An alternative approach for pin wise composition tracing in the used nuclear fuel assemblies

Zafar Iqbal ZAFAR and Myung Hyun KIM*
Department of Nuclear Engineering, Kyung Hee University
1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do, Korea, 446-701
mhkim@khu.ac.kr

1. Introduction

Importance of the knowledge of the detailed used nuclear fuel (UNF) is multi-dimensional, ranging from safety to economic savings and beyond [1]. Different ways have been proposed and used to trace isotopic inventory. A dedicated example of the pin-wise composition calculation with intention of reutilization is given by Aung et.al. [2]. The method was based on two main assumptions; (a) burnup of the each fuel pin in each fuel assembly is mere product of the corresponding assembly average burnup and shape factor of that assembly, (b) production or destruction of any isotope in a fuel pin is directly proportional to the burnup imparted.

Current work involves safety concerns of the UNF, and hence is limited to the radioactive isotopes only. That is with isotopes having half-life more than few hours (30 hours) but less than Uranium ore ($T_{1/2} \sim 2.6316 \times 10^9$y). From the table of the isotopes [2], we find nature has more than three thousand isotopes, and out of them, only 223 isotopes are produced in a PWR core. Only 143 isotopes (out of these 223) have half lives in the above range.

This choice of isotopes limits usefulness of the lattice code HELIOS 1.5 [3] for the composition table generation. Lack of data for the 93 isotopes out of these 143, in the HELIOS 1.5 library pushed to ORIGEN2 [4] for the composition table preparation. However, ORIGEN does incorporate effect of the fuel/moderator temperatures and core geometry by means of the one group x-section. Existing x-sections for a PWR core are generated for a typical 1000 MW PWR using 5% enriched UO_2 fuel.

So, current work is based on the assumption that (1) Burnup of the each fuel pin in each fuel assembly is mere product of the corresponding assembly average burnup and shape factor of that assembly. (2) Production or destruction of any isotope depends primarily on many parameters. These parameters include (a) Burnup, (b) initial composition, and (c) specific power.

This method is first applied to the normal fuel pins in the A0 type fuel assemblies loaded in the first cycle of the OPR-1000 reactor core. Then, it is extended to three dimensions. Axial variation of the content of each isotope is different due to difference of the burnup and also due to the difference of the specific power.

There is another improvement to the so called ‘interpolation technique’. The composition table preparation and then interpolation process is replaced with the on the flight ORIGEN2 running. This is possible because HELIOS 1.5 is a time consuming multi-tier venture, while ORIGEN2 is a single tier handy code. It is concluded that this ‘on the fly’ method is not only low on computing resources but also faster to implement than the previously applied methods.

2. Method and Results

The ‘on the fly ORIGEN run’ technique is based on numerous assumptions and observations. First, as quoted in literature, it is assumed that the standard reconstruction technique is reasonably valid. This assumption is well accurate because reconstruction of the pin-wise flux, power and then burnup from the so called form functions or shape functions and the nodal solutions is already highly tested and validated. Second assumption, that composition depends on three things; namely burnup, specific power and initial composition is also reasonably accurate. Neglecting of the reactor operating conditions, like boron concentration, temperature variations and other similar activities cause only minor difference to the results. Lastly the main assumption that core averaged one group cross section library of the ORIGEN2 is valid for the single assembly and also for the single pin composition could be a source of the error for special fuel pins. However, neutron spectrum in the vicinity of the so called normal fuel pins is more or less same as the assembly average one. Hence, this approximation is also justifiable for the standard fuel pin composition calculation. Needless to say, standard fuel pins make vast majority of the overall fuel pins in a core.

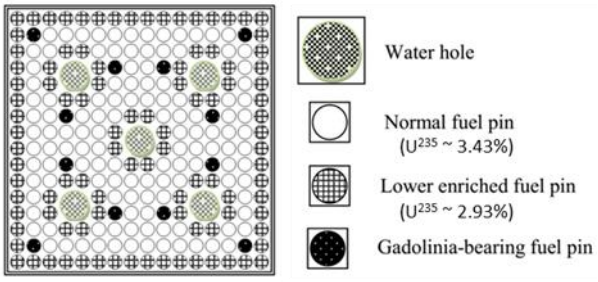

Fig. 1. A typical C-1 type fuel assembly used in OPR-1000

All fuel assemblies are modeled in HELIOS 1.5 one after another. A detailed view of the C-1 type fuel assembly is shown in Fig. 1. The lattice code HELIOS 1.5 gives the necessary x-section and form function libraries averaged over the entire fuel assembly. After modeling all fuel assemblies one by one, the main library files are prepared by accumulating these x-sections and shape functions into them.

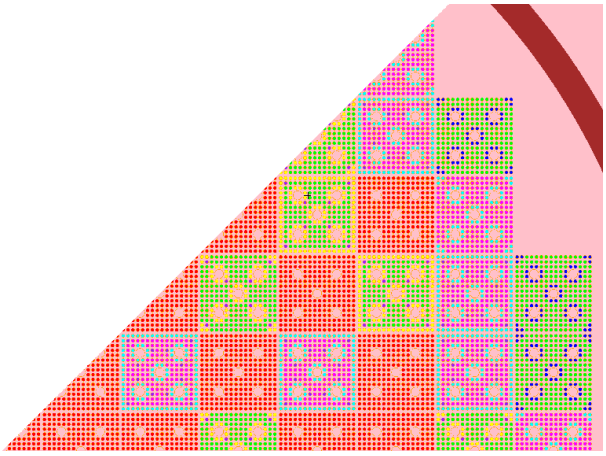

Fig. 2. An octant of the first cycle OPR-1000 core (MCNPX model, MASTER model is also similar)

MASTER 2.2 is used to model the entire core (Fig. 2) and pin wise burnup is calculated for each fuel pin of each fuel assembly. As time of stay inside the reactor core is same for all the fuel pins so, difference of the burnup is directly proportional to the specific power of the each pin.

The variation of the amount of different isotopes in a randomly chosen standard fuel pin along axial direction (Fig. 3) does not necessarily follow the burnup trend. At top and bottom of the fuel pin where overall burnup is low, effect of the little difference in burnup causes relatively bigger difference in the amount of the isotope produced or burnt.

To assess the accuracy of the calculated number densities of the selected isotopes, depletion of an identical model of the same core was performed on MCNPX 2.6 in parallel (Fig. 2). With exception to the isotopes produced in very small quantities, the two techniques (Monte Carlo i.e. MCNPX 2.6.0 and Deterministic i.e. MASTER 2.2) give results that are reasonably in agreement.

The difference may arise due to multiple possibilities, including truncation error, difference in the cross sections, the initial cross section data, and other similar things.

Current approach is, in principle, ought to be more accurate because it considers more than one hundred actinides. These actinides not only work as neutron absorbers but also serve as a big source of fission products, causing heat and radiation signature to be different (more accurate indeed) from the other techniques like HELIOS-MASTER-HELIOS, etc.

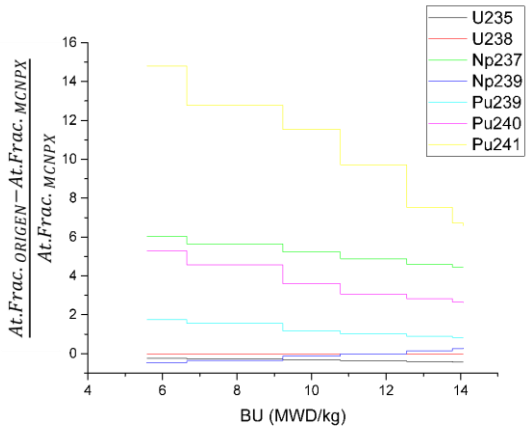

Fig. 3. Relative variation of the atomic fractions from two different calculation options (MCNPX 2.6.0vs. ORIGEN2) with burnup

A small variation in the number densities of the more important isotopes like U-235 and U-238 is due to their large quantities in the core and low burning rates. Other isotopes like Am-241 are produced in small quantities and so the number density changed with a small burnup difference is appreciable. However, due to their very small quantity the difference is not plotted here.. Axial variation of the BU is qualitatively identical to the corresponding pin-pin variation.

3. Conclusion

Pin-wise composition is calculated from ORIGEN2 using burnup calculated from the nodal code MASTER2.2. This so called, on the flight ORIGEN2 run approach of the composition calculation is reasonably accurate and gives results with much less resource utilization. The confidence in the results will be increased with comparing composition calculated for multiple fuel pins. The accuracy of the results could also be increased by using better ORIGEN2 library and by calculating burnup more precisely.

References

[1]. Z I Zafar and M H KIM, Inventory Assessment of Pin-wise Isotopic Composition in the Spent Fuel, Transactions of Korean Nuclear Society, 2016-Spring.

[2]. A T Daing and M H KIM, Investigation into fuel pin reshuffling options in PWR in-core fuel management for enhancement of efficient use of nuclear fuel, NED, 273 (2014) pp. 332–349.

[3]. HELIOS 1.5, User's manual, Studsvik Scandpower, 2005

[4]. Allen G. Croff, "A User's Manual for the ORIGEN2 Computer Code," ORNL/TM-7175 (CCC-371), Oak Ridge National Laboratory, 1980

[5]. MASTER 3.0 User's Manual, KAERI/TR-2061/2002, March, 2002