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A New Monte Carlo Photon Transport Code for Research Reactor Hotcell Shielding Calculation using Splitting and Russian Roulette Methods

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1. Introduction

The Monte Carlo method is a technique that is used for numerical analysis which is based on the generation of a sequence of random numbers to obtain a sample values for the problem variables, where sample values of the problem variables are obtained by selecting specific numbers from appropriate ranges for the variables in the problem using probability distribution for such a variable.[1]

The Monte Carlo method was used to build a new code for the simulation of particle transport. Several calculations were done after that for verification, where different sources were used, the source term was obtained using the ORIGEN-S code.[2] Water and lead shield were used with spherical geometry, and the tally results were obtained on the external surface of the shield, afterward the results were compared with the results of MCNPX[3] for verification of the new code.

The variance reduction techniques of splitting and Russian Roulette were implemented in the code to be more efficient, by reducing the amount of custom programming required, by artificially increasing the particles being tallied with decreasing the weight.

2. Source Term and Shielding Analysis

Several source terms were generated using the ORIGENS code. Figure 1 shows the histogram graph of the used sources such as a spent fuel of a 10 MW research reactor, and several radio-isotopes such as Ir-192, Mo-99, and I-131. The spent fuel is assumed to be depleted with a specific power of 272 MW/MTU and burn-up of 196 GWD/MTU. The weight of one fuel assembly is about 2 kg. The other radio-isotopes are assumed to be same weight of 1 kg. In the case of Ir-102, it is irradiated for 100 days with thermal flux of 1E+14 n/cm^{2}s. Mo-99 and I-131 are irradiated for 5 and 10 days with thermal flux of 1E+13 n/cm^{2}s.[4]

The generated source terms in the new code were given in a histogram distribution and also the same source terms were used in MCNPX for the purpose of verification of the new code. The number of particles for lead shield problem is 500,000,000 in order to obtain sufficient accuracy.

Shielding geometry were considered to be spherical in shape. The source was postulated to be a point source at the center of the sphere and different shielding thicknesses were used depending on the shielding material.

The average flux at the external surface of the shield was obtained and compared with the MCNPX f2 tally which is also for the same purpose.

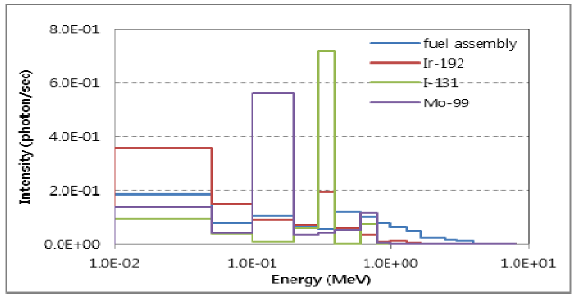

Figure 1 Gamma source terms of the different Sources.

3. Code description

Up to now the new code considers four types of interactions which are photoelectric absorption, incoherent scattering, coherent scattering and pair production.

The language of C++ was used, where several subroutines were implemented**.** Cross sections libraries were obtained from the website of http://atom.kaeri.re.kr**[5]** and it was implemented as a table. Interpolation was used to obtain the cross sections of photon energy in between the energies of the cross section tables.

3.1 Photon Interactions

3.1.1 Photoelectric effect

In photoelectric effect, a photon interacts with electron, the photon disappears, and an electron is emitted. The resulting electron vacancy results in an emission of characteristic X-ray later.

In the new code the photoelectric effect is just considered as pure absorption, and the characteristic X-ray (or the fluorescent radiation) has not been considered yet.

3.1.2 Thomson scattering (coherent scattering)

Thomson scattering is important over the energy range, especially at low energy. If Thomson scattering happens, then the photon is just scattered to the new direction without any energy loss.

The Thomson cross section was used to determine the angle of scattering depending on the equation:

$$T(\mu) = F(x,z)^2 \pi \, r_0^2 (1+\mu^2)$$

where

$F(x,Z)$: Correction factor depending on the initial energy and Z of the interaction atom **[6]**.

μ is the cosine of the scattering angle "cos(θ)".

r_0 is the classical electron radius.

3.1.3 Compton scattering (incoherent scattering)

In this interaction the photon interacts with an electron and scattered with new direction and new energy as well. The scattered photon energy is given by:

$$E' = \frac{E}{1 + \frac{E}{m_e c^2}(1-\mu)}$$

Where $m_e c^2$ is the rest mass electron energy and μ is the scattering angle cosine.

The Klein Nishina formula was used:

$$K(\alpha,\mu)d\mu = S(x,Z)\pi r_0^2 \left(\frac{\alpha'}{\alpha}\right)\left[\frac{\alpha'}{\alpha} + \frac{\alpha}{\alpha'} + \mu^2 - 1\right] d\mu$$

Where

$S(x,Z)$: Correction factor depending on the initial energy and Z of the interaction atom**[5]**.

α:Initial photon energy in unit of $m_e c^2$.

α':Scattering energy of the photon in unit of $m_e c^2$.

μ: The scattering angle cosine.

3.1.4 Pair production

When a photon interacts with a coulomb field, this may results in the production of an electron positron pair. Of course the photon must have an energy that at least equals twice of the electron rest mass energy. So the threshold of this interaction is 1.022 MeV.

In the code it's assumed that the newly produced positron is slowed down and that it produces two 0.511 MeV photons.

3.2 Variance Reduction

The variance reduction technique of geometry splitting was used, where this technique depends on increasing the number of particles being tallied on the required tally surface, by splitting each surviving photon particle depending on the position.

Russian roulette was used to save the time that can be spent on particles of low importance, Russian Roulette was performed by the generation of random number and then make a decision depending on this random number whether to kill the particle or increase its weight.

4. Results and Discussion

Figure 2 and Table 1 show a comparison between the new code and the MCNPX results for a point source at the center of a lead shield where in Figure 2 the X axis represents the distance from the source inside the shield and the Y axis represents the tallied flux. From the figure it can be noticed that the results of the new code when compared with MCNPX show lower flux value than the MCNPX with increasing the thickness, and this is predictable because in the new code, the electron production and transport have not been considered yet, since as we know that a characteristic X-ray (fluorescence radiation) results from the photoelectric effect and a secondary photons that can be resulted from the Compton scattering due to ejection or excitation of the electron also can be produced, which is not considered in the code up to this moment.

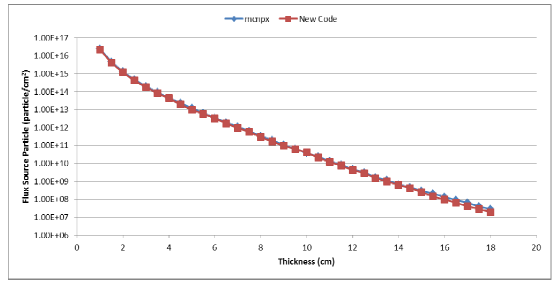

Figure 2 Comparison between the new code results and the MCNPX for the Iodine source, lead shield.

Table 1 Results comparison with MCNPX, fuel assembly source water shielded

Water thickness	20 cm	40 cm	60 cm	80 cm	100 cm
New code flux	2.456E+13	2.928E+12	5.930E+11	1.519E+11	4.566E+10
error	0.0041	0.0079	0.0098	0.01	0.07
MCNPX code flux	3.199E+13	4.045E+12	7.501E+11	1.686E+11	4.471E+10
error	0.0012	0.0061	0.0081	0.0089	0.0090

5. Conclusions and Future work

The code shows lower results than the results of MCNPX, this can be interpreted by the effect of the secondary gamma radiation that can be produced by the electron, which is ejected by the primary radiation.

In the future a more study will be made on the effect of the electron production and transport, either by a real transport of the electron or by simply using an approximation such the thick target bremsstrahlung (TTB) option which is used in MCNPX.

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