

# Study Neutronic of Small Pb-Bi Cooled Non-Refuelling Nuclear Power Plant Reactor (SPINNOR) with Hexagonal Geometry Calculation

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**Abstract.** Nuclear reactor technology is growing rapidly, especially in developing Nuclear Power Plant (NPP). The utilization of nuclear energy in power generation systems has been progressing phase of the first generation to the fourth generation. This final project paper discusses the analysis neutronic one-cooled fast reactor type Pb-Bi, which is capable of operating up to 20 years without refueling. This reactor uses Thorium Uranium Nitride as fuel and operating on power range 100-500MWtNPPs. The method of calculation used a computer simulation program utilizing the SRAC. SPINNOR reactor is designed with the geometry of hexagonal shaped terrace that radially divided into three regions, namely the outermost regions with highest percentage of fuel, the middle regions with medium percentage of fuel, and most in the area with the lowest percentage. SPINNOR fast reactor operated for 20 years with variations in the percentage of Uranium-233 by 7%, 7.75%, and 8.5%. The neutronic calculation and analysis show that the design can be optimized in a fast reactor for thermal power output SPINNOR 300MWt with a fuel fraction 60% and variations of Uranium-233 enrichment of 7%-8.5%.

## 1. Introduction

As the times, many nuclear technologies are increasingly prevalent developed into renewable technology, particularly in the development of the Nuclear Power Plant (NPP) [1]. Nuclear power plant should be able to overcome the problems encountered so far, such as the urge to improve nuclear safety, radioactive waste issues, the cost of investment and operation of reactors which are expensive, and the danger of proliferation of nuclear weapons.

During 1990 and 2000 a lot of innovation nuclear reactors have been developed, one of the most prospective is the kind of fast reactors cooled Lead-Bismuth (Pb-Bi). Over time, this time in various countries especially Japan has developed rapidly cooled reactor type Lead and Lead-Bismuth mixture. It is done to seek the weakness of the use of cooling agents such as sodium that are more explosive when interacting with water and air, such as the Japanese Monju reactor accident in 1999 [2,3].

SPINNOR reactor is cooled nuclear reactor concept of Lead-Bismuth with fast neutron spectrum that can be operated for long years without refueling. SPINNOR reactor is considered as a concept that has a high priority in the development of nuclear energy systems. SPINNOR concept focus on sustainable nuclear energy, efficient use of resources, minimal waste, and inherent safety [1].

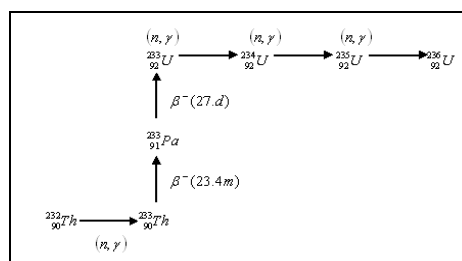


Fig. 1. Chain Conversion of Thorium[1]

Thorium produces 90% less waste compared to Uranium, and requires only about 200 a year to store the waste than uranium which requires 10,000 years. In the universe, we can say all are Th-232 which has a

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half life of about 14.05 billion years[1]. In this study, it will be designed reactors SPINNOR or type fast reactor cooled Pb-Bi, will now be analyzed neutronic reactor SPINNOR fueled Thorium Uranium Nitride in 20 years of operating time, and will be calculated the optimum design of SPINNOR reactor.

## 2. Design Concept and Calculation Methods

From the data presented in table 1, it is obtained several plots a graph of calculation results Pij burn-up during reactor operation

Table 1. Variance in reactor design parameter survey of SPINNOR

Percentage of fuel (%)	Fuel, Cladding, and Coolant Fraction (%)	Power thermal (MWt)
Case A: Region F1/F2/F3 7% / 7.75% / 8.5%	50% fuel, 20% cladding, 30% coolant fraction	100
		200
		300
		400
		500
	55% fuel, 20% cladding, 25% coolant fraction	100
		200
		300
		400
		500
	60% fuel, 20% cladding, 20% coolant fraction	100
		200
		300
		400
		500

Fuel used in this study based on Thorium enrichment that comes from U-233. Thorium, that has the ability to produce fissile material, is significant in this U-233 case.

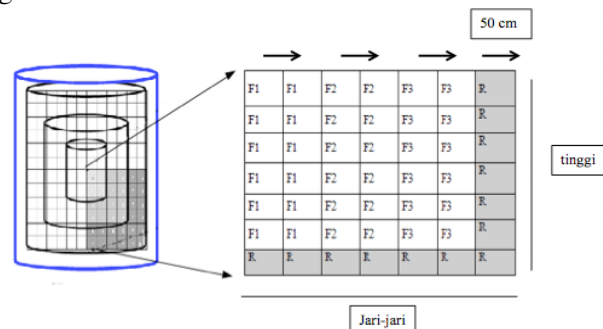


Fig. 2. Composition of fuel design in the reactor core and reflector

The calculation is performed by first making the system design modeling work SPINNOR reactor by using a computer simulation program SRAC (Standard Thermal Reactor Analysis Code) and using Ms. Excel for calculation of atomic density and power level. Calculation phase begins with the creation of the input file to the program SRAC for the calculation of burn-up with a variation of the percentage of uranium-233: Region Fuel1 / Fuel2 / Fuel3 by: 7%, 8.75%, 8.5%. The calculation using SRAC can be made in the form of a flowchart as follows:

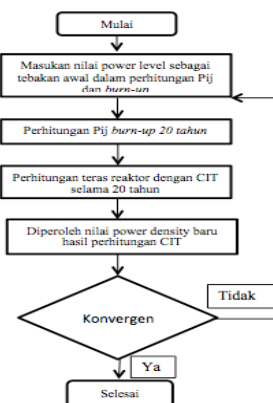
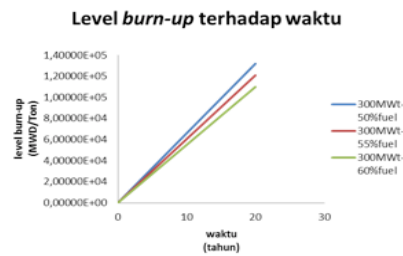
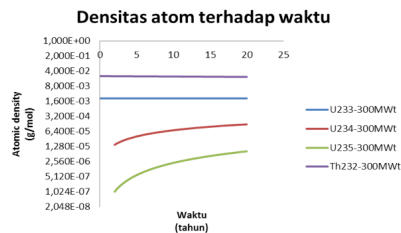


Fig. 3. Flowchart of SRAC Calculation

### 3. Results and Discussion



**Fig. 4.** Curve burn-up design with percentage of U-233 7%, 300MWt thermal power output, and variance of fuel fraction 50%, 55%, and 60%



**Fig. 5.** Curve of atomic density changes over a period of burn-up on SPINNOR reactor with 300MWt thermal power output

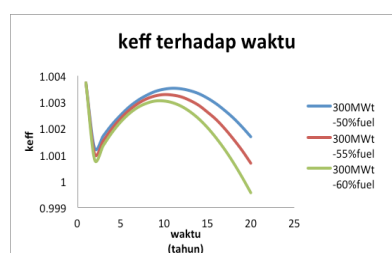
#### Burn-up Calculation

Figure 4 show the curves burn-up level of the burning time for 20 years on output power variation 300MWt the fuel fraction 50%, 55%, 60%, and variations in the percentage of U-233 by 7%. The graph can be seen that the smaller fraction of fuel used, the greater value of the level of burn-up. It shows that the smaller fraction of fuel the less amount of fuel for the reactor core size equal to the third variation of the fuel fraction. Therefore, the value of the level of burn-up fraction is inversely proportional to the increase in fuel, so that the value of the level of high burn-up explaining that the fuel to be used effectively.

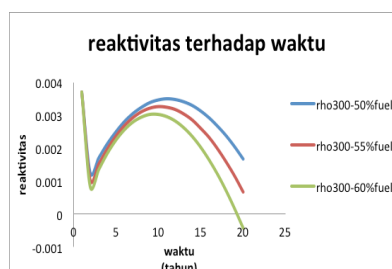
#### Atomic Density Analysis

The process of fuel burn-up greatly affects the density of the atoms making up the fuel. The density of atoms (N) is the concentration of atoms per unit volume. Figure 5 illustrate the changes in the density of the atoms during the burn-up on SPINNOR reactor with a thermal output power variation at 300MWt and fuel fraction 60%. On the graph shows that over time the operation of the reactor, the number density of atoms of each nuclide will decrease.

#### Calculation of Effective Multiplication Factor and Reactivity



**Fig. 6.** Curve of  $k_{eff}$  in SPINNOR reactor with thermal power output 300MWt and variance fuel fraction 50%, 55% and 60%



**Fig. 7.** Curve of reactivity on SPINNOR reactor with thermal power output 300MWt and variance fuel fraction 50%, 55%, and 60%

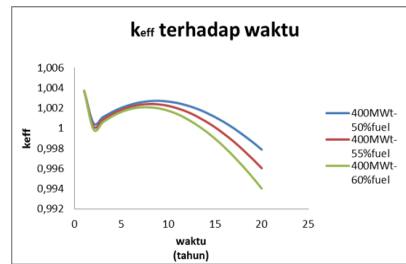


Fig. 8. Curve of  $k_{\text{eff}}$  in SPINNOR reactor with thermal power output 400MWt and variance fuel fraction 50%, 55% and 60%

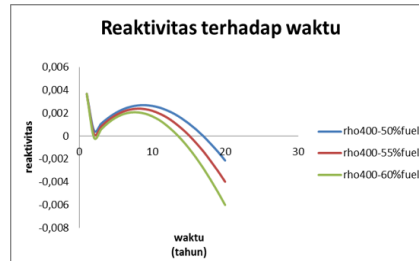


Fig. 9. Curve of reactivity on SPINNOR reactor with thermal power output 400MWt and variance fuel fraction 50%, 55%, and 60%

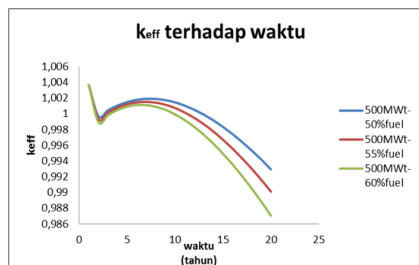


Fig. 10. Curve of  $k_{\text{eff}}$  in SPINNOR reactor with thermal power output 500MWt and variance fuel fraction 50%, 55% and 60%

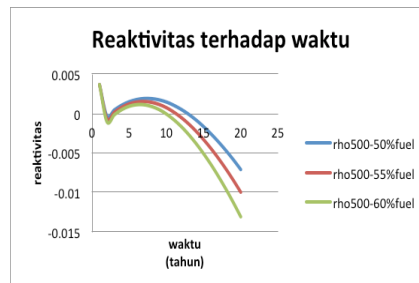


Fig. 11. Curve of reactivity on SPINNOR reactor with thermal power output 500MWt and variance fuel fraction 50%, 55%, and 60%

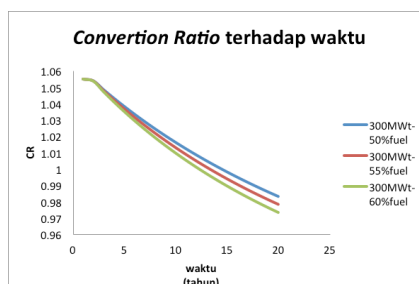


Fig. 12. Curve of *Conversion Ratio* for *Fuel 1* with variance fuel fraction 50%, 55%, and 60% and thermal power output 300MWt

### $K_{\text{eff}}$ and Reactivity Analysis

In figure 6, 8 and 10 show the  $k_{\text{eff}}$  initial value (year 1) is worth one for each fraction variance of the fuel. For a fraction of the fuel 50%, 55%, and 60% had  $k_{\text{eff}}$  same value which is equal to 1.00372. The  $k_{\text{eff}}$  value at the beginning of the process will decline until the 3<sup>rd</sup> year of operating time for the fuel fraction 50% and 55%, while for 60% fuel fraction  $k_{\text{eff}}$  value has decreased to the 4<sup>th</sup> year of operating time. After  $k_{\text{eff}}$  decreased in the early years of operation, in the next operation will increase the value of  $k_{\text{eff}}$  and toward a

stable state (critical) to the 20<sup>th</sup> year of the reactor operating time. The critical state of the reactor has been able to achieve 20 years of operation so that it can be said long-life reactor.

Meanwhile, for the value of the reactivity of each fraction can be seen in Figure 7, 9, and 11 where the shape of the graph resembles the graph  $k_{\text{eff}}$  value. The use of the total thermal output power greater terrace will affect the value of  $k_{\text{eff}}$  greater. Similarly, as in the case of power reactors 300MWt. Of some graphic images  $k_{\text{eff}}$  and reactivity to the time that has been described above, it can be concluded that in terms of value addition fraction of fuel (fuel), the value of  $k_{\text{eff}}$  obtained will also rise so that the reactor has a time critical situation long and will extend the operating life of the reactor. This is related to the addition of a fuel fraction, when the fraction or volume of fuel is increased, the amount of fuel will also increase which will cause a number of reactions occurring fissile increased. Increased fissile reaction this would trigger the production of neutrons more with increasing volume fractions. The value of the effective multiplication factor ( $k_{\text{eff}}$ ) is closely related to the number of neutrons in the terrace.

Fuel efficiency can be analyzed using the calculation of excess reactivity of the reactor design. Excess reactivity is a measure of the amount of capacity available to accelerate a nuclear reaction. Value excess reactivity also be used as a parameter whether the reactor can still operate during the first cycle of burn-up fuel. Reactivity value chart in Figure 7, 9, and 11 shows that the results of the calculation of excess reactivity in the fuel fraction 60% and thermal power 300MWt, reactors working optimally for eighteen years of operation. This is because in the 19th operation reactivity value is negative. However, this condition still shows the calculated optimum value of fuel fractions 50-60% in the case. Meanwhile, based on the graph the value of reactivity against time with a thermal power output of 400 and 500 MWT, as in figure (14 and 16) shows that the results of the calculation of excess reactivity to variations fraction of fuel by 50% of the reactor is able to work optimally until the 17th because the reactivity value in year 18 is negative. For a fraction of 55% of the reactor fuel is able to work optimally until the 15th year, and for a fraction of 60% of the reactor fuel is only able to work optimally until the 13th year of reactor operation. However, these conditions illustrates that the reactor is capable of maintaining a critical condition in a long time although it did not reach burn-up period of 20 years.

Analysis of the influence of the value of excess reactivity of a reactor during the burn-up in progress is needed because it will affect the performance of a reactor. Along with the duration of the period of burn-up, the reactor fuel would be less reactive over time. Value excess reactivity greater influence on the increase in reactivity is faster than a nuclear reaction. In normal conditions it must be ensured that the reactivity possessed a reactor must be small enough for the advanced nuclear reactions in the period subsequent burn-up.

In figure 12 show the value of CR (*Conversion Ratio*) to Fuel<sub>1</sub> with thermal power output and the variation fraction 300MWt fuel 50%, 55%, and 60% showed CR values above one. On the graph shows that the value of CR in year 1 amounted to 1.054969 and continued to decline until it reaches the value of CR amounted to 1.001312 in the 14th year of reactor operation time. In the 15th until the 20th year CR value reaches a value below one that is approximately 0.99794, of these explanations can be said that the reactor is classified into the reactor Breeding (Breeding Reactor). Breeding Reactor is a reactor that has the ability to produce its own fuel. But for the case of reactor A reactor breeding period is only able to reach a 15-year period of operation.

#### 4. Conclusion

In this study, there are several conclusions, among others:

1. It has been successfully carried out a design/design SPINNOR-cooled fast reactor with a Pb-Bi Thorium Uranium nitride fuel along neutroniknya analysis using SRAC program (Standard Thermal Reactor Analysis Code).
2. Having regard to the critical level of value-level burn-up fuel, the design of a terrace with a fuel fraction 50% Thorium Uranium Nitride most optimal for thermal power reactors.
3. Based on the level of criticality and power variation value, the maximum thermal power that can be produced terrace 150x100cm diameter using a fraction of the fuel input Thorium Uranium Nitride 60%, obtained the maximum thermal power is equal 300MWt.
4. The condition of the reactor design parameters with the variation of the thermal power output of 100, 200, 300MWt, 400MWt, and 500MWt, variations in fuel fraction 50%, 55% and 60%, and the percentage of U-233 by 7%, 7.75%, and 8.5 %. Under these conditions the system is able to maintain the reactor in a critical condition in operation long enough time mecapai 20 years, so that the reactor can be considered as long-life reactor.

5. From the graph  $k_{\text{eff}}$  and reactivity over time, it can be concluded that in terms of value addition fraction of fuel (fuel),  $k_{\text{eff}}$  value obtained will also be increased so that the reactor had a long period of critical state and will extend the operating life of the reactor. Because when the fraction or volume of fuel is increased, the amount of fuel will also increase which will cause a number of reactions occurring fissile increased. Increased fissile reaction this would trigger the production of neutrons more with increasing volume fractions.
6. Value excess reactivity indicates that the fast reactor SPINNOR has an optimized design and effective in a state with a fuel fraction 60% for thermal power reactors 300MWt. Because the value of the average excess reactivity to these conditions is 0.200039004%  $\Delta k / k$  ( $< \$1$ ).

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