Power Upgrade of the Subcritical Assembly in Dubna (SAD) to 100 KW

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Abstract

The paper present 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 design of the experimental subcritical assembly in Dubna (SAD) is based on the core with a nominal unit capacity of 30 kW (thermal). This corresponds to the multiplication coefficient Keff = 0.95 and the accelerator beam power of 1kW. A subcritical assembly has been modeled in order to increase power of this experimental set up. Different options for the target and fuel elements have been considered.

1. Introduction

As the first step in the studies of characteristics of ADS, a combination of installations available at JINR – the plutonium reactor IBR-30 and the 660 MeV proton phasotron was proposed [1], [2]. In the next step the subcritical assembly with a metallic weapon grade plutonium fuel was proposed ("Pluton" project) [3], [4]. However, the results of the calculations have shown that MOX fuel (PuO_2 + UO_2) is better than metallic plutonium for this subcritical assembly [5]. Simulation of various types of electronuclear systems and their components due to the preparation of the project SAD with MOX fuel is presented in [5], [6], [7], [8], [9] and [10].

2. Basic parameters of SAD

The proposed ADS facility consists of the 660 MeV proton accelerators, beam bending magnets, a spallation target with different materials, a subcritical core based on MOX fuel elements, reflectors, concrete shielding, control and auxiliary systems. The proton beam is transported vertically to the target through a vacuum track provided with a concrete shielding. The proton beam interacts with the lead or tungsten target. A blanket containing MOX fuel surrounds the multilayer target. The fuel is placed in a stainless steel vessel. A lead reflector and concrete shielding surround the core. The target and the fuel elements are cooled by air.

The fuel designed for the fast breeder BN-350 reactor will be adopted for the core of the assembly. The 18 fuel elements with external diameter equal to 6.9 mm are located in a hexagonal fuel assembles. The full length of a fuel element with its end details is about 70 cm, when the core length is 57 cm. The fuel element consists of fuel pellets diameter 5.95 mm with the plutonium and uranium oxides mixture (0.297 PuO_2+0.703 UO_2). In the core would be maximum 141 fuel element assembles. The distance between the center of the fuel assembles is equal to 36 mm. The ADS facility will be placed in the special hall equipped with monitoring system.

3. Power of subcritical assembly.

Special attention has been paid to a removable target and a subcritical core design for different levels of subcriticality. Replaceable spallation targets of different materials – W, Pb, Be – have been investigated. The importance of spallation neutron source has been assessed and the global energy gain has been estimated for each configuration. Simulations have been performed using two different codes - Dubna CASCADE code and MCNPX. An increase of the multiplication coefficient from 0.952 to 0.972 can result in a power increase SAD to about 100 kW. This can be achieved by either of the two procedures:

1. Replacement of the central section of lead target by the tungsten target, replacement of the last layer of lead spallation target by beryllium (Fig.1) and simultaneous increase of the beam power to 2 kW.

2. Replacement of the last layer of the lead spallation target by fuel element assemblies, replacement of the central section of lead target by tungsten target (Fig.2) and simultaneous increase of the beam power to 2 kW.

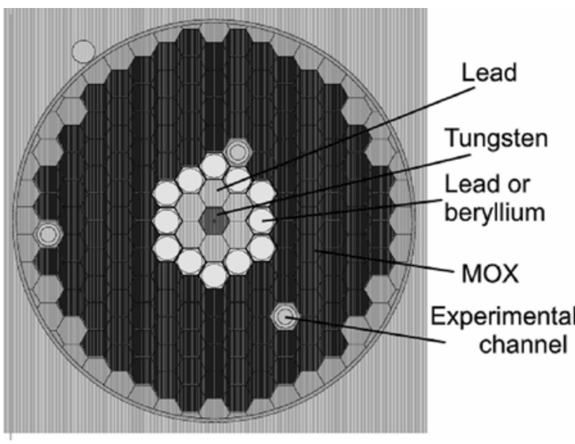

Fig. 1: Horizontal cross-section of the SAD Core: 133 fuels assemblies with tungsten, lead and beryllium target

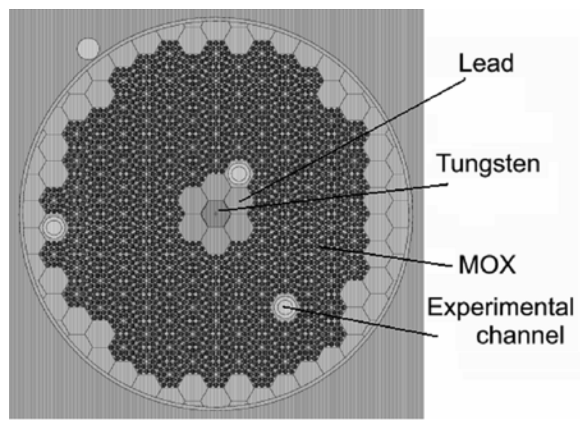

Fig. 2: Horizontal cross-section of the SAD core: 132 fuels assemblies with tungsten and lead target

The main fraction of the accelerator beam power is absorbed in a central section of the target. It therefore makes sense to use tungsten as the central part of the target with its higher melting temperature and higher density. Insertion of a tungsten section into the Pb-target can facilitate an increase of beam power from 1 kW to 2 kW. Emerging cooling aspects at this beam power level need to be investigated in details but first estimates do not indicate serious problems.

In Figure 3 the neutron flux density is presented in experimental channel near the spallation target for different geometry of subcritical assembly.

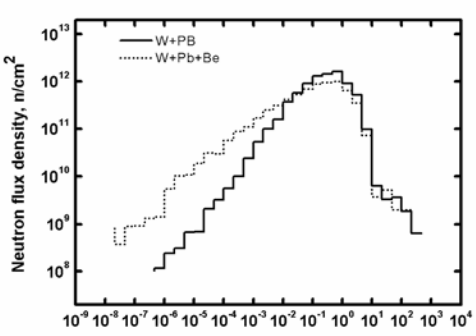

Fig. 3: Comparison of neutron spectra in experimental channel near target for geometry of core presented on Fig.1 and Fig.2

As we can see from Fig.3. the high energy part of spectrum is the same for different geometry of active zone.

3.1. The energy deposition.

The energy deposition (in Watts) in lead-lead and tungsten-lead target irradiated by protons with energy 660 MeV and beam power 1 kW is presented in Table 1.

Table 1: Energy realized (Watts) in multilayer targets

Spallation target	Pb+Pb+Pb	W+Pb+Pb
Central part (lead or tungsten)	463	586
First layer lead	158	92
Second layer lead	88	78
Total	709	755

As we can see from the table the main part of the energy is released in the central section of the target. It means that for a beam power 2 kW it will be better to use tungsten in the central target.

The dependence of energetic gain in the system with the lead target at various keff is presented in Fig.4.

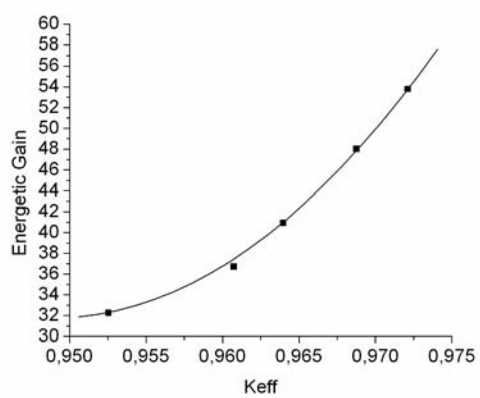

Fig. 4: The dependence of energetic gain on keff for subcritical system with lead target

Using the Fig.4. we can find the average gain G=30 for keff=0.95 and G=50 for keff=0.972.

The dependence of system power for different subcritical core design and for different levels of subcriticality is presented in Table 2.

Table 2: Subcritical assembly parameters for different targets

Spallation target	Pb	W+Pb+Be	W+Pb
Fuel element assemblies	133 -141	133	132
Keff	0.952 -0.972	0.974	0.974
Energetic gain	30 - 50	51	57
Beam power	1 kW	2 kW	2 kW
System power	30-50 kW	102 kW	114 kW

As we can see from table the maximum system power will be for subcritical assembly with tungsten - lead target presented in Fig.2.

3.2. The neutron flux density.

As we know transmutation radioactive waste needs neutrons with different energy. This is possible to achieve using different reflectors. Using an inner beryllium reflector between the spallation target and the fuel element assemblies, we may increase the neutron flux with different energy spectrum in experimental channels. The results for neutron spectra calculations for three vertical channels in the fuel part of the core (1-3) for different geometry of subcritical assembly are shown in Fig.5 and Fig.6.

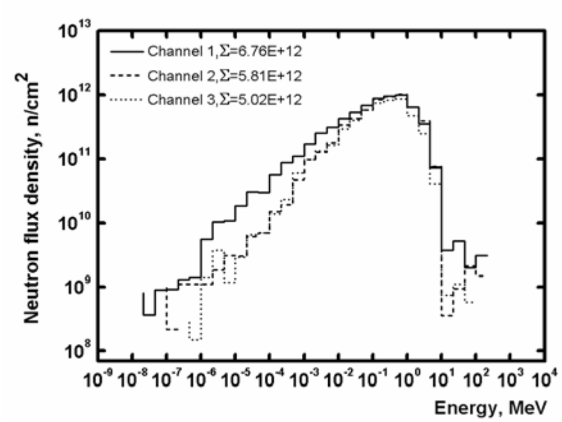

Fig. 5: Neutron spectra in the centres of vertical experimental channels 1-3 for subcritical assembly with tungsten, lead and beryllium target

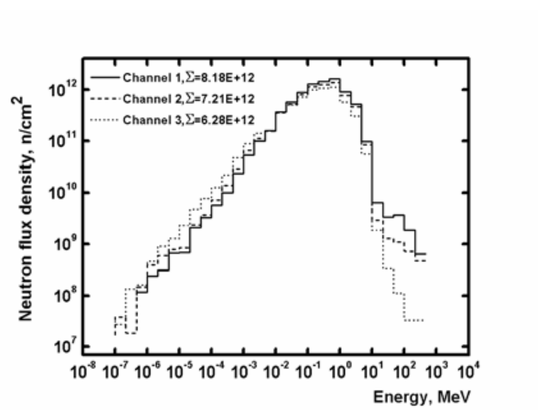

Fig. 6: Neutron spectra in the centers of vertical experimental channels 1-3 for subcritical assembly with tungsten plus lead spallation target

As we can see from Fig.5 and Fig.6 the maximum neutron flux is for neutron energy 1 MeV. The neutron spectra in energy region less then 1 MeV is different for beryllium mainly in first channel. The number of low energy neutron increase with increasing keff. Neutrons with energy greater than 1 MeV need special attention from shielding point of view. The spectra of high energy neutron are the same for different targets.

Conclusions

Based on maximum target power of 2 kW and on sub-criticality level slightly below 0.972, the SAD experiment could be run for specific experiments at a level of about 100 kW. Cooling aspects at this power level can be easily solved by the change of the central part of lead target on tungsten.

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