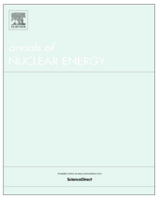
Annals of Nuclear Energy 114 (2018) 181–190

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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



Validation of the DYN3D-Serpent code system for SFR cores using selected BFS experiments. Part II: DYN3D calculations

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ARTICLE INFO

Article history:
Received 27 July 2017
Received in revised form 29 November 2017
Accepted 4 December 2017

Keywords:
SFR
BFS experiments
Group constant generation
ADF
SPH
Serpent and DYN3D

ABSTRACT

The capability of the DYN3D-Serpent codes system to simulate highly heterogeneous sodium-cooled fast reactor cores has been studied. The BFS-73-1 and the BFS-62-3A critical assemblies were chosen for the investigation. The study was performed in two parts. In the first part of the study, a 3D full model of each of the assemblies was simulated using the Serpent Monte-Carlo (MC) code, and the basic neutronic characteristics were evaluated and compared against experimental values. In the second part of the study, which is the subject of this paper, the assemblies were modeled using the DYN3D nodal diffusion code. The few-group cross-sections for the DYN3D analysis were generated using the Serpent MC code. The generation of effective few-group cross-sections of such assemblies is quite a challenge due to the substantial heterogeneity of the assemblies configuration. Therefore, the use of homogenization techniques was considered and evaluated. Initially, the GET and SPH techniques were applied for the analysis of the BFS-73-1 assembly core fuel rods, and of selected fuel rods from the BFS-62-3A assembly. Then, the SPH method was implemented and demonstrated for a pin-by-pin calculation of the BFS-73-1 assembly. It was shown that the GET and the SPH method noticeably improve the prediction accuracy of the DYN3D code. The results of the DYN3D pin-by-pin calculation with the SPH correction agree very well with that of the full assembly Serpent results, which in turn agree very well with the experimental data.

1. Introduction

A study to evaluate the numerical performance of the DYN3D-Serpent code system for sodium fast reactor (SFR) cores has been performed. The calculation system was tested against the BFS-73-1 (Manturov et al., 2006a) and the BFS-62-3A (Manturov et al., 2006b) critical experiments conducted at the Russian Institute of Physics and Power Engineering (IPPE). The BFS-73-1 and the BFS-62-3A critical experiments represent a uranium metal fueled SFR core, and a uranium-plutonium mixed-dioxide (MOX) fueled SFR core, respectively. The critical experiments are, in general, constructed from a set of vertical stainless steel (SS) tubes arranged in a hexagonal lattice. Each of the tubes is filled with pellets of fuel, sodium or structural materials. The space between the tubes is filled with cylindrical SS dowels (Dulin et al., 2014). A schematic view of the BFS-73-1 and BFS-62-3A critical experiments configuration is shown in Figs. 1 and 2, respectively. A detailed description of the experiments configuration can be found in (Rachamin and Kliem, 2017).

The study was performed in two parts. In the first part of the study (Rachamin and Kliem, 2017), a 3D full-core heterogeneous model of each of the experiments was simulated using the Serpent Monte-Carlo (MC) code (Leppänen et al., 2015), and the basic neutronic characteristics were evaluated and compared against experimental values. The calculated results showed a good agreement with the measured values. This part was meant as a first step towards the use of the Serpent MC code as a tool for preparation of homogenized group constants, and as a reference solution for code-to-code comparison with the DYN3D nodal diffusion code. The second part of the study, which is covered in this paper, is devoted to the DYN3D steady-state calculations of the experiments.

The feasibility of using the DYN3D code (Rohde et al., 2016) for steady-state calculations of conventional SFR core configurations was demonstrated in several studies (Fridman and Shwageraus, 2013;Rachamin et al., 2013;Nikitin et al., 2015a). The aim of the current study is to assess and demonstrate further the possibility of using the DYN3D code for the analysis of more complex, highly heterogeneous sodium-cooled fast systems, such as the BFS-73-1 and BFS-62-3A critical experiments. Obviously, the generation of effective few-group cross-sections for such systems is quite a challenge due to the strong spectral interaction between the different

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https://doi.org/10.1016/j.anucene.2017.12.036

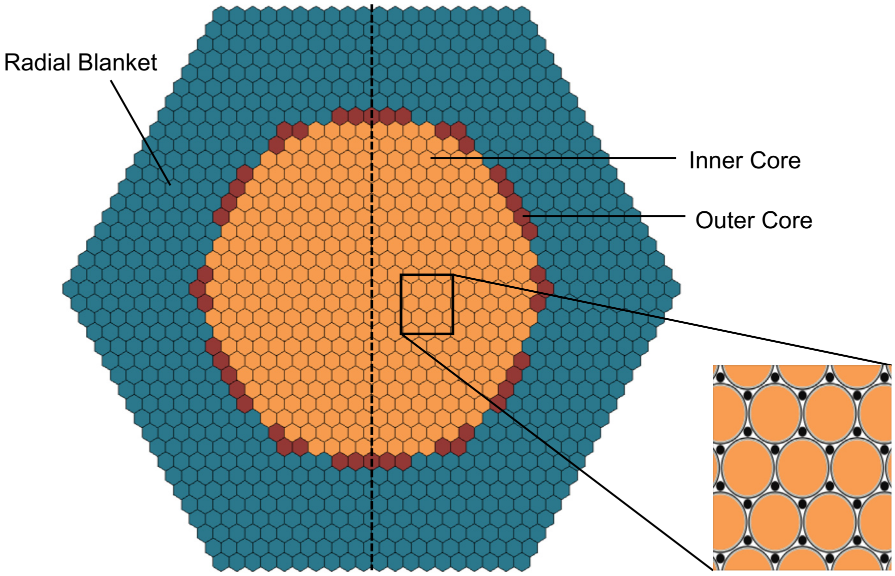

Fig. 1. Radial layout of the BFS-73-1 critical assembly.

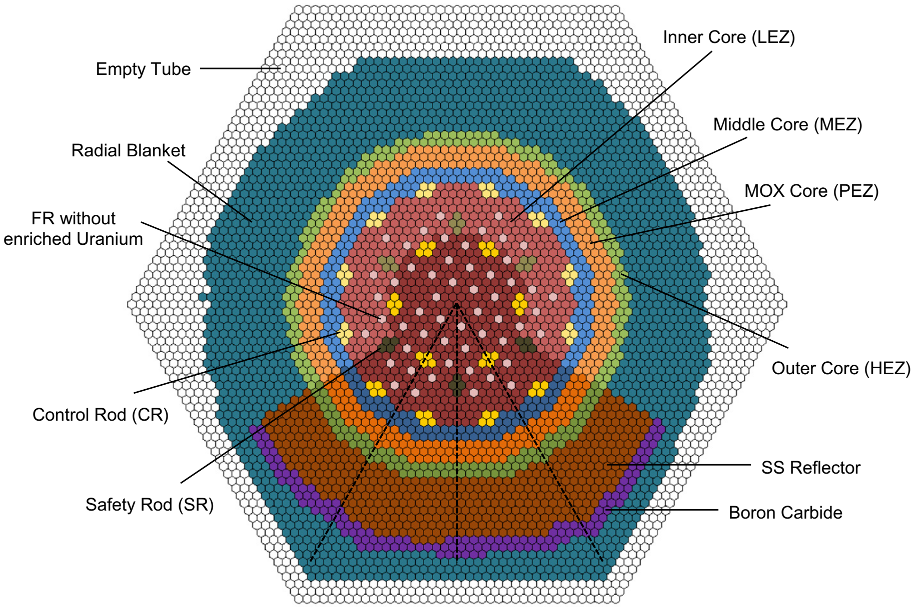

Fig. 2. Radial layout of the BFS-62-3A critical assembly.

regions of the systems. Therefore, the use of two homogenization techniques, namely the generalized equivalence theory (GET) and the Superhomogenization (SPH) method are considered and evaluated.

The paper is organized as follows. Section 2 presents the results of a 3D single fuel sub-assembly level analysis. It stands on the complexity of the experiments fuel sub-assembly geometry and stresses the need for homogenization technique. Then, the GET and SPH techniques are described and applied to the analysis of selected fuel sub-assemblies. Section 3 presents the results of a 3D full assembly level analysis. This section demonstrates the use of the SPH technique for pin-by-pin calculations of sodium-cooled fast systems. Finally, the main conclusions are given in Section 4.

2. Fuel sub-assembly level analysis

The fuel rods of the BFS-73-1 and BFS-62-3A critical assemblies are characterized by highly axial heterogeneity. Each fuel rod is composed of a stainless steel (SS) tube filled with pellets of fuel, sodium and structural materials, which are piled up to form a repeated cell arrangement. The pellets diameters are in the range of 4.6–4.7 cm and approximately 10 mm high, depending on the pellet material. Each of the pellets is bare or closed in SS or Aluminum can (Dulin et al., 2014). The general structure of the BFS-73-1 and BFS-62-3A fuel rods is shown in Fig. 3. The BFS-73-1 fuel rods are axially divided into three main regions: lower blanket, core, and top blanket. The BFS-62-3A fuel rods are axially divided into six main regions: mechanical support, lower blanket (DAB),