Prediction of the Sodium Void Reactivity in the Metal-fueled SFR Using the ENDF/B-VII.0 Library

Sunghwan Yun* and Jae-Yong Lim
Korea Atomic Energy Research Institute (KAERI)
989-111 Daedeok-daero, Yuseong-gu, Daejeon, Korea, 305-353
*Corresponding author: syun@kaeri.re.kr

1. Introduction

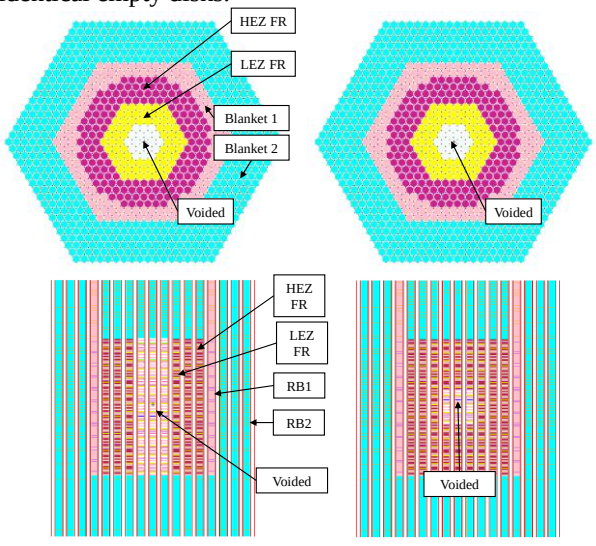
The SVR (Sodium Void Reactivity) is one of the most important parameters in SFR (Sodium-cooled Fast Reactor) safety analysis [1, 2]. In this paper, to estimate the error of the SVR in metal-fueled SFR, three physics experiments named as BFS-75-1, BFS-109-2A, and BFS-84-1 were examined using recent cross-section library, ENDF/B-VII.0 and the MCNP code [3-7].

2. Description of the Experiments

2.1 SVR Measurement in the BFS-75-1

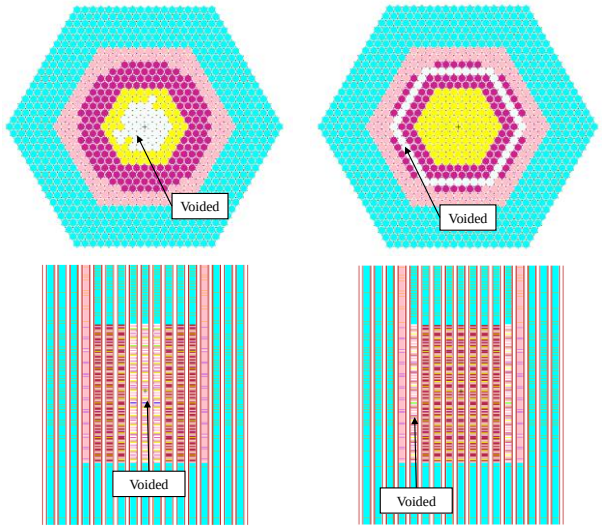
The BFS-75-1 critical assembly is a uranium metal-fueled core with two enrichment zones, LEZ (Low Enriched Zone) and HEZ (High Enriched Zone), surrounded by a depleted uranium blanket. Blanket 1 is composed of metal uranium and blanket 2 consists of depleted UO_2. Axially, core is surrounded by the blanket 2. More detailed description of the BFS-75-1 critical assembly is in the reference [8] and [9].

For SVR measurement, four stages were considered as shown in Figs. 1 and 2: stage 1 for radially central region voiding, stage 2 for most central region voiding, stage 3 for radially wide-central region voiding, stage 4 for radially peripheral region voiding. The sodium void phenomenon was simulated by changing sodium disks to identical empty disks.



(a) Stage 1 (b) Stage 2

Fig. 1. Radial and axial configurations for stages 1 and 2 SVR measurements in the BFS-75-1 experiment



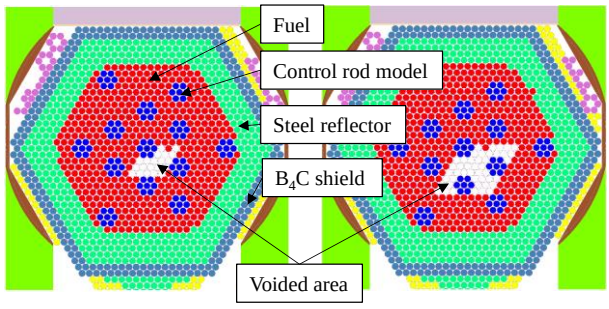
(c) Stage 3 (d) Stage 4

Fig. 2. Radial and axial configurations for stages 3 and 4 SVR measurements in the BFS-75-1 experiment

2.2 SVR Measurement in the BFS-109-2A

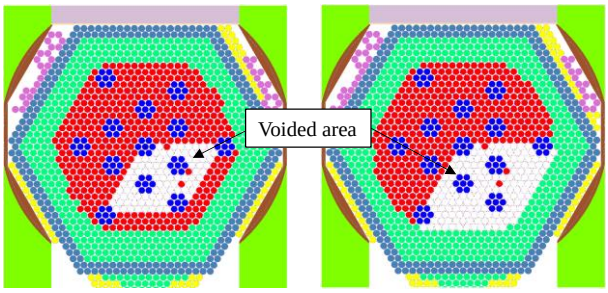
The BFS-109-2A critical assembly is a uranium metal-fueled core with single enrichment zones surrounded by a steel reflector. Axially, core is surrounded by lower steel reflector and sodium/gas plenum. Detailed description of the BFS-109-2A critical assembly is described in the reference [8] and [9].

In the BFS-109-2A experiment, sodium void effects in four radial regions were examined in a cumulative manner as shown in Figs. 3 and 4. For all of four stages, active core and sodium plenum regions were voided.



(a) Stage 1 (b) Stage 2

Fig. 3. Radial configurations for stages 1 and 2 SVR measurements in the BFS-109-2A experiment



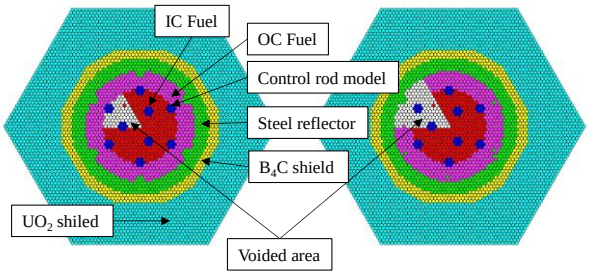
(c) Stage 3 (d) Stage 4

Fig. 4. Radial configurations for stages 3 and 4 SVR measurements in the BFS-109-2A experiment

2.3 SVR Measurement in the BFS-84-1

The BFS-84-1 critical assembly is a mock-up critical assembly of the PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) core. It is composed of uranium metal-fueled core with two enrichment zones surrounded by a steel reflector. Two enrichment zones consist of 15.9 wt.% enriched Inner Core (IC) zone and 16.8 wt.% enriched Outer Core (OC) zone to describe four batch inner core and five batch outer core in the PGSFR [10]. Axially, core is surrounded by lower steel reflector and sodium/gas plenum as the previous BFS-109-2A critical assembly.

In the BFS-84-1 experiment, sodium void effects in two radial regions and three axial regions were studied in a cumulative manner as shown in Figs. 5 and 6.



(a) Stage 1~3 (b) Stage 4~6

Fig. 5. Radial configurations for the SVR measurements in the BFS-84-1 experiment

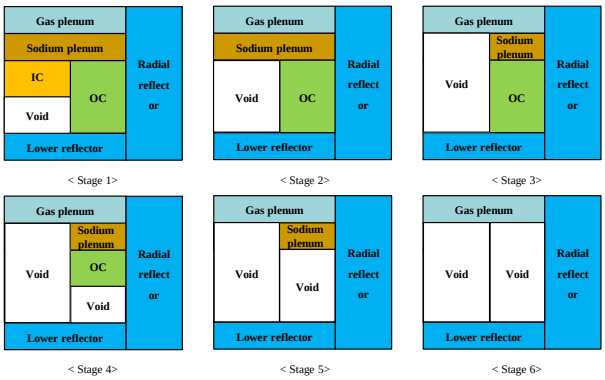


Fig. 6. Axial configurations for the SVR measurements in the BFS-84-1 experiment

3. Results and Conclusions

In the MCNP6 calculation, two million histories/generation with 50 inactive/300 active generations are used with the continuous-energy ENDF/B-VII.0 library. Table I shows C/E-1 results of SVR in three experiments.

Table I: C/E-1 results of SVRs (%)

Stages	BFS-75-1	BFS-109-2A	BFS-84-1
1	10.5±28.0	-16.1±7.9	-14.4±3.9
2	36.5±52.5	-0.5±5.4	-19.2±4.8
3	-18.1±9.4	-6.8±2.9	-4.4±4.4
4	-2.0±1.5	-6.7±2.8	-0.6±4.6
5	-	-	-3.8±5.2
6			-4.8±6.8

Results of stages 1 and 2 in the BFS-75-1 experiments are difficult to assess the accuracy of the ENDF/B-VII.0 library in SVR estimation, due to relatively large measurement uncertainty.

Results of stages 3 in the BFS-75-1, stage 1 in the BFS-109-2A, and stages 1 and 2 in the BFS-84-1 indicate that the ENDF/B-VII.0 library underestimates SVR significantly, i.e., about 15 %, at the core central region. Results of stage 4 in the BFS-75-1, stages 3 and 4 in the BFS-109-A, and stages 4 and 5 in the BFS-84-1 show that the ENDF/B-VII.0 library predicts SVR with acceptable accuracy, i.e., about 5 %, at the core peripheral region. Results of stages 3 and 6 in the BFS-84-1, which are SVRs at sodium plenum region, show similar trend with results of SVR at core peripheral region. Because change of neutron leakage due to voided sodium is the most dominant component in the SVR at both of sodium plenum and core peripheral regions, they showed similar errors.

We expect that accuracy of total cross-section of the sodium may play a dominant role in errors of SVRs at core peripheral and sodium plenum regions, whereas accuracy of capture cross-section of the sodium may play a dominant role for the results in errors of SVRs at core central region. In addition, capture cross-sections of the sodium in the ENDF/B-VII.0, the JEFF-3.2, and the JENDL-4.0 libraries show significant differences between each other, while total cross-sections of sodium in three libraries show good agreement [11, 12]. Hence, significant underestimation of the SVR at core central region by the ENDF/B-VII.0 library may be originated from the error in capture cross-section of sodium. To support our expectation, the sensitivity study for the above experiments using various cross-section libraries is planned as a future study.

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