Annals of Nuclear Energy 79 (2015) 133–142

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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

Neutronics comparative analysis of plate-type research reactor using deterministic and stochastic methods

Shichang Liu [a,*], Guanbo Wang [b], Gaochen Wu [a], Kan Wang [a]

[a] Department of Engineering Physics, Tsinghua University, Beijing 100086, China
[b] Institute of Nuclear Physics and Chemistry, China Academy of Engineering Physics, Mianyang 621900, China

ARTICLE INFO

Article history:
Received 18 October 2014
Received in revised form 26 January 2015
Accepted 28 January 2015
Available online 11 February 2015

Keywords:
Research reactor
Neutronics calculation
DRAGON and DONJON
RMC

ABSTRACT

Simulation of the behavior of the plate-type research reactors such as JRR-3M and CARR poses a challenge for traditional neutronics calculation tools and schemes for power reactors, due to the characteristics of complex geometry, highly heterogeneity and large leakage of the research reactors. Two different theoretical approaches, the deterministic and the stochastic methods, are used for the neutronics analysis of the JRR-3M plate-type research reactor in this paper. For the deterministic method the neutronics codes DRAGON and DONJON are used, while the continuous-energy Monte Carlo code RMC (Reactor Monte Carlo code) is employed for the stochastic approach. The goal of this research is to examine the capability of the deterministic code system DRAGON and DONJON to reliably simulate the research reactors. The results indicate that the DRAGON and DONJON code system agrees well with the continuous-energy Monte Carlo simulation on both k_{eff} and flux distributions if the appropriate treatments (such as the ECCO option) are applied.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

There are over 240 operational research reactors in the world (IAEA, 2010). These research reactors are constructed to generate neutrons for different purposes, such as neutron scattering, neutron activation analysis, radiography, irradiation testing of materials and production of isotopes, etc. These research reactors have the characteristics of high heterogeneity due to the existence of strong neutron absorbers and the large leakage due to the compact reactor design. In the traditional neutronics calculation tools and schemes, the typical three-level calculation, including cell transport calculation, assembly transport calculation and full core diffusion calculation, is usually applied to power reactors. Modifications have to be made in order to simulate accurately the neutronics behavior of the research reactors such as JRR-3M (Iwasaki et al., 1984, 1985; Hosoya et al., 2007) and CARR (Yuan and Kang, 1998) using full core diffusion calculation. For example, the Japan Atomic Energy Research Institute (JAERI) adopted the "inner boundary condition" method to deal with the effect of strong neutron absorbers when simulating the JRR-3M (Iwasaki et al., 1984, 1985). Liu (2006) or introduced the correction factors for the absorption cross-sections of the absorber elements in order to match the Monte Carlo calculations. Both the methods of "inner boundary condition" and correction factors are inconvenient and inefficient since the boundary conditions or cross-sections have to be modified manually to match the SN or Monte Carlo calculations.

In this paper, two different theoretical approaches are adopted, i.e., the deterministic method and the stochastic method, to calculate the neutronics behaviors of JRR-3M plate-type research reactor. The deterministic codes DRAGON (Marleau et al., 2014) and DONJON (Hebert et al., 2014) are validated based on the reference calculations by the 3D continuous-energy Monte Carlo code RMC (Reactor Monte Carlo code) (Wang et al., 2011). The ENDFB-VII rel. 1 library is used to ensure the consistency of nuclear data. RMC adopts the continuous-energy library, while DRAGON adopts the multi-group one.

RMC is a continuous-energy Monte Carlo neutron transport code being developed by Department of Engineering Physics at Tsinghua University. Both DRAGON and DONJON are open source codes programmed by Institute of Nuclear Engineering of Polytechnique Montréal, Canada. As widely used open source reactor physics codes, DRAGON and DONJON have been successfully used to simulate several types of reactors and solve a lot of practical problems such as the simulations of CANDU reactor core (Varin and Marleau, 2006), fuel loading pattern optimization for PWR

* Corresponding author at: LIUQING Building Room 919, Tsinghua University, Beijing 100084, China.
E-mail address: liu-sc13@mails.tsinghua.edu.cn (S. Liu).

http://dx.doi.org/10.1016/j.anucene.2015.01.027
0306-4549/© 2015 Elsevier Ltd. All rights reserved.

(Liu and Cai, 2012) and neutronic and thermohydraulic coupling of thorium-based fuel assembly in SCWR (Liu and Cai, 2013) etc.

The goal of this research is to validate the capability of this deterministic code system DRAGON and DONJON when applied to simulate the compact plate-type research reactor.

The remainder of this paper is organized as follows. Section 2 gives the descriptions of the calculation model of JRR-3M plate-type research reactor. Section 3 introduces the DRAGON calculation models which have been used to generate the macroscopic cross sections required for a full core diffusion calculation. The full core diffusion model of DONJON and the detailed full core transport model of RMC are given in Section 4. The comparisons between the results of DONJON and RMC have been carried out in Section 5, and the conclusions are presented in Section 6.

2. Core configuration of the JRR-3M plate-type research reactor

A model of the research reactor based on the design of JRR-3M has been established. JRR-3M is a light water moderated and cooled, beryllium and heavy water reflected pool type research reactor with maximum thermal power of 20 MW using low enriched uranium (LEU) plate-type fuels (Hosoya et al., 2007). Fig. 1 shows the overview of JRR-3M. The core contains 26 standard fuel elements, 6 follower fuel elements with neutron absorbers, and 12 pieces of beryllium reflector. A heavy water tank is installed around the core. JRR-3M is a typical "inverse flux trap" which has high thermal neutron fluxes in reflector region where beam tubes can be placed.

The studied model in this paper is not the exact JRR-3M, but a JRR-3M type research reactor. That means this model is a universal research reactor with similar parameters as JRR-3M. Different from the JRR-3M, the studied model is in square shape as is shown in Fig. 2, while JRR-3M has an annular heavy water reflector and light water reflector.

Due to the limitation of the geometry modeling of the RESINI module in DONJON, these modifications of the studied model can ensure the consistency of geometry in both DONJON and RMC. The dimensions of the realistic and modified JRR-3M research reactors are shown as in Table 1. The RESINI module needs a 3D Cartesian geometry with equally sized cells, as it cannot deal with bundle of different sizes. So the side length of core, heavy water reflector and light water reflector are equal to the multiple of the pitch, with the size of each pitch equal to a fuel element. From Table 1, it can be found that the areas of heavy water reflector and light water reflector of the modified core are a bit larger than that of realistic core. The k_{eff} of the realistic core with annular reflectors for S and R control rods partly inserted is 1.136867, while

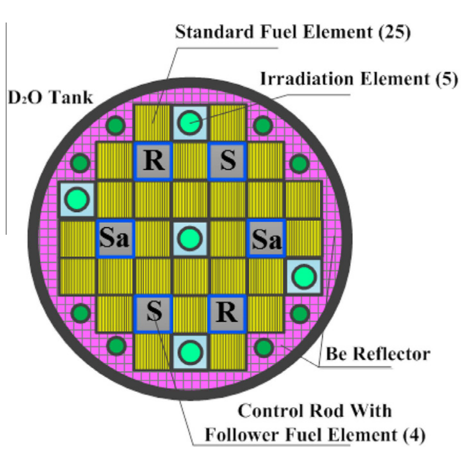

Fig. 1. Core configuration of JRR-3M.

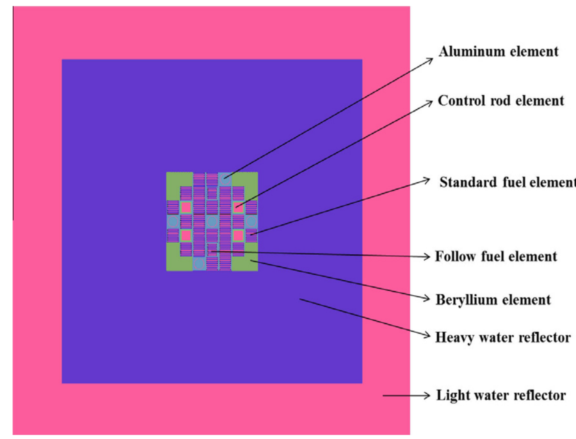

Fig. 2. Core configuration of JRR-3M type research reactor.

k_{eff} of the modified core with rectangular reflectors is 1.148726. The k_{eff} of modified core is 0.011859 larger than that of realistic core. It can be concluded that the differences between the realistic core and modified core meanly come from the differences of the areas of reflectors. Moreover, the objective of this study is to examine the applicability of DRAGON/DONJON for the analysis of research reactor with the characteristics of complex geometry, highly heterogeneity and large leakage of the research reactors. Although there are some differences between the rectangular reflectors and annular reflectors, the modified core with rectangular reflectors can preserve the characteristics of complex geometry, highly heterogeneity and large leakage of the research reactors. Therefore, the modified core with rectangular reflectors is valid and reasonable for validation of calculation codes, models and schemes.

For each standard fuel element, it contains 20 fuel plates in which the fuel meat is 0.038 cm thick. The fuel meat contains U_3Si_2 in Al matrix with uranium density 3.0 g/cm^3. The atomic densities of each component of the standard fuel element are listed in Table 2. It should be noticed that there is zero xenon in the initial fuel.

3. DRAGON modelling of the research reactor

DRAGON calculations are used to generate the macroscopic cross sections for a full core diffusion calculation of DONJON or other core analysis. Different from traditional codes, the first level cell calculations are no longer needed in DRAGON, by providing the direct 2D or 3D assembly level transport calculations. DRAGON is divided into many calculation modules lined together by the GAN generalized driver. In the first part, we present the geometry modelling of each part of the JRR-3M type reactor. Then we will introduce the calculation options used in DRAGON.

3.1. Geometry modelling

The two-dimensional geometry models of standard and follower fuel element are shown as Fig. 3(a) and (b) respectively, with the reflect boundary condition. There are 20 fuel plates in the standard fuel assembly and 16 fuel plates in the control fuel assembly. The geometry parameters are the same as JRR-3M. DRAGON has the ability to model the detailed geometry of each fuel meat, therefore the cell calculation are no longer needed.

The two-dimensional full core models of JRR-3M type reactor with four control rod elements inserted and all control rod elements inserted are shown in Figs. 4 and 5 respectively, including

Download English Version:

https://daneshyari.com/en/article/1728240

Download Persian Version:

https://daneshyari.com/article/1728240

Daneshyari.com