Preliminary Simulation of Low Energy Positrons Behavior in Matter with Code Named LEPRE

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1. Introduction

In order to estimate slow positron beam properties, we need tools to simulate positron production by electromagnetic interaction, positron slowing down in matter and reemission of positron. Monte Carlo simulation code for evaluating energetic positron production based on electromagnetic interactions has been developed by SLAC group, called EGS4 [1]. This code, however, has two cut-off energies. One is for photon, Ap, and the other is for positron (electron), Ae, and the lowest possible value of Ae is 10 keV. Because tracing of further low energy positrons to thermal diffusion is required, we have developed a Monte Carlo code, named LEPRE (Low Energy Positron REemission).

The basic idea is similar to the code SPG developed by JAERI [2]. The LEPRE traces positron behavior according to a stopping profile formula based on the Makhovian distribution with shape parameter m = 2 [3], which is followed by diffusion, annihilation and reemission. Material properties are set to the values of EGS4, and almost of the default parameters, such as positron work function and branching ratio of reemission, are adopted from reference [3].

2. Model

Monte Carlo simulation code, called EGS4 [1], for evaluating energetic positron generation based on electromagnetic interactions has been already developed by the SLAC group. Thus we have developed a Monte Carlo code to simulate the behavior of positrons in the moderator after slowing down to the lower cut-off energy (Ae) of EGS4.

We have assumed that positrons with nearly the cut-off energy (Ae) penetrate the moderator foil straight and that the stopping profile can be described by Makhovian profile. Makhovian distribution is given by

$$P(z) = (mz^{m-1}/z_0{}^m) \exp[- (z/z_0)^m], \qquad (1)$$

where z is the penetration depth and m is the shape parameter. The parameter z_0 is a function of incident positron energy given by

$$z_0 = \langle z \rangle / \Gamma[1 + 1/m], \qquad (2)$$

where <z> is the mean stopping depth. We assume m=2 for simplicity because Valkealahti and Nieminen find m nearly equals 1.9 [3]. Then the dependence of z_0 on the gamma-function becomes

$$z_0 = 2\langle z \rangle / \pi^{1/2}. \qquad (3)$$

The dependence of mean depth on energy E is assumed to be a power law,

$$\langle z \rangle = AE^n, \qquad (4)$$

where A is a constant. The values of A and n are given in reference [3]. As the probability distribution function p(z) can be described by

$$p(z) = 1 - \exp[- (z/z_0)^2], \qquad (5)$$

we can calculate the depth where a positron becomes thermal energy and starts thermal diffusion with uniform random number r by

$$L_{th} = z_0(- \ln r)^{1/2}. \qquad (6)$$

The thermalized positron is transported by a small length λ_d. The reaction probability after the transportation is

$$P(\lambda_d) = 1 - \exp(- \lambda_d /\lambda_T), \qquad (7)$$

where λ_T is the total mean free path given by collision length λ_c and annihilation length λ_a

$$1/\lambda_T = 1/ \lambda_c + 1/ \lambda_a. \qquad (8)$$

Collision length is assumed to be mean diffusion distance L_+, where $L_+ = (D_+\tau)^{1/2}$, D_+ is diffusion coefficient, τ is relaxation time ($\tau = 3m^*\mu/2$), m* is effective mass and μ is mobility ($\mu = D_+/kT$).

Using uniform random number r_1, if $r_1 > P(\lambda_d)$, then the positron goes straight without reaction. If $r_1 < P(\lambda_d)$, the reaction (collision or annihilation) occurs. If $r_2 > (1/\lambda_a)/(1/\lambda_T)$, the positron is scattered by collision and otherwise annihilates, where r_2 is another uniform random number. If a positron goes across one of the moderator surfaces, then the positron is emitted from the surface to the vacuum. We assumed that the positrons are emitted from the moderator surface perpendicularly as the thermal energy of positrons is small enough compared with the surface work function.

3. Results of Simulation

We have tried preliminary simulation of multi-moderator assembly system [4]. The scheme of converter-moderator system is shown in fig. 1. Stopping profile of tungsten foil calculated by equation (1) with m=2 is shown in Fig. 2. In this simulation, selected parameters to test are tracing length, moderator thickness, incident positron energy, effective mass ratio and moderator temperature. Figures 3 to 6 show the simulation results. We have selected the tracing length $\lambda_d = \lambda_c/10$, as there was no distinct difference in the results of simulation with λ_d from $\lambda_c/100$ to $\lambda_c/3$.

Unfortunately, we have quite few data to be compared with these simulation results. The quantitative features of the simulation results are in consistent with physical sense. In Fig. 3, when the thickness of the moderator foil is thin positrons can easily reach the moderator surfaces, otherwise it

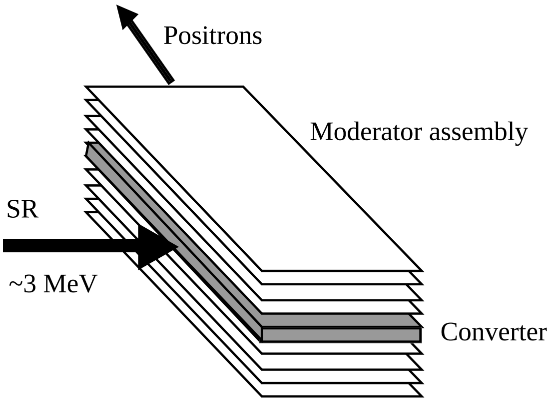

Fig. 1. Scheme of positron production and moderation.

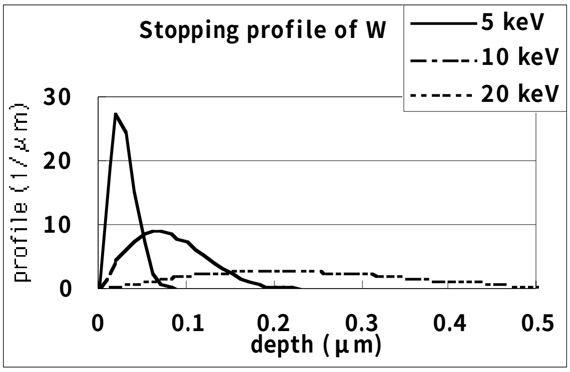

Fig. 2. Stopping profile of tungsten.

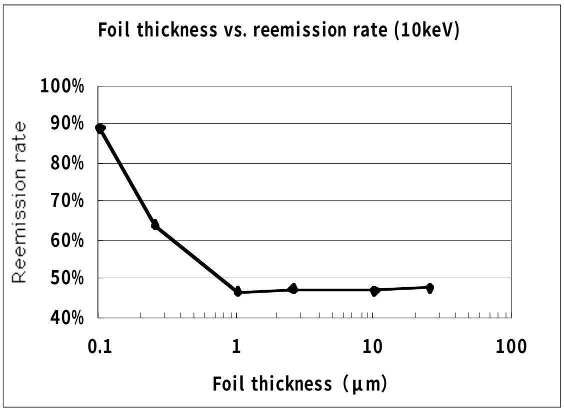

Fig. 3. Moderator foil thickness dependence of positron reemission rate. (Branching ratio of positron reemission is assumed to be 1.0.)

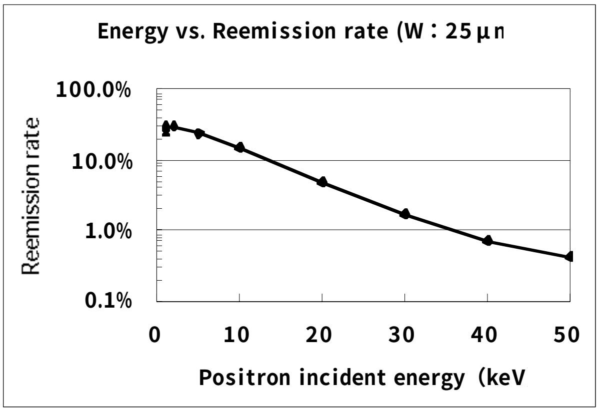

Fig. 4. Incident energy dependence of positron reemission rate. Cross at 1keV is the experimental data. (Default branching ratio 0.33 is used.)

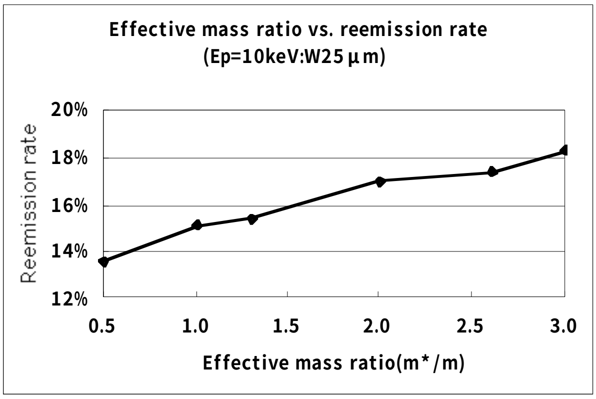

Fig. 5. Effective mass dependence of positron reemission rate. (Default branching ratio 0.33 is used.)

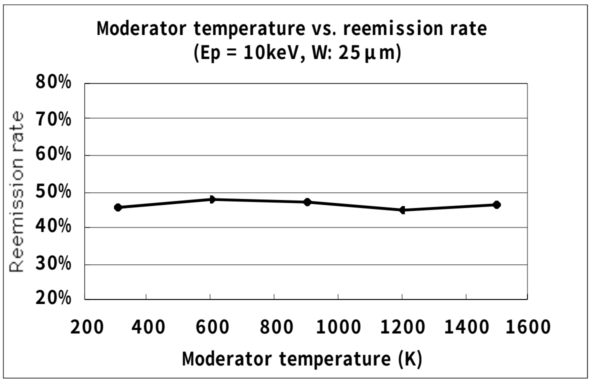

Fig. 6. Temperature dependence of positron reemission rate. (Branching ratio of positron reemission is assumed to be 1.0.)

becomes difficult to reach surfaces for positrons. Higher incident energy positron penetrates deeper than lower energy one, and total path length to the moderator surface becomes longer for higher incident energy position. This means that the probability of annihilation is higher for high incident energy positrons than for low energy positrons in Fig. 4. Collision length of positrons, namely mean diffusion distance L_+, is proportional to the square root of effective mass m^*. Thus the collision length becomes longer and the chance of annihilation smaller for large effective mass (Fig. 5). The temperature dependence of diffusion coefficient has been ignored in the code LEPRE. This may be the reason the temperature dependence of positron reemission rate seems to be very week as shown in Fig. 6.

4. Summary

We have developed a simulation code LEPRE to estimate the moderator efficiency for thermalized positron reemission. Preliminary simulations have been examined. Parameters tested are tracing length, moderator thickness, incident positron energy, effective mass and moderator temperature. In the case of tungsten moderator system, reasonable reemission rates are obtained.

We are now in progress to develop a new Monte Carlo code, add to the EGS4 abilities to LEPRE, in order to trace the positrons from pair production to thermal diffusion and reemission.

References

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