MONTE CARLO MODELING OF ELECTRONUCLEAR PROCESSES IN EXPERIMENTAL ACCELERATOR DRIVEN SYSTEMS*

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The paper presents results of Monte Carlo modeling of an experimental Accelerator Driven System (ADS), which employs a subcritical assembly and a 660 MeV proton accelerator operating at the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research in Dubna. The mix of oxides (PuO_2 + UO_2) MOX fuel designed for the reactor will be adopted for the core of the assembly. The present conceptual design of the experimental subcritical assembly in Dubna is based on the core with a nominal unit capacity of 30 kW (thermal). This corresponds to the multiplication coefficient $k_{\mathrm{eff}} = 0.945$ and the accelerator beam power of 1 kW.

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1. Introduction

As the first step in the studies of characteristics of ADS, a metallic weapon grade plutonium fuel was proposed. ("Pluton" project [1-7]). But, the results of calculations have shown that MOX fuel ($25\%PuO_2+75\%UO_2$) is better than metallic plutonium for this subcritical assembly.

The proposed ADS facility consists of: a 660 MeV proton accelerator, beam bending magnets , a spallation target with different materials, a subcritical core based on MOX fuel elements, reflectors, concrete shielding, control and auxiliary systems.

2. Main characteristics of the installation

The schematic layout of the subcritical assembly is presented in Fig. 1.

The assembly is driven by the 0.1–2 μA proton current from the 660 MeV phasotron. Main parameters of the ADS facility are given in Table I.

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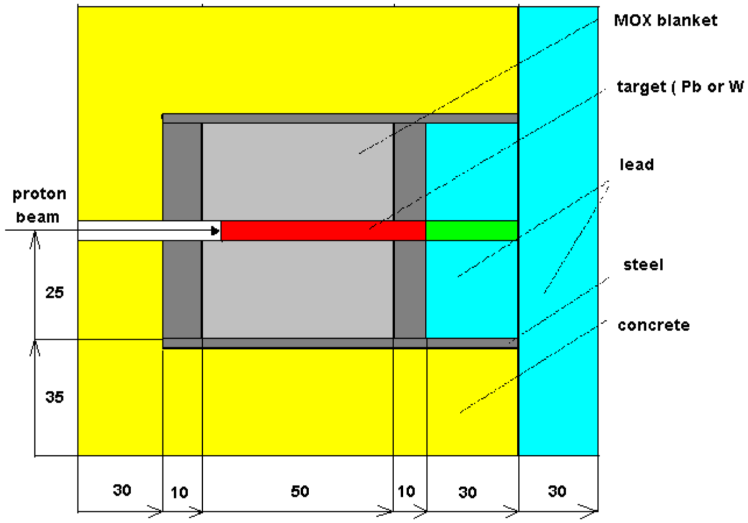

Fig. 1. Subcritical assembly scheme (sizes are given in cm).

TABLE I

Main parameters of the ADS facility:

Max. proton beam energy	660 MeV
Max. beam power	1.2 kW
Proton energy deviation	6 MeV
Max. beam intensity	2 10^{13} p/s
Number of protons per pulse	0.8 10^{11}
Repetition rate	250 Hz
Pulse length (fwhm)	20 μs
Pulse microstructure:	
Bunch length	10 ns
Interval between bunches	70 ns
Number of bunches per pulse	300
$k_{\rm eff}$	0.945
Energetic gain	30
Max. neutron intensity	6.34 10^{15} n/s
Max fission power	36 kW
Density of fissile material	10.96 g/cm^3
The full length of a fuel element	70 cm
Core length of a fuel element	50 cm
Core diameter	50 cm
Fuel load	524.33 kg
Fissile material	(25%PuO_2 + 75%UO_2)

The proton beam is transported horizontally to the target through a vacuum track provided with a concrete shielding. The proton beam interacts with the target placed in a steel tube. The target is surrounded by a blanket containing MOX fuel. The fuel is placed in a stainless steel vessel. The core is surrounded by a reflector and concrete shielding. The target and fuel elements are cooled by helium. To measure the spectra of the neutrons leaving the subcritical assembly, we propose to use a spectrometrical method of neutrons slowing down time in a block of lead. The fuel designed for the fast breeder BN-350 reactor will be adopted for the core of the assembly. The fuel elements with external diameter equal to 6.9 mm are located in a triangular grid. The full length of a fuel element with its end details is about 70 cm, when the core length is 50 cm. The fuel element consists of a stainless steel tube 0.3 mm thick with the plutonium and uranium oxides mixture. The ADS facility will be placed in the main accelerator hall equipped with radiation shielding. In the case of essential variations of radiation fields and the danger caused by a possible seal failure of the MOX rods, an automated system will be installed for radiation monitoring including the volume activities of gases and sprays in the installation. The experience of monitoring the radiation level obtained at the pulsed reactor IBR-30 currently operating at JINR will be used in this case.

3. Results of calculations

Properties of the experimental facility have been investigated by using the particle transport Dubna CASCADE code. The calculated quantities were: dependence of the energetic gain G on the proton energy, the neutron multiplication coefficient and the neutron production for different target materials. We have considered a cylindrical core with a PuO_2, UO_2 blanket, radius 25 cm, and the target with different materials (lead radius r=4 cm or tungsten radius r=2 cm). (See Fig. 1).

The blanket was considered to be homogeneous with a composition of: ^{239}Pu (11.02 %), ^{238}U (33.85%), ^{235}U(0.23%), O_2 (5.93%), steel (20 %) and helium as a coolant (30 %). The reactor core was surrounded by a steel vessel 2.0 cm thick and a heavy concrete shielding about 30 cm thick.

The dependence of the energetic gain and the number of neutrons per proton produced in the system with the lead and tungsten targets at various proton beam energies is presented in Fig. 2.

The energetic gain G is a ratio of the heat produced in the device to the beam energy. A decrease in the energy gain (see Fig. 2(a)) at low energies is caused by ionization losses of primary protons. For the supposed 650 MeV energy of protons the energetic gain is only 22% less than for 1.5 GeV. The energetic gain for the lead target is 20% more than for the tungsten

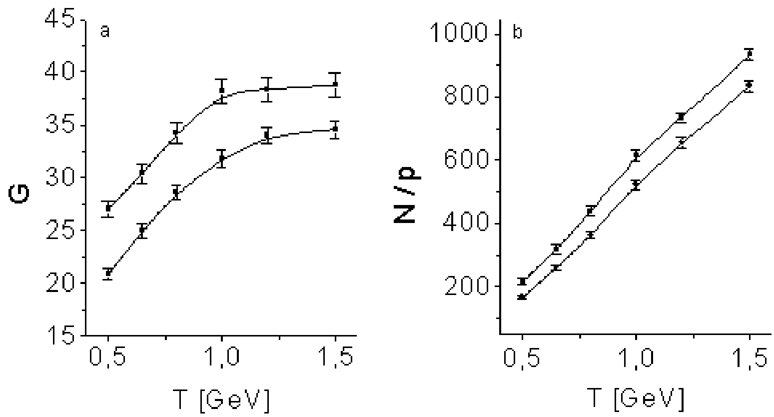

Fig. 2. Energetic gain G and the number of neutrons per proton produced in the system N/p *vs* incident proton energy T for $k_{\mathrm{eff}} = 0.945 \pm 0.003$. (The upper curve — for the lead target, the lower — for tungsten one.)

target. The smaller number of neutrons in the system with tungsten target (see Fig. 2(b)) in comparison with the lead target is explained by a strong absorption of fission neutrons in tungsten. Using $k_{\mathrm{eff}} = 0.945$ from Fig. 2(a) we find the average gain $G = 30$ for 650 MeV proton energy and $G = 38$ for 1.5 GeV proton energy. Assuming that the average proton beam intensity is equal to 2 10^{13} p/s (see Tabl. I) and the number of neutrons produced by 650 MeV protons is 317 (Fig. 2(b), we obtain the total number of neutrons produced in the system equal to 6.34 10^{15} n/s.

The dependence of the energetic gain G and number of neutrons per proton produced in the system on neutron multiplication coefficient k_{eff} is shown in Fig. 3.

According to Fig. 3(a), we have found that the Gaussian expression, with the following parameters: center= 1.112±0.002, width= 0.117±0.001, area= 137.5±0.3, offset= 19.6±0.1 can be used to calculate the ADS energetic gain for 1.5 GeV protons. We define the commercial power P_{com} of ADS:

$$P_{\mathrm{com}} = P_{\mathrm{ADS}} - P_{\mathrm{acc}} \,,$$

where: P_{ADS} — electrical power of ADS, P_{acc} — electrical power of accelerator. Assume that the power of the 1.5 GeV proton accelerator is 20 MW, k_{eff}=0.988, the ratio of the heat power of ADS to the beam power G=122 (see Fig. 3(a)), accelerator efficiency of 0.4 and the efficiency transformation from heat into electricity 1/3, we obtain ADS power P_{ADS} = 325 MW. In this case the commercial power will be P_{com} = 305 MW. Using k=0.988 from Fig. 3(b), we find the number of neutrons per proton produced in the

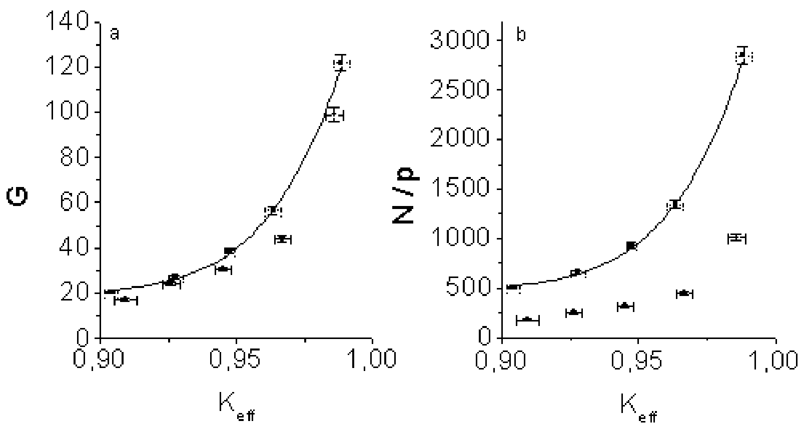

Fig. 3. Energetic gain G and the number of neutrons per proton produced in the system N/p *vs* neutron multiplication coefficient k_{eff} for the core with the lead target and the blanket containing: 23, 24, 25, 26, 27 % of PuO_2 at incident proton energy 1.5 GeV (the upper curve) and 650 MeV (the lower points). The solid line is Gaussian function for 1.5 GeV protons.

system N/p =2850 for 1.5 GeV proton energy. The total intensity of the produced neutrons in commercial ADS will be 9.4 $10^{19}\mathrm{s}^{-1}$. Neutron flux in this case will be 2.5 $10^{15}\mathrm{s}^{-1}\mathrm{cm}^{-2}$. This flux will be enough for incineration of actinides inside the reactor.

4. Experimental program

The main goal of the experiment is to study physics of ADS. That is why we propose the following:

- To study the energetic gain for different target materials (lead, tungsten, mercury, natural uranium), different current and energy of protons;

- To develop the monitoring on-line of the multiplication coefficient k_{eff} by correlation methods;

- to investigate the response of the subcritical system (neutron production, number of fissions) on the power, intensity and duration of the individual proton pulse at different levels of multiplication coefficient values of the zone. Multiplication coefficient values must be varied in the interval 0.94–0.95 by means of the special zone reflectors. Proton pulse duration will be varied from 5 to 20 microseconds.

- to carry out shielding for high-energy spallation neutrons. Energy and angle neutron distributions behind the shield area will be measured.
- to examine transmutation cross-sections and transmutation rates of different samples of radioactive isotopes in the neutron spectrum available in the assembly. Some radiochemical methods will be included in irradiated samples analysis.
- to study the time evolution of the nuclides concentration in fuel elements after long-term irradiation.

The results of the measurements will be compared with the results of the calculations of the corresponding processes to improve further the computation methods.

5. Conclusion

It is shown that the proposed project allows one to obtain the data for designing a full-scale set up for the energy production, incineration of plutonium and actinides, and transmutation of fission products.

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