Design Study of Modular Nuclear Power Plant with Small Long Life Gas Cooled Fast Reactors Utilizing MOX Fuel

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Abstract. Growing energy needed due to increasing of the world's population encourages development of technology and science of nuclear power plant in its safety and security. In this research, it will be explained about design study of modular fast reactor with helium gas cooling (GCFR) small long life reactor, which can be operated over 20 years. It had been conducted about neutronic design GCFR with Mixed Oxide (UO2-PuO2) fuel in range of 100-200 MWth NPPs of power and 50-60% of fuel fraction variation with cylindrical pin cell and cylindrical balance of reactor core geometry. Calculation method used SRAC-CITATION code. The obtained results are the effective multiplication factor and density value of core reactor power (with geometry optimalization) to obtain optimum design core reactor power, whereas the obtained of optimum core reactor power is 200 MWth with 55% of fuel fraction and 9-13% of percentages.

Introduction

Global demand for energy continues to increase, the world's population increases more rapidly and the sources of non-renewable energy tend to be decreased are important factors in effort to develop a new generation of power plant with advanced technology that can generate considerable amount of energy. The Rapid development in technology and science in the field of energy create an alternative energy source by nuclear reactors which utilize a controlled nuclear reaction. Indonesia have a serious problem with electricity shortage in some areas mainly outside Java and Bali islands. These problems show a possibility to introduce nuclear power plants in order to increase the electrical production. Nuclear power plants with long life characteristic are very prospective for remote areas, In such area small reactors are best fit [8]. But this alternative energy source has a lot of resistance in the community of the world, including in Indonesia. The accidents of Chernobyl and Fukushima nuclear while ago cause negative opinion and public rejection in the construction of nuclear power plants [6].

The development of nuclear power plants has reached a phase of fourth generation and certainly much better than the previous generation. The fourth generation nuclear power plants are alternative energy sources with high density of energy, better conversion energy to electricity and good for environment because it does not contribute to global warming gaseous production. These advanced NPPs can also resolve many problems from the early generation NPPs by have much higher efficiency using natural uranium as a fuel, passive safety, and lower energy prices [2-5].

IOP Conf. Series: Journal of Physics: Conf. Series **799** (2017) 012025 doi:10.1088/1742-6596/799/1/012025

Gas cooled fast reactors (GCFR) are among fourth generation NPPs with fast neutron spectrum and have excellent capability to utilize natural uranium during operation [1]. In this research study of small long life gas cooled fast reactors with Mixed Oxide fuel (MOX), helium as coolant, with total power level up to 200 MWth will be simulated. This nuclear power plants (NPPs) that has cylindrical pin cell and cylindrical balance of reactor core geometry will be optimized to obtain reactors that can be operate in long period with low reactivity swing.

Experimental Method

In general, the placement of the reactors under the surface can be realized with two different basic construction concepts, i.e. placing the entire section of the reactor and turbine in deep rock containment with below normal level in relation to water recipient and placing the reactor in deep rock containment with turbine in above ground building at normal level in relation to water recipient.

F1	F1	F2	F2	F3	F3	R
F1	F1	F2	F2	F3	F3	R
F1	F1	F2	F2	F3	F3	R
F1	F1	F2	F2	F3	F3	R
F1	F1	F2	F2	F3	F3	R
F1	F1	F2	F2	F3	F3	R
R	R	R	R	R	R	R

Figure 1 Configuration of reactor core

The reactor core was subdivided into four regions in radial direction with cylindrical pin cell and cylindrical balance of reactor core geometry. In Figure 1, three regions belong to fuel with different percentages of plutonium (F1, F2, F3) and one to reflector (R) with equal length in each fuel region. The outer region core has more plutonium percentages than inner core to obtain power density to be spread evenly across region of reactor core.

This paper will be focused on the parameters design of reactors core which is neutronic calculation. The calculation neutronic analysis were performed using SRAC code program (SRAC-CITATION code system) [7] with nuclides data by library of JENDL-3.2. In the SRAC code, the burn up calculations were performed using cell burn-up module to obtained the data energy group macroscopic cross section to be used in 2D R-Z geometry multi-groups diffusion calculation using CITATION module. The diffusion calculation will produce the data average power density of each region that will be reused into SRAC code for cell burn-up calculation, this process will be repeated until the result of data power density is converged

Result and Discussion

In table 1 shows design parameters of reactor with three variation were calculated at 100 MWth, 150 MWth and 200 MWth power level and fuel volume fraction were 50%, 55%, 60% using plutonium percentages at 9%, 11%, 13% of MOX fuel in region F1, F2, and F3.

IOP Conf. Series: Journal of Physics: Conf. Series **799** (2017) 012025 doi:10.1088/1742-6596/799/1/012025

Table 1. General parameters of the design core reactors

Parameter	Value
Power (MWth)	100-200
Core geometry	Cylindrical balance
Number of radial division of the main core	4 regions
Operation time without refueling (years)	20
Fuel / Cladding / Coolant type	MOX / SS316 / He gas
Active core radius / height (cm)	216 / 216
Reflector type / width (cm)	Stainless steel / 50
Plutonium percentages (%)	9-13
Fuel volume fraction (%)	50-60
Cladding volume fraction (%)	10
Coolant volume fraction (%)	10-20

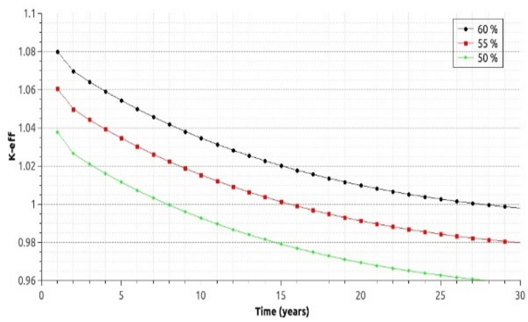

Figure 2. Figure 2 Effective multiplication factor changes over time in case of 100 MWth power level with variation in fuel fraction.

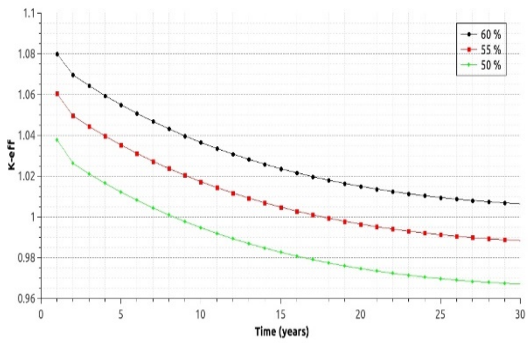

Figure 3. Effective multiplication factor changes over time in case 150 MWth power level with variation in fuel fraction.

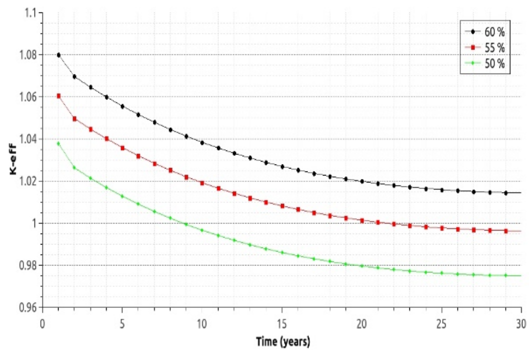

Figure 4. Effective multiplication factor changes over time in case of 200 MWth power level with variation in fuel fraction.

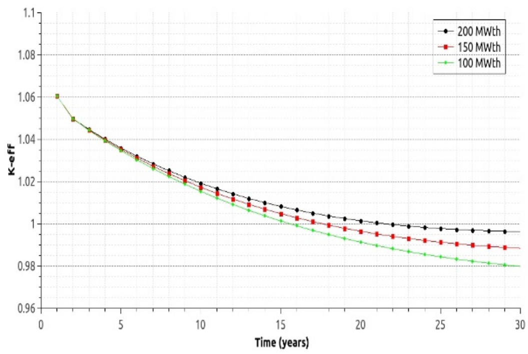

Figure 5. Effective multiplication factor changes over time in case of 55% MWth fuel fraction with variation in power level.

Figure 3 and 4 show the change in value of effective multiplication factor (K-eff) during burn-up in case of 100 MWth and 150 MWth reactor power level with variation in fuel volume fraction by 50 % , 55 % and 60 % using percentages of fuel plutonium by 9 % , 11 % and 13 % of the total fuel to the region F1 , F2 , F3. The results of 100 MWth's case shown that the value of effective multiplication factor steadily decreasing from beginning of life (BOL) to the end of life (EOL). By decreasing and increasing the fuel fraction parameters by 5%, the result will have a similar pattern. The effect for decreasing and increasing fuel fraction will shift down and shift up the K-eff pattern. The higher fuel fraction makes the longer operation of reactor. In case of 150 MWth's case, it has shown the effect for decreasing and increasing fuel fraction also shift down and shift up the K-eff pattern, same as the previous case but it have a few year longer.

Figure 5 show the change in value of effective multiplication factor (K-eff) during burn-up in case of 200 MWth reactor power level with variation in fuel volume fraction. The variation is also performed by decreasing and increasing the fuel fraction parameters by 5%. It shown that K-eff is still has the same pattern as two cases before. Increasing the fuel fraction makes the period of operating reactor is also increase by few years. In this case the reactor has the longest period of operating that up to over 20 years.

Figure 6 shows the change in value of effective multiplication factor (K-eff) during burn-up in case of 55% fuel fraction with variation in reactor power level by 100, 150 and 200 MWth. The variation is performed by decreasing and increasing the power level parameters by 50 MWth. It shown that the K-eff of three variation power level have similar value and shape at the beginning of life (BOL), has slight change of shape in medium of life (MOL) and major change of shape at end of life (EOL) indicate that the effect of power level make period operating of reactor increased.

Conclusion

Design study of modular nuclear power plant with small long life gas cooled fast reactors utilizing MOX fuel has been performed. The reactors are small size with helium gas cooled, fast neutron spectrum and have long lifetime that could be operate for 20 years without refueling. In this research the modular power plant have result in neutronic design for 100-200 MWth power level and 50-60% fuel fraction has been discussed. To obtain optimum design core reactor, optimum reactor power level is 200 MWth with 55% fuel fraction and 9%, 11%, 13% percentages of plutonium in region F1, F2, F3.

Acknowledgent

This research partially support by advanced nuclear laboratory of ITB.

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