ANALYSIS OF REACTIVITY COEFFICIENT CHANGE DUE TO BURN UP IN AP1000 REACTOR CORE USING NODAL3

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ABSTRACT

ANALYSIS OF REACTIVITY COEFFICIENT CHANGE DUE TO BURN UP IN AP1000 REACTOR CORE USING NODAL3. One of the important things in reactor safety is the value of inherent safety parameter namely reactivity coefficient. These inherent safety parameters are fuel and moderator temperature coefficients of reactivity. The objective of the study is to obtain the change of those reactivity coefficients as a function of fuel burn up during the cycle operation of AP 1000 reactor core. Fuel and moderator temperature coefficients of reactivity and in addition moderator density coefficient of reactivity were calculated using SRAC 2006 and NODAL3 computer codes. Cross section generation of all core material was done by SRAC 2006 Code. The calculation of core reactivity as a function of temperature and burn up were carried out using NODAL3 Code. The results show that all reactivity coefficients of AP 1000 reactor core are always negative during the operation cycles and the values are in a good agreement to the design. It can be concluded that the AP 1000 core has a good inherent safety of its fuel

Keywords: reactivity coefficient, burn up, AP1000, NODAL3.

ABSTRAK

ANALISIS PERUBAHAN KOEFISIEN REAKTIVITAS AKIBAT FRAKSI BAKAR TERAS REAKTOR AP1000 MENGGUNAKAN NODAL3. *Salah satu hal yang sangat penting dalam analisis kecelakaan pada reactor daya adalah koefisien reaktivitas untuk mengontrol daya reaktor. Penelitian ini bertujuan menentukan koefisien reaktivitas akibat perubahan fraksi bakar pada reaktor AP1000. Koefisien reaktivitas yang akan dihitung adalah koefisien reaktivitas bahan bakar dan moderator yang sering disebut inherent factor. Selain itu juga akan dihitung koefisien konsentrasi boron dan kerapatan moderator. Semua koefisien reaktivitas ini dihitung saat terjadi perubahan fraksi bakar untuk mempertimbangkan produk fisi dan konsumsi bahan bakar. Perhitungan neutronik teras reactor disimulasi dengan menggunakan program SRAC2006 dan NODAL3. Perhitungan tampang lintang seluruh perangkat bahan bakar dan batang kendali reaktor AP1000 dilakukan dengan program SRAC2006. Perhitungan parameter neutronik sebagai fungsi temperature dan fraksi bakar dilakukan menggunakan program NODAL3. Perhitungan koefisien reaktivitas ditentukan berdasarkan perbedaan nilai reaktivitas. Hasil perhitungan menunjukkan bahwa koefisien reaktivitas teras reaktor AP 1000 selalu berharga negative untuk sepanjang siklus operasinya dan mendekati harga desain. Kesimpulan yang dapat ditarik adalah bahwa teras AP 10000 mempunyai keselamatan melekat yang baik.*

Kata kunci: koefisien reaktivitas, fraksi bakar, AP 1000, NODAL3.

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INTRODUCTION

BATAN is assigned to be a Technical Support Organization (TSO) in nuclear power reactor technology, especially for pressurized water reactor (PWR) type. The AP 1000 nuclear power reactor was chosen as the object in this study based on considerations that this reactor has high electrical power of 1000 MWe with high passive safety features [1,2]. The reactor core contains about 157 UO_2 fuel assemblies, light water (H_2O) both as moderator and coolant. Each fuel assembly (FA) is composed of 17 x 17 arrays of UO2 fuel rods and guide tubes. The guide tube in the center is used for instrument guide thimbles. As the AP 1000 first core has a very high excess reactivity in amount of 17,01 (%Δk/k), therefore additional two types of partial reactivity control namely discrete burnable absorber rods(PYREX) and integral fuel burnable absorber (IFBA) were installed in the core. Reactivity change control and axial power distribution are carried out by 53 rod cluster control assembly (RRCA) and 16 gray rod control assembly (GRCA) [2].

NODAL3 Code has been developed for evaluating the safety of reactor operation at static and dynamic conditions. The code has been validated for static cases PWR benchmark, such as IAEA-2D, BIBLIS, KOEBERG and IAEA-3D[3] and for transient cases such as NEACRP 3D LWR core transient benchmark [4 - 7]. Several studies on AP 1000 have been done by BATAN's researcher group covering criticality, neutronic parameter analysis and reactivity coefficient calculations [8 - 12]. All those calculations are merely done at the beginning of cycle (BOC) without any consideration of the effects of burn up. At BOC, fuel material is dominated by U^{238} and U^{235} which have much resonance capture reactions. At the end of cycle (EOC), the U^{235} concentration decreases about 60% and some amount of plutonium are produced. This condition causes a change of reactivity coefficient values.

The objective of the research is to calculate the reactivity coefficients as a function of burn up of AP 1000 core. These parameters are very important for reactor safety analysis at all reactor operation conditions. Reactivity calculations shall be accurate as a function of fuel types, enrichment, core loading, burn up, poisoning and temperature at diffrent states of operations [13 - 15]. The reactivity coefficients, such as fuel temperature, moderator temperature and moderator density reactivity coefficients were analyzed. Cross section and core calculations were performed using SRAC2006 Code [16] generatrion and NODAL3 Code [4], respectively. Calculations were conducted at hot full power (HFP) conditions for burn up from BOC to EOC.

METHODOLOGY

The overall calculations were performed using combination of SRAC2006 and NODAL3 computer codes. For core reactivity calculations, NODAL3 Code needs input data of core material cross sections namely, fuel, control rod and structural materials. Those macroscopic cross sections for fuel cell were generated by SRAC2006 Code which used ENDF/B7.0 nuclear data library, to provide 2 groups of neutron energy.

Reactor core was modelled in 3 dimensional cartesian coordinates. The number of nodes in the X, Y and Z axis are 17, 17 and 21 respectively. Calculations were carried out for a quarter core and axially it was devided into 19 layers. It was consisted of thickness of 20.3 cm (2 layers), 8.9 cm (2 layers), 24.5533 cm (15 layers). On the top and bottom of the core, there are reflectors with 24.5 cm of thickness.

Core configuration of AP 1000 is illustrated in Figure 1[2]. It was loaded with three type of enriched UO_2 fuel assembly that are 2.35 w/o, 3.4 w/o and 4.45 w/o. Calculations of reactivity coefficient were done from the beginning of cycle (BOC) to the end of cycle (EOC). The other required input, namely boron concentration as a function of burn up was derived from reference values as shown in Figure 2. At BOC the excess reactivity of AP 1000 core was high, then, a boric solvent was added to the moderator/coolant. The function of added boron in moderator is to increase the absorber macroscopic crosssection in order to decrease the thermal utilization factor (f), finally decreasing the core k_{eff}. When reactor is in operation, burn up increases as boron concentration decreases and the reactivity is laanced to keep the value of $k_{eff} = 1$.

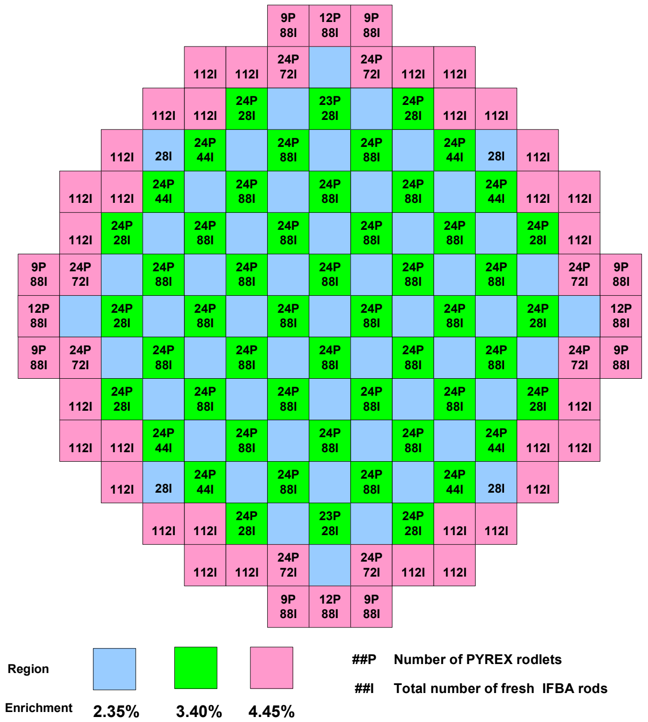

Figure 1. Pyrex and IFBA core configuration within the AP 1000 [2]

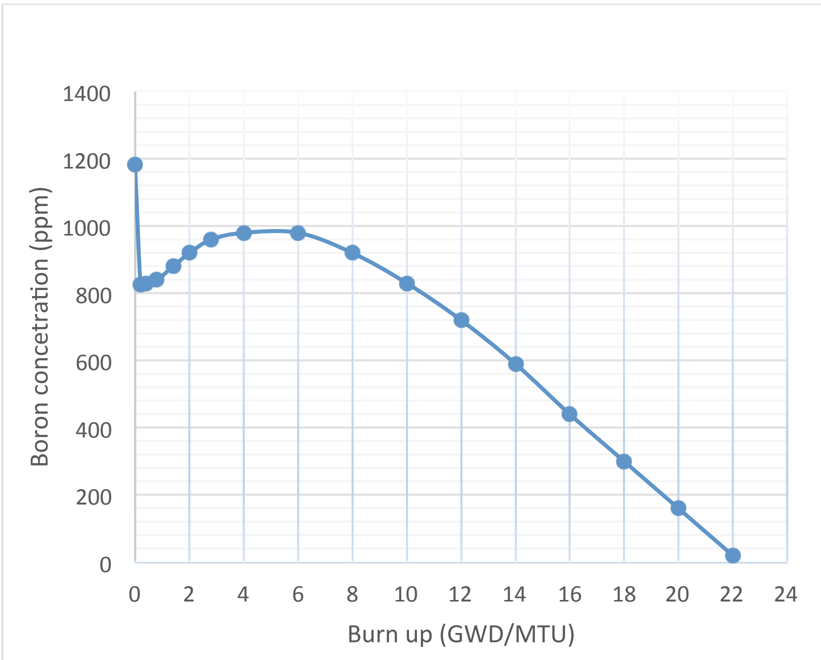

Figure 2. Boron concentration as a function of burn up of AP1000 core[2]

Core calculations were done at reactor conditions of HFP with all control rods at fully up positions and with the existance of boron in the moderator. Normal conditions of HFP are at fuel

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temperature of 627°C and moderator temperature of 327°C. Reactivity coefficients were obtained by calculating reactivity value or multiplication factor for each step of fuel temperature and moderator and each step of moderator density. The temperature step was taken more or less than 5 °C from normal operation while density step was taken more or less than 0.005g/cm^3 from normal density. The other parameters were kept constant.

RESULTS AND DISCUSSIONS

At a certain value of fuel burn up, the change of core reactivity are mostly caused by the changes in fuel temperature, moderator temperature and moderator density. As the fuel is burned from the beginning to the end of operation cycles, it will be followed by the change of reactivity coefficients as well. Fuel temperature reactivity coefficient (FTC) is the most prompt effect as compared to the moderator temperature coefficient (MTC). That is why FTC is more important in compensating the power change during positive reactivity insertion accident.

The content of the plutonium Pu^{239} raises which results in the increasing of Pu^{240}, that has higher resonance capture than U^{238}. Calculation results of U^{235} and U^{238} loss mechanisms and the gain of Pu^{239} and Pu^{240} are shown in Figure 3. It shows that fuel reactivity becomes more negative as the Pu^{240} raises.

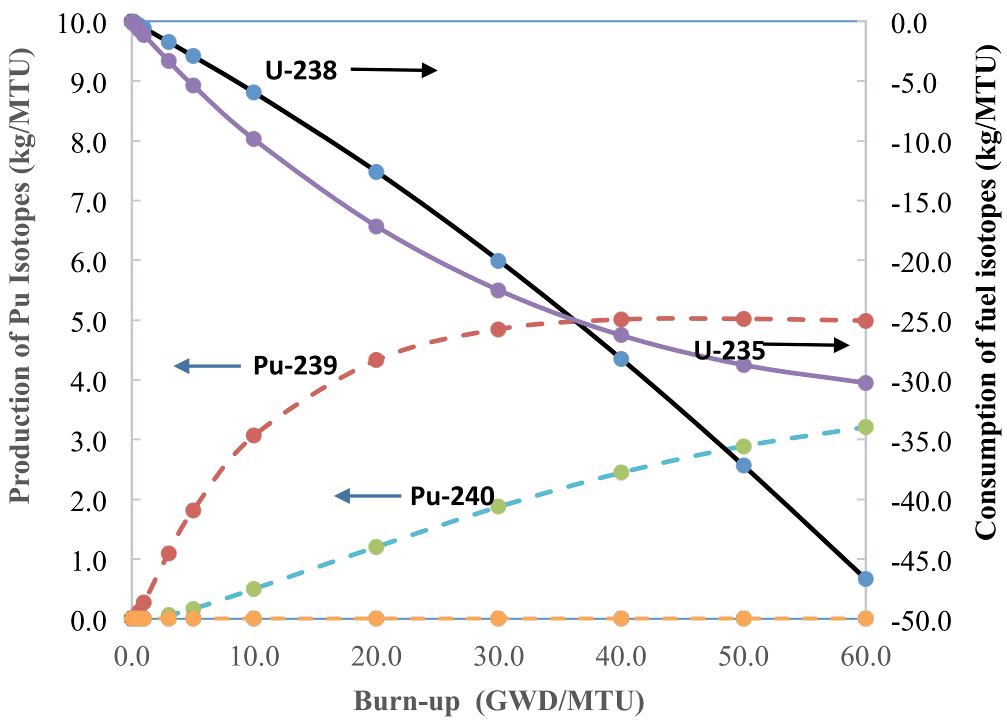


Figure 3. The consumption of fuel isotopes and production of Pu isotopes at AP1000 core

The calculation results of the fuel temperature reactivity coefficient (FTC) as a function of burn up or operation time of AP 1000 is shown in Figure 4. It shows that as long as the operation cycle from burn up value between 0 and 25000 (MWD/T), hence the fuel reactivity coefficient is always negative.

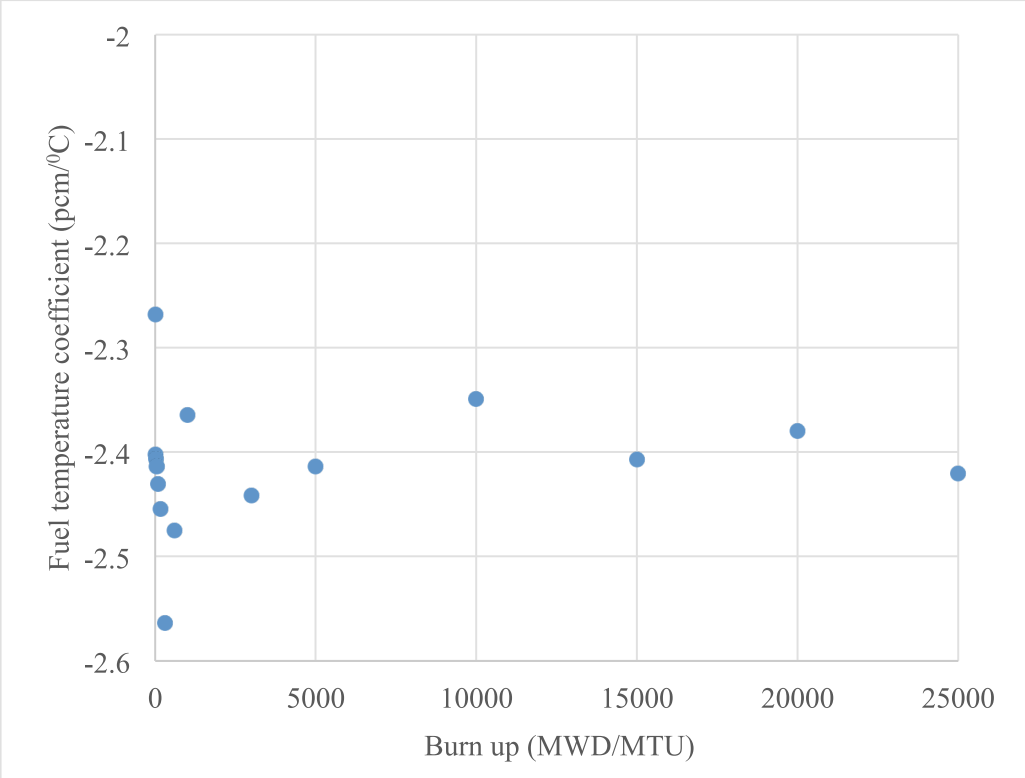
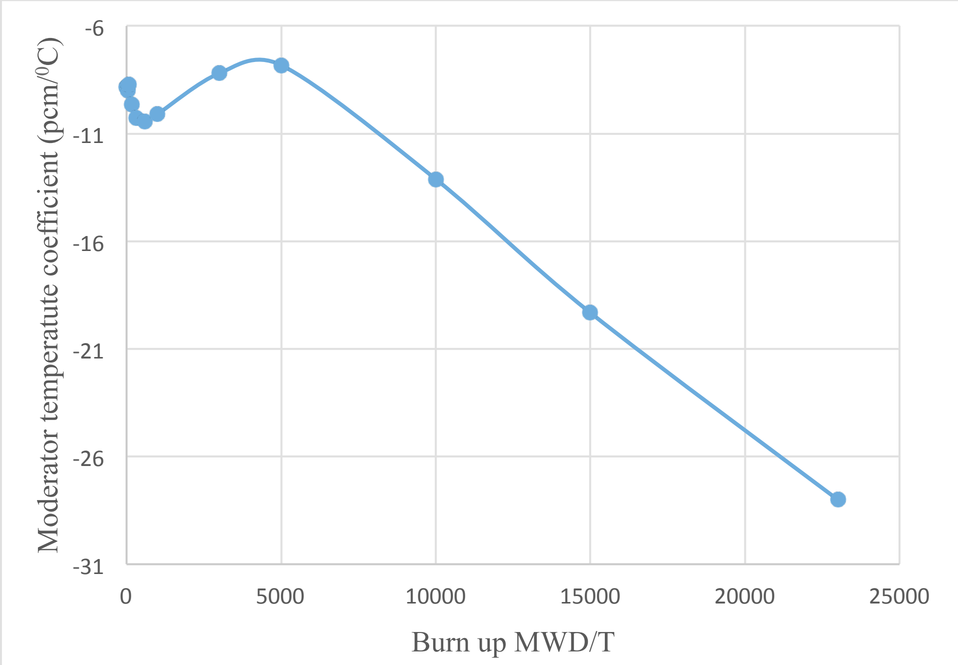


Figure 4. Reactivity coefficient of fuel temperature as a function of burn up

This is the case of reactivity coefficient of AP 1000 core that is always negative although the burn up increases. The main point is reactor will be not safe when the reactivity coefficient is positive. On the contrary to negative value, reactor with positive reactivity coefficient will raise the power when the fuel temperature rises. Therefore, fuel reactivity coefficient must be negative during the operation cycle.

The calculation results of reactivity coefficients as a function fuel burn up are between –2.4 and –1.6 pcm/^{o}C. In comparison to the design values of –6.3 to –1.80 pcm/^{o}C, those calculation values from NODAL3 are laid inside the design range.

The value of moderator temperature reactivity coefficient (MTC) depends partly on the change of neutron leakage due to the moderator temperature change. The other reason of this change is caused by decreasing of boron and increasing of plutonium and other fission products. The calculation results of these coefficients are presented in Figure 5. It shows that the values are more negative as compared to the fuel temperature coefficients. The values are between – 8.84 and – 28.0 pcm/^{o}C which are laid in the range of design values of 0.0 to -72.0 pcm/^{o}C



- Figure 5. Reactivity coefficient of moderator temperature as a function of burn up

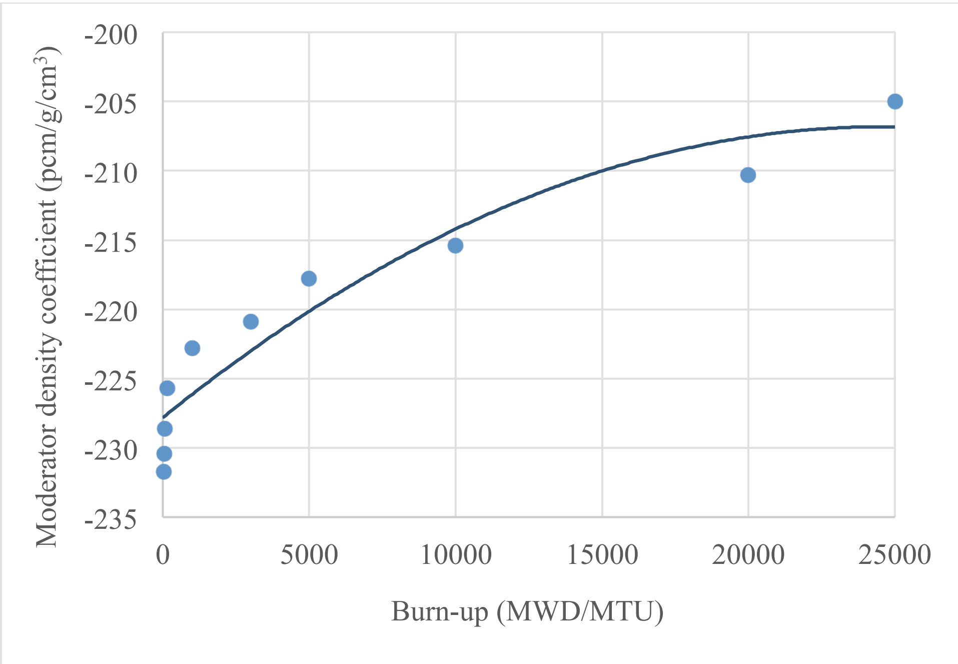


Figure 6. Reactivity coefficient of moderator density as a function of burn up

Calculation results of moderator density reactivity coefficient as a function of burn up is presented in Figure 6. The moderator density coefficient is defined as reactivity change per unit of moderator density change. It is a common that effects of moderator density change is calculated at the same time with boron. Boron solute as reactivity control gives effect to the moderator density coefficient since boron density and moderator density decreases as temperatur increases. The decrease of boron density contributes to a positive value of the moderator coefficient. When boron concentration is in adequate amount, thus the value of moderator density coefficient of reactivity could be more positive. This case can be seen in Figure 6 where the increase of burn up leads the moderator density coefficient becomes more positive, however the value are still negative.There is no available design data of this parameter, then the calculation values unfortunately can not be compared.

CONCLUSIONS

Reactivity coefficients of fuel temperature, moderator temperature and moderator density as a function of burn up of AP 1000 reactor core have been calculated. Cross sections of fuel and core material were generated by SRAC2006 and burn up effects to the reactivity coefficients of AP 1000 have been calculated by NODAL3 computer codes. All reactivity coefficients of the AP 1000 core have negative values and in a good agreement to the design values as the fuel burn up increases from the beginning to the end of operation cycle. It shows that the AP 1000 core performs a good inherent safety feature.

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