COMPUTER SIMULATION OF FISSION WAVE PROPAGATION IN SUBCRITICAL ASSEMBLY USING CODE MCNP

A.V. Gann, V.V. Gann*

National Science Center "Kharkov Institute of Physics and Technology", 61108, Kharkov, Ukraine

(Received December 12, 2008)

Computer simulation of neutron kinetics in the electron accelerator driven subcritical assembly was carried out using the code MCNP. Propagation of fission wave along the fuel rod to both sides of the neutron source after switching-on the electron beam and neutron field relaxation after switching-off the beam was investigated. It was found that the fission wave couldn't reach the end of the fuel rod for electron beam single pulse time of $3\mu s$. It results in heavy space-time non-homogeneity of energy deposition in the fuel rod.

PACS: 28.50.Dr, 29.25.Dz, 28.41.Kw

1. INTRODUCTION

Monte Carlo code MCNP is used to be successfully applied for calculations criticality, energy deposition and neutron fluxes in fission material containing facilities. In paper [1] stationary distributions of gamma-quanta and neutrons in the electron accelerator driven subcritical assembly were calculated using the code MCNP. Wide spread of high-performance PC's allowed using code MCNP for calculation of non-stationary problems and computer simulation of neutron kinetics. As the linear electron accelerators works in pulse operation mode, investigation of non-stationary processes in subcritical assemblies take on great importance. Neutron kinetics in deuteron beam driven subcritical assembly YALINA was investigated in [2] using code MCNP. Possibility of successful description non-stationary processes in subcritical assembly using point kinetic approximation was shown in work [3] for the most common cases. However, in some cases this approximation is not valid. The goal of this work is methodology development for 3D simulation of neutron kinetics in a subcritical assembly using code MCNP. Propagation of fission wave along the fuel rod to both sides of the neutron source after switching-on and switching-off the beam was investigated. Computer modeling for evolution of neutron field induced by a $3\mu s$ single pulse of the electron beam was also provided.

2. COMPUTER SIMULATION OF NEUTRON KINETICS

Let us consider a simple subcritical assembly containing uranium rod (20% enrichment) of $11.5\,cm$ in diameter and $120\,cm$ in length, surrounded with graphite cylindrical reflector of $120\,cm$ in diameter and $130\,cm$ in length (see Fig.1), which is exiting with an electron accelerator driven external neutron source. The effective neutron multiplication coefficient of this assembly is equal to $k_{eff} = 0.98$. The neutron source is considered to have a cylindrical form of $11.5\,cm$ in diameter and $\Delta x = 1\,cm$ in height, it is situated in the middle of the assembly and emits neutrons having Watt spectrum, which rather likes the real photo-neutron spectra. A time dependent Green function of this problem was calculated using code MCNP, and computer simulation of neutron kinetics after switching-on and switching-off the beam was provided. Fast neutrons coming from the source get to graphite, slow down there, come back to uranium, and produce fission of U^{235} nuclei. Using code MCNP a computer simulation of neutron kinetics in subcritical system shown in Fig.1 was carried out. We used standard time dependent tally for fission

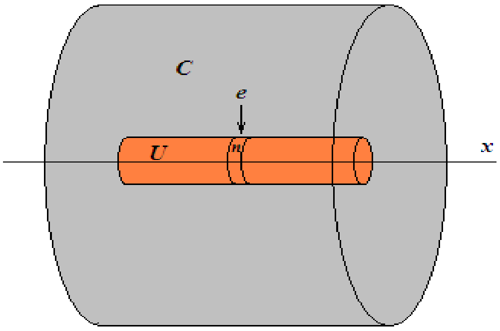

Fig.1. *A model of subcritical assembly*

---

[*] Corresponding author E-mail address: gann@kipt.kharkov.ua

energy deposition in a cell, determining a time dependent Green function of this problem. In that way space distribution of energy deposition in the fuel rod after switching-on and switching-off the electron beam was calculated.

Propagation of fission waves along the fuel rod to both sides of the middle of the rod after switching-on the beam is shown in Fig.2.

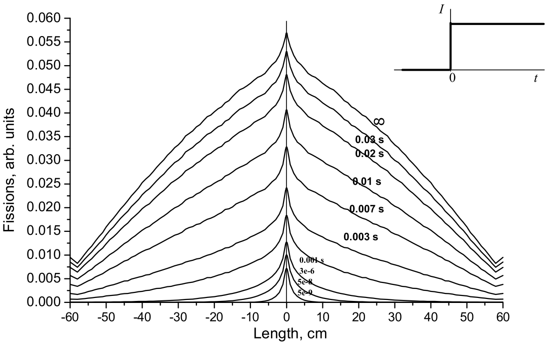

Fig.2. *Propagation of fission waves after switching-on the electron beam*

Time is specified near curves. Symbol ∞ labels the stationary profile of fission rate. Peak of fission near the middle of rod is due to neutron source proximity. Two stages of fission wave propagation process were observed: the first stage – fission due to fast neutrons – takes $10^{-5}\,s$, the second stage based on thermal neutron processes has duration of $\sim\ 0.1\,s$ [4]. During the second stage the fast neutrons are slowing down, being thermalized in graphite, come back to uranium, and produce fission of U^{235} nuclei.

Neutron field relaxation after switching-off the beam is shown in Fig.3. The fission peak in the middle of the rod disappears during time $\sim\ 10^{-9}\,s$, and after time $\sim\ 0.01\,s$ system begins slow relaxing to the fundamental mode.

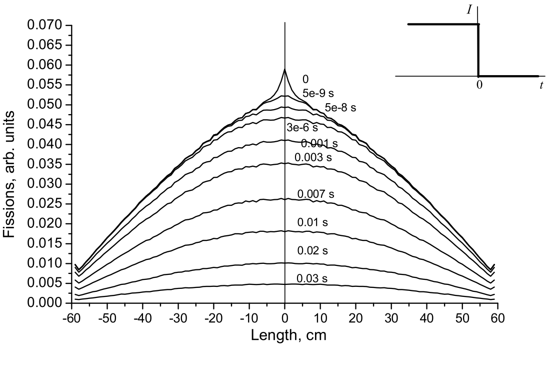

Fig.3. *Relaxation of fission zone after switching-off the electron beam*

Calculation results are presented in Fig.4 showing fission wave which is induced by single electron pulse of 3 micro-second duration: for $t < 3\mu s$ - in Fig.4,a and for $t > 3\mu s$ - in Fig.4,b. One can see that the fission wave couldn't reach the end of the fuel rod for electron beam single pulse duration and the first stage of relaxation process time $\sim\ 4\mu s$. It results in heavy space-time nonhomogeneity of energy deposition in the fuel rod.

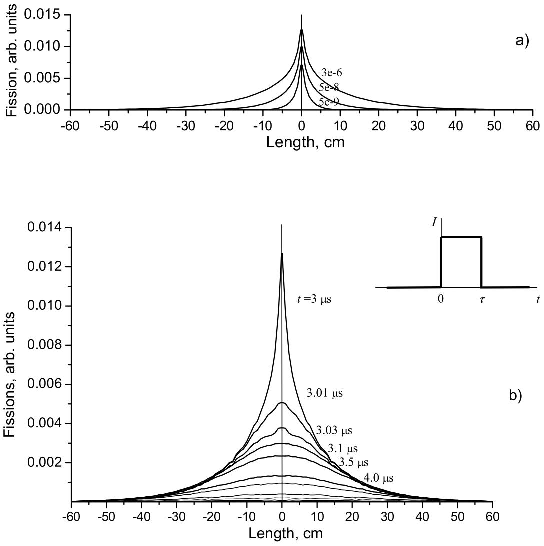

Fig.4. *Evolution of fission wave after electron beam single pulse of duration $\tau = 3\mu s$: a) at $t < \tau$; b) at $t > \tau$*

Fig.5 shows dependence of the total fission rate (areas under the curves in Fig.4) on time for various subcritical assemblies: Fig.5,a - at time interval up to $0.10\,\mu s$; Fig.5,b - at time interval up to $0.12\,s$. The dependence of neutron flux on time analogous to Fig.5,b was obtained in [4] for subcritical assembly YALINA. As one can see from Fig.5,a the total fission rate show week dependence on keff at small time. On the other hand, as it is seen from Fig.5,b, at the large time interval the total fission rate drastically depends on k_{eff}, if it is greater then 0.95.

The curve slope increases $\sim$ 10 times when k_{eff} increases from 0.95 to 0.99. This gives a possibility to carry out the precise measurements of k_{eff}, by switching the accelerator on a single pulse mode, measuring the fission power in subcritical assembly and estimating the relaxation parameter at large time, when system comes to fundamental decay mode.

The results obtained using MCNP in this paper are in qualitative agreement with the experimental results obtained in [2] and with the found in [5] analytical solutions of neutron kinetic equations that describe the accelerator driven subcritical system in two-group approximation.

3. CONCLUSIONS

Full-scale computer simulation of neutron kinetics in subcritical systems using high-performance PC is quite practicable, running time amounts not more then $30\,min$ for simple systems.

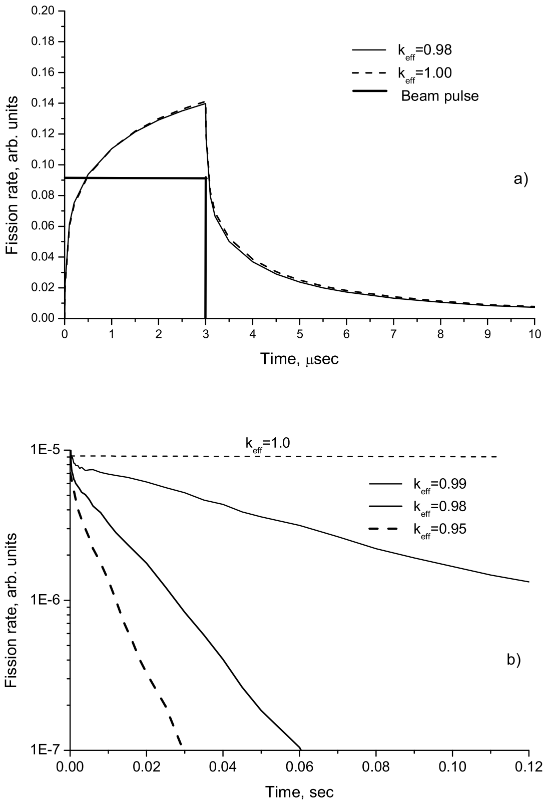

Fig.5. *Dependence of assembly fission power on time for several values of k_{eff} for subcritical assembly under electron beam single pulse*

Pulsed electron beam generates in subcritical assembly the fission wave, which propagates along the fuel rod. The fission wave could not reach the end of the fuel rod during the pulse duration $\sim 3\,\mu s$. So, the process of energy deposition in subcritical assembly is an essentially non-stationary in time and non-homogeneous in space.

There is a possibility of reliable monitoring the assembly criticality by switching the accelerator on a single pulse mode and measuring the response of the system on a single electron beam pulse.

References

1. Y. Gohar, I. Bolshinsky, D. Naberezhnev, et al. Accelerator-driven Subcritical Facility: Conceptual Design Development //*Nuclear Instruments and Methods in Physics Research. Section A.* 2006, v. 562, N2, p. 870-874.

2. C.-M. Persson, P. Seltborg, A. Ahlander, et al. Analysis of Reactivity Determination Methods in the Subcritical Experiment YALINA //*Nuclear Instruments and Methods in Physics Research. Section A.* 2005, v. 554, N1-3, p. 374-383.

3. M. Eriksson, J.E. Cahalan, and W.S. Yang. On the Performance of Point Kinetics for the Analysis Accelerator-driven Systems //*Nuclear Science and Engineering.* 2005, v. 149, p. 298-311.

4. A.V. Gann, V.V. Gann. Computer Simulation of Fission Wave in Subcritical Assembly Using Code MCNP //*Theses of VI Conference on high energy physics, nuclear physics and accelerators.* Kharkov, 25-29 February 2008, p. 74 (in Russian).

5. V.V. Gann. Mathematical Models for Accelerator Driven Neutron Source //*PAST. Series "Physics of Radiation Effects and Radiation Materials Science".* 2007, N2(90), p. 150-154 (in Russian).

МОДЕЛИРОВАНИЕ ВОЛНЫ ДЕЛЕНИЙ В ПОДКРИТИЧЕСКОЙ СБОРКЕ С ПОМОЩЬЮ ПРОГРАММЫ MCNP

А.В. Ганн, В.В. Ганн

С использованием программы MCNP проведено моделирование нейтронной кинетики в подкритической сборке, управляемой внешним источником нейтронов на базе линейного ускорителя электронов. Изучено распространение зоны делений от источника вдоль твэла при включении пучка, и исследован процесс релаксации нейтронных потоков при выключении пучка. Показано, что за время импульса электронного пучка длительностью 3 мкс волна не успевает добежать до концов твэла, и это приводит к сильной пространственно-временной неоднородности энерговыделения в твэле.

МОДЕЛЮВАННЯ ХВИЛІ РОЗПОДІЛІВ У ПІДКРИТИЧНІЙ ЗБІРЦІ ЗА ДОПОМОГОЮ ПРОГРАМИ MCNP

А.В. Ганн, В.В. Ганн

З використанням програми MCNP проведено моделювання нейтронної кінетики в підкритичній збірці, керованої зовнішнім джерелом нейтронів на базі лінійного прискорювача електронів. Вивчено поширення зони розподілів від джерела уздовж твела при включенні пучка і досліджено процес релаксації нейтронних потоків при вимиканні пучка. Показано, що за час імпульсу електронного пучка тривалістю 3 мкс хвиля не встигає добігти до кінців твела, і це приводить до сильної просторово-тимчасової неоднорідності енерговиділення у твелі.