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Integral neutronics experiments in analytical mockups for blanket of a hybrid reactor

Rong Liu*, Tonghua Zhu, Xinxin Lu, Xinhua Wang, Xiaosong Yan, Song Feng, Yiwei Yang, Mei Wang, Li Jiang

Institute of Nuclear Physics and Chemistry, China Academy of Engineering Physics, Mianyang 621900, Sichuan, China

HIGHLIGHTS

- For checking property of the hybrid blanket by integral experiments, three mockups are established.
- In spherical mockup with depleted uranium and cubic mockup with natural uranium, the plutonium production rates and uranium fission rates are measured.
- In spherical mockup with depleted uranium and LiPb, tritium production rates are measured.
- The measured results are compared to the calculated ones with MCNP-4B code and ENDF/B-VI library data.

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ABSTRACT

The paper describes recent progress in integral neutronics experiments in the analytical mockups for the blanket in a fusion-fission hybrid energy reactor. A conceptual blanket of the hybrid reactor is mainly loaded with natural uranium and lithium material. In the fission fuel region, uranium material and light water are arranged alternately. The mockups of the conceptual blanket are designed and used for checking neutron property of the blanket by integral experiments. Based on materials available, the spherical fission mockup for fission research and plutonium production consists of three layers of depleted uranium shells and several layers of polyethylene and graphite shells. The spherical lithium mockup for tritium production consists of depleted uranium and LiPb alloy shells. The cubic mockup consists of natural uranium and polyethylene and its structure is basically consistent with one of the fuel region. In the mockups with the D-T neutron source, the plutonium production rates, uranium fission rates and tritium production rates are measured, separately. The measured results are compared to the calculated ones with MCNP-4B code and ENDF/B-VI library data.

1. Introduction

The fusion-fission hybrid energy reactor (FFHER) is designed in China Academy of Engineering Physics and consists of magnetic confinement fusion device and a subcritical reactor [1,2]. FFHER's concept is that fusion energy is multiplied by released fission energy from the subcritical reactor. The uranium fuel of the subcritical reactor can be natural uranium, LWR spent fuel, or depleted uranium. The design can increase the utilization rate of uranium. It would be one of the effective ways of applying fusion technologies to solve the future energy crisis. A conceptual blanket of the hybrid reactor is mainly loaded with uranium (UZr alloy) as nuclear fuel and lithium material (Li_4SiO_4) as tritium breeder. The schematic diagram of the conceptual blanket is shown in Fig. 1. In the fission fuel region, the uranium and light water are arranged alternately. Light water is coolant and moderator. In the uranium, fertile nucleus ^{238}U is used to breed ^{239}Pu by ^{238}U capture reaction, and fission nuclei are used to multiply fusion energy by fission reaction. In the tritium production region, fertile nuclide ^{6}Li is used to breed T for maintaining tritium self-restraint by ^{6}Li (n,α) T reaction. The hybrid energy reactor has been never operated. In order to deal with various nuclear problems originating from D-T neutrons in applications for hybrid energy, it is crucial to check nuclear data and code used in the design, and neutron property of the conceptual blanket by integral neutronics experiments.

We have performed a series of benchmark integral experiments for validating nuclear data and code used in the design [3–7]. In the first stage experiments, spherical shells available were combined to

* Corresponding author. Tel.: +86 13981115591; fax: +86 0816 2495280.
E-mail address: liurongzy@163.com (R. Liu).

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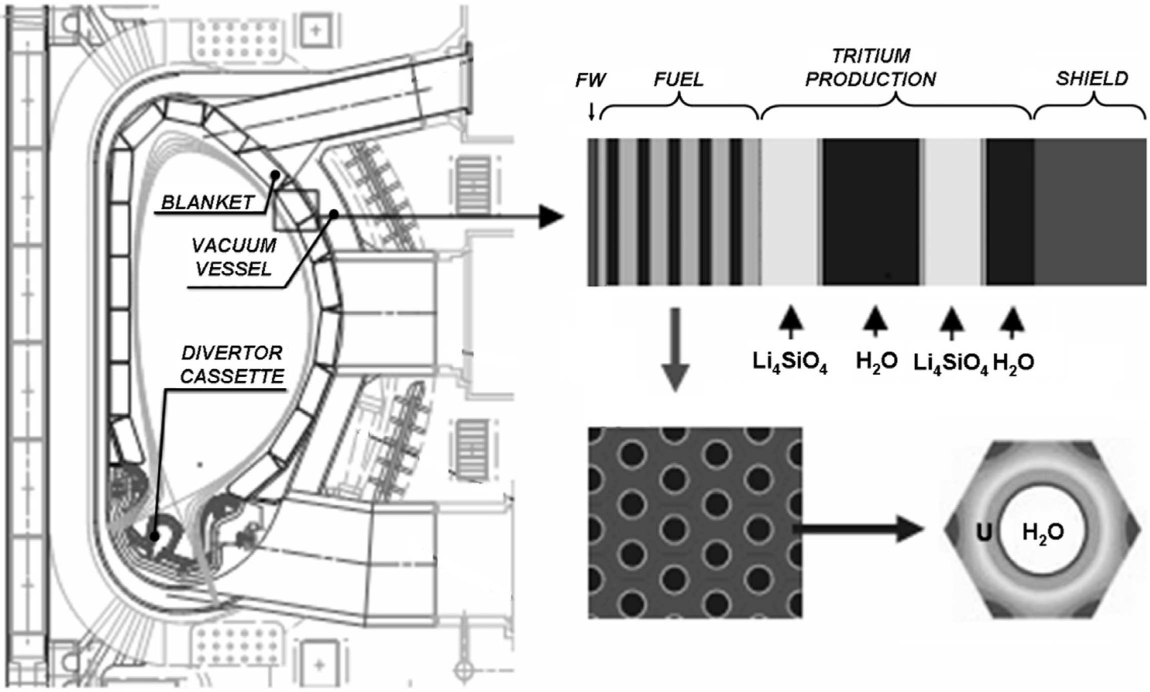

Fig. 1. Schematic diagram of the conceptual blanket.

setup benchmark simulation assemblies in which neutron spectra similar to ones in the conceptual blanket. The spherical assemblies are different combinations of depleted uranium, polyethylene or LiH spherical shells. Depleted uranium is used for fission fuel, while polyethylene for light water and LiH for tritium production. The reaction rates and leakage neutron energy spectra were measured in the assemblies. The experimental results were calculated by the MCNP code employing ENDF/B-VI nuclear data library, and the ratios of calculation to experiment (C/E) were obtained. The results indicated that the code and relevant nuclear data were applicable to analyze the integral experiments. It was concluded that a special database needs to be established and checked before the physics design of the subcritical reactor, in particular a database for the thermal neutron to ensure the feasibility of the design. In addition, the integral neutronics experiments relevant to fusion neutrons in other laboratories were performed [8,9], and the difference of ^{238}U capture reaction rates between experiment and calculation was generally about 10%.

Based on demand for checking neutron property of the conceptual blanket, we implement the integral experiments further. In this paper, the recent progress of the integral experiments is described. Referred to the blanket design, we have established the analytical mockups which are integral parts of the whole blanket. One kind of mockups is still spherical and mainly consisted of depleted uranium and polyethylene shells, available. In the spherical mockups, graphite reflector and iron shells for simulating the first wall are increased, and LiPb alloy shell is used to simulate a breeder. As for the lack of thermal neutron S (α, β) scattering model in the neutron data library of the LiH, the calculated tritium production rate was smaller than the measured ones [7]. So, we substitute LiPb for LiH in the design of the spherical mockup so that tritium production rates can be compared and analyzed further. Other kind of mockup is cubic and its structure and material are basically consistent with ones of the fission fuel region. The integral experiments in the mockups have been performed. The plutonium production rates, uranium fission reaction rates and tritium production rates are measured in the mockups, separately.

2. Mockups

In the physical design of the hybrid reactor, the blanket consists of the first wall loaded with iron, the fuel region loaded with UZr alloys of natural uranium (NU), the tritium production region loaded with Li_4SiO_4 and the shielding region loaded with iron [1,2]. The structure of the fuel region is lattice cell. The volume ratio of NU to light water is about 2:1. Aiming at researching the neutron property of the blanket, the ways for establishing two kinds of mockups are that the neutron spectra, material and structure are relevant for a hybrid reactor blanket. One kind of mockups based on materials available is still spherical, and the neutron spectra in the mockups are nearer to ones in the blanket. Other kind of mockup based on physical design is cubic, and its material and structure are basically consistent with ones of the fission blanket.

2.1. Spherical fission mockup

The schematic diagram of the spherical fission mockup to mimic the fission blanket is shown in Fig. 2. This mockup consists of depleted uranium (~99.6% ^{238}U, ~0.4% ^{235}U) available, polyethylene, graphite and Iron. Polyethylene has similar property to light water as a neutron moderator [3]. The graphite shell is used as

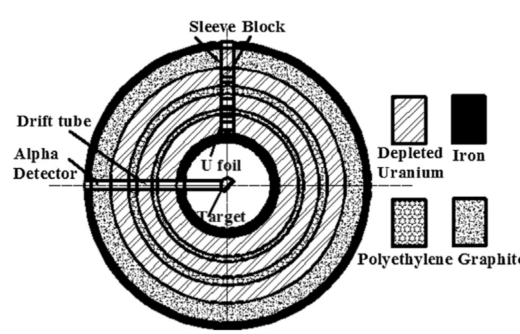

Fig. 2. Spherical fission mockup with alternate depleted-uranium and polyethylene shells.