Available online at www.sciencedirect.com
ScienceDirect
Fusion Engineering and Design 81 (2006) 2761–2766
Fusion Engineering and Design
www.elsevier.com/locate/fusengdes

Development of three-dimensional neutronics calculation system for design studies on helical reactor FFHR

T. Tanaka[a,*], A. Sagara[a], T. Muroga[a], M.Z. Youssef[b]

[a] *National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan*
[b] *University of California, Los Angeles, CA 90095, USA*

Abstract

Construction of a three-dimensional neutronics calculation system has been started for design studies on the helical reactor FFHR2. In the calculation system, geometry data of the helical structures are generated according to numerical equations for quick feedback between neutronics evaluation and design modification. The tritium breeding abilities of the FFHR2 with the Flibe + Be/JLF-1 (Reduced Activation Ferritic/Martensitic Steel) and the Li/V-alloy blanket systems were investigated by using the calculation system. Since the original design could not achieve the tritium breeding ratios (TBRs) > 1.0 due to neutron leakage through opening between the blanket components, the dimensions have been modified to enhance the breeding ability. After the modification, the TBRs of 1.08 and 0.98 were obtained for the Flibe + Be/JLF-1 and Li/V-alloy blanket systems, respectively. The present results indicate that the blanket systems have potential to achieve adequate tritium breeding ability in the FFHR2 by further design optimization.

Keywords: Helical reactor; Neutronics; Tritium breeding; Neutron transport calculation

1. Introduction

In the design activity of the helical-type fusion reactor FFHR2, Flibe cooled advanced blanket systems have been studied for the attractive merits on safety aspects, the low MHD resistance in a high magnetic field, etc. [1]. The present design is adopting the Flibe cooled STB (Spectral-Shifter and Tritium Breeding Blanket) concept to achieve a maintenance-free first wall by reducing irradiation damage with a thick carbon armor [2]. In addition to the original Flibe cooled concepts with JLF-1 (Reduced Activation Ferritic/Martensitic Steel) structural material, alternative Li/V-alloy and Flibe/V-alloy blanket systems also have been proposed for high-temperature operation of the FFHR2 [3]. Neutronics feasibility of the candidate blanket concepts has been investigated previously by one-dimensional discrete-ordinates transport calculations [4] or Monte-Carlo transport calculations for a simple torus geometry fully covered with uniform blan-

---

[*] Corresponding author. Tel.: +81 572 58 2319;
fax: +81 572 58 2676.
E-mail address: teru@nifs.ac.jp (T. Tanaka).

0920-3796/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.fusengdes.2006.07.076

ket layers, i.e. geometry with no neutron leakage [2,3]. The results of the calculations indicated that all of the candidate blanket concepts have potential to achieve the compatibility of adequate tritium self-sufficiency and neutron shielding ability within the blanket space of 1.2 m.

To proceed into further neutronics evaluation simulating the geometric features of the FFHR2, three-dimensional neutron transport calculations have been required, since the blanket system has a complicated helical structure consisting of four pairs of breeder and shielding layers. As to neutroronics investigation for helical reactors, two-dimensional discrete-ordinates and three-dimensional Monte-Carlo transport calculations have been performed for the Heliotron-H reactor design [5,6]. Although the investigation was focused on understanding of neutronics characteristics rather than quantitative evaluation due to the computer power at that time, the importance of neutron streaming has been pointed out in the discussion. In the present study, the construction of a three-dimensional neutron transport calculation system has been started for understanding of neutronics characteristics in the FFHR2. Total tritium breeding ratios (TBRs) in the FFHR2 have been investigated for Flibe and Li cooled blanket systems using the calculation system.

2. Neutronics calculation

The cross-section of the original FFHR2 design is shown in Fig. 1. The blanket system consists of four pairs of a breeder layer and a shielding layer running helically in the toroidal direction. Two pairs of them are shielding the super-conducting helical coils from neutrons. Structures of the blanket components are defined by numerical equations for helical geometry [7]. Since the purpose of the present study is understanding of neutronics characteristics in the FFHR2 and modification of the blanket design from the neutronics aspect, three-dimensional geometry data for neutron transport calculations have been generated also using the numerical equations to repeat investigations quickly for various conditions.

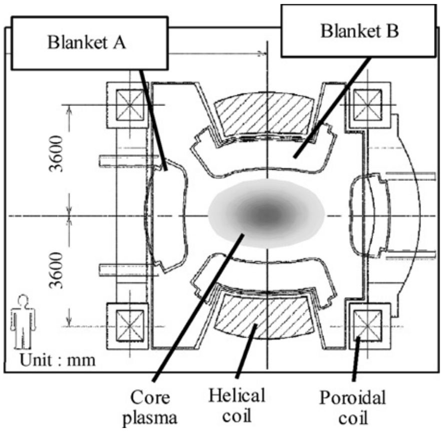

Fig. 1. Cross-section of helical reactor FFHR2 [2]. The left blanket is inside of the torus.

The neutronics evaluation has been performed using the Monte-Carlo neutron transport calculation code MCNP-4C [8] and nuclear data library JENDL 3.2 [9]. As shown in Fig. 2(a), the cross-sections of the helical blanket components were divided into quadrangular meshes on the design drawings. The coordinates of the quadrangular meshes were input data for a conversion program, which was written in Visual Basic for the present neutronics evaluation of the FFHR2. Each of the meshes generates a helical structure by proceeding spirally along the toroidal axis as shown in Fig. 2(b). The vertices of the helical structure were calculated according to the numerical equations at every 6° in the toroidal direction and cell data for the MCNP code were generated by the conversion program. Side surfaces of each cell were divided into triangles. Fig. 2(c) is the example of three-dimensional geometry for the present evaluation consisting of ∼3000 cells. The plasma major radius and minor radius of the FFHR2 are 14.0 and 1.73 m, respectively.

In the calculations using the MCNP code, shapes of vacuum areas, i.e. vacuum cells, also have to be defined as well as those of the blanket components. They were defined by subtracting the blanket components from the calculation area using the Boolean operation command of the MCNP code. However, the full torus blanket geometry is too complicated for this procedure and an error has been induced, since the maximum data length allowed for defining a cell is limited in the MCNP code. To avoid this limitation, the torus-shaped calculation area was divided into thin disc-shaped areas in the present calculation as shown in Fig. 2(d). While the number of vacuum cells increased, the data length for defining each cell could be reduced.