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Fission blanket benchmark experiment on spherical assembly of uranium and PE with PE reflector

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HIGHLIGHTS

- The fission rate distribution on two depleted uranium assemblies was measured with plate fission chambers.
- We do calculations using MCNP code and ENDF/B-V.0 library.
- The overestimation of calculations to the measured fission rates was found.
- The observed discrepancy are discussed.

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ABSTRACT

New concept of fusion-fission hybrid for energy generation has been proposed. To validate the nuclear performance of fission blanket of hybrid, as part of series of validation experiment, two types of fission blanket assemblies were setup in this work and measurements were made of the reaction rate distribution for uranium fission in the spherical assembly of depleted uranium and polyethylene by Plate Fission Chamber (PFC). There are two PFCs in experiment, one is depleted uranium chamber and the other is enriched uranium chamber. The Monte-Carlo transport code MCNP5 and continuous energy cross sections library ENDF/BV.0 were used for the analysis of fission rate distribution in the two types of assemblies. The calculated results were compared with the experimental ones. The overestimation of fission rate for depleted uranium and enriched uranium were found in the inner boundary of the two assemblies. However, the C/E ratio tends to decrease for the distance from the core slightly and the results for enriched uranium are better than that for depleted uranium.

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1. Introduction

The conceptual design of the fusion fission hybrid energy reactor [1,2] (FFHER), mainly consisting of a fusion neutron source and a sub-critical blanket, proposed in China, was considered to be the key way of applying fusion technologies to solve the present energy crisis. In which, the sub-critical blanket is designed to be fueled with natural uranium, depleted uranium or even spent fuel generated by PWRs with coolant of light water [3]. The volume ratio of about 1.0–2.0 for uranium to water was investigated to determine which structure is the best one for energy production and fissile breeding, and also for heat transmission [4,5]. The FFHER was mainly designed for energy production. As the energy generation and neutron breeding in blanket are mainly due to the fission reaction of uranium, so it is of great importance to accurately determine the fission reaction and neutron transport in FFHER. The method, code and data are of fundamental importance in this stage as it in the design of fission plants and fusion devices [6,7].

Therefore, to validate the conceptual design of the sub-critical blanket, a series of integral experiments on the assemblies having similar configuration with the blanket are ongoing [8]. Measurements of fission rate on the spherical fission blanket assembly (FBA) have been finished [9]. To investigate the influence of blanket structure to fission and to check the accuracy of calculation, in this work, two types of fission blanket assembly (FBA) of three layers of depleted uranium (named DU in describing experimental assemblies) and two layers of polyethylene (PE) was established, in which the volume ratio of uranium to polyethylene is about 2.0. The radiation transport tool MCNP5 and nuclear data library ENDF/BV.0, the candidate code and data library for calculation of fission reaction in the blanket design, were used for comparison with the experimental data.

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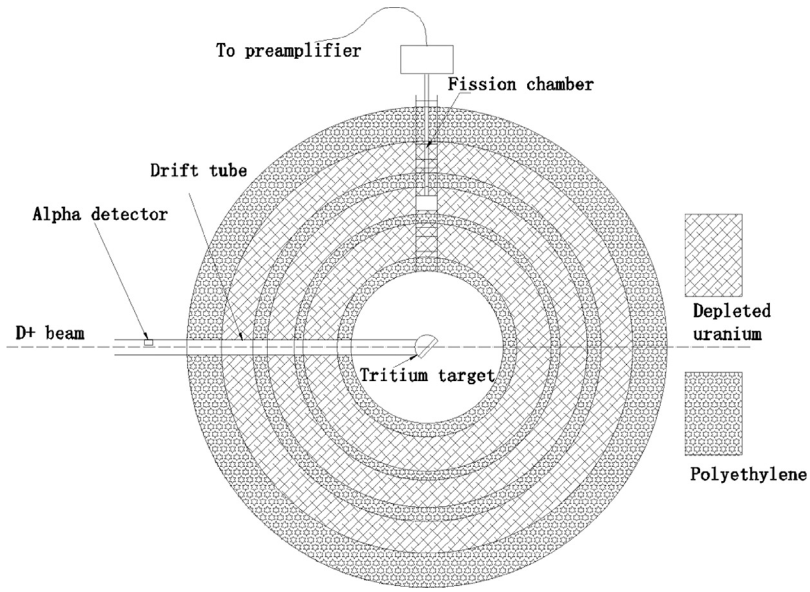

Fig. 1. The cross section view of spherical assembly of PE/FBA/PE.

2. Experiment and procedure

Neutronics experiments of fission rate distribution in two types of spherical blanket assemblies of DU and PE were performed with D–T neutron source at the center in China Academy of Engineering Physics. D–T neutrons were generated by bombarding 225 keV and 100 uA deuteron onto a tritiated titanium target. The intensity is about 3×10^{10} neutrons/s while beam intensity on the target is 200 uA. The fluence of D–T neutrons were monitored with counting the associated 3.5 MeV alpha particles by a silicon surface barrier detector at the angle of 178.2° to the incident deuteron beam and the experimental uncertainty of the fluence of D–T neutrons is about 2.5% [10].

The two types of assemblies are a fission blanket assembly with PE reflector, with and without an inner layer of PE, i.e. FBA/PE and PE/FBA/PE. The FBA/PE assembly are of 131 mm in inner radius (IR) and 350 mm in outer radius (OR) while the PE/FBA/PE assembly are of 111 mm in IR and 350 mm in OR. Fig. 1 shows the arrangement between the experimental assembly, D–T neutron source and fission chambers. As in the previous experiment on FBA [9], the assemblies were formed by combining the semi-spherical shells of DU and PE. There is one vertical channel in the assembly for detector arrangement. The uranium sleeve also be used in the channel for detector to keep the blocks of uranium and polyethylene from dropping down and to install the detector at a specific position. The material in the sleeve is the same as the material in the shells by combining various blocks with different thickness of 0.2 cm–5.0 cm except for the detector.

Depleted uranium and enriched uranium Plate-Fission-Chambers (PFCs) were used to measure the fission rate, the measurements were conducted along the channel as a function of distance from the core of the assembly to the detector position. The atomic densities of fissile material in the PFCs have been accurately measured from the alpha particle emitted from the fissile material before the PFCs were fabricated. Table 1 shows the characterizations of PFCs, including atomic densities, dimensions and so on. More detailed descriptions for the measurement techniques were present in a previous report [9].

Fission rates have been estimated by the following formula:

$$f(R) = N_{f/}(AN\eta) \quad (1)$$

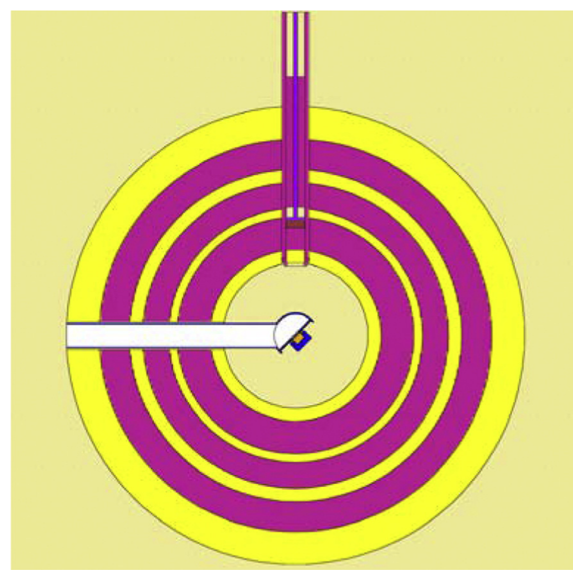

Fig. 2. Calculation model.

where *f(R)* is the fission rate of depleted uranium or enriched uranium at a specific position the radius of which is R and N_f, A, N, η are the sum of yields obtained by PFCs, the number of fission nuclei atomic density in the PFC, total amount of neutrons emitted from D–T reaction and the efficiency of fission fragments shaping a pulse in PFCs, respectively. In addition, N_f have been corrected by dead time. The uncertainty of measured results are 4.1% for depleted uranium and 4.7% for enriched uranium.

3. Monte carlo analysis

Analyses of the fission rate experiment were carried out with the Monte-Carlo code MCNP 5 [11] and attached continuous energy cross section library ENDF/BV.0 [12], the candidate code and data library for calculation of fission reaction in the blanket design. The experimental configuration was modeled in detail, including target chamber, drift tube, void in channels, the sheet for detector and other structures. The detailed configuration of the PE/FBA/PE setup

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