Effect of New Cross Section Data File on the Criticality of the RSG-GAS Research Reactor

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Abstract. The 30 MW RSG-GAS reactor, is routinely operated with a cycle of 600 MWD. At the end of the cycle, a new reactor core is built for the next cycle operation. Twelve fuel elements are taken out from the core. Then, the fuel elements are inserted one by one until a certain excess reactivity is achieved, according to loading steps from calculations. The research aims to evaluate the criticality experiment data of the reactor core by calculation using the new cross-section data generated from the newest ENDF/B-VIII.0 by Serpent 2. The calculations were done by the Batan-FUEL code. By using the existing cross-section, the critical conditions occurred at insertion step no. 3, while with the new cross-section critical occurred at step no. 4. The experiment reaches critical conditions at step no. 5. It shows that criticality calculation results are closer to the experiment value when using the new cross-section data.

Keywords: criticality, macroscopic cross-section, Batan-FUEL.

1 Introduction

The RSG-GAS is a research reactor that has a nominal power of 30 MW, using light water as a moderator and cooling and beryllium as a reflector. The reactor uses uranium oxide fuel, U_3O_8-Al with a density of 2.96 g/cc, and low enriched uranium (LEU) 19.75 w/o U-235. Starting from operation cycle Core no. 36, the fuel is converted to silicide uranium U_3Si_2-Al, with the same uranium density. Fuel conversion was done by operating the reactor through mixed oxide-silicide fuel in several operation cycles until all silicide fuel is achieved [1, 2]. The reactor is routinely operated with a cycle length of 25 full power days to serve its utilization for radioisotope production and experiments. In order to assure that the reactor is safely operated, at the beginning of the operation cycle (BOC), some important nuclear parameters are measured such as excess reactivity and control rod worth [3–6]. Some of the safety parameters were also evaluated by appropriate analytical tools [7–9]. The RSG-GAS reactor produces an average thermal neutron flux of 2×10^{14} neutron cm^{-2} s^{-1} at a nominal power of 30 MW [10]. Several irradiation facilities are provided for radioisotope production and experiments namely one central irradiation position (CIP), four irradiation positions (IP), five rabbit systems, a power ramp test facility, six beam tubes, and neutron transmutation doping.

The core setup at BOC is based on the calculation of the criticality parameter of the core to get a safe core configuration. The in-core fuel management is scattered type and 5/1 mode. The

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core consists of 8 burn-up classes: 0% (fresh), 7%, 14%, 21%, 28%, 35%,42%, and 49%, with the removed fuel burn-up at 56%. At the end of the cycle (EOC) 5 fuel elements and 1 control element reaching burn-up of 56% are taken out and then changed by new fuel elements.

Since the RSG-GAS has been operated for 100 cycles, the beryllium reflector has many impurities from other elements. Some elements have a high thermal neutron cross-section that makes the efficiency of the reflector function decrease [11–13]. For that reason, at operation cycle no. 88 burnup parameter has been measured and then compared to the calculations [4, 14]. The burnup measurement results core no. 88 is then taken as initial data for the next core criticality calculation. For the cycle operation of the reactor, criticality calculation is very important to guarantee the nuclear safety of the operation. For these reasons, verification of criticality as well as the effects of cross-section using analytical tools is needed [15–17].

The purpose of the study is to calculate the core criticality of the RSG-GAS reactor with new cross-section data in which the impurity in beryllium is taken into account. The criticality parameter is effective multiplication factor (k_{eff}), core excess reactivity, and control rod reactivity worth. Calculations of core criticality and fuel management of the RSG-GAS reactor are carried out by a computer code Batan-FUEL [18]. The code uses neutron diffusion, multi-group energy, and two geometry dimensions X-Y and R-Z for the simulation of fuel burnup. In this research, core criticality is calculated using a cross-section generated for 4 energy groups (4G) and 16 energy groups (16G) from the newest cross-section library ENDF/BVIII [19]. The calculation was done for core number 91 using burnup calculation data of core number 90. The k_{eff}, core excess reactivity, and control rod reactivity were to be compared to the experiment results, while the burnup values are compared to calculation results by Serpent 2.

2 Methodology

The core components are placed in a 10 x 10 grid having dimensions of 81.0 mm in length and 77.1 mm in width. The equilibrium core of the RSG-GAS reactor is composed of 40 fuel elements, 8 control fuel elements, and 8 irradiation positions, as can be seen in Fig. 1 [20]. The fuel element is an MTR type consisting of 21 fuel plates with a length of 868.5 mm. Each fuel plate has a thickness of 1.30 mm, fuel meat of 0.54 mm, and is covered by 2 clads of 0.38 mm. The meat length is 600 mm, with a width of 62.75 mm as shown in Figure 2. While the control element consists of 15 fuel plates and on both sides is space for fork-type control rods with absorber blades. The absorber blade has a width of 65 mm and a thickness of 5.08 mm as illustrated in Figure 3. The active length is 625 mm and uses stainless steel SS 321 as cladding material. The absorber material is made of Ag-In-Cd (80% Ag, 15% In, 5% Cd) with a thickness of 3.38 mm [20].

The in-core fuel management of the RSG-GAS is carried out by a computer code namely Batan-FUEL. The loading schema is scattered type since it is a combination of outer to inner and center to outer type. Fuel elements are classified into 8 burnup classes. The fresh fuel is placed in the outer region which will be shifted to the center in the next cycle. But for the lower burn class group is shifted from the center to the outer region. The fuel loading pattern is 5/1 with the maximum burnup class is 56%. The accuracy of loading pattern 5/1 has been proved from measurements of core excess reactivity and control rod worth that is always consistent at each operation cycle [21]. Based on the measurements of several operation cycles, core formation at BOC has nearly the same core excess reactivity at every cycle.

In order to increase the accuracy of criticality calculation, the new cross-section is generated from the newest nuclear data library ENDF/B-VIII.0. Data of cross-section (XS) are generated for two different energy structures that are 4 energy group (4G) and 16 energy group (16G). The 4G structure is identical to the group constants available at WIMS-D5 whereby now implemented in core calculations of the RSG-GAS reactor. On the other hand, structure 16G is aimed to increase the accuracy by finer neutron energy groups, especially in the thermal energy range.

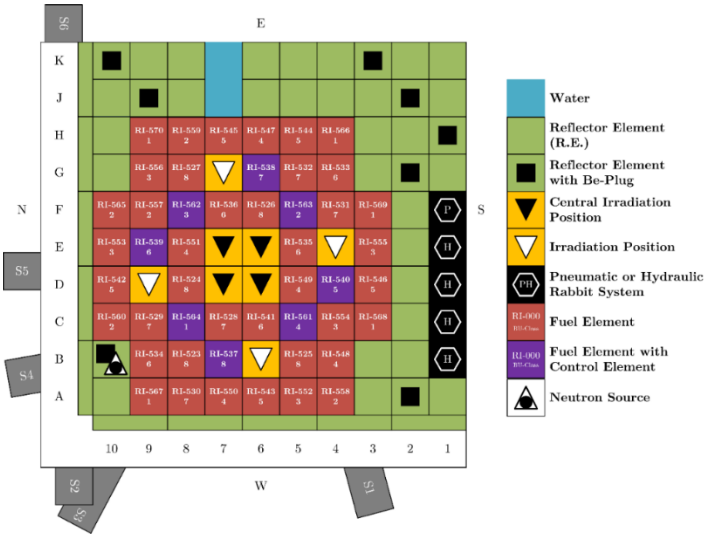

Figure 1. The RSG-GAS core configuration [18]

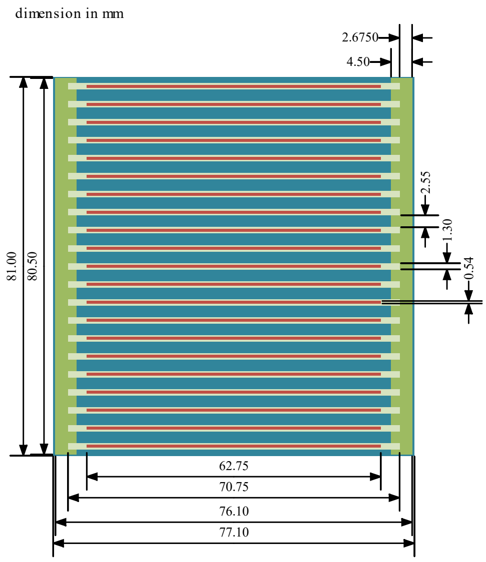

Figure 2. The RSG GAS standard fuel element [7]

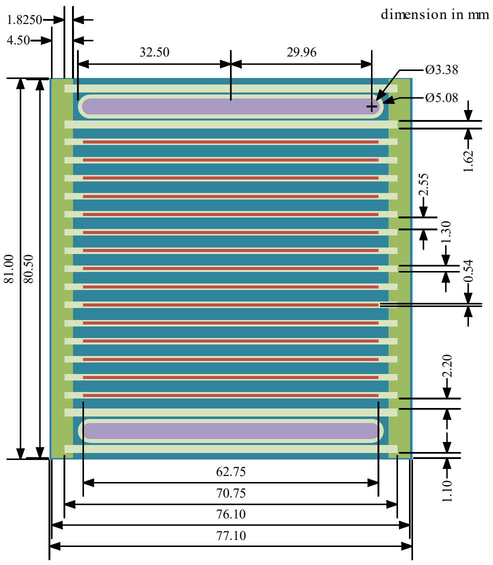

Figure 3. The RSG GAS controls element with absorber blades (7).

The calculation k_{eff}, core excess reactivity, and control rod reactivity with new cross-section has been done for core number 91. Calculation results then compared to the experiment results. The burn-up values at BOC of the core number 91 used in this calculation are illustrated in Figure 4.

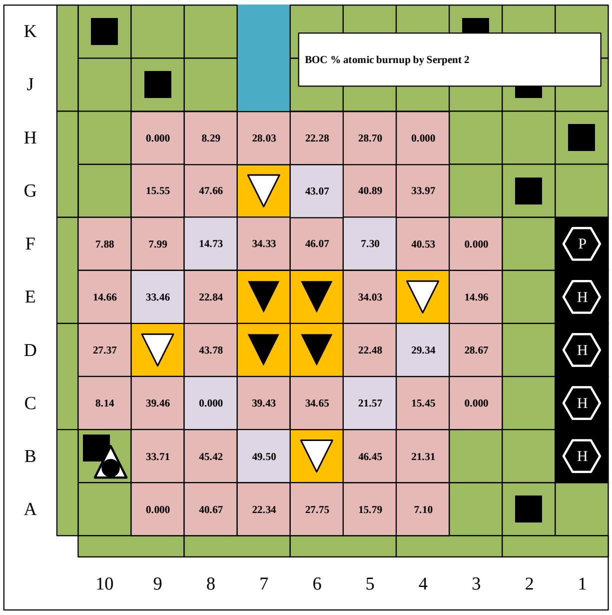

Figure 4. Burn-up distribution at BOC

3. Results and calculation

At the beginning of each RSG-GAS core operation (shuffling and refueling), there will be 12 fuel elements taken out from the core. And then fuel elements are loaded one by one following certain procedures or steps resulting from the core calculations. This in-core fuel management is carried out by a computer code, Batan-FUEL. The calculation results for Core no. 91 are summarized in Table 1. The criticality is achieved at loading step no 3 with multiplication factor (keff)1.011814 using the existing cross-section. Meanwhile, by using new cross-sections of 4G and 16G, the criticality occurs at loading steps no. 4 with keff of 1.004278 dan 1.001920. On the other side, the experiment shows that criticality is achieved at loading step no. 5.

Table 1. Criticality values of fuel loading to build equilibrium core no. 91.

Loading Step	Loading position	k_{eff} XS existing 4G	XS new 4G	XS new 16G
0	-	0.977068	0.955731	0.947789
1	A-4	0.982035	0.960358	0.955484
2	A-9	0.996862	0.976648	0.972480
3	B-5	1.011673	0.992551	0.988755
4	C-3	1.023831	1.004278	1.001920
5	C-4	1.042615	1.023540	1.019795
6	C-10	1.055272	1.036189	1.032123
7	D-3	1.065928	1.047032	1.043057
8	F-3	1.077564	1.058553	1.056245
9	F-10	1.082577	1.063088	1.057054
10	G-8	1.088486	1.068392	1.064059
11	H-8	1.094348	1.073871	1.070620
12	H-9	1.102713	1.082516	1.080126

The fissile material (nuclear fuel) decreases as it is consumed for fission reaction as long as the reactor operation cycle. In other words, some excess fuel mass shall be available after core formation at BOC. This excess mass will provide reactivity to compensate for reactivity loss during reactor operations such as burn-up, xenon poisoning, temperature effects, and experiment.

The core excess reactivity values from the calculation and experiment results are presented in Table 2. The calculation results using existing 4G show a difference of 7.7 % in comparison to the experiment value. Calculation using new cross-section 4G and 16G give deviations to experiment in amount to 9.19 % and 8.31 % respectively. These results show that neutronic calculations by using new cross-sections give more accurate results than using existing cross-sections.

Table 2. Excess reactivity values (%) from Experiment and calculation

Core No.	Experiment	Batan-FUEL Calculation		
		XS new 4G	XS new16G	XS existing 4G
91	7.29	7.96 (9.19%)	7.896 (8.31%)	9.31 (27.70%)

In nuclear reactor operation, the control rod plays an important role in safety and operation manipulation namely to control the reactor to start up, control reactor power, and shut the reactor down. The control rods are made from a strong neutron absorber material that can absorb all neutrons when it is inserted in the core. It shall have negative reactivity much greater than the core excess reactivity. The control rod position controls the level of neutron flux or reactor power. Then, this control rod reactivity worth indicates the safety level of the reactor that will ensure that the reactor can be shut down, at any time, under any circumstances.

Reactor operation management of the RSG-GAS reactor routinely carries out both calculation and measurement of this important parameter, control rod reactivity worth. The results of control rod reactivity either from calculation or measurement are presented in Table 3. It is shown that calculations using new cross-sections 4G and 16G give differences of 2.65% and 0.67% in comparison to the measurement ones. As for calculation using the existing 4G, it gives a higher difference of 6.43%. It means that calculations of control rod reactivity using new cross-sections give much better and more accurate results than that from the existing cross-section.

Table 3. Control rod worth (%) data from experiment and calculation

Core No.	Experiment	Batan-FUEL Calculation		
		XS new16G	XS new16G	XS existing 4G
91	-13.20	-13.55 (-2.65%)	-13.29 (-0.67%)	-14.05 (6.43%)

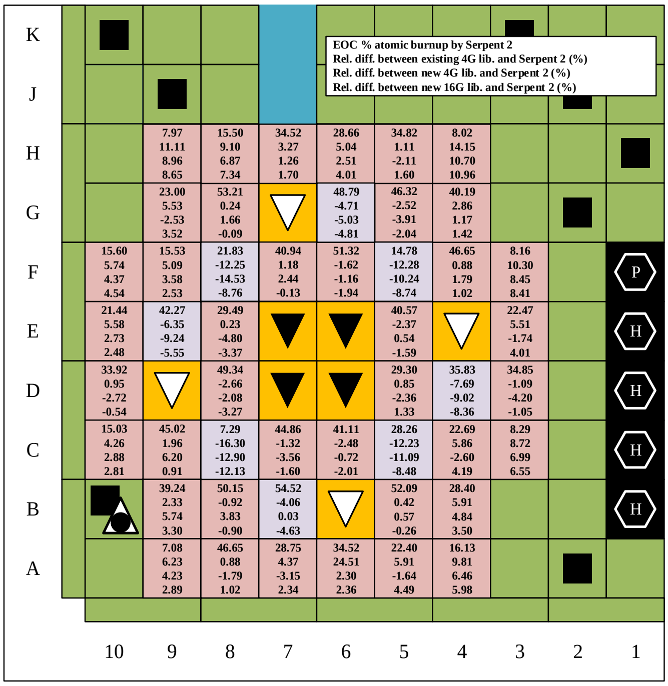

Figure 5. Burnup distribution at the EOC of 91th RSG-GAS core

The availability of fuel burn-up data is very important in supporting the safety, economy and performance of nuclear reactor operations The burn-up of fuel elements shows the amount of energy generated from fuel. Burn-up is often defined as fission energy release per mass unit of fuel elements. Normally, the burn-up unit is a Megawatt-day per metric ton of uranium (MWd/t), but in this paper, we use the remaining U-235 fraction to address a similar physical meaning. The fuel elements are arranged in the core to have a specific distribution of its burn-up in order to have a working core with a flat power or neutron flux.

The burn-up calculation results of fuel elements in core no. 91 have been done and presented in Figure 5. These are then compared to calculation using Serpent 2. The figure shows that new cross-sections 4G and 16G give a better result in comparison to that of using existing cross-sections. At low burn-up the difference maximum of about 10.96 %, while for higher burn-up, the maximum difference is 5 %.

4. Conclusion

Criticality analysis especially excess reactivity and control rod reactivity was done for Core no, 91 of the RSG GAS reactor. The calculation results were compared to the experimental values. The core excess reactivity from a calculation using a new cross-section of 4G and 16G have differences of 9.19 % and 8.31 % in comparison to the experiment values. Meanwhile using the existing cross-section of 4G, the calculation results give a 27.7 % difference in comparison to the experiment result. The control rod reactivities calculated by the new cross-section give a lower than 3 % difference to the experiment data, while by existing cross-section has a difference of 6.43 %. It could be concluded that the new cross-section data could lead to improve criticality calculation results, especially when compared to experiment values.

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