THE PHYSICS SCALE MODEL PROJECT OF TWO-CASCADE POWER BLANKET FOR ELECTRONUCLEAR REACTOR

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A danger of non-controlled power increase on selfcritical atomic power stations and low economy of nuclear fuel used in them (in energy release there participate practically only isotope 235U whose nature uranium fraction constitutes 0.72%) assign a priority to creating principally new free from explosion accidents subcritical reactors with a significant increase of nuclear fuel "combustion" fraction in them.

Yet since 50-s years the world scientific community have been considering going over to electronuclear facilities with a subcritical core (blanket) as one of possible ways for rising safety of nuclear power facilities (NPF) [1-6]. In this case NPF core operates in a mode of enhancing the neutron flux of external source supplied by a particle accelerator. Going over to electronuclear facilities allows to significantly decrease a probability for reactivity accidents occurrence and simplify the reactor power control, as in this case it may be performed through the change of particle current in the accelerator.

The main difficulty in the way of electronuclear facilities implementation consists in too high requirements to accelerator power. For this purpose there are required, for example, proton beams of (40-100) MW.

Lowering of requirements to the accelerator power, as it was shown in papers [7, 8], can be reached on the basis of using two-cascade blankets with cascade one-way neutron coupling, i.e. using diode blankets. From the mentioned papers there follows that the property of unidirectional conduction of cascade neutron coupling is major at this process. The factor of blankets two-cascade structure brings no advantages without it. In all cases, in order to benefit significantly by going over to a two-cascade structure of blankets, there is necessary to provide a high (on 100-1000 - fold level) relation of factors of cascade coupling.

Physically, the most efficient method to create a cascade diode coupling was proposed at VNIIEF [9]. This method is based on application of threshold fissile material - neptunium-237 in one of cascades and separation of cascades by a neutron moderator layer. Initially, the method was oriented to applications in the field of pulsed boosters serving as neutron irradiators. Development of these devices faces the difficulties, similar to those in case of electronuclear power facilities, as the generation of neutron pulses with short duration in boosters necessary for irradiating experiments usually needs very powerful pulsed electron accelerators. Basing on the mentioned proposal, at VNIIEF in Russia and in Sandia National Laboratories in the USA there were developed designs of irradiating boosters with unique parameters [10, 11]. Boosters taking the two-cascade structure with cascade diode coupling allowed (according to calculations) to decrease abruptly neutron pulses duration (at invariable accelerator power).

Basing on the proposals and analysis of papers [9, 12], in the early eighties there was developed in VNIIEF a design of booster-reactor "Kaskad" (BR-K) with the internal core made of 237Np- + Ga alloy and the external core – of uranium-molybdenum alloy [10]. It was supposed that BR-K would operate combined with high-current electron accelerator LIU-30 [13] which is to provide the core of neptunium-237 with 1·1015 primary neutrons per 20-100 ns long pulse. In the design of BR-K there are taken into account to a maximum extent the requirements conditioned by the desire to get possibly highest values of neutron fluence and gamma-radiation dose per pulse at points of samples irradiation, larger volume of irradiation cavities and to make easier the access to the places of samples irradiation. The selection of cylindrical booster-reactor geometry, horizontal orientation of its axis, degree of uranium enrichment in the external core, volume and configuration of internal cavity was governed by the above requirements.

Basic elements of BR-K design are presented on Fig.1. BR-K has a cylindrical shape with coaxial arrangement of internal and external cores, layer of tungsten, accelerator target and cavity for irradiation. The axis direction is horizontal.

The internal core (core-1) is made of alloy of 237Np with 9% of gallium by mass. The diameter and length of core 1 are correspondingly equal to 23 and ~25 cm. The full mass of alloy in core 1 constitutes 120-130 kg. Core 1 is collected of cylindrical components 0-6, 6-16 and 16-23 cm in diameter and ~8 cm long.

The external core (core 2) is made of alloy of uranium (36% -enrichment by ^{235}U) and 9% of molybdenum by mass; it has a form of a hollow cylinder 105 cm long with a maximum external diameter ~70 cm, diameter and length of the channel for irradiation is equal to 36,5 cm (the dimensions are specified by fuel. The total mass of alloy in core 2 is equal to ~2400 kg.

The space between core 1 and core 2 is filled with tungsten (to be more precise - with the alloy of tungsten, nickel and copper; mass content: tungsten - 95%, nickel - 3%, copper - 2%) of 18,0 g/cm^3 density.

It should be mentioned, that all known papers on diode two-cascade systems refer to calculation-theoretical or design ones. The experiments on diode systems have been conducted nowhere till now. Theoretical conclusions on diode cascade systems properties are to be proved experimentally.

BR-K VIEW IN AXIAL SECTION [10]

Performance of this type experiments is one of main tasks of the proposed investigations. The planned experiments will aim, first of all, at affirmation of reality of information on strong suppression of one of cascade neutron coupling factors due to neptunium-237 employment as well as to the fact that strong suppression of one of coupling factors really raises electronuclear facility efficiency.

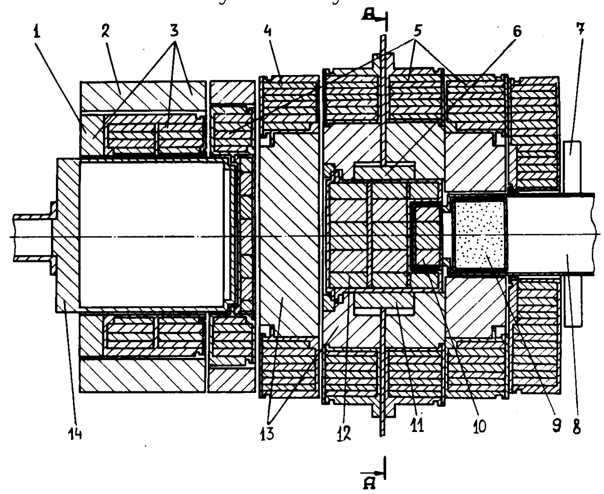


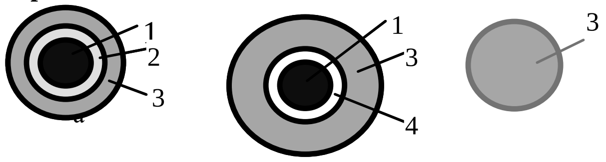
Fig. 1.
1 - reflector of neutrons; 2 - regulating block of core 2 (RB-2); 3 - mobile block of core 2 (MB-2); 4 - emergency block (EB); 5 - immobile block of core 2 (IB -2); 6 - regulating block of core 1 (RB-1); 7 - stop-block (SB) and pulse block (PB-2); 8 - channel for bremsstrahlung run; 9 - ^{6}LiH-type neutron moderator; 10 - mobile block of core 1 (MB-1); 11 - pulse block of core 1 (PB-1); 12 - immobile block of core 1 (IB-1); 13 - tungsten massif; 14 - container for irradiated samples.

At present at our institute there are planned investigations of physics blanket neptunium cascade model. As a primary neutron generator it is supposed to use a target of the electron linear accelerator LU-50 [14], operating at VNIIEF; the neutron yield from this target can be brought up to 10^{14} n/sec. The accelerator is designed to operate continuously in the mode of generation of neutron pulses with a different amplitude and repetition frequency up to 2400 Hz.

As a result of a large number of calculations conducted under Monte-Carlo programs there were grounded the most rational configurations of diode two-cascade blanket models, suitable for carrying out experiments under the Project. There were selected blanket configurations using comparatively small fissile materials amounts and known to satisfy nuclear safety requirements without taking special safety measures (Fig.2).

Besides the above-mentioned arguments, the expediency of low k_{eff} value assemblies employment in the planned experiments is also proved by the fact that exactly on such assemblies type there is possible to compare directly data of experiment and numerical calculation. As it is shown in paper [8], the direct calculation of k_{eff} and total numbers of diode blanket fissions with the help of modern Monte-Carlo programs, in the case of blankets with large value of k_{eff} (>0.9), is extremely difficult. In this case, k_{eff} and total fission numbers are calculated with the aid of theoretical formula of relationship between these magnitudes and easily calculated factors of neutron multiplication in cascades k_{eff1}, k_{eff2} and factors of cascade neutron coupling k_{12}, k_{21}.

Model assemblies with low k_{eff} planned for executing experiments



a b c

a - two-cascade assembly with an intermediate moderator layer; b - two-cascade assembly without an intermediate moderator layer; c - one-cascade assembly; 1 - neptunium-237; 2 - polyethylene; 3 - high-enriched uranium; 4 - vacuum.

Diagrams of model assemblies with k_{eff}=0.53

Neutron
source

0	2,9	8,0	9,07 cm
Neptunium-237	Polyethylene	Uranium	
ρ = 20,45	ρ = 0,92	ρ = 18,7 g/ cm^3	
M = 2 kg		M = 18,0 kg	
		^{235}U - 90%	
		^{238}U - 10%	

Neutron
source

0	**2,9**	**8,0**	**9,80 cm**
Neptunium-237	Vacuum	Uranium	
ρ = 20,45		ρ = 18,7 g/ cm^3	
M = 2 kg		M = 33,6 kg	
		^{235}U – 90%	
		^{238}U – 10%	

Neutron source

0	4,53 cm
Uranium	
ρ = 18,7 g/ cm^3	
M = 7,28 kg	
^{235}U – 90%	
^{238}U – 10%	

Fig.2.

In the experiments there will be measured the factors of section neutron coupling k_{12}, k_{21} and, what is more important, absolute spatial distributions of fissions density in sections allowing to determine total numbers of fissions in cascades and assemblies in the aggregate, with normalization per one source neutron. The data of measurements on two-cascade assemblies will be compared to similar measurements on one-cascade assemblies. At this process, an important requirement is maintenance of equality of k_{eff} of assemblies. Removal of intermediate layer diminishes the magnitude of cascade coupling factors relation, but, however, in this case the assembly also remains a two-cascade diode one. The intermediate layer removal may be compensated through a change of uranium layer thickness or by an external reflector.

The computations testify to acceptability of these assemblies with low k_{eff} values as a base for conducting the planned experiments. The difference in efficiencies of one-cascade and diode two-cascade blankets is not large in this case, but, however, it is quite enough to be noted in the experiment. The aforesaid is proved by data for the models with k_{eff} =0.53. Total fission numbers in these blanket models, referred to one neutron of a central source with a fission spectrum, are equal to 1.26; 0.803 and 0.633. This means that efficiency of the two-cascade diode blanket models is 1.99 and 1.27 times higher than that of the one-cascade blanket (cascade coupling factors k_{21},k_{12} in the upper assembly and the following one equal, relatively: 0.657; 0.0078 and 0.337; 0.017).

In spite of small masses of used fissile materials and, correspondingly, low levels of keff neutron multiplying factors, these blanket configurations provide a possibility for precise experiment recording of quantitative indexes of these models of diode two-cascade blanket as compared to common blankets indexes. As expected, the experimentally obtained data will directly prove the rightness of theoretical knowledge on diode blankets advantages and will serve a reliable benchmark base for correcting calculation methods.

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