Indonesian Journal of Physics
Vol. 23. No.1, July, 2012
Journal homepage: http://ijphysics.com

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

Dwita Nur Krisna, Zaki Su'ud

Department of Physics, Bandung Institute of Technology, Indonesia

Received: 23 January 2012, Revised: 15 April 2012, Accepted: 29 June 2012

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 is capable of operating up to 20 years without refueling. This reactor use Uranium Nitride Thorium as fuel and operating on power range 100–500MWtNPPs. The method of calculation used a computer simulation program utilizing the SRAC. SPINNOR reactor design 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%. Neutronik the 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%

Keyword: Burn-up, Conversion Ratio, Neutronic Analysis, SPINNOR

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 are expensive, and the danger of proliferation of nuclear weapons. In addition, nuclear reactor accidents that often occur in the environment of nuclear installations add bad views about nuclear energy. Chernobyl reactor accident on April 26, 1986, ultimately encouraging scientists and engineers to make a revolution regarding the design of nuclear power plants in order to avoid the same thing happening in the future.[2]

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. This 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.[3-4]

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 focuses on sustainable nuclear energy, efficient use of resources, minimal waste, and inherent safety.[1]

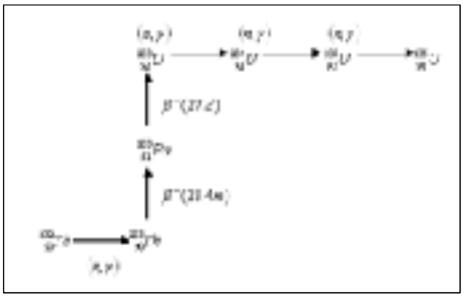

Figure 1. Chain Conversion of Thorium[1]

Corresponding author.
E-mail address: szaki@fi.itb.ac.id

The use of thorium as a nuclear power plant began to be considered because of the security and availability of more than Uranium. 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 Thorium0232 Thorium (Th-232) which has a half life of about 14.05 billion years.Gambar 1. Rantai Koversi Thorium.[1]

In this study will be designed reactors SPINNOR or type fast reactor cooled Pb-Bi, will now be analyzed neutronik reactor SPINNOR fueled Thorium Uranium nitride in 20 years of operating time, and will be calculated reactor designs SPINNOR are plaing optimal to do some variations survey parameters, such as thermal power output, fuel fraction, and the percentage of Uranium-233.

REACTOR DESIGN AND METHOD EXPERIMENT

Design of Fuel Cell and Assembly Reactor

Fuel used in this study based Thorium enrichment that comes from U-233. Thorium has the ability to produce fissile material is significant in this case the U-233. By using Thorium is expected to be achieved breeding value ratio is quite large. Breeding ratio is a parameter that describes the availability of fuel at each subsequent fission process.

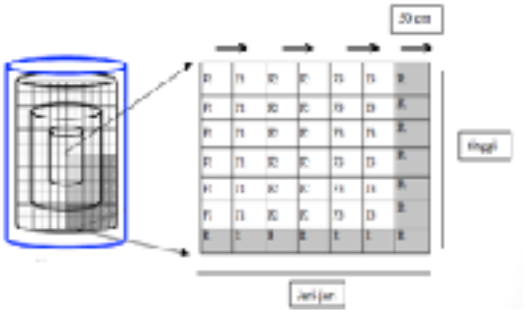

Figure 2. Composition of fuel design in the reactor core and reflector

CALCULATION METHOD

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.

1. First do the calculation of atomic density (N) for each element used in this SPINNOR reactor operation. Such elements include fuel elements, cladding and coolant.
2. Then do the calculations for the design of the reactor power level SPINNOR using Ms. Excel
3. Having obtained the required parameters from the calculation, the parameter value input into the program library SRAC calculation à PijBurn
4. With so we can plot curves keff value, reactivity, level burn-up, conversion ratio versus time (years) to variations 100-500MWt thermal power output, fuel fraction of 50-60%, and the percentage of fuel by 7%, 7.75%, and 8.5%

RESULTS AND DISCUSSION

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% Program SRAC can characterize the design of various types of reactor core to finish neutronik calculation. Using data nuclides in the library JENDL-3.2, SRAC program will perform calculations and produce data neutronik microscopic and macroscopic cross section of each material in the reactor core.

The steps are as follows:

1. Do the calculation of the cell and the burn-up for each fuel cell by SRAC
2. Do process homogenasi neutron energy level according to the amount specified group
3. Do the calculations are repeated in accordance many steps prescribed burn-up and the fuel cell are inputted
4. The result of the above calculation will be stored in the user library
5. Data from the macroscopic user library will be used as input data CITATION in the search for effective multiplication factor and the distribution of power density of each region and the mesh in the reactor core.

The calculation using SRAC can be made in the form of a flowchart as follows:

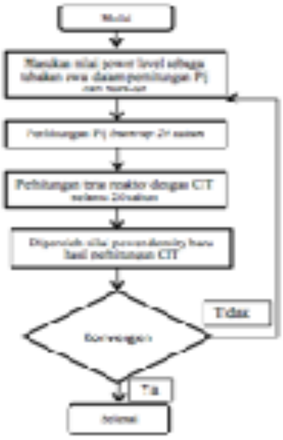

Figure 3. Flowchart of SRAC Calculation

Table 2. 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

From the data presented in Table 2, obtained several plots a graph of calculation results Pij burn-up during reactor operation.

BURN-UP CALCULATION

a. The percentage of U-233 7%, 300MWt thermal power output, high active terrace: 1m and active radius core: 0,75m

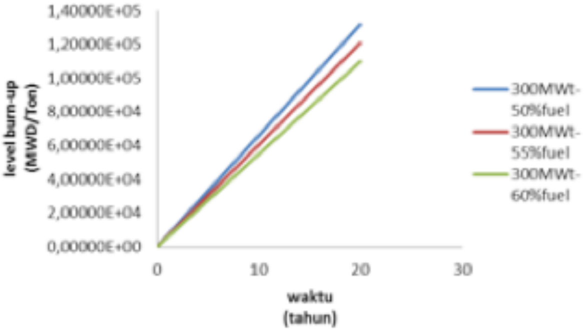

Figure 4. Curve *burn-up* design of SPINNOR reactor with percentage of U-233 7%, 300MWt thermal power output, and variance of fuel fraction 50%, 55%, and 60%

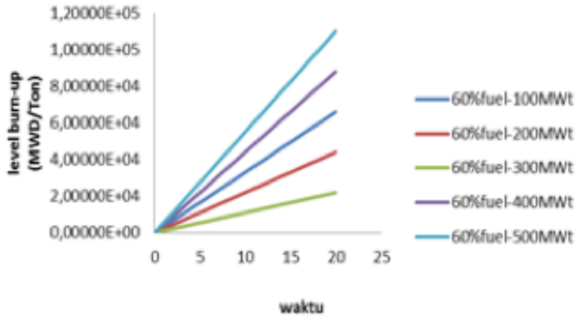

Figure 5. Curve level *burn-up* of SPINNOR reactor with percentage of U-233 7%, fuel fraction 60% with variance of thermal power output

b. The Percentage of U-233 7.75%, 300MWt thermal output power, high active terrace: 1m and active radius core: 0,75m

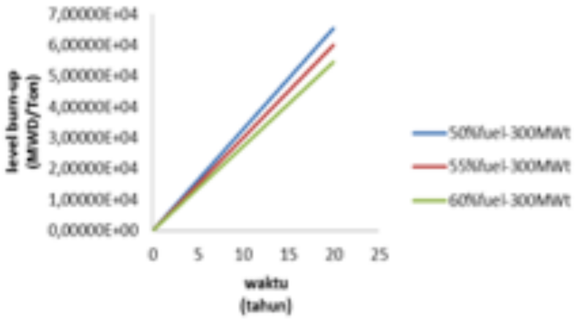

Figure 6. Curve *burn-up* design of SPINNOR reactor with percentage of U-233 7.75%, 300MWt thermal power output, and variance of fuel fraction 50%, 55%, and 60%

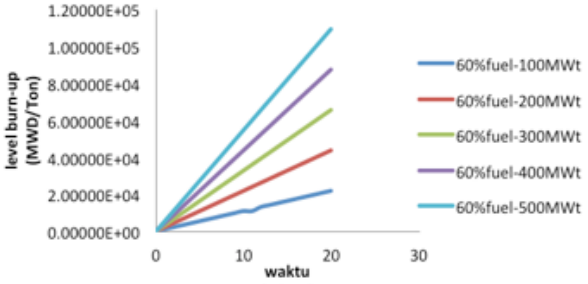

Figure 7. Curve level *burn-up* of SPINNOR reactor with percentage of U-233 7.75%, fuel fraction 60% with variance of thermal power output

ATOMIC DENSITY CALCULATION

a. Atomic density with 100MWt thermal power output and fuel fraction 60%

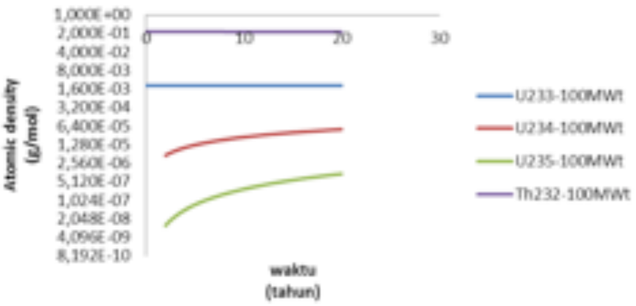

Figure 8. Curve of atomic density changes over a period of burn-up on SPINNOR reactor with 100MWt thermal power output

b. Atomic density with 200MWt thermal power output and fuel fraction 60%

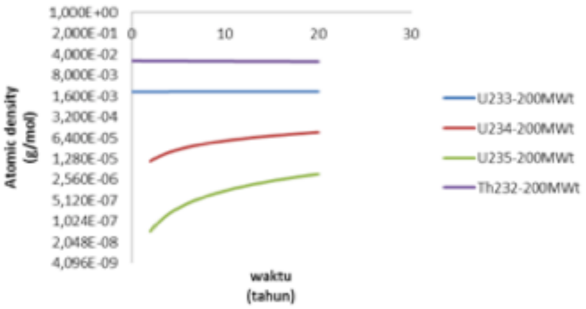

Figure 9. Curve of atomic density changes over a period of burn-up on SPINNOR reactor with 200MWt thermal power output

c. Atomic density with 300MWt thermal power output and fuel fraction 60%

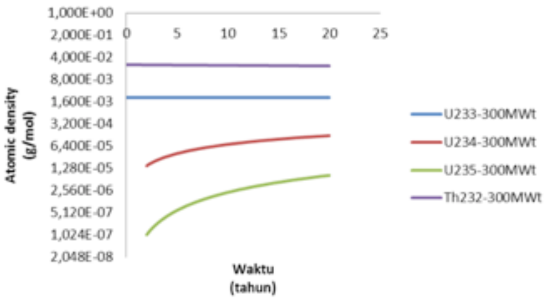

Figure 10. Curve of atomic density changes over a period of burn-up on SPINNOR reactor with 300MWt thermal power output

3. Calculation of Effective Multiplication Factor and Reacivity

a. Percentage of Uranium-233: 7%, 7.75%, 8.5%

i. Thermal power output 300MWt and variance of fuel fraction fraksi 50%, 55%, and 60%

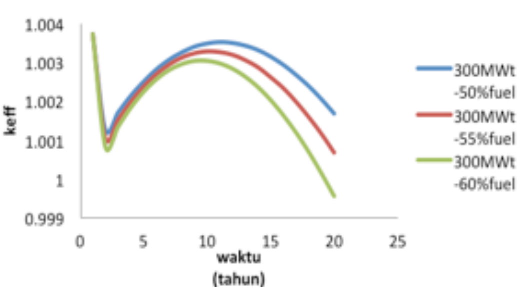

Figure 11. Curve of k_{eff} in SPINNOR reactor with thermal power output 300MWt and variance fuel fraction 50%, 55% and 60%

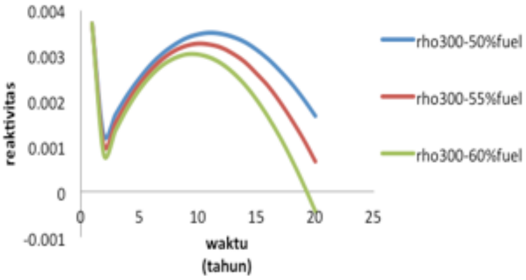

Figure 12. Curve of reactivity on SPINNOR reactor with thermal power output 300MWt and variance fuel fraction 50%, 55%, and 60%

ii. Thermal power output 400MWt and variance of fuel fraction fraksi 50%, 55%, and 60%

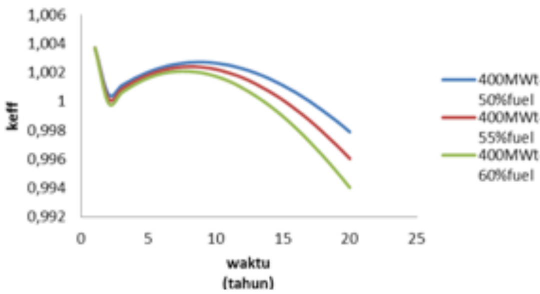

Figure 13. Curve of k_{eff} in SPINNOR reactor with thermal power output 400MWt and variance fuel fraction 50%, 55% and 60%

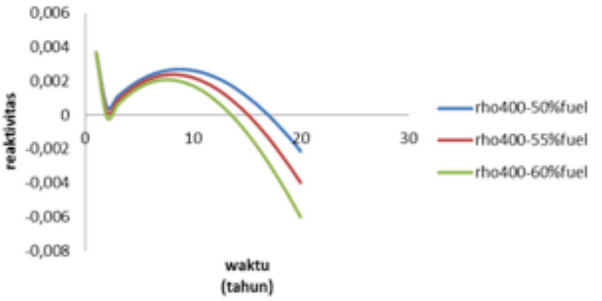

Figure 14. Curve of reactivity on SPINNOR reactor with thermal power output 400MWt and variance fuel fraction 50%, 55%, and 60%

iii. Thermal power output 500MWt and variance of fuel fraction fraksi 50%, 55%, and 60%

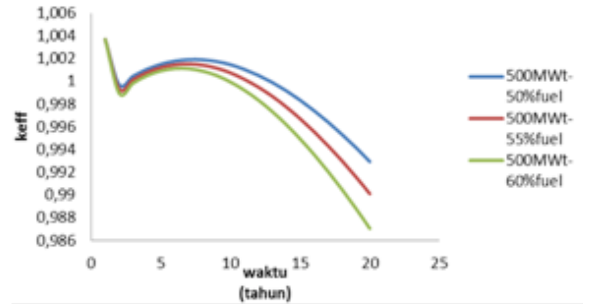

Figure 15. Curve of k_{eff} in SPINNOR reactor with thermal power output 500MWt and variance fuel fraction 50%, 55% and 60%

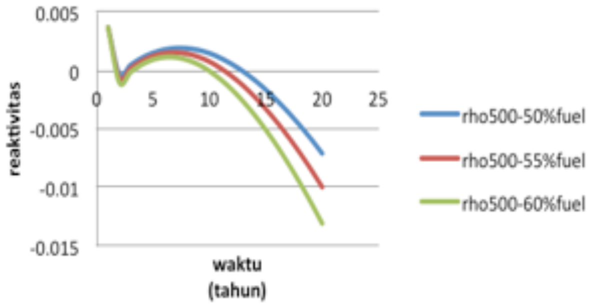

Figure 16. Curve of reactivity on SPINNOR reactor with thermal power output 500MWt and variance fuel fraction 50%, 55%, and 60%

Conversion Ratio Calculation

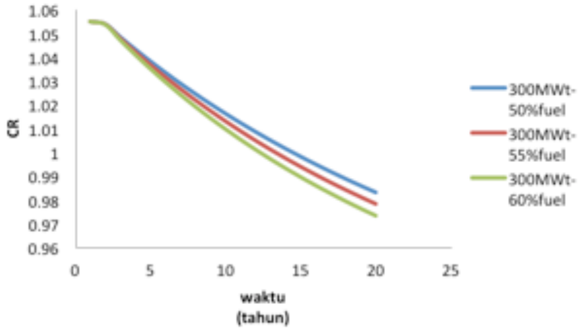

Figure 17. Curve of *Conversion Ratio* for *Fuel 1* with variance fuel fraction 50%, 55%, and 60% and thermal power output 300MWt

ANALYSIS

Level burn-up analysis

Figures 4 and 6 show the curves burn-up level of the burning time for 20 years on output power variation 300MWt the fuel fraction 50%, 55% and 60%, as well as variations in the percentage of U-233 by 7% and 7.75%. In both graphs can be seen that the smaller fraction of fuel used, the greater value of the level of burn-up. This shows that the smaller the 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.

Furthermore, in Figure 5 and 7 presented a graph on the calculation level burn-up in the value of the highest fuel fraction of 60% with a variation of the thermal power output 100MWt, 200MWt, 300MWt, 400MWt, and 500MWt. The graph explains that SPINNOR reactor with a thermal power output of 300 MWT has a value of burn-up levels are high as well. That is, the fuel consumption will be more efficient when used in high-power reactors. The higher the thermal power generated, the higher the density of thermally generated power so that fuel needed becomes less. As for the value of the thermal power output 500MWt 400MWt and demonstrate the value of burn-up levels are high, but for these two reactor designs SPINNOR power value is less than optimal because the value of power density is high enough. To power 400MWt power density generated by 113,234W / cm3, while for power 500MWt power density generated by 141,543W / cm3.

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 8, 9, and 10 illustrate changes in the density of the atoms during the burn-up on SPINNOR reactor with a thermal output power variation at 100, 200, and 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.

K_{eff} and Reactivity Analysis

For 11 visible image keff initial value (year 1) is worth one for each variation fraction of the fuel. For a fraction of the fuel 50%, 55%, and 60% had keff same value which is equal to 1.00372. The keff value at the beginning of the process will decline until the 3rd year of operating time for the fuel fraction 50% and 55%, while for 60% fuel fraction keff value has decreased to the 4th year of operating time. After keff decreased in the early years of operation, in the next operation will increase the value of keff and toward a stable state (critical) to the 20th 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-lived reactor. Meanwhile, for the value of the reactivity of each faction can be seen in Figure 12 where the shape of the graph resembles the graph keff value.

Use of the total thermal output power greater terrace will affect the value of keff greater Similarly, as in the case of power reactors 300MWt. Of some graphic images keff 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 keff 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 (keff) 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 12 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 the picture 17 value CR to Fuel1 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.

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 uranium-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-lived reactor

5. From the graph keff and reactivity over time, it can be concluded that in terms of value addition fraction of fuel (fuel), keff 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% Δk / k (<$ 1)

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