Improved Retrieval Technique of pin-wise composition for spent fuel recycling

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1. Introduction

Spent fuel recycling became an issue since spent fuel pool in nuclear power plant is almost full recently. There are two ways for spent fuel recycling, reprocessing and reutilization. Reprocessing option is impossible in Korea, although pyro-processing was partially admitted by ROK-U.S. Atomic Energy Agreement. Reutilization option like DUPIC (Direct Use of Spent PWR Fuel in CANDU)[1] fuel cycle has some advantage such as having nuclear non-proliferation and utilizing uranium resources more efficiently. DUPIC fuel has an advantage that does not need to extract fissile isotopes from spent fuel. However, DUPIC fuel requires fabrication to use in CANDU reactor.

New reutilization method which does not require fabrication processing was suggested and showed feasibility by Dr. Aung Tharn Daing.[2] This new reutilization method is predict spent nuclear fuel pin composition, reconstruct new fuel assembly by spent nuclear pin, and directly reutilize in same PWR core. There are some limitation to predict spent nuclear fuel pin composition on his methodology such as spatial effect was not considered enough.

This research suggests improving Dr. Aung Tharn Daing's retrieval technique of pin-wise composition. This new method classify fuel pin groups by its location effect in fuel assembly. Most of fuel pin composition along to burnup in fuel assembly is not highly dependent on location. However, compositions of few fuel pins where near water hole and corner of fuel assembly are quite different in same burnup. Required number of nuclide table is slightly increased from 3 to 6 for one fuel assembly with this new method. Despite of this little change, prediction of the pin-wise composition became more accurate.

2. Retrieval Technique of pin-wise composition

The retrieval technique of pin-wise composition was performed by conventional two-step core analysis code package. The first step of this technique is producing homogeneous cross section and form function for each fuel assembly. Second step is performing core calculation by nodal code. Third step is predict pin-wise burnup prediction by pin power reconstruction technique from nodal code. Forth step, nuclide number density table is generated by function of burnup with lattice code. At the last step, fuel pin composition is retrieved with interpolating burnup value on nuclide number density table.

There are two limitations of previous method. First, axially averaged fuel pin burnup represents fuel pin burnup. The other problem is the number density table generated by single pin calculation which is not considered location effect in fuel assembly.

3. Spatial effect

Impact of axial effect and location effect was checked in fuel assembly to improve his technique. The reference core is OPR-1000(Ulchin unit 5). HELIOS-1.8 and MASTER-2.2 were used for 2-step code calculation. [3,4,5]

3.1. Axial effect

Axially averaged fuel pin burnup represents as fuel pin burnup to predict isotope number density. It might be a source of error because retrieved isotope lost axial information. Fig. 1 show previous pin-wise composition retrieval technique. Fig. 2 is explains how to check axial effect. Cycle-3 D0 fuel assembly which is located in (P,12)[6] was chosen for this evaluation. Assembly inventory, fuel assembly k-inf value and axial flux distribution were chosen for comparison parameter.

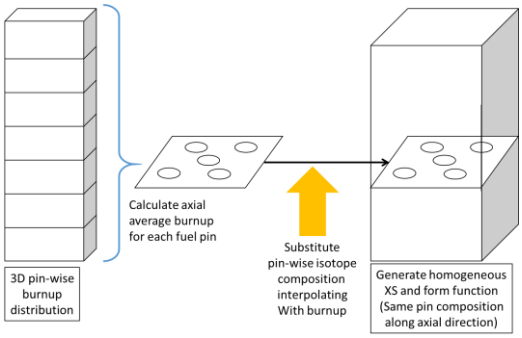

Fig. 1. Previous pin-wise composition retrieval technique

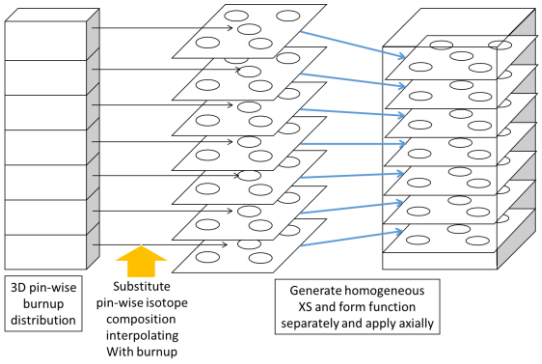

Fig. 2. Pin-wise composition retrieval technique with axial effect

Table 1 and Table 2 shows fuel assembly inventory at BOC and EOC. Every isotopes was arrayed in descending order. Case 1-1 is retrieving pin-wise isotope composition by axially averaged burnup. Case 1-2 is retrieving pin-wise isotope composition axially. Assembly isotope inventory have less than 2% difference between two cases except Pu238 and Pu242. However, Amount of Pu238 and Pu242 is small enough to neglect comparing with major actinides.

Table 1. Fuel assembly inventory at beginning of cycle

BOC	Case 1-1	Case 1-2	Relative error
U238	6.305E-03	6.304E-03	0.00%
U235	2.052E-04	2.055E-04	0.15%
Pu239	2.821E-05	2.795E-05	-0.91%
U236	1.616E-05	1.608E-05	-0.46%
Pu240	4.177E-06	4.198E-06	0.50%
Np237	7.580E-07	7.680E-07	1.31%
Pu241	4.350E-07	4.343E-07	-0.15%
Pu238	2.333E-07	2.481E-07	6.33%
Pu242	9.626E-08	1.031E-07	7.06%

Table 2. Fuel assembly inventory at end of cycle

EOC	Case 1-1	Case 1-2	Relative error
U238	6.270E-03	6.270E-03	0.00%
U235	1.594E-04	1.603E-04	0.60%
Pu239	3.412E-05	3.370E-05	-1.23%
U236	2.421E-05	2.401E-05	-0.85%
Pu240	8.148E-06	8.111E-06	-0.45%
Pu241	3.649E-06	3.656E-06	0.18%
Np237	1.568E-06	1.574E-06	0.34%
Pu242	4.577E-07	4.692E-07	2.50%
Pu238	4.089E-07	4.252E-07	4.00%

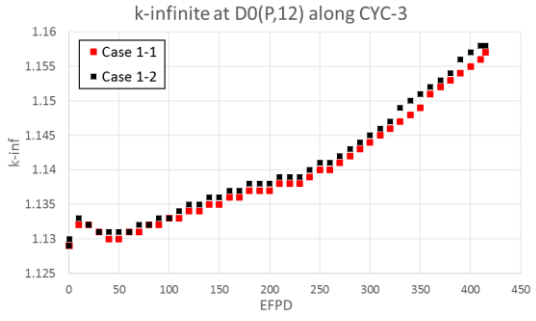

Fig. 3. D0 assembly k-inf value along CYC-3

Fig. 3 shows D0 assembly k-inf value about two cases. There is no k-inf difference at BOC-3. And at ECO-3, there are 100pcm difference. However, it is not very big difference considering that the smallest unit of assembly k-inf is 100pcm in MASTER code.

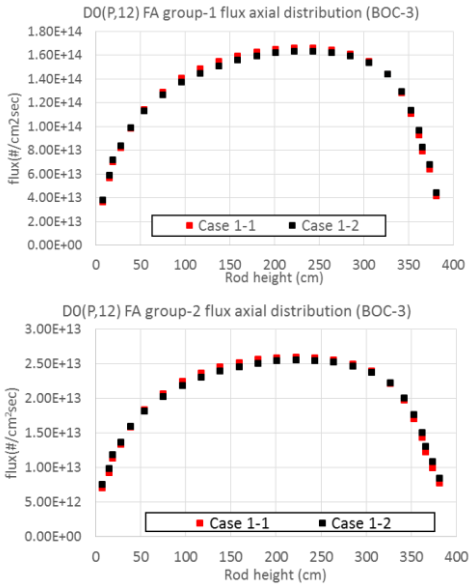

Fig. 4. Axial flux distribution at beginning of cycle

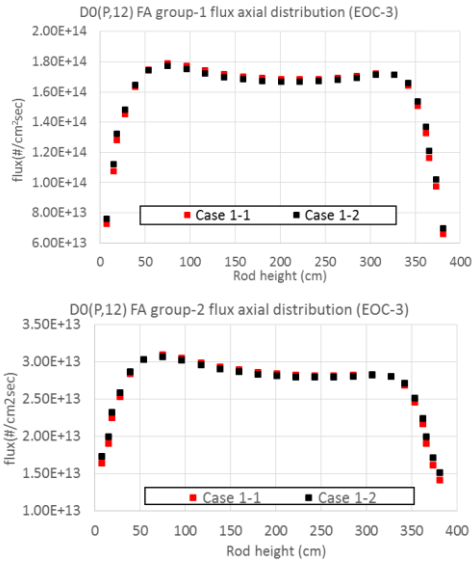

Fig. 5. Axial flux distribution at end of cycle

Fig. 4 and Fig. 5 shows 2-group axial flux distribution of D0 fuel assembly at BOC and EOC. There is only minor difference was observed on axial flux distribution.

There were only minor difference between two cases. Therefore, the previous method is good enough.

3.2. Location effect in fuel assembly

Nuclide number density table was generated by single pin calculation. Dr. Aung Tharn Daing classify fuel pin types according to initial U-235 enrichment only.

Location effect in fuel assembly was checked by substituting nuclide number density table which is generated by single assembly calculation. B1 fuel assembly which is located at (K,5) in Cycle-2 was used for this evaluation.[7] Fuel assembly k-inf value and isotope inventory were chosen for comparison parameters.

There are 3 cases to check location effect. Every case was conducted under HELIOS condition; 500 ppm fixed soluble boron concentration, Xenon and Samarium transient condition along the fuel cycle. Case 2-1 is MASTER calculation result without pin-wise isotope retrieved. Case 2-2 and Case 2-3 are pin-wise isotope composition retrieved assembly. Single pin calculation was performed for number density table generation for case 2-2. Single assembly calculation was performed for case 2-3, on the other hands.

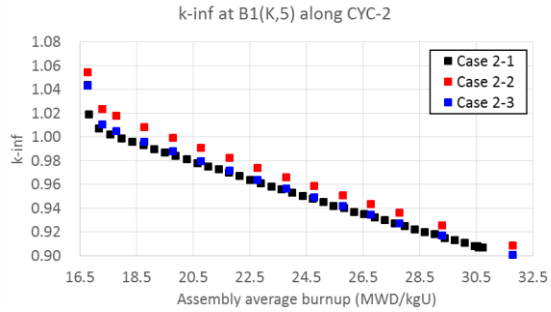

Fig. 6. k-inf curve of B1(K,5) assembly at CYC-2

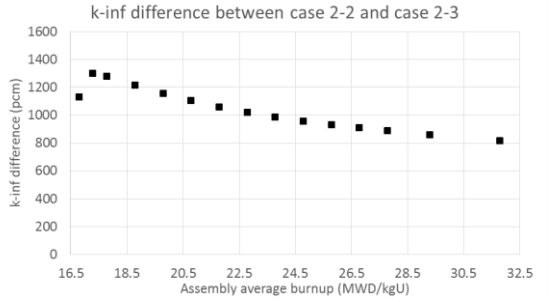

Fig. 7. k-inf value difference between retrieved by single pin database and single assembly database

Fig. 6 shows k-inf curve of B1 fuel assembly along cycle 2. Case 2-2 has higher reactivity to the other cases. Fuel assemblies with retrieved fuel pins (case 2-2, case 2-3) have quite different reactivity to each other. The k-inf difference showed on fig. 7. They have at least 800pcm difference and the highest difference is 1300pcm along the cycle 2. Case 2-2 has more inventory of all major actinide except U238 on Table 3. This is the reason why retrieved fuel assembly with single pin calculated table has higher reactivity. It means data table with single pin calculation overestimates reactivity with same burnup. Therefore, location effect in fuel assembly need to consider for fuel-pin isotope retrieving technique.

Table 3. Fuel assembly inventory after retrieved

	Case 2-2	Case 2-3	Relative error
U238	2.17E-02	2.17E-02	-0.1 %
U235	3.15E-04	3.09E-04	2.0 %
Pu239	1.18E-04	1.07E-04	11.1 %
U236	5.59E-05	5.57E-05	0.4 %
Pu240	2.88E-05	2.83E-05	1.8 %
Pu241	1.56E-05	1.43E-05	9.5 %
Np237	3.89E-06	3.55E-06	9.7 %
Pu242	2.44E-06	2.41E-06	1.3 %
Pu238	6.94E-07	6.00E-07	15.7 %

4. Improved retrieval technique

Chapter 3 shows location effect in fuel assembly is quite important. To improve this technique, location effect in fuel assembly has to be applied. However, there is a problem that we need to prepare 32 nuclide tables for every kind of fuel assemblies. Preparing 32 nuclide tables takes quite long time, and becomes a source of human error by its huge data. To solve this problem, we need to reduce nuclide table preparation.

4.1. Fuel pin grouping

We can reduce nuclide table preparation by fuel pin grouping with importance of fuel pin location effect. U235 and Pu239 number densities at same burnup from every fuel pins were compared to check fuel pin location effect in fuel assembly. B1 assembly having 35MWD/kgU at every fuel pin was chosen for the test. Fig. 8 and Fig. 9 shows importance of fuel pin location. Blue box means contains much less isotopes than average, red box means contains much more isotopes than average on the other hands.

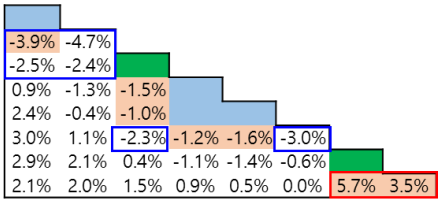

Fig. 8. U235 number density relative error to average number density

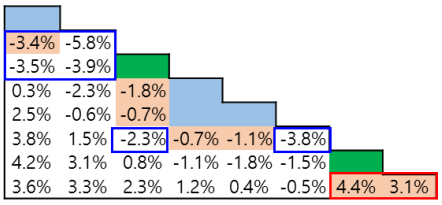

Fig. 9. Pu239 number density relative error to average number density

Therefore, 3 groups of fuel pins are existed in fuel assembly roughly.

Group-1: Fuel pins located near water hole
Group-2: Fuel pins located at corner
Group-3: Fuel pins having small location effect

So there will be 6 types of fuel pins are exist in B1 assembly. Table 4 and Fig. 10 show fuel pin types by grouping.

Table 4. Fuel pin types on previous method and new method

Fuel types on previous method	Fuel types on new method
Normal fuel pin (NFP)	NFP-Group1 NFP-Group3
Lower enriched fuel pin (LEFP)	LEFP-Group1 LEFP-Group2 LEFP-Group3
Burnable absorber (BA)	BA-Group3

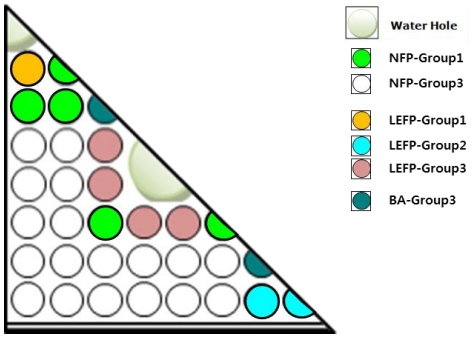

Fig. 10. B1 fuel assembly with grouping

4.2. Feasibility of new method

Fuel assembly retrieved with grouped fuel pin nuclide tables was compared with full single assembly nuclide tables for retrieval. Retrieved fuel assembly inventory and k-inf curve were chosen for comparison.

Table 5. B1 assembly inventory after retrieved

	Case 2-3	New Method	Relative error
U238	2.17E-02	2.17E-02	0.0 %
U235	3.09E-04	3.09E-04	0.2 %
Pu239	1.07E-04	1.06E-04	-0.2 %
U236	5.57E-05	5.57E-05	0.0 %
Pu240	2.83E-05	2.83E-05	0.1 %
Pu241	1.43E-05	1.42E-05	-0.6 %
Np237	3.55E-06	3.56E-06	0.3 %
Pu242	2.41E-06	2.40E-06	-0.6 %
Pu238	6.00E-07	6.03E-07	0.6 %

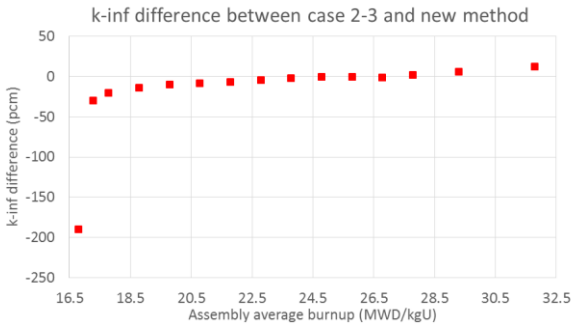

Fig. 11. k-inf value difference between retrieved by full single assembly database and grouped database

Table 5 and Fig. 11 show the difference is small between two cases. Every major actinides has less than 1% difference. k-inf value difference at retrieved point is 190pcm which is quite big difference. However, the difference became less than 50pcm after 0.5MWD/kgU. Thus, using new method instead of using full single assembly database is very reasonable.

5. Conclusion

This new method guarantees two advantages than previous retrieving technique. First, accurate pin-wise isotope prediction is possible by considering location effect in a fuel assembly. Second, it requires much less nuclide tables than using full single assembly database.

Retrieving technique of pin-wise composition can be applied on spent fuel management field useful. This technique can be used on direct use of spent fuel such as Dr. Aung Tharn Daing showed or applied on pin-wise waste management instead of conventional assembly-wise waste management. These research become more accurate and valuable with this improved technique.

REFERENCES

[1] Won Il KO & Ho Dong KIM (2001) Analysis of Nuclear Proliferation Resistance of DUPIC Fuel Cycle, Journal of Nuclear Science and Technology, 38:9, 757-765

[2] Aung Tharn Daing & Myung Hyun Kim (2014) Investigation into fuel pin reshuffling options in PWR in-core fuel management for enhancement of efficient use of nuclear fuel, Nuclear Engineering and Design, 273, 332-349

[3] "HELIOS 1.9 User's Manuals", Studsvik Scandpower, 2005

[4] "PROLOG 1.1 User's Manual", KAERI/UM-4/99, September, 2004

[5] "MASTER 3.0 User's Manual", KAERI/UM-8m2004, March, 2004

[6] "The Nuclear Design Report for Ulchin Nuclear Power Plant Unit5 Cycle 3", KNF-U5C3-06024 Rev.0, KNFC, September, 2006

[7] "The Nuclear Design Report for Ulchin Nuclear Power Plant Unit5 Cycle 2", KNF-U5C2-05019 Rev.0, KNFC, July, 2005