Feasibility of Burning Wave Fast Reactor Concept with Rotational Fuel Shuffling

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Abstract. Rotational fuel shuffling was tried in the burning wave fast reactor concept with movement of burning wave for radial direction to make the stable radial power density profile. The result of preliminary analysis showed the possibility to achieve it. It is possible achieve equilibrium condition with almost constant excess reactivity and stable power density profile in the core.

Key Words: Burning wave fast reactor, Breed and burn reactor, Fuel shuffling

1. Introduction

Several studies have been performed for the once-through fuel cycle fast reactor concepts, for example CANDLE burning reactor [1], Traveling Waver Reactor [2], and Breed and Burn Reactor [3]. It has very attractive feature that it can achieve high burnup using natural uranium or depleted uranium as fuel and it dose not need fuel reprocessing facilities. This kind of reactors can be categorized into three groups. The first one is the reactor whose burning wave is moving for axial direction of the core. The second one is that whose burning wave is moving for the radial direction of the core. The last one is that there is no burning wave by the introduction of random shuffling. Each concept has advantages and disadvantages. In the case of axial movement of burning wave, it has an advantage that radial power density profile dose not change during the operation, but it is necessary to load and discharge fuels at the axial edges of the core and shift the fuel in the core. In the case of radial movement of burning wave, there is no difficulties in reloading of the fuels, but it is necessary to load fuel assemblies whose multiplication factor is low at the core center, whose neutron importance is large. It will make difficult to make the reactor critical. In addition to that, the radial power density profile will be changed during the operation. It will cause the difficulties in the stable cooling of the core. In the case of random shuffling, the power density of neighboring fuel assemblies can be very different because of difference of multiplication factors of the assemblies. It will cause the difficulties in stable cooling of the core also.

One of the ideas to solve the problems is the introduction of “Rotational fuel shuffling”. In the fuel shuffling, fresh fuel, which is natural uranium or depleted uranium, is loaded at the edge of the core, approaching to the core center continuously and moving out to the core edge. By the procedure, fuel assemblies which have high multiplication factor will be loaded at the high neutron importance region and multiplication factor of neighboring fuel assemblies can be close.

The purpose of study was to show the possibility of once-through fuel cycle fast reactor that has enough reactivity in operation, stable power density profile, and small power difference between the neighboring fuel assemblies by the the rotational fuel shuffling by preliminary analysis.

2. Analysis condition

In the preliminary analysis, metallic fuel core with lead-bismuth coolant core is assumed. Total number of fuel assemblies were set to 168. There is a coolant channel at the center of the core (FIG. 1). TABLE I shows the core design in the analysis. The fuel assembly has a hexagonal lattice. The fuel which is loaded at each shuffling step is natural uranium.

3. Analysis method

For the neutron transport calculation and burnup calculation, continuous energy Monte Carlo code MVP2.0 and MVP-BURN [4] with JENDL-4.0 [5] nuclear data library were used. An original code to treat the fuel assembly shuffling was developed and used in the analysis.

At the beginning, a burnup calculation was performed for the infinite fuel cell lattice. The initial fuel is natural uranium. FIG. 2 shows the change of the infinite multiplication factor along burnup. It shows that the infinite multiplication is low at the beginning because the initial fuel is natural uranium. The factor increases rapidly by the accumulation of plutonium by neutron irradiation. It has a peak value and begins to decrease gradually by the depletion of fissile plutonium and the accumulation of fission products. In the once-through fuel cycle fast reactor concept, to make the reactor critical in the equilibrium condition is important and often difficult because the core needs to do the transmutation of uranium to plutonium with keeping fission products accumulated in the core. To solve the problem, it is effective to put the low burnup fuel assemblies, whose infinite multiplication factor is less than unity, in the region whose neutron importance is low until the infinite multiplication factor becomes high enough, and to put the high burnup fuel assemblies, whose infinite multiplication factor is also low, in the low neutron importance region. It is also needed to make the infinite multiplication factors of neighboring fuel assemblies close, to make the radial power density profile continuous and stable. This requirement can be satisfied by the rotational fuel shuffling procedure concept shown in FIG. 3.

In this preliminary analysis, an analysis was performed for the 1/6 of the core. FIG. 4 shows the fuel assembly shuffling procedure. The fresh fuel assembly, i.e. natural uranium, is loaded at the edge of the core. It moves stepwise at each shuffling step along the edge of the core. After that, it moves to the center of core. After it reach near the core center, it moves outward of the core and is discharged. By this procedure, it is expected that the loaded fuel can go to the center, whose neutron importance is high, after its infinite multiplication becomes high enough and the high burnup fuel is loaded at the region whose neutron importance is rather low. It is also expected the infinite multiplication factors of the neighboring fuel assembies can be close.

The question for this shuffling procedure is whether the reactor can have an equilibrium condition or not, and if it has an equilibrium condition, whether the reactor can be critical or not. To make clear them, neutron transport calculation and burnup calculation were performed. Natural uranium is loaded in the all assemblies of initial core. At each fuel shuffling, a natural uranium fuel assembly was loaded at the loading point and a fuel assembly at the discharge point was discharged. The interval of the shuffling was set to 1,000 days. Simulation of fuel assemblies movement by the shuffling were continued until it becomes to an equilibrium condition. In the calculations, the core was divided into 87 tally regions. In the neutron transport calculations, the neutron histories per batch was set to 10,000 with 50 skipped batches and 50 active batches. The neutron transport calculation interval was set to 125 days in the burnup calculation.

4. Analysis results and discussion

The burnup characteristics became equilibrium condition by the repetition of the shuffling. FIG. 5 shows the change of the effective factor after the repetition of the shuffling for sixty times from the initial core. The figure shows that the same change of the effective multiplication factor is repeated between the shuffling. In addition to the fact, the change of the factor is less than 0.1%, i.e. the excess reactivity of the reactor is almost constant. The burnup of discharged fuel was 300GWd/t, which correspond about 30% of burnup, by using natural uranium for fresh fuel. FIG. 6 and FIG. 7 show the average power density of each fuel assembly at the beginning of the shuffling cycle and at the end of it in the equilibrium condition respectively. The figures show that power density profile for radial direction is almost unchanged in the equilibrium. FIG. 8 shows the change of radial power peaking factor in a shuffling interval. It also shows that the power density profile in the core is almost unchanged in the shuffling interval.

5. Conclusion

The concept of rotational fuel shuffling scheme was proposed for the one-though fuel cycle fast reactor and a preliminary analysis was performed by Monte Carlo based calculations with the fuel shuffling shame. The results show the reactor can achieve equilibrium condition and be critical. In this example, the reactor power density profile was almost stable in the equilibrium condition. It means the shuffling scheme concept has a possibility to design a once-thorough fuel cycle fast reactor by solving the issues which the conventional concepts have. This preliminary analysis was to discuss in the equilibrium condition. The study for the optimum initial core will be a future work. The integrity of fuel cladding is another issue to be solved.

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TABLE I: Design parameters of the core

Parameter	**Value**
Thermal power	740MW
Core height	220.0cm
Core equivalent radius	123.4cm
Reflector thickness	About 1 m
Fuel	Nat. U+10%Zr
Fuel cladding material	9Cr-ODS
Coolant and reflector	44.5%Pb+55.5%Bi
Fuel radius	4.5mm
Fuel smear density	75%
Fuel pin radius	5.1mm
Fuel pin pitch	10.8mm
Number of fuel assemblies	168 + 1 coolant channel
Fuel temperature	800K
Coolant temperature	700K

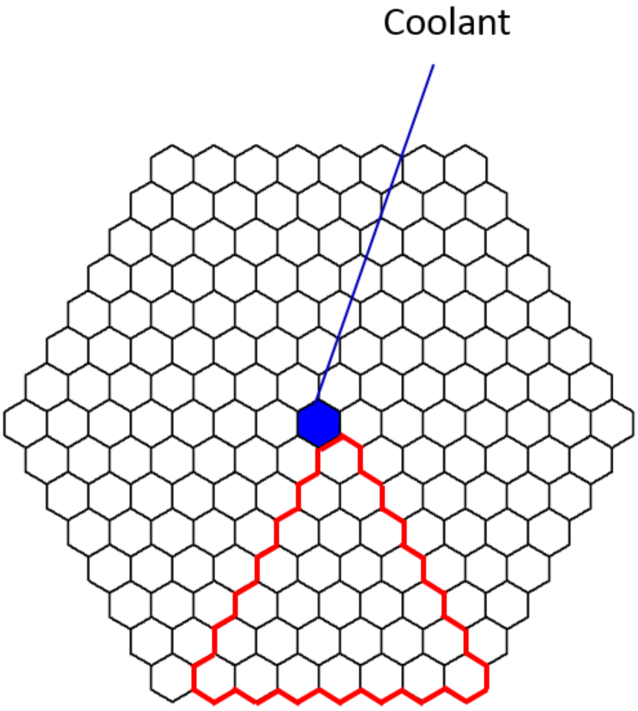

FIG.1. Core geometry

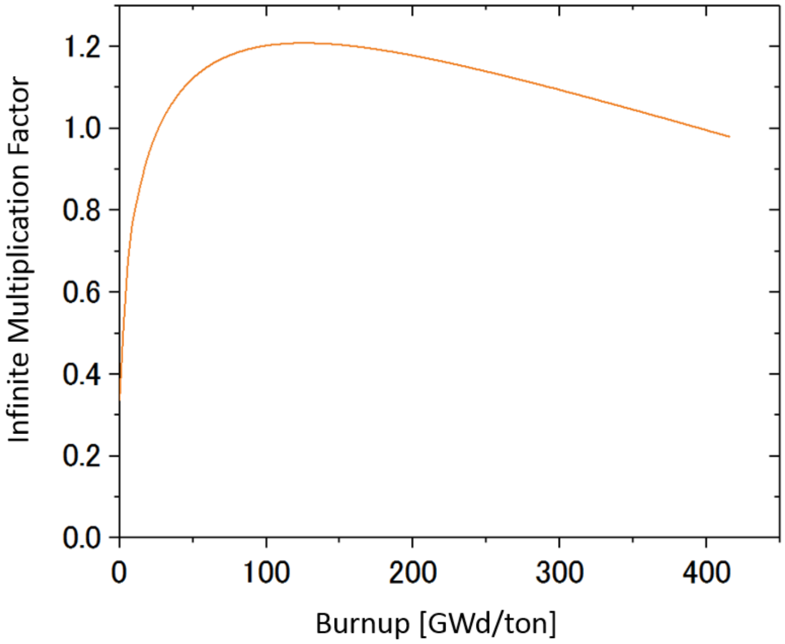

FIG. 2. Change of infinite multiplication factor along burnup

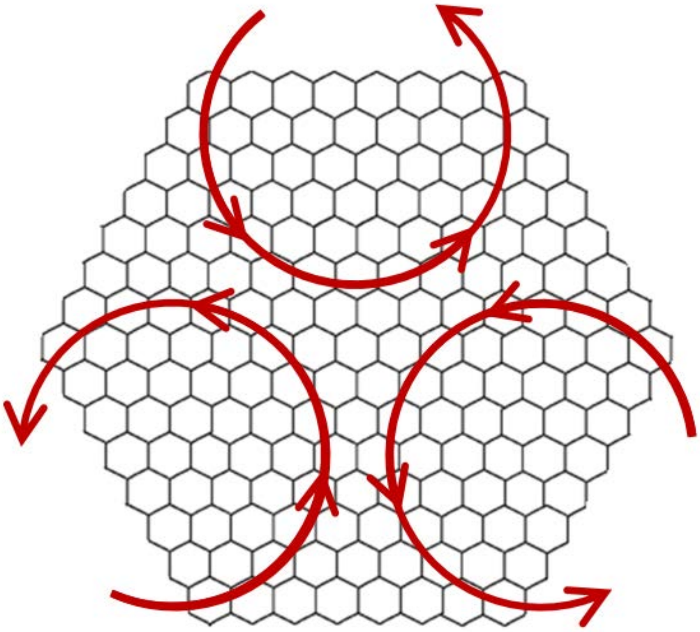

FIG. 3. Concept of rotational fuel shuffling scheme

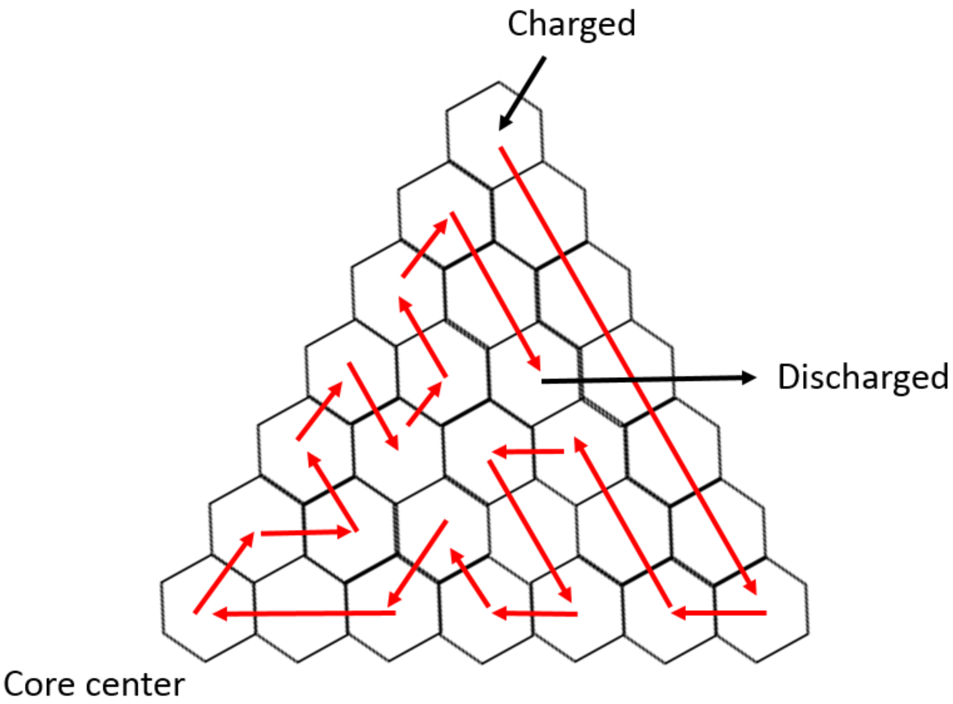

FIG. 4. Procedure of fuel assembly shuffling in the analysis

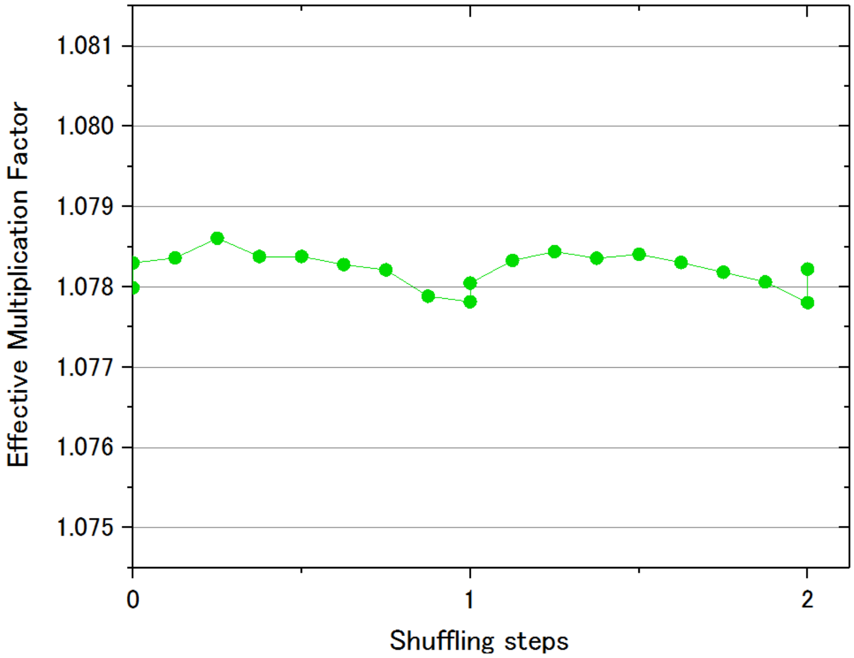

FIG. 5. Chang of effective multiplication factor in the equilibrium condition

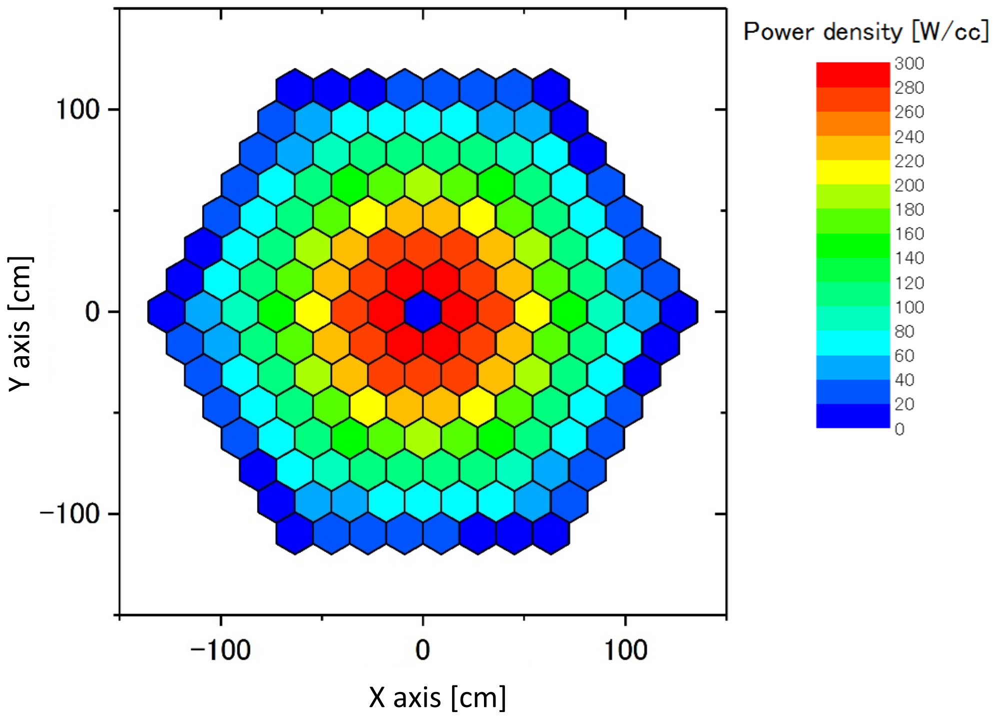

FIG. 6. Average power density of each assembly at the begging of shuffling interval

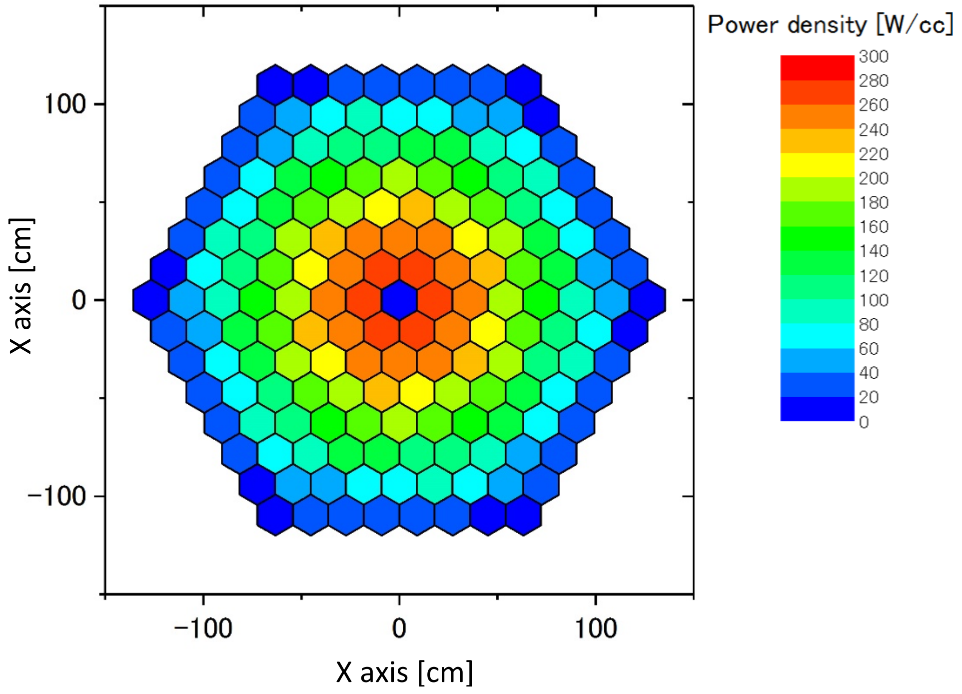

FIG. 7. Average power density of each assembly at the end of shuffling interval

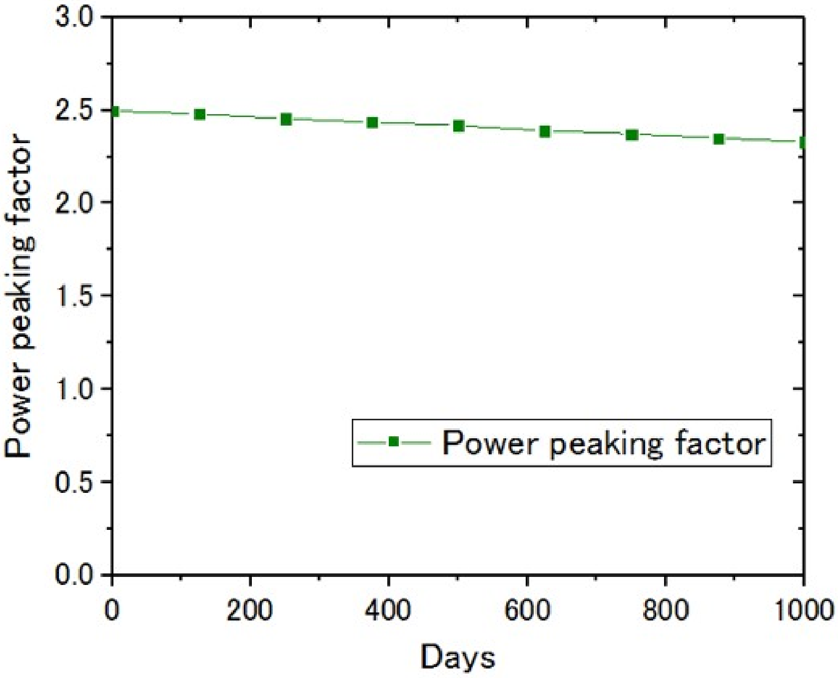

FIG. 8. Change of power peaking factor for radial direction in a shuffling interval