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Approximation method of determining initial core design parameters with a given energy requirement

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1. Introduction

When nuclear engineers start a new initial core design, it is challenging work to decide core parameters such as average fuel enrichment, the concentration of burnable absorber (BA) and the number of BA rods.

In this study, a new method for determining the mentioned parameters is proposed for a single gadolinia weight percent case (8w/o). Four parameters are taken into consideration in constructing a net graph: average UO_2 enrichment, the number of gad rods, critical boron concentration (CBC) at beginning of cycle (BOC) and cycle length. The process described in this paper uses simulation data based on the APR1400 reactor model. Using the proposed method, nuclear engineers can use it as a first step in determining a fresh fuel batch for an initial loading pattern.

2. Methods and Results

2.1 Fuel assembly specification

The assembly type used for the initial core design is a 16x16 lattice and it uses only gadolinia as a burnable absorber which is the most widely used burnable poison. The fuel specification data used in this CASMO3 simulations are listed in Table 1.

Parameter	Value
Fuel type	16x16
No. of guide tube	5
No. of fuel rod	236
Pellet radius	0.409 cm
Inner clad radius	0.418 cm
Outer clad radius	0.475 cm
Rod pitch	1.244 cm
Pellet material	UO_2
Clad material	Zircaloy-4
Burnable absorber	Gadolinia
Fuel stack density	10.31 g/cm^3
Gd rod stack density	10.06 g/cm^3

Table 1. Fuel specification

2.2 Constructing the net graph

Using the data listed in Table 1, 42 individual fuel assemblies are simulated. The infinite multiplication factor for each individual case was obtained using a fuel assembly burnup program, CASMO3 [1].

The following considerations have been taken into account in generating the 42 cases:

- UO_2 enrichment from 1.5% to 4.0% (6 cases), Δ=0.5;
- No. of BA rods from 0 to 24 (7 cases), Δ=4;
- Octant symmetry applied in positioning gad rods;
- Position of gadolinia rods follows the Nuclear Design Report (NDR) of Shin Kori Unit 3 [2];
- Only one weight percent of gadolinia is considered
- No fuel zoning is applied.

When designing a new loading pattern the energy requirement is represented by the cycle length. Another important parameter is the CBC. This value needs to be maintained under a certain value, in order to keep a negative moderator temperature coefficient at any one time. The two parameters mentioned above represent the target values that need to be met, these values will be the main axis of the net graph. The average core enrichment and average number of gad rods are the variables that need to be found to satisfy the target values.

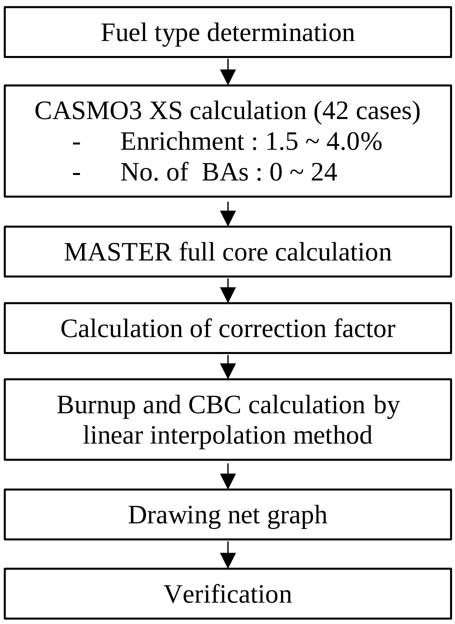

Figure 1. Working logic

CASMO3 simulations for the 42 cases are performed at 500 and 1000 boron concentration, with burnup from 0 to 60 GWd/T. Considering that the CASMO3 code only calculates its values in an infinite boundary medium [1], the result cannot be directly applied to full reactor core. For this, the effects of neutron leakage have to be taken into account to provide a correction in the generated net graph. A leakage correction factor is applied to the infinite multiplication factor provided by CASMO3 after a series of full core calculations that are performed using MASTER code [3]. The process in which this study is carried out can be observed in Fig. 1.

2.3 Results and verification

Using the construction method with k-infinite values from CASMO3, CBC at BOC and cycle length were calculated with the leakage correction equal to 1.051. Figure 2 shows the plot of calculated CBC with given enrichments and the number of gadolinia. The x-axis represents cycle length at which CBC equals 0 ppm and y-axis represent CBC at BOC. It shows that CBC increases proportionally with core average enrichment while the average number of gadolinia rods marginally affects the cycle length.

In order to verify CBC and cycle length of the net graph, a three dimensional core depletion calculation for the APR1400 initial cycle was carried out with MASTER code. Table 2 shows the core characteristics used in reference case calculation. The fuel rod pattern for each assembly and fuel assembly loading pattern of core were referred from NDR [2]. Note that the BA types and weight present for each assembly are same as used in the net graph construction.

Figure 2 and Table 3 shows the results of two different CBC and cycle length from MASTER code and expected values using the net graph. The relative error of CBC and cycle length from simulation and the net graph are less than 10% as shown in Table 3. This verifies two parameters out of four that can be simply estimated using the net graph without the considering the power distribution of the core.

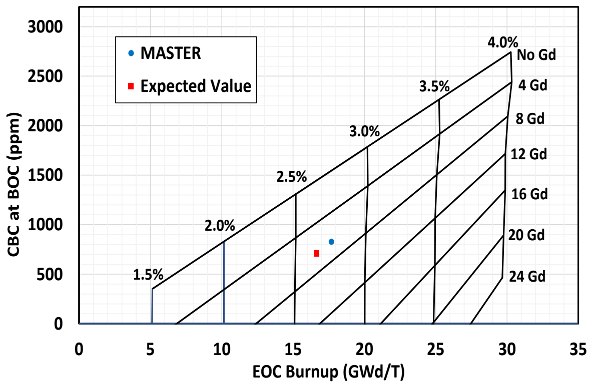

Figure 2. Net graph for initial core design parameters determination

Parameters	Value
Thermal power (MWt)	3983
Hot full power temperature (°C)	308.9
Inlet temperature (°C)	290.6
Primary system pressure (kg/cm^2)	158.2
Total number of fuel assembly	241
Total number of BA rods	1680
Core average enrichment (%)	2.66
Avg. Number of BA rods	6.4

Table 2. Input parameters for reference case

Source	CBC (ppm)	Cycle length (GWd/T)
MASTER	781.2	17.67
Expected by net graph	708.8	16.66
Relative error	9.27 %	5.72 %

Table 3. Result comparison

3. Conclusions

Our result shown in Figure 2 and Table 3 proves that this model can provide a guide for the first steps in determining a fuel batch for an initial loading pattern. By inputting the desired cycle length and target CBC value, average core enrichment and average number of BA rods for fuel batch search, can be determined. Furthermore the generated net graph can be used by nuclear core engineers to predict an approximate CBC value at BOC for a given batch of fresh fuel assemblies before performing a full core simulation. There are a large number of potential combination of fuel assemblies in order to produce a loading pattern for APR1400 reactor core with a given target CBC and cycle length. Because of this, the work of loading pattern determination has been traditionally performed by heuristic rules and trial and error methods [4]. Future work will be to investigate a systematic approach such as a mathematical ranking potential batch candidates.

Acknowledgment

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