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# Development of new computational approaches to radiation transport equation in the nuclear engineering application

Tair Askar, 1st year PhD student, Nazarbayev University, KazakhstanAbstract

Today the radiation plays a crucial role in a wide range of critically-important phenomena. Boltzmann transport equation describes its behavior, which, however, is very hard to solve. In the last several decades, two different classes of computational approaches have emerged. These are the deterministic and the Monte Carlo (MC) or stochastic approaches. Despite of the hard work done towards these techniques, each of these methods has big disadvantages, which limit their accuracy, scalability and efficiency. Our purpose, in this term project, is to develop novel approaches to radiation transport that address these drawbacks especially in the nuclear engineering application. Keywords: Radiation transport equation, deterministic method, stochastic method, Monte Carlo (MC) code, computation.

The radiation transport equation was derived in 1872 by L. Boltzmann. He found out the equation which describes the transport of microscopic molecules. For the atomic particles, neutrons and photons the same equations were derived, and all these expressions are known as a radiation transport equation or Boltzmann equation. In this paper we consider the neutron transport equation, and it is very important to be familiar with it in order to perform any design and analysis in the nuclear reactor core physics. The neutron transport equation is an integro-differential equation, and it is very difficult to solve because of the fact that it has seven independent variables: three for position, two for neutron directions, one for energy and one for time. All of these factors make the neutron transport equation very hard to solve, and, therefore some assumptions were made in order to linearize this equation and have some approximate analytical solution [1].

To find more less close solutions to the neutron transport equation two numerical methods were developed. They are deterministic and stochastic or Monte Carlo methods. With the emergence and fast development of the computers the technology and, especially, the science are achieving very high goals. Based on the powerful computers the Monte Carlo simulation method was developed to estimate with high accuracy the radiation transport equation. The working principle of the Monte Carlo method is based on the probability technique and random variables [2]. This method has its advantages and disadvantages. For advantages we can include minimum limitations on geometry, realistic values of the characteristics of the objects with stochastic forms, good scalability characteristics for parallel computing and the possibility of the simulation of real physical phenomena [1].

The main disadvantages are statistical unclearness and slow rate of the convergence. Another method to solve the radiation transport equation is deterministic method which replaces the independent and continuous variables in this integro-differential equation by the complex set of discrete values. Comparing with the stochastic method (Monte Carlo) it has much more simple technique of value calculation and also the rate of the convergence is faster. However, this method has some drawbacks such as a very bad scalability to the sophisticated geometries, the computational and calculation time becomes enormously big with the dimension of the task. So far many codes have been developed in the world. Today some Monte Carlo simulation codes are very popular to calculate the radiation transport equation due to the factor that they can perform computations of the radiation transport problems with the very sophisticated geometry.

One of such codes is The Super Monte Carlo Program for Nuclear and Radiation Simulation (SuperMC), which was created by the FDS Team. It is very accurate, smart, common, intelligent and pretty much reliable [2, 3, 10]. Another good simulation program is a General Monte Carlo N-Particle Transport Code, which was created by the Los Alamos National Laboratory. It is well designed for computation and simulation of heavy charged particles [11]. Also code TRIPOLI, which was developed by the French Alternative Energies and Atomic Energy Commission, is a 3D Monte Carlo code. It is very good for neutron and photon transport simulation and computation [12]. Serpent is another good Monte Carlo code for simulation and computation of the photon and neutron transport. Serpent is created by the National Technical Research Center of Finland [4].

The European Organization for Nuclear Research (CERN) developed the Geant4 simulation toolkit which can be applied to simulate and compute many kinds of particles, such as gluons, neutrons, muons, ions, protons and others [5]. Fluka is another Monte Carlo computation and simulation package created by the Italian Institute for Nuclear Physics and CERN. It can be useful in computation and transport simulation of different particles including electrons, photons, neutrons, hadrons, neutrinos and many others [6]. Also the Japan Atomic Energy Agency (JAEA) developed the Monte Carlo code PHITS, which can be applied for computation and transport simulation of the mesons, neutrons, ions, photons, electrons and many others [7]. There exist some good deterministic codes as well. The deterministic code DOORS was developed by the Oak Ridge National Laboratory. This code is 1D, 2D, and 3D transport code for calculation and transport simulation of neutrons and photons [8]. Another deterministic code is ATTILA which was created by the Transpire company. It is a 3D code designed for neutron/photon transport simulation and computation.

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