Progress in Nuclear Energy 71 (2014) 82–88

Contents lists available at ScienceDirect

Progress in Nuclear Energy

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

Accuracy of nuclear design of fast and thermal neutron coupled core by SRAC

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A R T I C L E I N F O

Article history:
Received 22 January 2013
Received in revised form
28 October 2013
Accepted 1 November 2013

Keywords:
Supercritical-pressure
Light water cooling
Fast reactor
MVP
SRAC
Zirconium hydride

A B S T R A C T

Supercritical-pressure light water cooled fast reactor adopts the blanket fuel assemblies with depleted uranium fuel and zirconium hydride layer in the core for negative coolant void reactivity. Thermal neutrons are generated in the core of fast reactor. It is called “fast and thermal neutron coupled core”. The purpose of the present study is to examine the accuracy of assembly and core calculations including preparation of the macroscopic cross sections with the SRAC code system for “fast and thermal neutron coupled core” in comparison with the Monte Carlo codes, MVP and MVP-BURN. Accuracy of the neutron multiplication factor and coolant void reactivity calculation has been evaluated in four types of cores of different fractions of the blanket fuel assembly with zirconium hydride rods. The conventional analysis is based on the macroscopic cross sections which are prepared with infinite lattice. The conventional SRAC calculation underestimates the neuron multiplication factor for all types of cores. Other findings are that the conventional SRAC calculation overestimates coolant void reactivity for the cores without zirconium hydride rods, and underestimates coolant void reactivity for the core of all blanket fuel assemblies having zirconium hydride rods. To overcome these problems, it has been proposed that the macroscopic cross sections of seed fuel assembly are prepared with the model that a seed fuel assembly is surrounded by blanket fuel assemblies in order to take into account the effects of the surrounding fuel assemblies. Evaluations show that accuracy of the neutron multiplication factor by the SRAC calculation can be improved by the proposed method.

1. Introduction

Supercritical-pressure light water cooled fast reactors (Super FR) (Oka et al., 2010, 2013; Liu and Oka, 2013) adopt the blanket fuel assemblies with zirconium hydride layer in the core for negative coolant void reactivity. Thermal neutrons are generated in the core of fast rector. It is called “fast and thermal neutron coupled core”. It is unique in the history of reactor physics.

The core design of Super FR with the zirconium hydride layer is conducted by the SRAC code system (Okumura et al., 2007). The SRAC code adopts a collision probability method for preparing macroscopic cross sections and a neutron diffusion calculation method for core design. It is the conventional method for reactor design. The neutron spectrum of “fast and thermal neutron coupled core” is broad and coupled between fast and thermal region with burnup. It is unprecedented neutronic characteristic. The heterogenity in “fast and thermal neutron coupled core” is substantially larger than conventional fast reactors. Negative reactivity characteristic at coolant voiding is required as the design criterion for the light water cooled fast reactor.

In the past studies of supercritical-pressure light water cooled reactors, the conventional calculation method for homogeneous fast reactor has been used. In addition, it is not possible to design the reactor with continuous energy Monte Carlo code including burnup and refuelling scheme, in particular for design study purposes that requires many calculations. Furthermore, it is necessary to carry out neutronic and thermal hydraulic coupled calculation for the design study. Deterministic method is necessary for core design. Therefore, it is necessary to evaluate the deterministic calculation method and the accuracy for the design of “fast and thermal neutron coupled core”.

The objective of the present study is to examine nuclear calculation method of the SRAC code system in comparison with the Monte Carlo code, MVP.

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http://dx.doi.org/10.1016/j.pnucene.2013.11.002

2. Fuel assemblies and core layout

The fast and thermal neutron coupled core consists of 3 types of fuel assemblies in Fig. 1 such as the seed fuel assembly with mixed oxides fuel and 2 types of the blanket fuel assembly with depleted uranium rods. One is the blanket fuel assembly including zirconium hydride (ZrH1.7) rods and the other is the blanket fuel assembly without zirconium hydride rods.

The role of zirconium hydride rods is to moderate the fast neutrons from the seed fuel assemblies at coolant voiding and to absorb them with the depleted uranium rods inside for making coolant void coefficient negative. The example of "fast and thermal neutron coupled core" is shown in Fig. 2. It is "radiating" layout of seed fuel assemblies. The radial heterogeneous and "distributed" layouts of seed fuel assemblies are also "fast and thermal neutron coupled core".

In this study, the cores with new fuel assemblies without gap for high breeding are analyzed. The specification of the fuel assembly is the same as that with high breeding light water cooled fast reactor (Oka et al., 2013). The fuel rod diameter is 1.2 cm. Plutonium and uranium mixed oxides (MOX) is used for the seed fuel and depleted uranium (99.8% U-238) is used for the blanket fuel. The isotopic composition of the MOX is assumed as follows: Pu238/Pu239/Pu240/Pu241/Pu242 = 0.4/51.3/37.8/6.5/4.0% (Ishiwatari et al., 2002). It is the isotopic composition of spent PWR fuel with 33 GWd/t burn-up. The fraction of fissile plutonium among the total plutonium is 57.8%. The density of MOX pellet is 95% of theoretical density. The cladding material is the stainless steel of 17.47% Cr and 12.5% Ni (Oka et al., 2011).

3. SRAC & MVP system and calculation model

3.1. SRAC system

SRAC system developed by Japan Atomic Energy Agency (JAEA) has been used as a neutronics code. SRAC Ver.2006 is currently used for Super FR core design. It includes nuclear data libraries, JENDL-3.3 (Shibata et al., 2002) with 107 group neutron macroscopic cross sections for more than 300 nuclides. SRAC system is a multipurpose code system applicable to neutronics analysis of a variety of reactor types.

PIJ (collision probability method code) is one of these code modules and provides three kinds of resonance integral methods: narrow resonance (NR) approximation, intermediate resonance (IR) approximation, and direct calculation with hyper-fine neutron energy group (PEACO). PIJ with PEACO resonance integral methods has been used in Super FR core design.

SRAC system also includes two auxiliary codes: ASMBURN for assembly burnup calculations and COREBN for multi-dimensional core burnup calculations, which are based on neutronics calculation of PIJ and CITATION, respectively.

COREBN calculation is based on three-dimensional diffusion solution in triangular mesh geometry of CITAION. The burnup and coolant density distributions are evaluated by assembly at given axial intervals to be consistent with assembly burnup calculation. Script files on C shell and awk language as well as perl language was developed for the assembly branch-off calculation, core geometry generation, whole core pin-power reconstruction, equilibrium cycle search etc. (Han, 2010).

3.2. SRAC calculation model

SRAC calculation model of Super FR core design is depicted in Fig. 3. Calculation for seed and blanket without zirconium hydride assembly uses unit cell geometry in SRAC and assembly geometry in ASMBURN. However, calculation for blanket fuel assembly with zirconium hydride uses assembly geometry in both SRAC and ASMBURN. The macroscopic cross section of blanket fuel assembly with zirconium hydride needs to be prepared them in heterogeneous geometry.

In COREBN calculation, assembly geometry is approximated by trigons meshes and axial meshes. Mesh mean difference schemes of neutron diffusion equation and gives neutron flux distribution. These meshes are defined by input of X-region. X-region means a spatial division in which homogenized cross sections are calculated by the flux-weight spatial integration of cross sections of constituent materials. In order to consider differenced plutonium inventory in radial regions, the meshes of blanket fuel assembly with zirconium hydride use 6 types of X-regions in radial direction. Thickness of zirconium hydride layer does not exactly fit into triangular mesh size. Zirconium hydride layer is homogenized with surrounding structural materials when macroscopic cross sections are prepared in ASMBURN calculation. Otherwise, the meshes of seed and blanket fuel assembly without zirconium hydride use only 1 type of X-region. After that, the core characteristic is analyzed by COREBN which uses the 9 neutrons groups and a diffusion calculation scheme with trigons and axial mesh geometries.

3.3. MVP

MVP is Monte Carlo code based on the continuous energy model. The code is developed by JAEA. MVP-version2 (Nagaya et al., 2005) and MVP-BURN (Okumura et al., 2000) is used in this study. It includes major neutron data libraries of JENDL-3.3.

4. Analysis of blanket fuel assembly with zirconium hydride layer

The neutron spectrum near zirconium hydride layer in the blanket fuel assembly varies significantly in a radial direction due to collision with hydrogen molecule in zirconium hydride. The

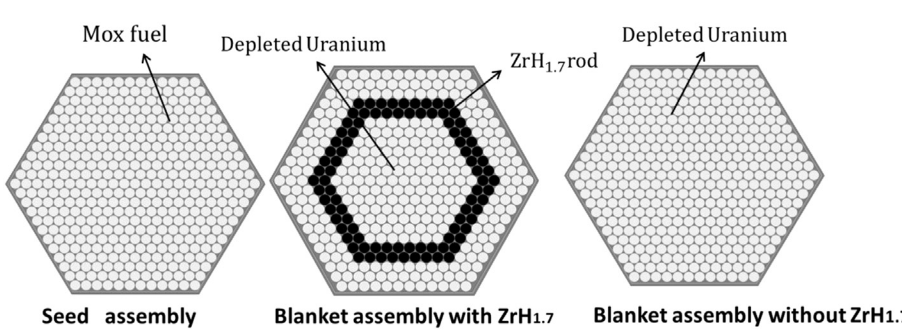

Fig. 1. Types of fuel assembly loaded in the core of super FR.