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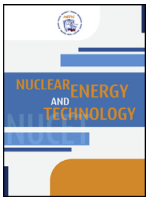

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On the physical conditions for arising a controlled fusion chain reaction supported by neutrons in fusion facilities with magnetic plasma confinement

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Abstract

When nuclear reactors operate, a fission chain reaction (FCR) of heavy nuclei proceeds. In thermonuclear facilities with magnetic confinement of (DT)-plasma as a result of fusion reaction, along with the energy generation, the neutrons are generated too. Due to the extremely low concentration of ions in the plasma compared with the concentration of atomic nuclei in the blanket a neutron balance in the facility is completely determined by the blanket physical properties.

The aim of this work is to create the physical conditions in which the rates of neutrons absorption in the plasma and in the blanket would be comparable. Such conditions could arise, if, first, the plasma has a component with a large cross-section of neutron absorption (for example 3-He, 6-Li and 10-B), and second, if materials of the blanket are characterized by record low neutron capture cross-section (e.g., 208-Pb, heavy water, graphite). Thus, in general, a controlled fusion chain reaction supported by neutrons (FCRn) could also take place in the thermonuclear facility.

During implementation of the work a concept of suppressed neutron generation (D-3He)-cycle was used. To substantiate the idea suggested in the article, it is proposed to use (DT-3He)-fuel cycle facilities with low neutron absorption blanket.

We obtain the following results:

(1) Unlike the suppressed neutron generation (D-3He)-fuel cycle, the (DT-3He)-fuel cycle considered here is profitable by its potential for generation of neutrons, i.e. the fact that there could be generated neutrons, which are also generated in FCRn.
(2) Tritium breeding as a result of n(3-He, T) 1H reaction takes place in the plasma volume rather than in the blanket (as is usually the case). Tritium will be reproduced in the plasma, where it should be consumed, which will improve its use.
(3) An additional heating of the plasma as a result of neutron absorption in the plasma is provided.

The fusion neutron source is considered to be the "richest": neutron generation is accompanied by relatively small-scale processes. The thermonuclear facility with low neutron absorption blanket under consideration here could create a high density neutron flux in the blanket. It can be concluded from the above that such thermonuclear facilities could be used for fast transmutation of long-lived fission products with low neutron absorption cross-section, and perhaps even without their preliminary isotopic separation.

Keywords: Thermonuclear facility; Blanker; Neutron absorption cross-section; High density of neutron flux; Transmutation.

Introduction

The fission chain reaction (FCR) takes place in a nuclear fission reactor [1]. Neutron-induced fission of Uranium not only results in energy release but also is followed by next

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Table 1
Total number of neutrons in an infinite blanket, slowing down below the (n, 2n) reaction threshold, per one fusion neutron [6].

Element	Be	C	Fe	Mo	W	Pb
Nuclei concentration, 10^{24} 1/cm^3	0.120	0.08	0.085	0.064	0.063	0.063
Total number of neutrons below (n, 2n) threshold	1.78	1.0	1.29	1.84	1.82	1.84

generation neutrons that ensure the subsequent uranium fissions and generation of new neutrons.

In a fusion facility with magnetic confinement of the (DT)-plasma, the fusion reaction is followed by generation of neutrons as well (thermo-nuclear, with energy 14.1 MeV). These neutrons are multiplied in the blanket, slow-down, diffuse in the blanket and finally disappear due to absorption and leakage. Obviously, as a result of diffusion, neutrons in the plasma chamber interact with the plasma. However, due to an extremely small ion concentration in the plasma, as compared to the concentration of nuclei in the blanket, the neutron balance in the whole facility is defined mainly by the physical properties of the blanket.

Provided the plasma contains some components with large neutron absorption cross-section, a considerable part of neutrons could be absorbed in the plasma as well. Examples of these components are 3-He, 6-Li and 10-B that are currently considered in potential fuel cycles of the controlled nuclear fusion. For example, as a result of reaction 3He (n, 1-H) T, Tritium appearing in the plasma interacts with Deuterium (resulting in another neutron-emitting fusion reaction), and the reaction energy is released to the plasma thus heating it up (that in turn intensifies the fusion reactions with additional generation of neutrons). In this way, a controlled fusion chain reaction supported with neutrons (FCRn) can take place.

This reaction has already been considered in 40s and 50s of the last century in the context of thermonuclear weapon development. Particularly, it was proposed in the "Mike" thermonuclear device (tested by USA 1 November 1952 on Enewetak atoll in the Pacific Ocean) [2]. In USSR, this fusion chain reaction was proposed in the A. D. Sacharow's "layer cake" (tested 12 August 1953 at Semipalatinsk polygon) [3,4]. In the following thermonuclear device tests, both in USSR and USA, the 6-LiD-based reaction (this compound was gently called "Lidochka") has been successfully applied. Strictly speaking, the above mentioned implementation of the FCRn must be categorized as uncontrolled thermonuclear fusion.

In this work we consider conditions at which a **controllable** FCRn becomes relevant for the balance of the processes that take place in a fusion reactor.

Physical conditions for FCRn

It is appropriate to consider FCRn in a fusion facility with magnetic plasma confinement, equipped with a blanket for energy conversion. Principal feature of this type of facilities is the combination of the plasma zone with low concentration of the components, and the blanket zone containing solid (liquid) materials (i.e. a zone with many orders of magnitude higher nuclide concentrations). Utilization of neutrons, generated in the fusion reactions in a facility with such heterogeneous zones, is limited, as a rule, to the blanket, while the plasma is almost transparent to neutrons.

One can, however, imagine conditions for comparable neutron absorption in the plasma and blanket. This can be reached, **first** when the plasma contains as a component a nuclide with large neutron absorption cross-section, and **second** when at the same time materials with extremely low neutron capture cross-section are used in the blanket.

For the plasma, such a nuclide (that strongly absorbs neutrons) with a low mass number, can be for example 3-He, characterized by the large absorption cross-section of thermal neutrons (~5330 barn at thermal energy) in the reaction 3-He(n, 1-H)T. This is an exothermic reaction with energy +0.764 MeV, which can be used for plasma heating. In this case not only (D—3-He), but also the (DT—3-He) thermonuclear cycle comes into the question.

As a nuclide with small absorption cross-section for the blanket, 208-Pb, D (heavy water), graphite can be considered, for whose the thermal neutron absorption cross-section has an order of magnitude of milligrams, or less.

Further we rely on the use of 3-He (note that Helium has already been considered as an admixture for additional plasma heating, based on the ion-cyclotron resonance method [5]). Traditionally one assumes that fusion neutrons are multiplied in (n, 2n) and (n, 3n) reactions on the blanket materials, and slow down and diffuse in its volume (see Table 1 in [6]).

From this table one can see that fusion neutrons can be multiplied considerably in a (Pb, Mo, W, Be) layer of the blanket's first wall.

Part of the neutrons during slowing down and diffusion will be captured by the 3-He nuclei in the plasma and lead again to the birth of Tritium nuclide that will participate in the fusion reaction and generate new neutrons. In this way, the neutronics chain link, that comprises fusion reaction, will be closed. For the (DT)-plasma as the main component, the neutrons born in(DT)-fusion will be multiplied and transported in the blanket, in the plasma chamber and captured by the 3-He, i.e. participate to the chain reaction.

Neutron-physics basis for relevant FCRn (overcoming the plasma and blanket density ratio "damnation")

The interaction rate between neutrons and plasma or blanket nuclei is assessed by the formula

$$F = \langle \sigma V_{rel} \rangle n_t n_n,$$

where V_{rel} is the relative neutron speed with respect to the medium nuclei, σ is the neutron microscopic cross-section; $\langle \sigma V_{rel} \rangle$ is the product of the cross-section and the relative