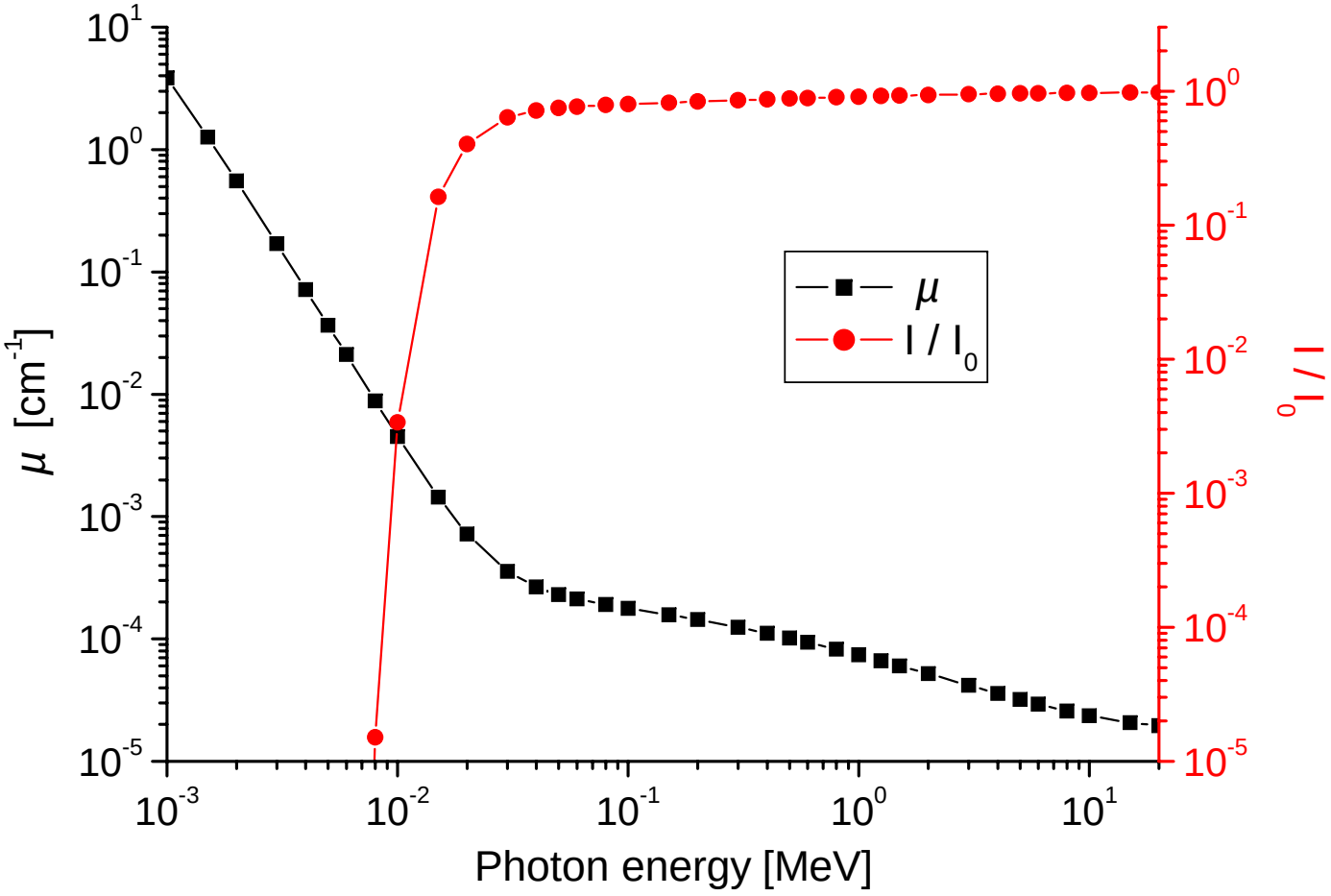
$$I / I_0 = e^{-\mu t}$$

t : 1260 cm

Photon Attenuation through Aluminum Barrier in Air

Energy	I / I_0
0.002	0
0.004	4.43E−52
0.006	3.66E−16
0.008	2.87E−07
0.010	4.21E−04
0.015	8.62E−02

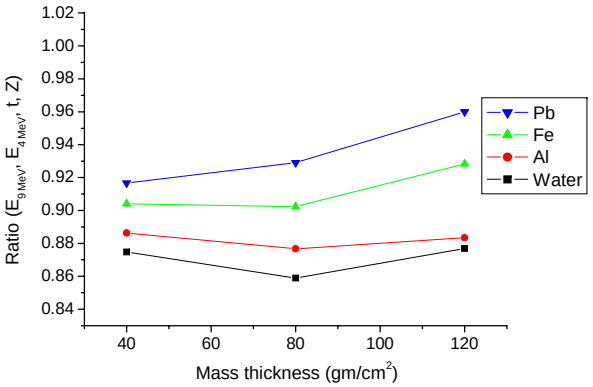
In this simulation, particle number was set to 10^6.



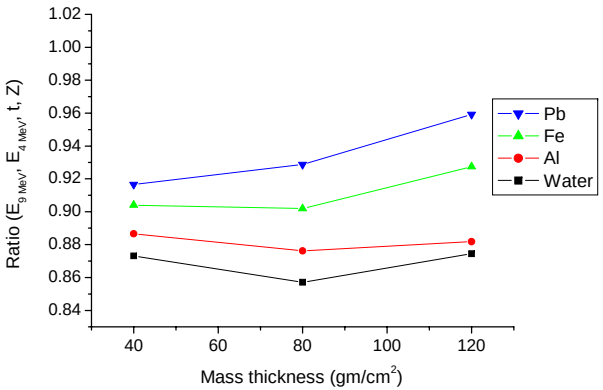
The disagreement in low energy is considered to be caused by the attenuation of low energy photons in air.

Results of Spectral Filtering in Dual Energy X-rays (Cont's)

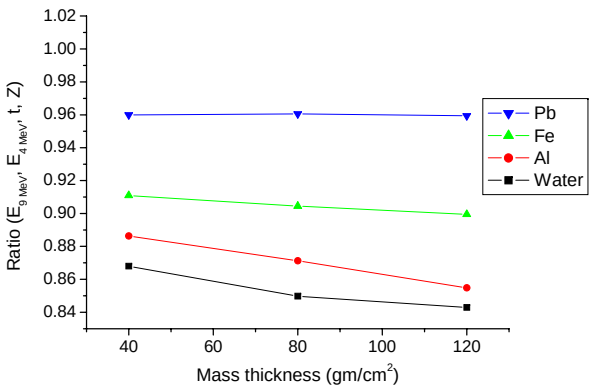
Whole energy



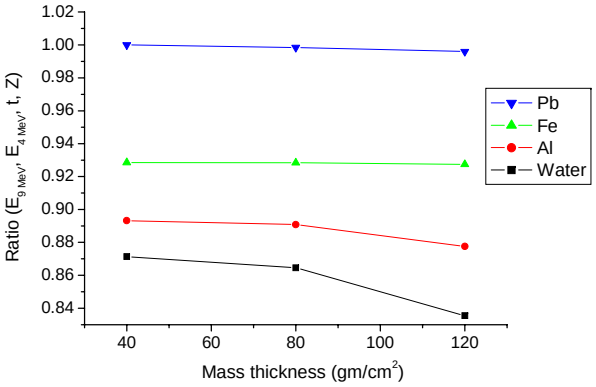
0.1 MeV ~



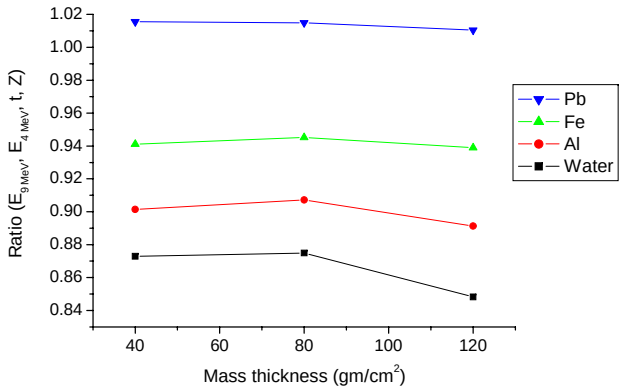
1 MeV ~



2 MeV ~

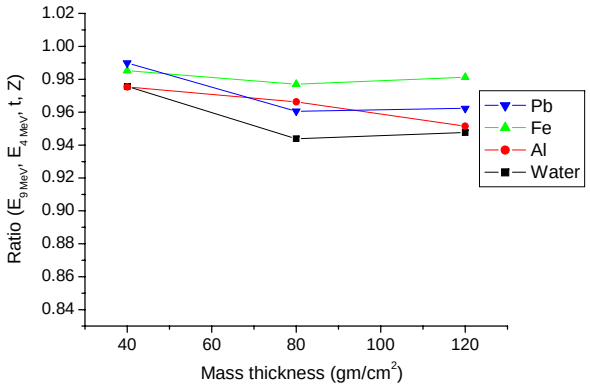


3 MeV ~

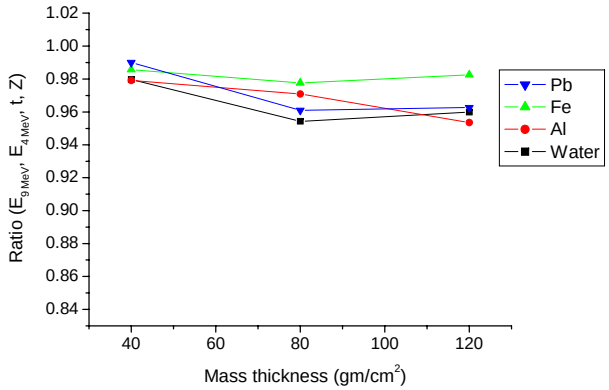


Results of Spectral Filtering in Dual Energy X-rays

0.01 ~ 1 MeV



0.1 ~ 1 MeV



The discrimination effect is not so good for the region in low energy. It is needed to analyse the causes of this phenomenon.

Conclusion

- The aim of this research is to search the optimal method of spectral filtering.

- We have estimated the ratios of attenuation coefficients for the materials using the bremsstrahlung beams with 9 MeV/4 MeV dual boundary energies.

- It is considered that low energy region corresponding to photoelectric effect region is not necessary for material discrimination.

- It is needed to analyse the causes of this phenomenon in the future.