Fusion Engineering and Design 137 (2018) 43–47

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

An online method to measure tritium production rate of fusion-fission hybrid reactor in CAEP

He Tie[a,b,*], Wang Xinhua[b], An Li[b], Yang Jian[b], Zheng Pu[b]

[a] Institute of Nuclear Physics and Chemistry, Chinese Academy of Engineering Physics, Mianyang 621900, China
[b] Institute of Nuclear Science and Technology, Sichuan University, Chengdu 610064, China

ARTICLE INFO

PACS:
28.20.-v
28.41.Ak
28.52.Av

Keywords:
Fusion-fission hybrid reactor
Blanket benchmark mockups
Tritium production rate
MCNP

ABSTRACT

As an important parameter of neutronics integral experiment, tritium production rate could not only be used for validation of programs and evaluation database, but was also related to tritium self-consistency after the activation of the sub-critical reactor. This parameter was a key component of the sub-critical reactor design. Four blanket benchmark mockups of a fusion-fission hybrid reactor were established utilizing lithium materials, which consisted of depleted uranium/lithium hydride, uranium/lithium hydride/polyethylene, uranium/lithium hydride/graphite/iron, and uranium/Li-Pb alloy/polyethylene. Based on the Cockcroft–Walton neutron generator, the distribution of tritium production rate by D–T neutrons in the four mockups was evaluated by two pairs of different sizes lithium glass detectors. The distribution was then quantitatively assessed using MCNP5 program and ENDF/B-VII database. The tritium production rates of the mockups with lithium hydride significantly deviated from the experimental results; whereas those of the mockup with lithium-lead alloy were agree well with the experimental results.

1. Introduction

Fusion-fission hybrid reactor driven by magnetic confinement fusion has been designed by the Chinese Academy of Engineering Physics (CAEP) for energy supply [1,2]. The reactor consists of Tokamak fusion reactor core and sub-critical energy blanket. Fusion D–T neutrons are produced during fusion of the Tokamak fusion reactor and interact with natural U(Th) alloy to convert the difficult-to-fission U-238 into easy-to-fission Pu-239 and thus attain energy amplification. Neutrons in the natural U(Th) alloy also interact with tritium production materials to produce tritium for tritium self-consistency in the fusion reaction. As an important parameter of neutronics integral experiment in fusion-fission hybrid reactor, the accuracy of tritium production rate (TPR) not only determines tritium self-consistency in the reactor but is also related to the energy multiplication coefficient of the sub-critical blanket. Despite numerous studies on the tritium production rate of pure fusion reactors worldwide [3–6], understanding of this parameter still remains at the theoretical level attributed to complicated blanket materials, structures, and neutron spectra. A series of blanket benchmark mockup experiments on TPR have been carried out to validate relevant programs and evaluation database and ensure their reliability in the physical design of fusion-fission hybrid reactors. In tradition, the TPR measurement was utilizing lithium-containing pellets as neutron irradiated sample and the amount of tritium produced in them was measured with a liquid scintillation counter [7]. This method, however, might cost a long time to get the value of TPR, which we called it off-line method. In this work, we introduced a new online, fast and real-time method to measure the TPR in the Fusion-Fission Hybrid Reactor.

2. Experimental setup

Four blanket benchmark mockups of fusion-fission hybrid reactors were established using depleted uranium, lithium hydride, polyethylene, graphite, lithium-lead alloy, and iron shell (Fig. 1). Fig.1(a)–(d) show the mockups of depleted uranium/lithium hydride (I), uranium/lithium hydride/polyethylene (II), uranium/lithium hydride/graphite/iron mockup (III), and uranium/Li-Pb alloy/polyethylene mockup (IV), respectively:

(1) The depleted uranium shells in the four mockups were identical in size and composed of two hemispherical shells (diameter: 80 mm–262 mm). The shell density was 18.8 g/cm^3, and the isotope abundance was ^{238}U (99.579%), ^{235}U (0.415%), ^{234}U (0.002%), ^{236}U (0.003%), and impurities (< 0.1%).
(2) The lithium hydride shells in I-III consisted of two hemispherical shells (diameter: 262 mm–600 mm). The average density of the

* Corresponding author at: Institute of Nuclear Physics and Chemistry, Chinese Academy of Engineering Physics, Mianyang 621900, China.
E-mail address: jjxy_02@aliyun.com (T. He).

https://doi.org/10.1016/j.fusengdes.2018.08.012
Received 23 March 2018; Received in revised form 9 July 2018; Accepted 22 August 2018
0920-3796/

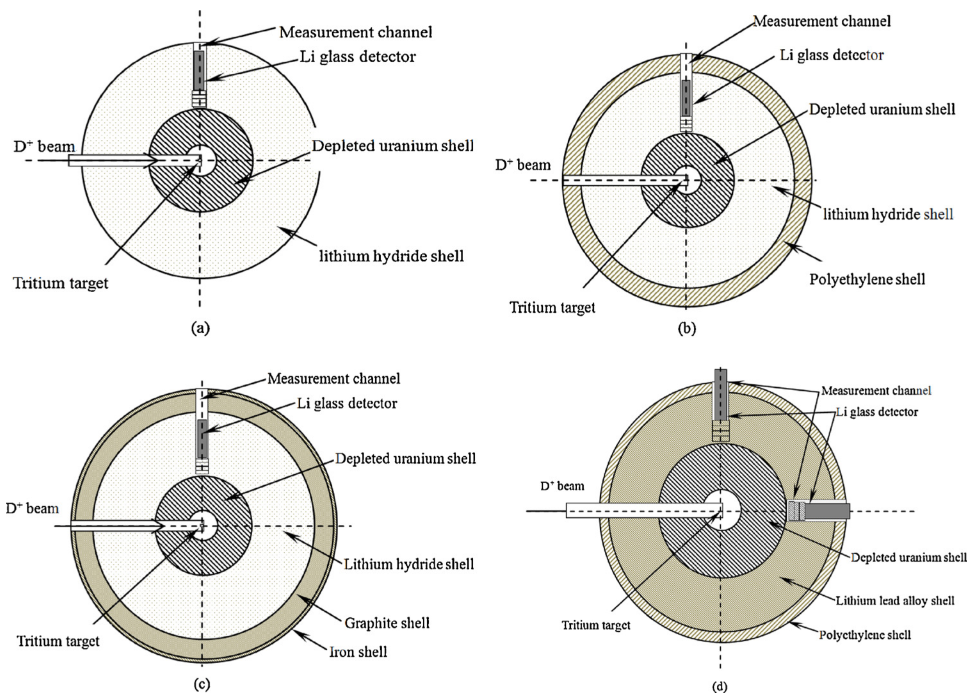

Fig. 1. Cross-sectional view of the four blanket benchmark mockups for fusion-fission hybrid reactor.

shells was 0.746 g/cm^3. The mass percentages of different components were: ^{7}LiH (90.3%), ^{6}LiH (8.7%), and impurities (1%, including O, C, N, Cl, Si, K, Na, Ca, etc.).

(3) The polyethylene shell in II was composed of two hemispherical shells (diameter: 600 mm–700 mm), with a shell density of 0.95 g/cm^3.

(4) The graphite shell in III was composed of two hemispherical shells (diameter: 600 mm–700 mm), with a shell density of 1.8 g/cm^3.

(5) The iron shell in III was composed of two hemispherical shells (diameter: 700 mm–730 mm). The percentages of iron and carbon are 98% and 2%, respectively.

(6) Li-Pb alloy shell in IV was composed of two hemispherical shells (diameter: 262 mm–467 mm), with shell density of 10.2 g/cm^3. Li was evenly distributed in the shell, and the concentration magnitude was 18 ± 5 at%. The proportion of nuclides in Li and Pb represented natural abundance. The total impurity content was ≤300 ppm. Two measurement channels were placed on the equatorial plane, and the channel diameter was 25 mm.

(7) The polyethylene shell in IV was composed of two hemispherical shells (diameter: 467 mm–508 mm), with a shell density of 0.95 g/cm^3.

(8) A target chamber channel, with 35 mm diameter, was placed on the combination surface of the upper and lower hemispherical shells.

3. Experimental measurement

The neutron source was the direct current D–T neutrons generated by the Cockcroft–Walton neutron generator, which was built in Institute of Nuclear Physics & Chemistry (INPC), China. The average energy of D$^+$ was 134 keV, and the corresponding neutron energy at the 0° direction was 14.89 MeV. The experiments used stainless steel single tritium target chamber to reduce the effects of materials of the neutron target chamber on the experimental accuracy. Deuterium particle drifting and α particle monitoring were accomplished in the same channel, which had limited beams of diaphragms to restrict beam spot size and reduce scattering of α particles. The bottom lining of the tritium target consisted of a piece of Φ28 mm × 0.8 mm oxygen-free copper and the active target area in the Φ12 mm tritium absorption film. The target surface was cooled by compressed air produced by the air compressor. The neutron source intensity was monitored by associated α particle during D–T reactions. The Au–Si surface barrier detector was placed on the direction that formed an angle of 178° with the D$^+$ beam. The blanket benchmark mockups were placed on a mobile support platform, and the mockup center was overlapped with the tritium target center.

The TPR measurements were performed by a pair of lithium glass detectors. The pair detectors contained one with ^{6}Li enrichment of 95% and the other with ^{7}Li enrichment of 99.99%. The scintillators used are small disks (two sizes: 10 mm diameter by 1 mm and 0.22 mm thickness, respectively) manufactured by Bicron and NE Technologies. A diagram of the front-end electronics which implemented the TPR measurement is shown in Fig. 2. The signals produced from two detectors are coupled to preamplifier and then connected to amplifier. Pulse height spectra (PHS) are recorded by multi-channel analyzer. All of the electronics modules are ORTEC company production.

The process reaction of a neutron with ^{6}Li atom is that $^6Li + n \rightarrow {}^3H + {}^4He + 4.71$ MeV. The reaction above proceeds with a high cross-section (for thermal neutron 940 barn) as well as releasing a large amount of energy. However, neutrons with ^{7}Li atoms reactions have high threshold energy and small reaction cross-section. As a result, neutron bombarding on ^{6}Li detector produces a large pulse height while bombarding on ^{7}Li detector produces a lower pulse height. Moreover, the ^{7}Li with neutron reaction leads to three products, one of which is a neutron that mostly escapes from the scintillator, therefore only a continuum of small deposited energy should be expected even for monoenergetic incident neutrons. Thus the contribution of the neutrons to the PHS of ^{7}Li-detector is negligible. The gamma photon bombarding on the two detectors deposits almost the same energy. Accordingly the PHS from ^{6}Li detector subtracted that from ^{7}Li detector, the "clean" tritium pulse height spectrum could be obtained. In order to subtract the gamma background exactly, a standard ^{137}Cs gamma source was used to calibrate the measuring system. Fig. 3 shows the PHS of the pair lithium glass detectors after calibrating by standard ^{137}Cs gamma source. Fig. 4 shows a typical pulse height spectra getting from a neutron/gamma mixed radiation field and as a result the clean tritium pulse height spectrum could be obtained by subtracting that from ^{6}Li