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Lecture Note Education for Radiations using EGS4PICT32

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Education for Radiations using EGS4PICT32

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1 Introduction

The features that we cannot see or fell radiations causes the difficulty for understanding radiations. The use of radiation trajectories shown on a personal computer(PC) will be useful to overcome this difficulty.

The use of PC will be interesting for students and the study of radiation trajectories will be very effective way for understanding radiation behaviors inside materials.

The system called "EGS4PIC" to show trajectories, such as photons, electrons or positrons, calculated with the elector-magnetic cascade Monte Carlo code, EGS4[4] has been developed at KEK[1, 2, 3]. This system runs on the most of PC under Microsoft Windows even the geometries treated in this system are restricted to cylinders and planes. If the EGS4 user code is written for the specified program to be used for this display system, it is possible to control various conditions like a type of particle, an energy of particle etc. by communication with program.

We explain the newest version of our display system (`EGS4PICT32`) and the two EGS4 user codes (shield and detecc) written for the education purpose on radiations together with examples of a practice.

It is desired to explain about the EGS4 code system and the uses of the Monte Carlo code used at the related fields briefly. It is more effective to use this system connected with the practice of a radiation measurement using calibration source.

2 Brief Explanation about Monte Carlo Method and EGS4

2.1 Monte Carlo method

The calculation using the random number is generally called as "Monte Carlo method". The name of Monte Carlo method was introduced by J. von Neumann and S. M. Ulan around 1945. It may be related to the name of Capital of Monaco, Monte Carlo which is famous as the place for gambles.

In a radiation transport calculation using Monte Carlo method, a behavior of radiations inside a material is followed by determining a interaction point of radiations like photon and electron, a type of interaction, scattering or absorption, etc. using the random number. It is possible to apply for the various problems like a absorbed dose calculation to a cancer or a noise of a X-ray film. The Monte Carlo method can be possible to apply the complex geometry like a real human body and its uses in the medical physics are increasing drastically together with the increase of the performance of computer.[1]

2.2 EGS4

The EGS4 code system is the Monte Carlo code to treat electro-magnetic particles like photons, electrons and positrons inside materials.

In EGS4, the following interactions are treated:

- photons – photoelectric effect, Compton scattering, pair creation and Rayleigh scattering,
- electrons – Møller scattering, bremsstrahlung, multiple scattering and continuous energy loss,
- positrons – Bhabha scattering, bremsstrahlung, multiple scattering, continuous energy loss and annihilation in flight and at rest.

EGS4 are used wide areas like in the medical physics, the high energy physics, the radiation shielding and the radiation physics.

[1]Lecture Notes about the particle transport by Monte Carlo method which include simple example by hand calculation is published as KEK Internal[5].

3 How to Use Trajectory Display System(EGS4PICT32)

3.1 Start operation of EGS4PICT32

When you double click egs4win32.exe, which is the newest version of EGS4PICT system, following display appears first.

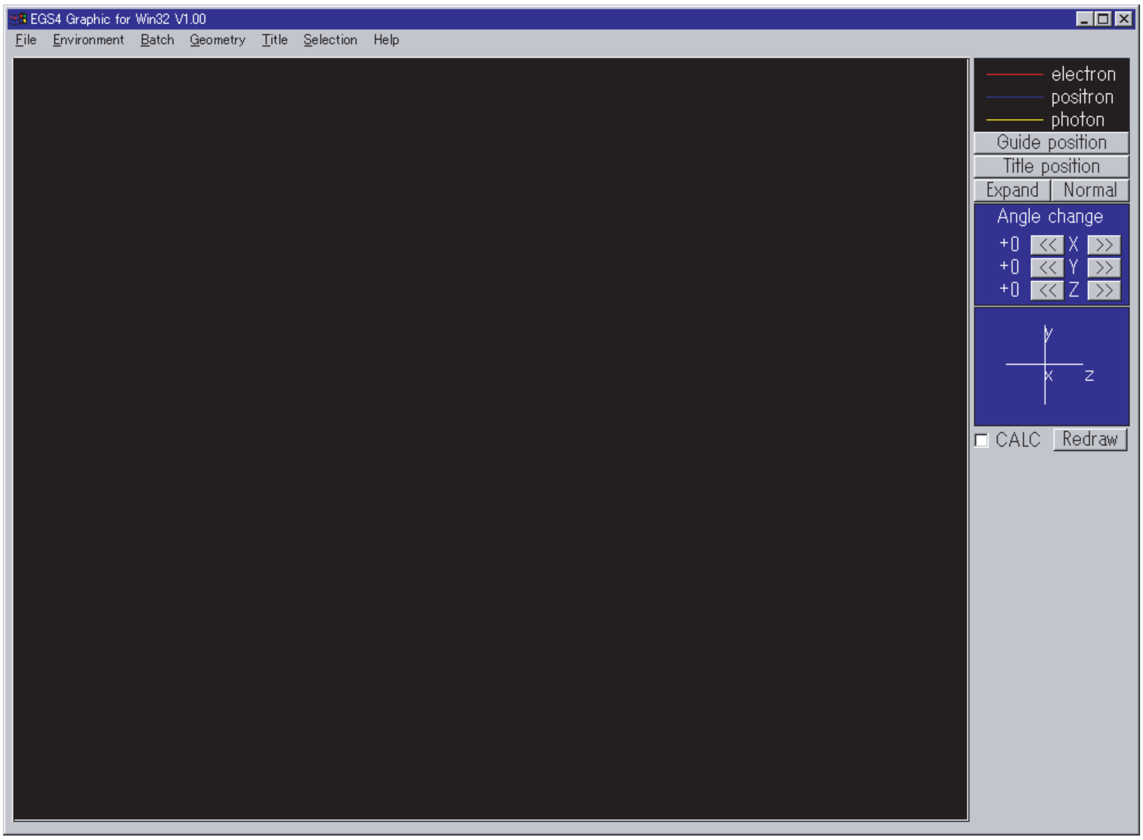

Figure 1: Main display.

The display size can be changed by dragging the edge of the display window.

If "Environment" is selected, the following environmental window appears:

Color select The colors of an electron, positron or photon are selected from the color-selection pallet.

Line select The line type of an electron, positron or photon is selected from the line-type selection window.

Scale unit Define the unit of the scale in cm.

Angle change value Define any change in the view angle of each axis with one mouse click.

Cut-off energy Define the cut-off energy in the total energy below that energy for which the trajectory is not drawn.

Background, Geometry and Character color Change the background, geometry or character color. If 'Color Button' of corresponding item is clicked, the color-selection pallet appears.

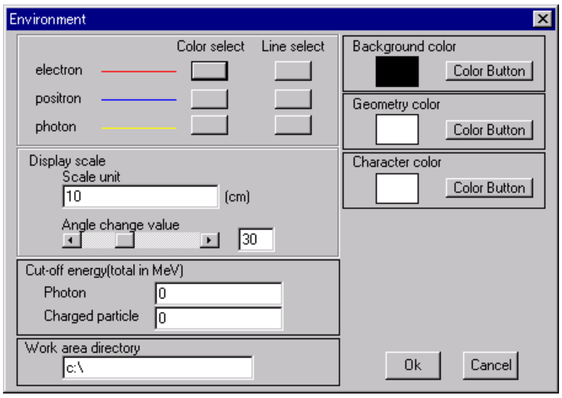

Figure 2: Environment display.

If the "CALC" is selected, the Command prompt (MS-DOS prompt) becomes active.

3.2 How to use EGS4 user code

We will explain how to use the EGS4 user code using shield.exe including in this tool kit.

Start program by executing shield.exe in the Command prompt (MS-DOS prompt).

Key in parameter for a given question.

1. **Key in Material number**
   1:Al, 2:Fe, 3:Pb, 4:Air, 5:PMMA, 0:end
   Enter the material number. (2)

2. If you select lead as the material, a following question will appear.
   Do you want to produce K X-ray of Lead ? (0:no, 1:yes)
   You must key in 0 or 1 depending your requirement for K X-rays production.

3. **Key in particle type**
   -1:electron, 0:photon, 1:positron, 9:new material
   Enter the type of source particles.(0)

4. **Key in particle kinetic energy in MeV (0 means new particle)**
   Enter the kinetic energy of source particles in MeV unit. (0.5)

5. **Key in slab thickness in cm (0 means change energy)**
   Enter the thickness of the shield in cm. (3)

6. When the calculations for 50 sources is finished, "Key in slab thickness in cm (0 means change energy)" will be displayed again.
   Click "File" and select "Data file open". Define the file which include the particle trajectories (mortjob.pic in this example) and click "OK" .

7. By clicking "Redraw", particle trajectories will appear.

Following procedures can be possible to apply for the shown display.

Expand Any part of the trajectories can be expanded by clicking on the Expand box. Push the left button of the mouse at the start point (the upper left) and drag until the end point (the lower right). It is possible to expand any part of the expanded trajectories by using the same procedure. The ESC-key cancels this procedure. If the Normal box is clicked, the expanded display is canceled and the original display appears.

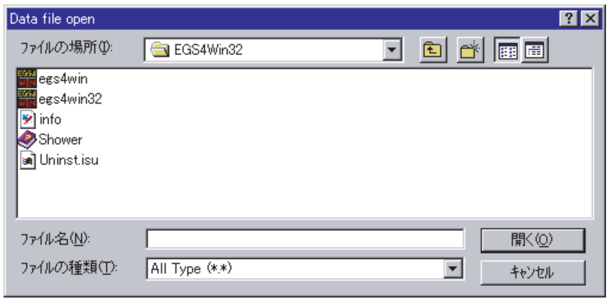

Figure 3: Define the file which includes the particle trajectories.

Angle change If the >> button or the << one of x is clicked by the mouse, the x-axis rotate counter-clockwise or clockwise, respectively. The situation of the coordinate is shown at the box below that of the angle change.

Selection On/off the drawing of each type of particles.

Title Write the title of the picture in the title set window. You can display the title at any place by clicking at the position that you want to display. ("Fe, 0.5 MeV Photon" in Fig. 4)

Guide position Guidance to show the color and the line type of each particle can be included inside the display window by clicking the guide position. You can display this guide box at any place by clicking at the position that you want to display.

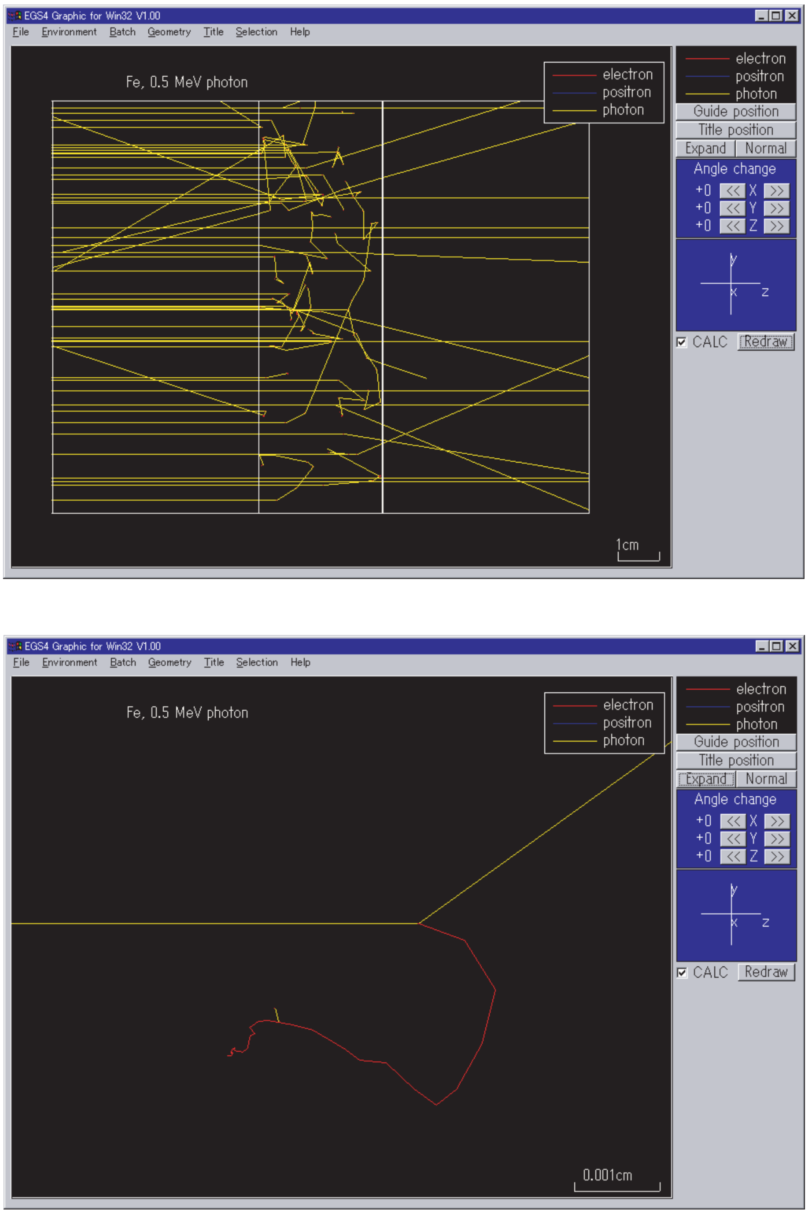

Figure 4: Trajectories inside 3 cm iron for 50 photon incidents with 0.5 MeV and its expanded display.

4 Examples of Practices using EGS4PICT32

In the following examples, it is assumed that the PC installed EGS4PICT32 and files necessary is prepared for a each or several students.

4.1 Study of interactions of 0.1-10 MeV photons with Al, Fe and Pb

In this example, EGS4PICT32 and shield.exe are used.

A: Explain how to use the system to students. (It is desired to show the way of handling using the projector connected to a PC.)

1. Double click the pict4win32.
2. Click "CALC" of EGS4PICT32.
3. Command prompt (MS-DOS prompt) will appear. Enter shield on this prompt.[2]
4. Enter 1 for "Key in Material Number". (This means that the material is aluminum.)
5. Enter 0 for "Key in Particle Type". (This means that the particle type is photon.)
6. Enter 0.1 for "Key in particle kinetic energy in MeV (0 means new particle)".
7. Enter 0.1 for "Key in slab thickness in cm (0 means change energy)".
8. When "Key in slab thickness in cm (0 means change energy) will appears again, return to the display system. Define the trajectory data file (mortjob.pic) by using the sub-menu "Data file open" of the "file" menu.
9. The trajectories will appear by clicking "Redraw".
10. Counts un-scattered and scattered photons.
11. Counts the type of interactions for 1 cm shield.
12. For determining the type of interactions, Fig. 5 will be used.
13. How to distinguish between K X-ray emission after photoelectric effect and Compton scattering.
    - Set the cut-off energy of photon to a slightly higher than the highest energy of K X-rays. In the case of lead, set to 0.088MeV.
    - If the trajectory of this photon disappears, the interaction is photoelectric effect.
14. If the above counting is finished, click "CALC" and return to the Command prompt (MS-DOS prompt) and repeat procedure after 7.
15. If you enter 0 at the step 7, you will return to the step 6 and change energy of source particles.
16. If you enter 0 as the energy, you will return to the step 5. Enter 9 and repeat from the step 4.

B: Example of subjects to students

1. Calculate the probability of un-collided photons (P) and that of transmitted scattered photons (S) by counting the un-scattered and transmitted scattered photons during 50 source photons for the following cases.
    - material – Al, Fe and Pb
    - incident photon energy – 0.1, 1.0, 10.0 MeV
    - plane thickness – 1, 2, 5, 10 cm

[2] It is assumed that shield.exe and shield.dat is put on the same directory with EGS4PICT32.

2. Count the type of interactions for 1 cm case. Use the "EXPAND" function to determine the type of interaction.
3. Plot P on a semi-logarithmic graph as the function of thickness including 1 for 0 cm for each material and an incident photon energy.
   - Perform a regression calculation with an exponent.
   - Calculate the thickness at that the P becomes 1/e (e=2.72).
   - This thickness is called as "photon mean free path (mfp)".
   - Consider the material or incident photon energy dependence of the mean free path.
   - Express the physical meaning of the mean free path.
4. Consider energy dependence of the mean free path of Pb for the incident photon energy of 60, 80, 100 and 120 keV.
5. (P+S)/P is the quantity called as a "number buildup factor". Consider the dependence of the number buildup factors to the plane thickness, the incident photon energy and the material.
6. Consider how the main interaction varies depending on the source energy and the material.
7. Express how is each interaction used at the diagnostics or the treatments using photons.
8. Compared the obtained mean free paths of Al, Fe, and Pb for 1 MeV photons with the theoretical ones.[3]

C: Theoretical values of photon cross sections

Al, ρ=2.699g/cm^3

Energy	μ/ρ	$\lambda = 1/\mu$	Photo/Total	Compt/Total	Rayl./Total
0.1MeV	0.1704	2.17cm	0.11	0.84	0.05
1.0MeV	0.06146	6.03cm		1.00	
10.0MeV	0.02318	16.0cm		0.64	

Fe, ρ=7.874g/cm^3

Energy	μ/ρ	$\lambda = 1/\mu$	Photo/Total	Compt/Total	Rayl./Total
0.1MeV	0.3717	0.342cm	0.55	0.37	0.08
1.0MeV	0.05995	2.12cm	0.006	0.99	0.004
10.0MeV	0.02994	4.24cm	0.0004	0.48	

Pb, ρ=11.35g/cm^3

Energy	μ/ρ	$\lambda = 1/\mu$	Photo/Total	Compt/Total	Rayl./Total
0.1MeV	5.549	0.0159cm	0.95	0.02	0.03
1.0MeV	0.07102	1.24cm	0.26	0.71	0.03
10.0MeV	0.04972	1.77cm	0.01	0.25	0.0006

[3] If the corresponding measurement using ^{60}Co γ-rays was done in advance, it is better to compare with the experimental ones.

4.2 Simulation of γ-ray energy measurement by a radiation detector

In this practice, the EGS4 user code detecc.exe which is written for the energy deposition calculation of various radiation detector together with EGS4PICT32. A diameter of the detector is fixed to 3 inches(7.62 cm) but its thickness of the detector can be set by the student. Ge, NaI and BGO are prepared as the detector.

A NaI detector with 3 inches thickness is supposed in the following example.

A: How to use the system

1. Double click the icon of the EGS4PICT32.
2. Click "CALC".
3. Enter detecc.exe when the Command prompt (MS-DOS prompt) appears. [4]
4. Enter a type of energy spectrum for "Key in absorbed energy spectrum form" depending on the graphic software that student will use.

   0: A response is given for corresponding to the middle value of the energy bin.

   1: A response is given both for corresponding to the lower and upper energy of the energy bin.
5. Enter 2 as a type of the detector for "Key in Material number (1:Ge, 2:NaI, 3:BGO, 0:End of run)". (This means that the detector is NaI.)
6. Enter 0 as the type of particle for "Key in Particle type (-1:electron, 0:photon, 1:positron)". (This means that the source particle is photon.)
7. Enter 7.62 as a detector thickness for "Key in slab thickness in cm (0.0 means change energy). (This means that the thickness 7.62 cm.)
8. Enter 1 as a source particle energy for "Key in particle kinetic energy in MeV (0.0 means change material and particle).
9. Enter 1 as a number of cases for "Key in number of cases (0 means change energy)".
10. Key in number of cases (0 means change energy) will appear again when a required calculation is finished.
11. Return to the display system.
12. Select mortjob.pic as the trajectory data file using a sub-menu "Data file open" of the menu "file" and click "OK".
13. Particle trajectories will appear by clicking "Redraw".
14. Sketch trajectories and record a type of interaction and an energy deposited in the detector.
15. How to distinguish between K X-ray emission after photoelectric effect and Compton scattering.
    - Set the cut-off energy of photon to a slightly higher than the highest energy of K X-rays. In the case of lead, set to 0.088MeV.
    - If the trajectory of this photon disappears, the interaction is photoelectric effect.
16. Click "CALC" and return to the Command prompt (MS-DOS prompt). Repeat from the step 9.
17. After 20 times attempts, enter 5,000 as a number of cases for "Key in number of cases (0 means change thickness)" and study a distribution of absorbed energy.
    The distribution of the absorbed energy is written on a mortjob.17o.

[4] It is assumed that detecc.exe and detec.dat is put at the same directory of EGS4PICT32.

18. Repeat from the step 8 by entering 0 for "Key in number of cases (0 means change thickness)".

B: Example of subjects for students

1. Enter a 1 MeV photon to a 3" length NaI detector using detecc.exe, and sketch trajectories. Record the type of interactions and energy absorbed inside the detector. Repeat this 20 times. (see Figs. 7 and 8) (Rotate 90° around Y-axis to see a leak of a radiation from the detector)

   Study following items after 20 times trials.

   (a) How is the absorbed energy when all particles are absorbed inside the detector?

   (b) How is the absorbed energy when part of particles are absorbed inside the detector?

   (c) How is the absorbed energy when a photon transmits without any interaction?

2. Calculate the absorbed energy distribution for 5000 source photons. (Fig. 9) Record a total and a peak efficiencies. A total efficiency is the sum of the energy distribution and a peak one is a probability that an energy of an incident photon is absorbed inside the detector.

   (a) What reaction in the sketch of trajectories is corresponding to a full energy absorption peak?

   (b) What reaction is corresponding to other peaks it they are exits? (Hints: There is a possibility to make a peak if K X-rays(K_α=0.028, K_β=0.033) or annihilation photons leaks from the detector.)

   (c) What reactions in the sketch is corresponding to a continuous part? Why does a peak not appear in this case?

3. Repeat the same things for 0.3 Me and 3.0 MeV photons.

4. What is the reason of the difference between the highest energy of the continuous part and the peak energy (ΔE)? Plot ΔE as the function of an energy of source photons and compare with a theoretical value.

   Hints

   - A recoil photon energy, k_c (MeV), after Compton scattering can be calculated by a following equation for a energy of incident photons, k_0 (MeV), and a scattering angle, θ. $k_c = k_0/\{1 + k_0(1 - \cos\theta)/0.511\}$
   - A recoil energy, k_c becomes a minimum for $\theta = 180°$. This minimum value of k_c is corresponding to the theoretical value of the above comparison.
   - Consider a source energy dependence of total and peak efficiencies.
   - Make problems about a response function or basic interactions by yourself and consider about them.

5 How to get Files

Get pict_edu.exe from the "KEK Radiation Science Center" Web page.
(`http//rcwww.kek.jp/research/shield/education/index.html`)
In the case that link was disconnected, please search by the key word of "egs radiation education".
Extract files on PC by execution pict_edu.exe.
The following files are extracted:

- egs4win32.exe
- info.$$$
- Shower.hlp
- shield.exe
- shield.dat
- detecc.exe
- detecc.dat

6 Summary

We presented examples of the lecture for students in medical physics above. It is possible to apply these examples to students in other fields. It is also possible to make other subjects using the programs including in this system.

Subjects and items to be studied are different for each research field. It is possible to make a user code which produces trajectories suitable for each field if he/she understands how to use EGS4 system.

We hope that this system is used as the tool of various lectures and is useful for understanding of radiations.

References

[1] H. Hirayama, Y. Namito, S. Ban, R. Ikeda and Y. Tokuda, "EGS4 Shower Display System, EGS4PICT(2), Windows Version", *KEK Internal 94-10* (1994).

[2] H. Hirayama, Y. Namito, S. Ban, R. Ikeda and Y. Tokuda, "EGS4 Shower Display System (EGS4PICT), Windows Version 2.0", *KEK Intetnal 96-9* (1996).

[3] H. Hirayama, Y. Namito, S. Ban, N. Numajiri and R. Ikeda, "EGS4 Shower Display System, Windows 32bit Version (EGS4PICT32)", to be published as KEK Internal.

[4] W. R. Nelson, H. Hirayama, D. W. O. Rogers, "The EGS4 Code System", *SLAC-265* (1985).

[5] H. Hirayama and Y. Namito, "Lecture Notes of Radiation Transport Calculation by Monte Carlo Method", *KEK Internal 2000-20* (2001).

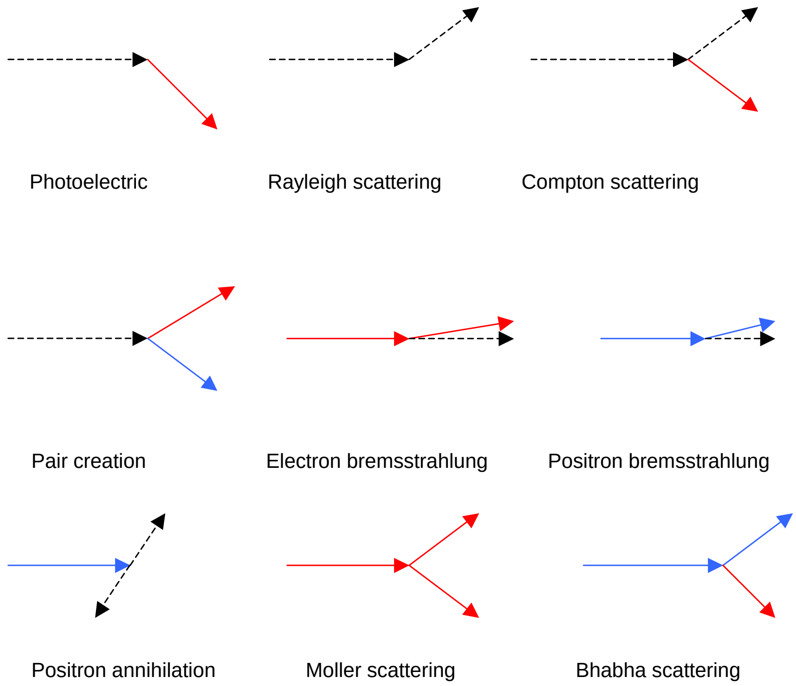

Figure 5: Schematic diagrams of each reaction. photon: black dotted line, electron: red line, positron: blue line. (On display, photons are displayed as yellow line.)

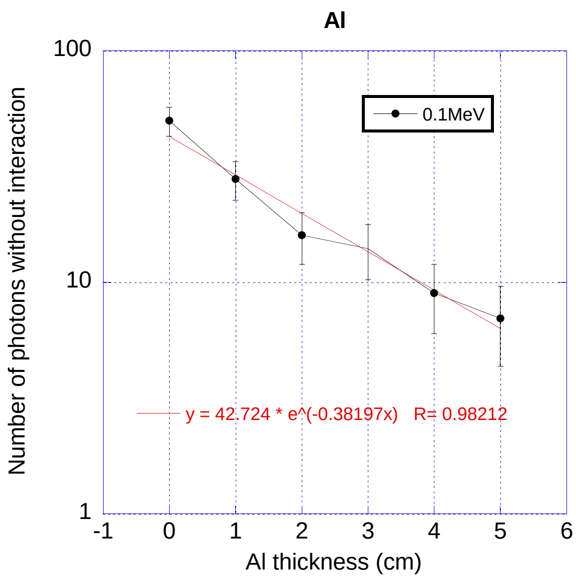

Figure 6: An example of the plot of attenuation curve.

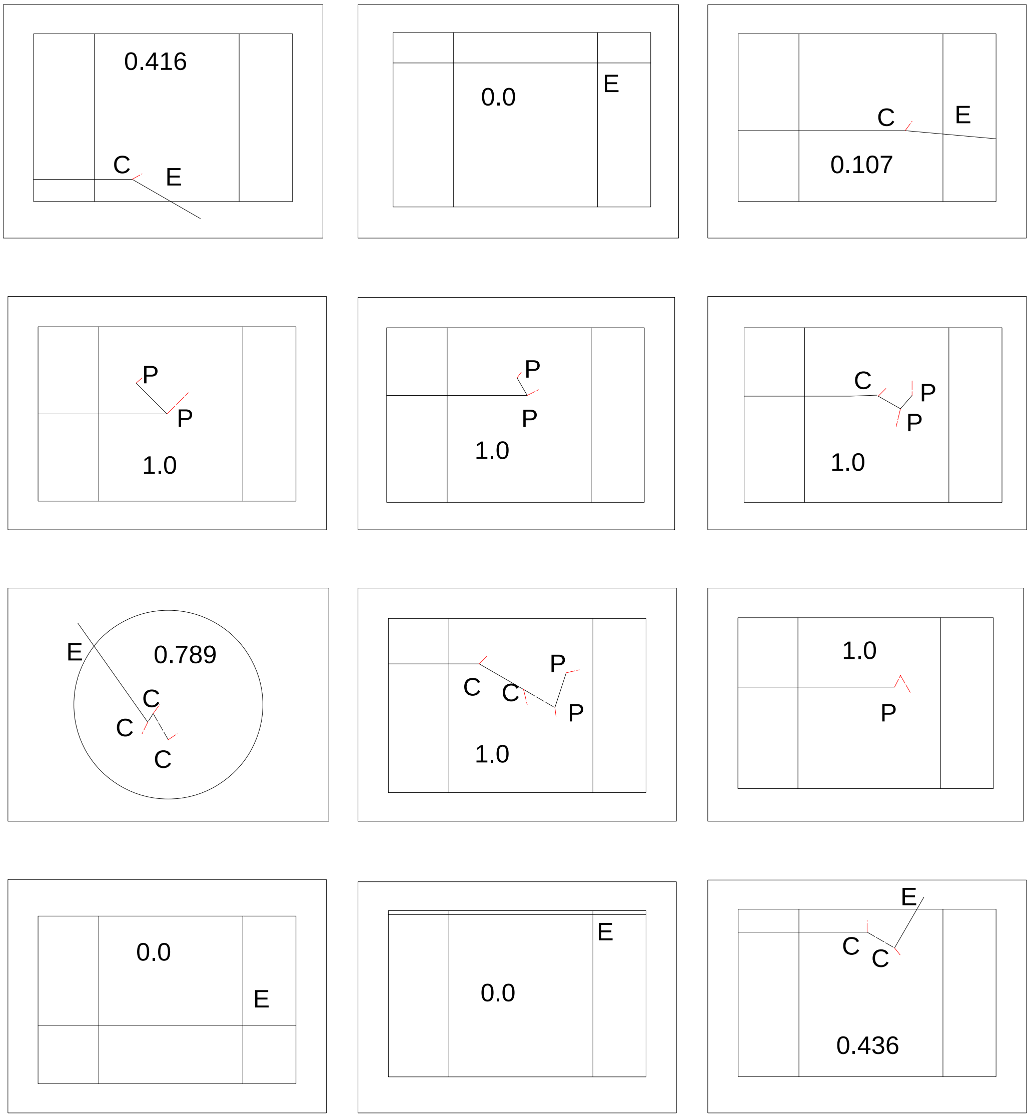

Figure 7: Example of sketches of trajectories. A trajectories of an electron is hard to see due to short distance. Therefore, a trajectory of electron in this sketch is written longer than the real one. C, P, and E in the figure indicate Compton scattering, photoelectric effect and an escape from the detector, respectively. An absorbed energy shown at the command prompt (MS-DOS prompt) is also written for each sketch.

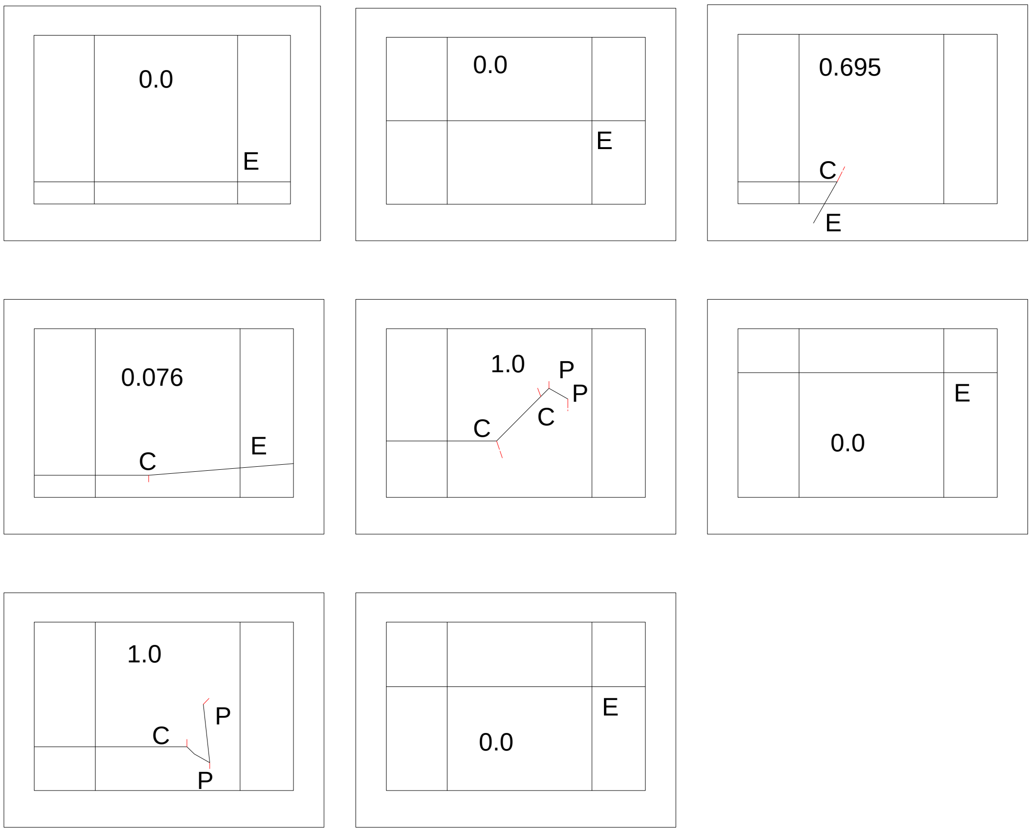

Figure 8: Example of sketches of trajectories. A trajectories of an electron is hard to see due to short distance. Therefore, a trajectory of electron in this sketch is written longer than the real one. C, P, and E in the figure indicate Compton scattering, photoelectric effect and an escape from the detector, respectively. An absorbed energy shown at the command prompt (MS-DOS prompt) is also written for each sketch.

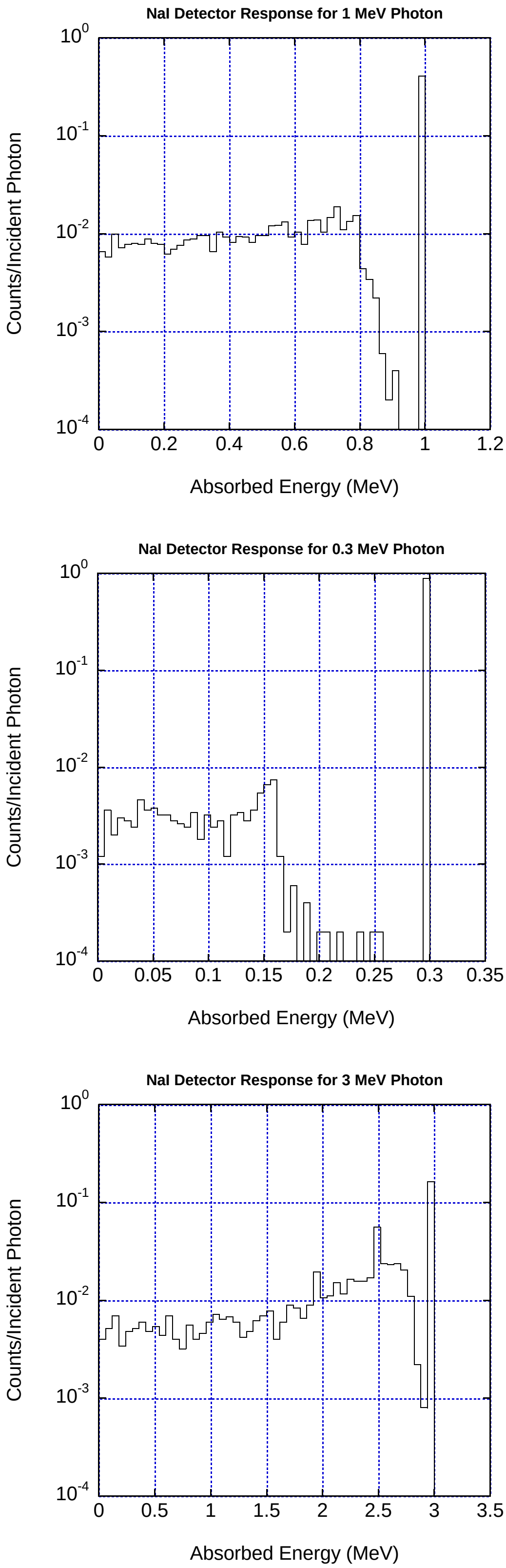

Figure 9: Absorption energy distributions for 1MeV, 0.3 MeV and MeV photons.