Simulation of Positron Production by Electromagnetic Interaction, Slowdown to Thermal Energy and Reemission of Positrons in the Target-Moderator System

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1. Introduction

We developed a Monte Carlo code, named LEPRE (Low Energy Positron REemission) to simulate positron behavior in a moderator system [1]. LEPRE starts simulation from positron energy near the positron cutoff energy, Ae, of EGS4 [2] which is 10 keV in the present stage.

We need tools to simulate positron production by electromagnetic interaction and positron slowing down to cutoff energy in matter in addition to slowing down to the thermal energy and reemission of positron to estimate slow positron beam properties. We developed a Monte Carlo simulation code for evaluation from energetic positron production to reemission, named PCM (Positron Creation and Moderation), based on EGS4 and LEPRE.

Material properties are set to the values of EGS4, and most of the default parameters, such as positron work function and branching ratio of reemission, are adopted from reference [3].

2. Model

The Monte Carlo simulation code, named PCM, consists of the following three steps:

- 1st step = positron production by electromagnetic interaction
- 2nd step = positron slowing down to cutoff energy in matter
- 3rd step = positron slowing down to thermal energy in matter, thermal diffusion and reemission (This step corresponds to LEPRE)

In the first step, the interactions, photoelectric effect, Compton scattering and pair production, are involved. We adopted the photoelectric cross section of H. Hall [4], though EGS4 uses the data of Storm-Israel [5]. EGS4 also uses the data of Storm-Israel as pair production cross section, but we used the equation of EGS4 with Ap'=1.0, where Ap' is a correction factor and 1.0 for incident positron energy higher than 50 MeV. For Compton scattering, the same expression as EGS4 is used in the code PCM.

If a positron is produced, then the code proceeds to the second step. First, the energy and direction of the positron produced is determined based on the method of EGS4. Then, the following interactions are considered: annihilation, Bhabha scattering, Bremsstrahlung, continuous energy loss and multiple scattering.

The cross sections of annihilation and Bhabha scattering for PCM are the same as EGS4. The absolute value of the Bremsstrahlung cross section is, however, not the EGS4 value. We have adopted the exact relativistic (ER) expression with complete shielding given in reference [6], though the EGS4 equations have been used in the computation of the radiation probability density function because the relative value of the differential cross section should be used. The total cross sections of Bremsstrahlung have been prepared as a table of positron energy (Ep) by numerical integration of the ER expression from the positron cutoff energy (Ae) to Ep.

Two terms are included in continuous energy loss; the first is soft Bremsstrahlung under cutoff energy and the second, sub-cutoff corresponding to ionization loss. The cross sections for the first term have been also prepared as a table of positron energy (Ep) by a numerical integration of the ER expression. The second term is evaluated based on the method of EGS4. EGS4 has default values of parameters for some compounds, but PCM treats only the atomic elements.

The basic treatment of multiple scattering is similar to EGS4, but a small modification has been introduced to save time in computation.

After a positron reaches the cutoff energy, the positron goes straight following the stopping profile described by Makhovian profile as in LEPRE and thermal diffusion starts. This last step corresponds to LEPRE.

At the end of the simulation, the reemission rate for incident photons and produced positrons are evaluated for each moderator foil.

3. Results of Simulation

We attempted the preliminary simulation of a multi-moderator assembly system [7]. The scheme of the converter-moderator system is shown in Fig. 1. In Fig. 1 only eight moderator foils are shown, though upper ten and lower ten (or nine) tungsten foils are assumed in the simulation.

The thickness of the most outer foils is assumed as 0.15mm for all cases given here. Figure 2 shows the energy distribution of incident photons assumed in this simulation. In this simulation, the horizontal plane is the x-y plane and the vertical direction is the z direction and photons are assumed to be incident in the direction (u, v, w) = (1.0, 0.0, -1.0E-3) as shown in Fig. 3. Here only the results obtained in the case shown in Fig. 3 are described. The geometrical sizes of the converter and the moderators are as follows:

Converter $\Delta X \times \Delta Y = 20 \times 35$ cm^2

Moderator $\Delta X \times \Delta Y = 30 \times 35$ cm^2; 1cm spacing

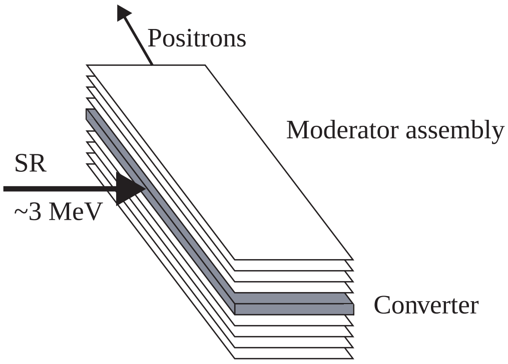

Fig. 1. Scheme of positron production and moderation.

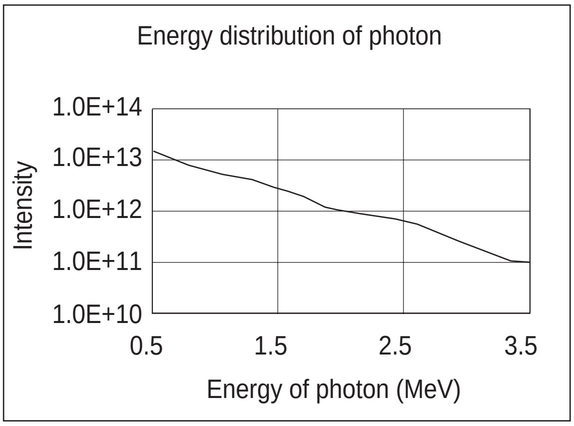

Fig. 2. Energy distribution of incident photons assumed in this simulation.

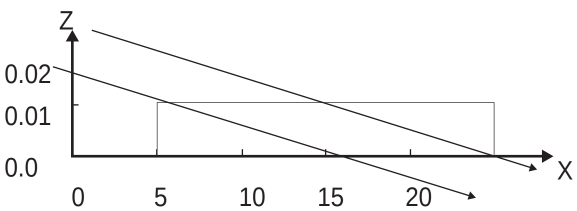

Fig. 3. Incident direction of photons and target geometry in cm.

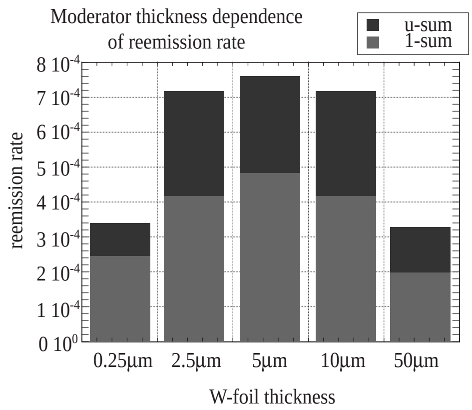

Fig. 4. Moderator foil thickness dependence of positron reemission rate. The notation u_sum and l_sum refer to the contribution of the upper and lower moderator foils.

Figures 4 to 7 show the simulation results. Figure 4 shows the moderator foil thickness dependence of positron reemission rate to incident photons. In this figure, the u-sum is the summation of the contributions of all the upper ten foils. Tungsten is assumed as the moderator foil material.

Converter material dependence of reemission rate to incident photons is shown in Fig. 5 and 6. In these cases, the number of upper and lower moderator foils is nine. In the tungsten case, contribution of reemission from the converter (target) is included, though there are no contribution from the converter for other materials, because of the positron work function on the moderator surface. Thus, the reemission rate for tungsten is the largest at foil_1, which includes contributions from the converter, upper and lower first moderators. The moderators are numbered from the inside to the outside.

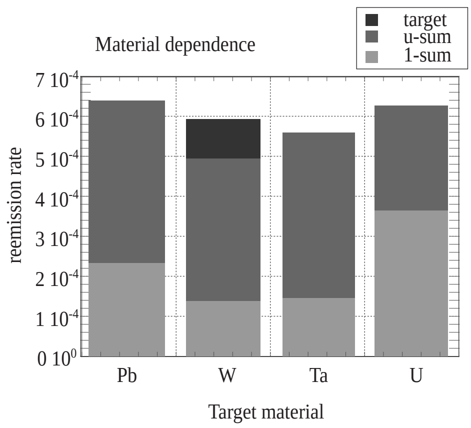

Fig. 5. Material dependence of reemission rate. In the tungsten case, the contribution of reemission from the target is included, though there is no contribution from the target for other materials.

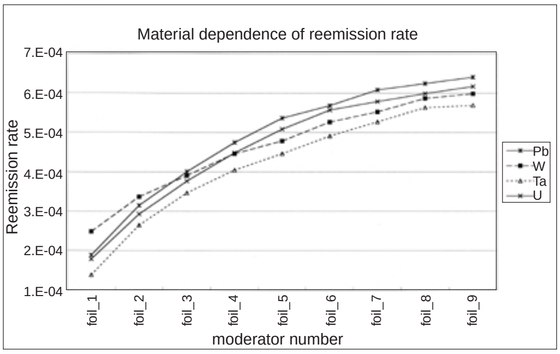

Fig. 6. Material dependence of reemission rate. Moderator number foil_n means sum of reemission rate from i=1 to n upper and lower foils. The reemission rate consists of re-emitted slow positrons / incident photons. In the tungsten case, the contribution of reemission from the target is included in foil_1.

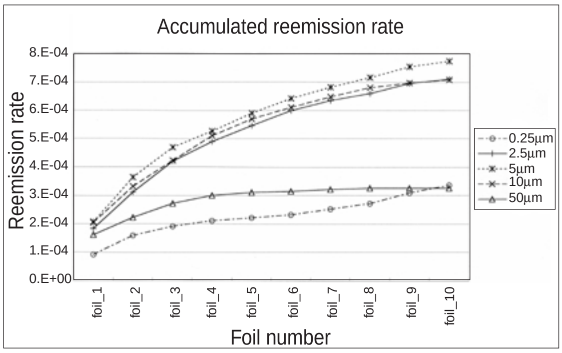

Fig. 7. Moderator foil thickness dependence of positron reemission rate. Foil number foil_n refer to the sum of the reemission rate from i=1 to n upper and lower foils. The reemission rate consists of re-emitted slow positrons / incident photons.

Figure 7 shows the moderator-foil thickness dependence of positron reemission rate to incident photons (this figure corresponds to Fig. 4). If the moderator is too thick, positrons become thermal energy in the inner moderator foils, and must travel a longer path to reach the surface of the moderator. Thus it becomes difficult to reemit positrons for thick moderator foils. On the other hand, if the moderator is too thin, the stopping probability becomes small and almost positrons from the converter pass through the moderator foils. There seems to be some contribution from foil_9, which may reflects the back-scattered positrons from foil_10 because of the sufficient thickness of foil_10.

4. Summary

We developed a simulation code PCM to trace the positrons from pair production to thermal diffusion and reemission based on EGS4 and LEPRE. Some preliminary simulations have been examined. The parameters tested were the moderator thickness and the converter material. In this simulation, we believe reasonable reemission rates were obtained, though code verification with experimental data should be completed.

References

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