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Validation of the axial expansion reactivity worth for a metal-fueled Sodium-cooled Fast Reactor via a physical experiment

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ABSTRACT

For a metal-fueled SFR (Sodium-cooled Fast Reactor), the negative feedback of the reactivity due to the thermal expansion of fuel has been a principal safety mechanism to guarantee passive reactor shutdown after undercooling accidents. In this paper, an experimental model of the fuel axial expansion reactivity in a metal-fueled SFR was proposed and measured values using the BFS-109-2A critical assembly was compared with calculated values using as-built MCNP models based on the ENDF/B-VII.0 library. The energy-dependent axial expansion reactivity components of the BFS-109-2A model showed good agreement with those of the target core. The difference in the calculation/experiment ratio between the as-built MCNP models and measurements vary from −10.2% to 2.6% for the axial expansion reactivity, meanwhile the suggested axial expansion model showed a 25% discrepancy comparing to the target core.

1. Introduction

The Korea Atomic Energy Research Institute (KAERI) has been developing a metallic-fueled blanket-free SFR (with the long-term goal of attaining design approval for the Prototype Gen-IV SFR (PGSFR) before 2020 (Kim, 2013).

For a metal-fueled SFR, negative reactivity feedback is caused by the thermal expansion of the fuel. This feedback has been used as a principal safety mechanism to guarantee passive reactor shutdown after undercooling accidents (Planchon et al., 1988). However, there are few operational reactors similar to the innovative PGSFR, limiting available experimental data from an operating reactor. Hence, a crucial experiment is required to validate the core's neutronics design and related safety parameters, such as sodium void reactivity, core radial expansion reactivity, and control rod worth. In this paper, validation of the fuel axial expansion reactivity was performed based on the BFS-109-2A reactor physics experiment, which was carried out at the Russian BFS facility under a collaboration between KAERI and IPPE (Klinov, 2013).

The BFS critical assembly comprises hundreds of tightly coupled experimental rods in which several types of cylindrical disks were filled. In contrast, the target uranium core contains dozens of subassemblies composed of fuel rods, sodium coolant, and steel ducts. Therefore, an assessment of the similarity between the critical assembly and target core is required to create the fuel axial expansion model.

In this paper, the direct reactivity decomposition method (Hong et al., 2008) was used to confirm the similarity between an experimental model and a target uranium-fueled core model for the fuel expansion phenomenon.

Finally, the measured axial expansion reactivities of the BFS-109-2A critical assembly are presented in comparison with the calculated results by the as-built MCNP models based on the ENDF/B-VII.0 library (X-5 Monte Carlo Team, 2003; Chadwick et al., 2006).

2. Basic models for the critical assembly and target core

2.1. Configuration of the target core

The target core, shown in Figs. 1 and 2, is configured based on the early stage design of the PGSFR core [J.Y. Lim, personal communication, 2012]. The core consists of 48 drivers, 30 radial reflectors, 36 radial shields, and 13 control subassemblies. The core is loaded with single-enriched U-Zr fuel. The primary control system contains nine control subassemblies, and the secondary system contains four control subassemblies located near the core center. The nominal power of the target core is 100 MWe, and the core inlet and bulk outlet temperatures are 390 °C and 545 °C, respectively. The parameters for the subassemblies are listed in Table 1, and the material information is shown in Table 2.

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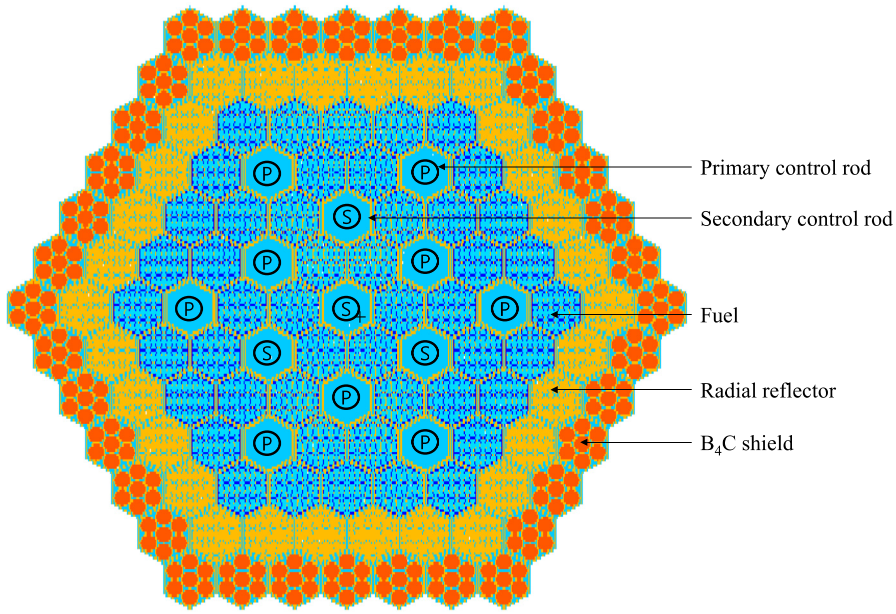

Fig. 1. Radial layout of the target U-Zr core.

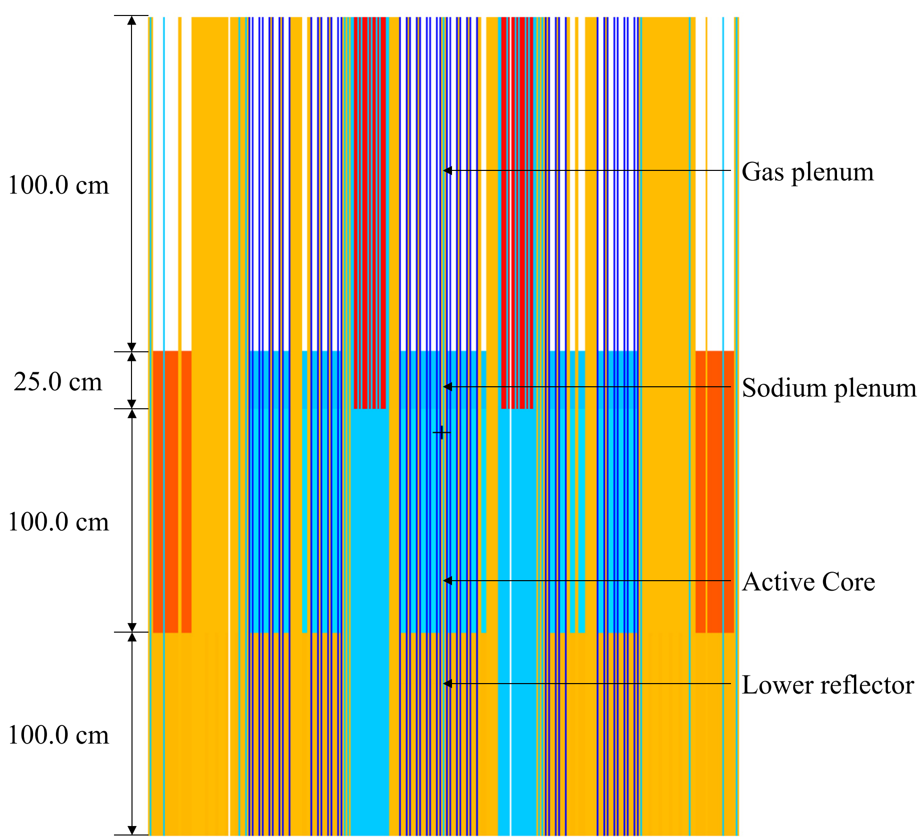

Fig. 2. Axial layout of the target U-Zr core.