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Abstract

The goal of collecting the escaping neutrons and produced prompt gamma yield during the Monte Carlo simulation of a neutron scattering instrument is to help the calculation of the realistic dose rate around the instrument, thus to increase the accuracy of the shielding calculations.

The program packages written for Monte-Carlo modelling of the neutron scattering instruments can only calculate the transport of the thermal or cold neutrons. Other Monte Carlo codes like MCNP or Geant 4 can calculate the transport in the matter of many particles having wide energy ranges. These codes generally cannot take into account the coherent scattering of neutrons i.e. the reflection of the thermal and cold neutrons, and their absorption yield in the reflection coating. The neutron supermirror is a multilayer structure consisting of some hundred to some ten thousand nickel and titanium layers. The neutron is reflected either by total reflection on the top Ni layer or via Bragg reflection on the deeper layers. The Bragg reflection can be described only by using dynamical scattering theory, that means that the neutron absorption in the reflective layer cannot be calculated using simple geometrical considerations. A general linearized conservative (that overestimates the dose rate) calculation however, can be found in the work of Rodion Kolevatov[4].

The aim of this work is to modifiy the Vitess (Virtual Instrumentation Tool for the European Spallation Source) program package to calculate and store the gamma photons produced by the neutrons in the reflective layer of the neutron guides due to prompt gamma activation.

Introduction

Vitess[1] is built to simulate neutron scattering instruments using the Monte-Carlo ray tracing technique. It's philosophy is to provide a user friendly simple tool for building modular virtual instrument. That means that there are predefined neutron optical elements - like sources, neutron guides, monochromators, spin polarizers etc. - with predefined input- and output variables. The components are written in C, but - not like in McStas - they are compiled during the installation i.e. the package is modular and flexible, but the components cannot be changed without changing the source code and recompiling the component.

In a previous work[2] we have calculated the prompt gamma yield by an external program applying geometrical considerations using the position, direction and wavelength values of the reflected and non reflected neutrons.

There are two ways to produce the gamma source file:

- Collection of the gamma photon and escaping neutron yield on the mirror segments, and poduction of a source term with the averaged spectra of photons and neutrons like in [2]
- Collection of the particles in an MCPL[3] file as an input for other Monte-Carlo codes.

Since the first version works only for one program package amongst the programs able to calculate shielding properties, we choosed the second version.

Results

In order to register the gamma yield arising from absorption of neutrons in the coating we changed the source code of the guide component (guide_parallel.c written for parallelized calculation of the neutron transport in neutron guides).

We extended the component by:

- Calculation of the prompt gamma lines during reflection using the linearized conservative calculation of Rodion Kolevatov[4]
- Storing of the produced photons and neutrons escaping from the guide in MCPL structure[3]
- Saving the result in an MCPL file that works as input for Monte-Carlo based program packages used for shielding calculations.

To check the code we simulated a neutron bender which is a curved neutron guide designed for fast curving of the neutron beam. The bender has many neutron channel to have many thin neutron guides enabling the curvature with small radius. Both walls of the channels are coated with neutron supermirror. The material of the wall is thin borofloat glass containing 12 mass % of natural boron. The borofloat substrate does not absorb all of the neutrons due to its width and the scattering of the glass, but the neutrons reaching the substrate have such direction that make them impossible to be reflected on the other reflecting layers. Thus the absorption and the scattering in the other layers and substrates can be calculated by applying geometrical considerations i.e. the escaping neutrons can be handled by other Monte-Carlo programs. In Figure 1. the spatial distribution of the prompt gamma yield is visible projected to different planes, where both the coating, and the decreasing intensity of the beam – the decreased reflection density - is visible. In Figure 2. the gamma spectrum is shown binned in 17 different energy bins.

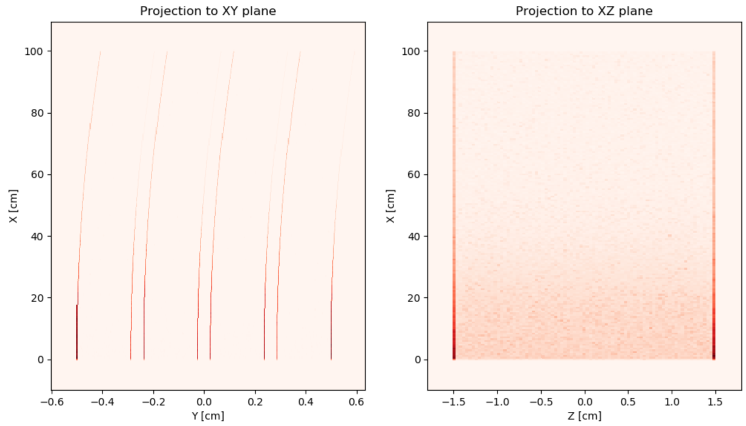

Figure 1. Gamma production yield projected to the horizontal plane (left) and the vertical plane parallel to the incident beam direction.

In the Figure 1. the spatial distribution of the gamma production rate is visible. On the left side the coating on the substrate is clearly visible. At the beginning many neutron got lost due to the high divergence of the neutrons. Later there are larger rate on the outer planes due to the larger reflection angles. On the right side the gamma absorption on the top and bottom plane is clearly visible together with the decreasing of the absorption as the function of the flight path. The increased yield at the walls is due to the projection i.e. the top and bottom walls are parallel with the projection direction.

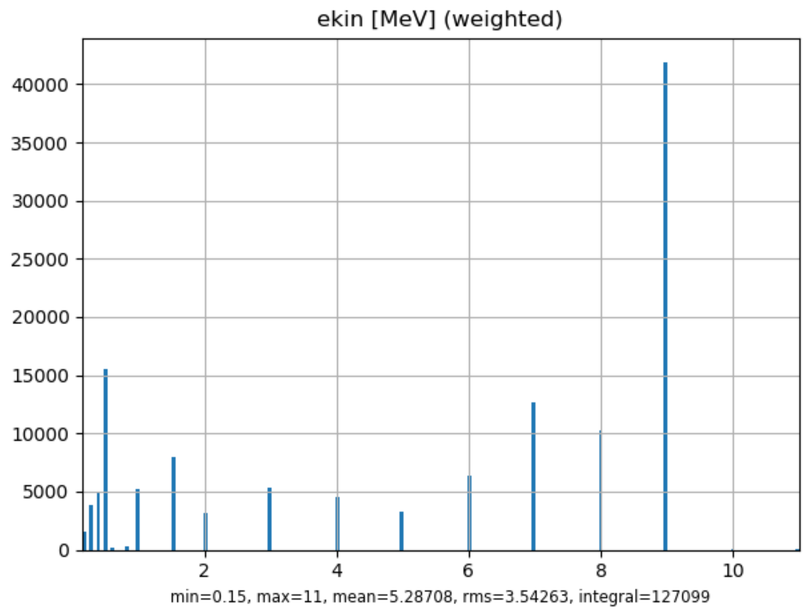

Figure 2: Gamma energy distribution due to prompt gamma absorption in the reflective layer.

In Figure 2 the binned energy distribution of the gamma yield is seen. Instead of the real gamma lines the intensities are collected in 17 energy bins. This solution decreases the number of particles in the MCPL file while stays conservative since the upper limit of the bins are given as energy values. The high energy lines of Ni and Ti are strong showing that the prompt gamma activation of the reflective mirror can have significant part of the dose rate outside the shielding because the half length of the concrete for the half MeV gamma photons arised from absorption of boron is 3-4 times smaller than the half length for the high energy gamma photons.

Conclusion

We have modified the guide component of the Vitess program package to calculate and store the prompt gamma photons produced in the reflective layer of the neutron supermirror and the neutron leaving the neutron guide. The particles are stored in a standardised MCPL file format to give input for other MonteCarlo program packages to calculate the shielding around the neutron guides. We simulated a neutron bender to caluclate the gamma production rate which gave realistic results.

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