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Design and Analysis on Initial Core for Pb-Bı Cooled Fast Reactors using Modıfıed CANDLE Burn-up Approach

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Abstract

Nuclear reactor for power production which can directly consume natural Uranium has some advantages, e.g., no necessity to bult enrichment plant which may drive controversy such as in the case of Iran. CANDLE and Modified CANDLE type reactors are an example of Nuclear Power plant which can directly consume natural Uranium in its fuel cycle. In this study the preliminary analysis of start-up process of modified CANDLE burn-up scheme based long life Pb-Bi Cooled Fast Reactors has been performed. The basic strategy is to put different plutonium content in each core regions by considering its equilibrium plutonium content in each region. The system then is started as a Modified CANDLE reactor system until relatively stable cycle obtained. The calculation has been done by using SLAROM, SRAC, and FI-ITB CH1 system codes. Two dimensional multi-group diffusion and burn-up calculation has been adopted during simulation. As results, the start-up scheme of several Modified CANDLE core with power level of 1150-1350 MWt have been performed. In this case LWR plutonium is used to initiate the MCANDLE reactors. The simulation results show that the system can work well with maximum excess reactivity of 3% dk/k

Keywords: Breeding, Burning, Burn-Up Level, Iterative Calculation, Plutonium Content, Shuffling Strategy

1. Introduction

Sustainability of nuclear energy depend on the ability to effectively utilize U-238 or Th-232 in nuclear fuel. Using second generation of nuclear power reactors existing uranium resources in the World can only be utilized for few hundred years. However using fast reactor technology in general Uranium resources canbe utilized up to abouut 10000 years. Recently nuclear power plant which can directly consume natural Uranium receives wider attentions. There are three major category of such reactors: CANDLE type, Breed-Burn type, and rather specific system with some complicated characteristics for special purpose design. CANDLE system originally developed by Prof. Sekimoto from Tokyo Institute of Technology has some varians and widely developed[1]. Modified CANDLE is one varian of CANDLE type burn-up[2–5]. Travelling wave reactor as a varians of Breed-burn system is widely developed in MIT and Berkeley together with Tera Power. Some additional system can be categorized as the third type which are rather specific. The CANDLE and Modified CANDLE simulations are generally based on equilibrium or semi equilibrium conditions. In this study we investigate the behaviour of the system when we start with actual condition of existing materials from existing LWR plutonium. The simulation is performed by inserting different Plutonium content in each region and then perform long run burn-up analysis process.

2. Design Concept

The proposed Nuclear power plant is a type of NPP which can consume natural Uranium for its refueling[2–5]. However it needs initial core as starting condition. The process of converting U-238 from input fuel cycle include breeding stage in about hallf of the core and then entering burning

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zore and the second half part of the core. In the proposed concept the core is comprised of several regions/divisions with similar volume. In the breeding area (first half part of the core) U-238 is converted to plutonium through neutron capture reaction and beta decays. The operating cycle is 10 years and after that the content of the first part of the core is moved to the second part, the content of second part is moved to the third part, and so on. The content of the last part is moved out of the core while the first part is filled using Uranium without enrichment. This mechanism is shown in Figure 1. It means that once the reactor is operated we can just extend the operation by just inserting Uranium without enrichment or depleeted Uranium to the first part of the reactor core.

The propose reactor core need high breeding capability and therefore advanced fuel is necessary andd here nitride fuel is used. The relatively high volume fraction of fuel is also used for this purpose also.

3. Calculation Method

The simulation in this study include the iterative calculation including multigroup diffusion calculation and burn-up calcluations[2–5]. The diffusion equation is formulated as follows.

$$-\nabla \bullet D_g(r)\nabla\psi_g(r)+\Sigma_g(r)\psi_g(r)=\frac{\chi_g}{k_{eff}}\sum_{g=1}^{G}\nu_p\Sigma_{fg}(r,t)\psi_g+\sum_{g'=1}^{G}\Sigma_{g'->g}(r)\psi_g \quad (1)$$

The diffusion equation is discreetized using finite difference method with R-Z geometry using 8 group of energies. The calculation is then transformed into inner-outer iterations in which inner iteration is solved using SOR method while outer iterations is solved using power method.

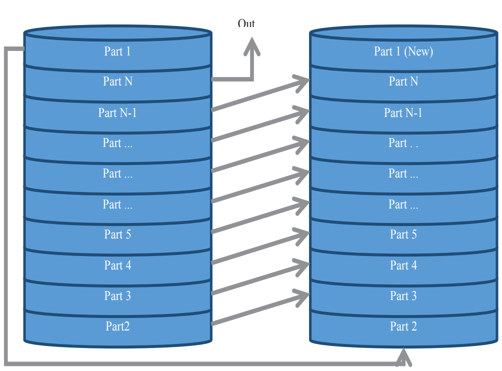

Figure 1. Modified CANDLE burn-up scheme illustration.

$$\frac{dN_A}{dt}=-\lambda_A N_A-\left[\sum_g \sigma_{ag}^{A}\varphi_g\right]N_A+\lambda_B N_B+\left[\sum_g \sigma_{cg}^{C}\varphi_g\right]N_C \quad (2)$$

The burn-up process in general is shown in Figures 2 and 3. Figure 2 shows that nucleus B experience neutron capture to become A, nucleaus C experience a decay to become A, while A experience decay and neutron capture. On the other hands Figure 3 shows the burn-up chain used in this study. SRAC and SLAROM standard programs is used to generate multigrup constant for this simulations. FI-ITB CH1 standard programs is used for diffusion-burn-up calculations.

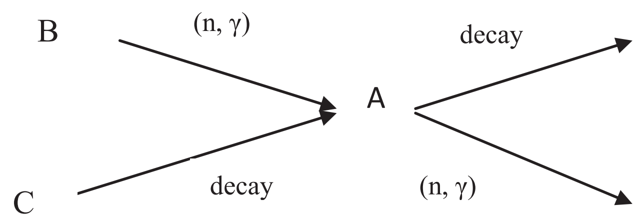

Figure 2. General burn-up process of nucleus A.

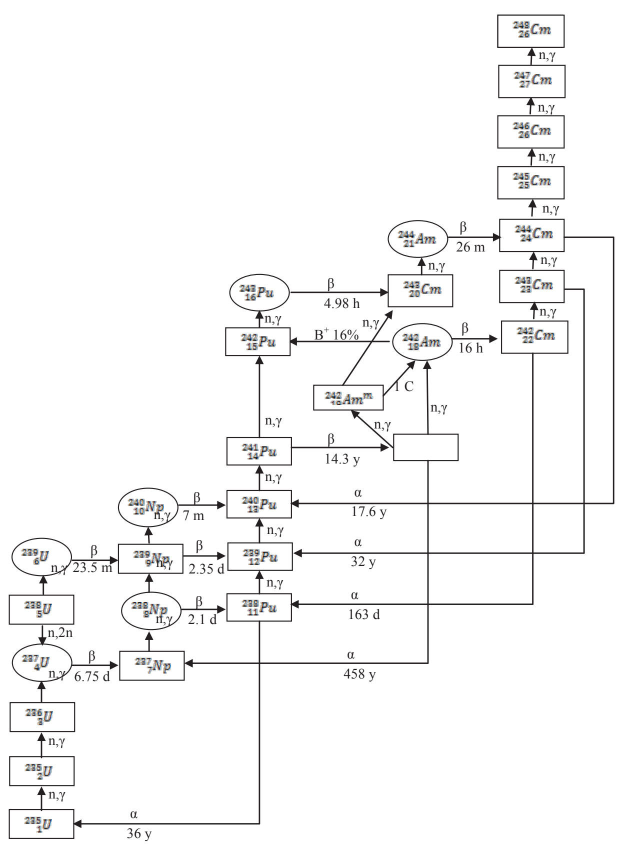

Figure 3. Nuclear Burn-up chain used in this study.

4. Calculation Results and Discussion

Table 1 gives information about the parameters of the standar case core in this study, and the calculation results are shown in Figures 3-5. Relatively high fuel volume fraction 56% and 60% nitride fuels are used in this study. There are three cases based on the power levels: Case A: 1150 MWt, Case B: 1250MWt, dan Case C: 1350MWt.

Table 2 shows energy group specification used in this study. This 8 group energy specifications is specific for fast reactors. This 8 groups are collapsed from about 70 groups energy used during cell homogenization calculations.

Table 3 gives detail specification of each core composition during start up process. There are inner and outer core and reflector regions. Basically all reflectors have similar compositions. The content of plutonium is varied from 0% (Natural Uranium) to 15%.

Figure 4 gives illustration of effective multiplication change during burn-up for case A (1150 MWt). After 70 years of burnup, the generic pattern of pereodic scheme is obtained. Higher power tend to give lower k-eff value due to lower stock of U-238 at the end of cycle. Both 56% and 60% fuel volume fraction give working system but 60% fuel volume fraction give higher margin in k-eff value. Figure 5 shows effective multiplication change during burn-up for case B (1250 MWt). The general pattern is similar to that of case A. the generic pattern of pereodic scheme is also obtained after 70 years of burnup. Higher power tend to give lower k-eff value due to lower stock of U-238 at the end of cycle.

Campared to that of case A the k-eff value in the case B is relatively lower than that of case A in every position. As in the case of A, both 56% and 60% fuel volume frac-

Table 1. General reactor characteristic

Parameter	Value
Thermal Power	1150MWt, 1250MWt; 1350MWt
Core Radial Width	172.5 cm
Pin type	Cylindrical cell
Pin radius	0.725 cm
Fuel Volume fraction	56% dan 60%
Coolant volume fraction	34% dan 30%
Core axial width	200 cm
Reflector width	130 cm

Table 2. Energy group specifications

Grup	Jarak energi (eV)
1	1.00000E+07 - 1.35340E+06
2	1.35340E+06 - 1.83160E+05
3	1.83160E+05 - 2.47880E+04
4	2.47880E+04 - 3.35460E+03
5	3.35460E+03 - 4.54000E+02
6	4.54000E+02 - 6.14420E+01
7	6.14420E+01 - 8.31530E+00
8	8.31530E+00 – 1.0E-05

Table 3. Startup core specifications

No. Axial Region	Central Core Region	Outer Core Region	Reflector region
1	Upper Reflector	Upper Reflector	Upper Reflector
2	Natural Uranium	Natural Uranium	Radial Reflector
3	12.5%	12.5%	Radial Reflector
4	15.0%	15.0%	Radial Reflector
5	12.5%	12.5%	Radial Reflector
6	10.0%	10.0%	Radial Reflector
7	7.5%	7.5%	Radial Reflector
8	5.0%	5.0%	Radial Reflector
9	3.0%	3.0%	Radial Reflector
10	2.0%	2.0%	Radial Reflector
11	1.0%	1.0%	Radial Reflector
12	Lower Reflector	Lower Reflector	Lower Reflector

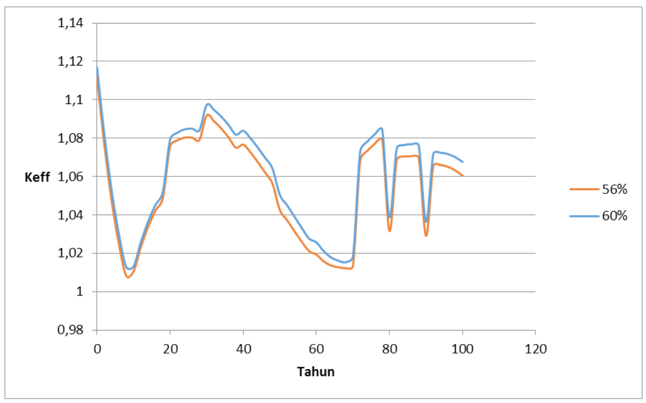

Figure 4. K-eff change with time during MCANDLE start-up simulation case A 1150 MWt.

tion give working system but 60% fuel volume fraction give higher margin in k-eff value. In the case of B the k-eff margin from the value 1.0 (criticallity condition) is lower than that of case A especially for the 56% fuel volume fraction.

The last case is shown by Figure 6 about effective multiplication change during burn-up for case C (1350 MWt). The general pattern is similar to that of case A and B. We can though that the case C is near the limit for the operability of the Nuclear power plant due to the k-eff margin which become very small from 1.0 value.

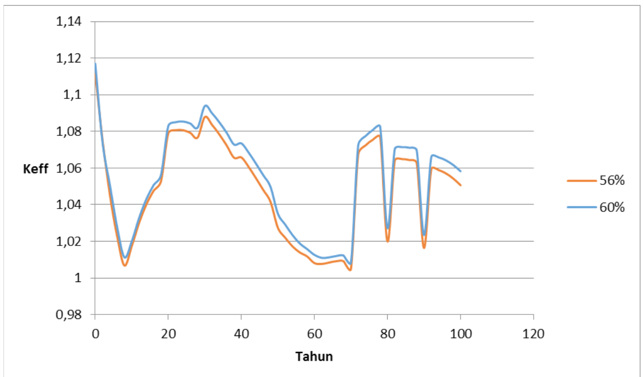

Figure 5. K-eff change with time during MCANDLE start-up simulation case B 1250 MWt.

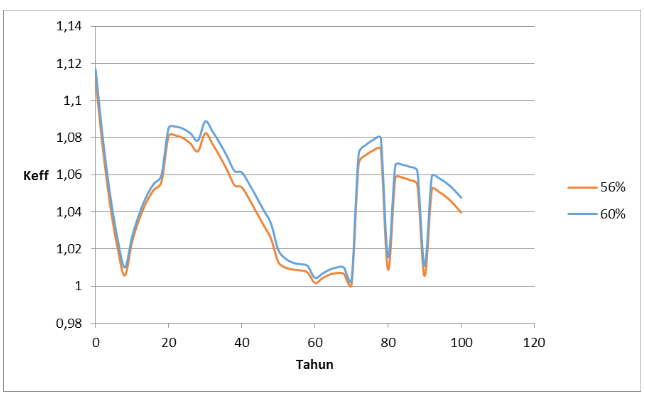

Figure 6. K-eff change with time during MCANDLE start-up simulation case C 1350 MWt.

The burn-up level is more than 40% HM in all cases and it can be though that the stock of U-238 is become very limited at the end of cycle to supply continuously plutonium productions.

5. Conclusion

Start-up strategy discussed in this study by introducing appropriate Plutonium content in each 10 regions Modified CANDLE system can work preperly and the pereodic pattern can occur after 70 years of initial burnup. Comparing three power levels for the same core configuration, 1150MWt, 1250 MWt, and 1350 MWt, the higher power tend to give lower k-eff value due to lower stock of U-238 at the end of cycle. Both 56% and 60% fuel volume fraction give working system but 60% fuel volume fraction give higher margin in k-eff value.

6. References

1. Sekimoto H, et al. CANDLE: The new burnup strategy. Nucl Sci and Eng. 2001; 139:1–12.
2. Su'ud Z, Sekimoto H. The prospect of gas cooled fast reactors for long life reactors with natural uranium as fuel cycle input. Annals of Nuclear Energy. 2013; 54:58–66.
3. Asiah AN, Su'ud Z, Aziz F, Sekimoto H. Conceptual design study of small long-life gas cooled fast reactor with modified CANDLE burn-up scheme. AIP Conf Proc. 2010; 1244:62–5.
4. Merriyanti, et al. Preliminary design study of medium sized gas cooled fast reactor with natural uranium as fuel cycle input. AIP Conf Proc; 2010. p. 31–4.
5. Su'ud Z, Sekimoto H. Design study of long-life Pb-Bi cooled fast reactor with natural uranium as fuel cycle input using modified CANDLE burn-up scheme. Int Journal of Energy Science and Technology (IJNEST). 2010; 5(4):347–68.
6. Okumura K, et al. SRAC (Ver.2002). The comprehensive neutronics calculation code system. JAERI Report; 2002.
7. Nakagawa M, Tsuchihashi K. SLAROM: A Code for Cell Homogenization Calculation of Fast Reactor. JAERI Report; 1984.
8. Su'ud Z. 2000. FI-ITB CH1 Code: Code for fast reactor design analysis. Internal Report ITB; Indonesia.