IJSES

Volume 4, Issue 8, pp. 4-8, 2020.

International Journal of Scientific Engineering and Science

ISSN (Online): 2456-7361

Analysis of Enhance Reliability Gas-Cooled Fast Reactor (GFR) Based on Fuel Uranium Nitride (UN)

Sari Novalianda, Andri Ramadhan

Faculty Engineering, Universitas Al-Azhar

Pintu Air IV street No. 214, Kwala Bekala, Medan, North Sumatera, Indonesia

Abstract— *Energy demand will continue to increasing number of human populations and needs in the industrial world. PLTN (Nuclear Power Plant) is one alternative energy source that utilizes nuclear fission reactions to produce energy and in its operation does not produce air pollution. This study presents an analysis of the reliability design of a Uranium-Nitride (UN) based GFR reactor, with a cladding of stainless steel (SS316) and helium-cooled. The calculation is done using a set of Standard Reactor Analysis Code (SRAC) programs. The results of the calculation design of the fast reactor core based on Uranium Nitride with 9.5% enrichment Uranium 235, using 60% fuel volume fraction, 10% cladding and 30% coolant showed critical values> 1 (1,008-1,051) with excess reactivity 0.031% then the reactor can operate for 10 years without refueling.*

Keywords— *GFR, k_{eff}, Uranium, Core.*

I. INTRODUCTION

Along with the increasing human population and increasing demand in industry, the greater the need for energy sources, especially electricity. Electrical energy sources that are used in Indonesia mainly use fossil fuels such as coal, petroleum, and gas whose availability continues to run low and in their operations produce air pollution in the form of CO2, NO2, and SO2.

To overcome the limitations of fossil materials, the government continues to implement acceleration in the development of New Renewable Energy (EBT) to achieve the target of 23% EBT in the national energy mix in 2025 by the National Energy General Plan (RUEN) and ESDM Regulation Number 50 of 2017 concerning the utilization of EBT.

One form of EBT that has great potential as an alternative energy source is nuclear energy. Nuclear energy is an energy source that utilizes the use of fuels in the form of uranium and thorium. Where geologically a quarter of Indonesia's land area is estimated to contain radioactive minerals, especially Uranium (BATAN, 2014).

Research on nuclear reactors for nuclear power plants (PLTN) in Indonesia was developed by the Indonesian Nuclear Power Agency (BATAN). Where Indonesia actively joined the International Atomic Energy Agency - International Atomic Energy Agency (IAEA). BATAN plans to build an Experimental Power Reactor (RDE) with an electricity capacity of around 3.5 MWe in the Puspiptek Area, Serpong, Tangerang which can be used for power generation, heat generation and producing hydrogen. The main advantages of nuclear power plants are that it does not produce air pollution, greenhouse gases, and relatively low operating costs (IAEA, 2014).

NPP is a type of power plant where the heat it generates is obtained from one or more nuclear reactors. The working principle of a nuclear power plant is almost the same as a conventional power plant such as a power plant, only the main difference lies in the source of energy and the type of fuel used. The energy source in conventional power plants comes from fossil combustion (for example coal, petroleum), whereas in nuclear reactors the energy source comes from a fission reaction with fuel in the form of Uranium or Thorium (Novalianda et al. 2016).

There are 450 nuclear power plants worldwide which supply 11% of the world's electricity supply. NPP technology continues to experience rapid development starting from generation I to generation IV. This generation IV reactor is planned to start operating in 2030, where this research was started by The Generation IV International Forum (GIF). One type of NP generation IV is Gas-cooled Fast Reactor (GFR). GFR is a type of fast reactor that uses fast neutrons, which has a closed fuel cycle and uses Helium (He) as a cooling medium and can be operated at 850o which can produce hydrogen gas. GFR has advantages in the field of safety that is made naturally (inherent) and does not depend on the operator or active tools (passive safety), (GIF, 2009).

Before the construction of the NPP first, careful planning and calculation are made. Where one of the most important factors in designing a nuclear reactor is the neutronic aspect, namely the behavior of neutrons in the reactor core. Where in the reactor core there is fission, which is the fission of the atomic nucleus (Uranium) with the triggering material is a neutron. In this fission reaction, neutrons will experience capture, scattering, and leakage reactions (solly aryza,2019).

The number of neutrons reacting will determine the emergence of new neutrons from the fission reaction which is a new generation of neutrons. To measure the number of neutrons in two successive neutron generations, we can define the ratio of neutrons to neutrons known as the effective multiplication factor 〖(k〗 eff) with the form of the equation (Duderstadt & Hamilton, 1976):

$$k_{eff} = \frac{number\ of\ neutron\ ini\ one\ geeration}{number\ of\ neutron\ ini\ previous\ generation}$$

The k_eff value represents the number of neutron populations inside the reactor core. The k_eff value has a rule, where if k_eff <1, then the number of neutrons in a generation will be less than the number of neutrons in the previous generation, this condition is called subcritical. Subcritical conditions are not expected in the design of a nuclear reactor because the fuel will be depleted before the operation of the nuclear power plant ends. The second condition if k_eff> 1, meaning that the number of neutrons in a generation is more than the number of neutrons in the previous generation, so that the neutrons that are produced are getting more and more. This is not expected because it will cause uncontrolled neutron polulation and can cause an explosion. The last condition where the value k_eff = 1, where the number of neutrons in a generation will be the same as the number of the next generation, this condition is called critical. This critical situation is what is wanted in designing a nuclear reactor.

$$\frac{1}{v_g}\frac{\partial \phi_g}{\partial t} = \nabla . D_g \nabla\phi_g - \Sigma_{ag}\phi_g + S_g - \Sigma_{sg}\,\phi_g + \sum_{g'=1}^{G}\Sigma_{ag'g}\,\phi_{g'}$$

Another factor that determines the neutronic analysis of nuclear reactor designs that can operate is the burnup calculation. Burnup calculations relate to long-term (day-month-year) changes in the composition of materials in a reactor due to various nuclear reactions that occur during the operation of a nuclear reactor. Where the fission materials of fission reactions are very large (more than 1200 nuclides) and their characteristics are very diverse (Ariani et al, 2013) with the form of the equation:

$$\frac{dN_A}{dt} = -\lambda_A N_A - \left[\sum_g \sigma_{Ag}^{A}\,\phi_g\right] N_A + \lambda_B N_B + \left[\sum_g \sigma_{\lambda g}^{C}\,\phi_g\right] N_C$$

II. Method of System

The fuel cell used is in the form of pins consisting of fuel (fuel), cladding and coolant. The fuel used is Uranium Nitride (UN). Where UN is considered as a potential fuel for generation IV reactors such as GFR due to high levels of fission density, thermal conductivity and radiation stability (Su'ud, 2013). The cylindrical cell geometry with its cross section can be seen in Figure 1.

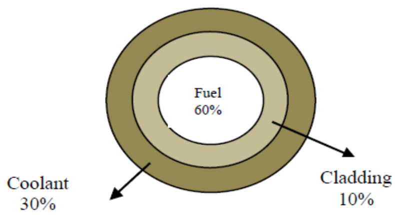


Figure 1. Fuel Cell Cylinder Geometry

The GFR reactor design parameters to be studied can be seen in Table I.

This research uses the Standard Reactor Analysis Code (SRAC) program developed by the Japan Atomic Energy Research Institute (JAERI). SRAC calculation is done through two stages, namely at the cellular level and reactor core. Cell and burnup calculations use the PIJ Module which adopts the Collison Probability Method (CPM) method which will produce macroscropic cross section values. The resulting cross section macroscropical value is used for the reactor core calculation using the Multi-Dimensional Diffusion Calculation (CITATION) module to solve the multigroup diffusion equation (Okumura et al, 2007).

TABLE I. GFR reactor design parameters

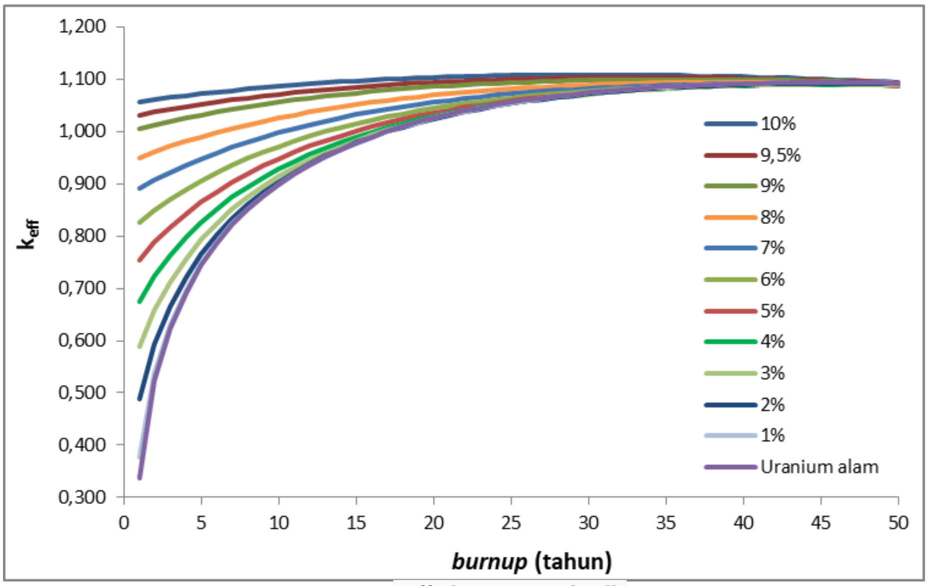
No	Parameters	Specification
1	Reactor Power	500 MWt
2	Fuel Material	Uranium Nitride (UN)
3	Uranium enrincment	1 - 10%
4	Cladding Material	*Stainless steel* (SS316)
5	Coolant Material	Helium
6	Volume Fraction Fuel:Cladding:Coolant	60%:10%:30%
7	Pitch Diameter	1,4 cm
8	Active terrace active (diameter x height)	240 cm x 350 cm
9	Reflektor Width	100 cm
10	Refueling Period	10 years

III. Analyze and Result

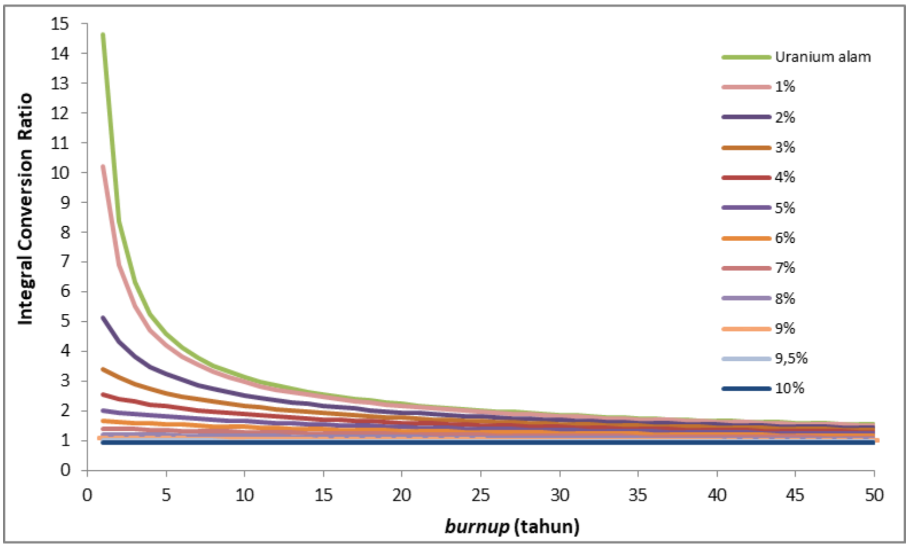
SRAC calculation results on fuel cells produce several survey parameters that have been determined as follows: Uranium contained in nature consists of three isotopes, Uranium 238 (99.284%), Uranium 235 (0.711%), and Uranium 234 (0.005%). Of the three isotopes only Uranium 235 is fissile which is able to directly emit neutrons which produce fission products in the reactor (Novalianda et al, 2018). Due to the limited number of Uranium 235, the enrichment process of Uranium 235 is needed so that the atomic density of Uranium 235 also increases. This can be seen in Figure 2 where the value of keff for Natural Uranium (0.337) and enrichment of Uranium 235 by 1% to 8% keff value <1 (0.375 to 0.978) which means the reactor has not yet reached a critical condition which means the number of neutrons from one generation over small compared to neutrons in the next generation. As for enrichment of Uranium 235 9%; 9.5%, and 10% of the reactors have reached a critical state with a keff value of 1.005 each; 1,031; and 1,056. Fuel cells that have reached a critical condition (keff> 1) can be arranged on the reactor core.

Figure 3 shows the value of Conversion Ratio (CR) to burnup time, where fuel cells using natural uranium have decreased CR from 14.6 to 1.53 (CR> 1). This is due to a continuous reduction in the production of fissile material, but conversely the level of consumption of fissile material is much greater. Whereas the enrichment of Uranium 235 is 9.5% and 10% the value of CR <1 where the amount of Uranium 238 continues to decrease as the enrichment of Uranium 235 is given, which means the amount of fissile consumed is far greater than the fissile material used. This CR value will identify the consumption of fissile fuel so that fission chain reactions continue to occur and the reactor will be able to operate during the burnup time.

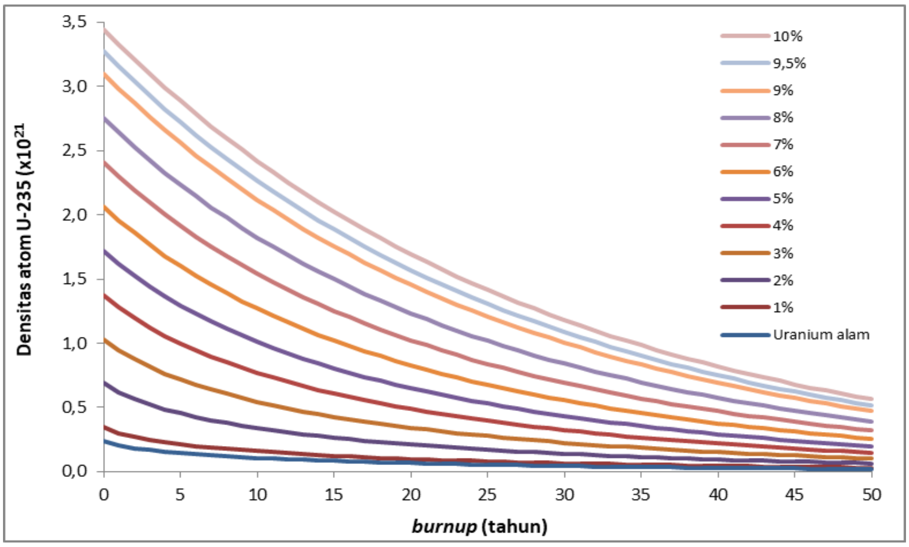
During the burnup process, the density of each atom will change according to the burnup time. Where among the atoms experiencing significant changes can be observed in Uranium 235, Uranium 238, and Plutonium 239.



Figures 2. Keff Changes In Fuel Cells



Figures 3. Conversion Ratio Changes



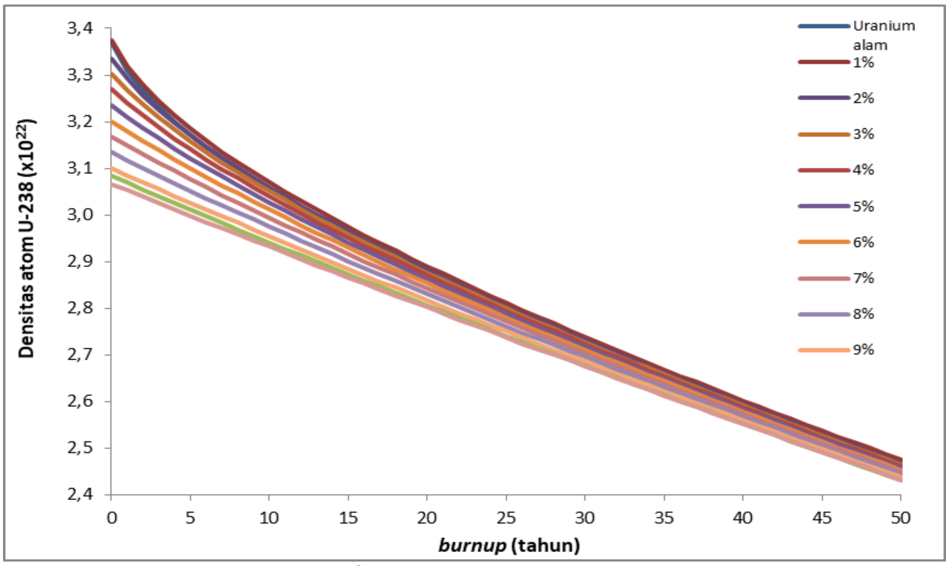
Figures 4. Changes in Uranium Atomic Density 235

IJSES

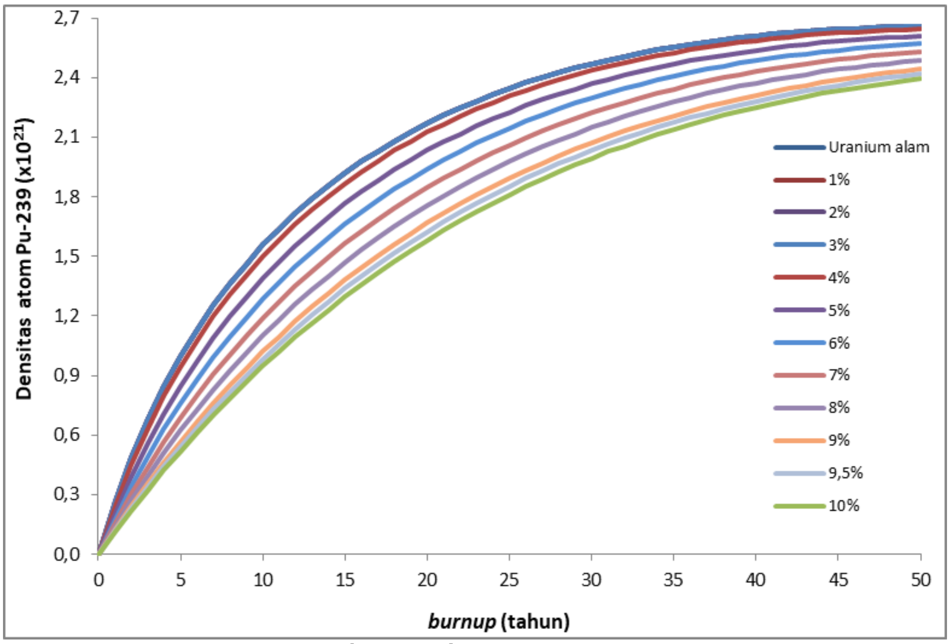
Volume 4, Issue 8, pp. 4-8, 2020.

International Journal of Scientific Engineering and Science

ISSN (Online): 2456-7361



Figures 5. Changes in Uranium Atomic Density 238



Figures 6. Changes in Plutonium Atomic Density 239

Figure 4 shows a decrease in Uranium 235 density. While Figure 5 for fertile Uranium 238 also decreases its density and turns into other elements including producing Plutonium 239. The density of Plutonium atoms 239 which at the beginning of the fission reaction does not exist, until the burnup process runs Plutonium 239 will begin to be created and will increase during the burnup process as shown in Figure 6.

IV. CONCLUSION

Uranium Nitride-fueled helium GFR design with 9.5% Urannium enrichment of 9.5%, using a 60% fuel volume fraction, 10% cladding and 30% coolant resulting in a value of keff> 1 (1.008 to 1.051) during one burnup cycle with excess reactivity 0.031%. The GFR reactor can operate for 10 years without refueling.

ACKNOLEDGEMENT

This research is a 2020 Lecturer Research Grant Grant funded by the Ministry of Research and Technology / National Research and Innovation Agency Deputy for Research and Development Strengthening.

REFERENCES

[1] Ariani, Menik. Zaki Su'ud., Fiber Monado, A.Waris, Khairurrijal, I.Arif, Ferhat A, and H.Sekimoto. Applied Mechanics and Materials, Vols.260-261 (2013) pp 307-311.

[2] Dewan Energi Nasional RI. Outlook Energi Indonesia 2014.

[3] Duderstadt & Hamilton. 1976. Nuclear Reactor Analysis. JOHN WILEY & SONS, INC

[4] GIF. (2009). GIF R&D Outlook For Generation IV Nuclear Energy Systems.

[5] IAEA. (2014). International Status and Prospects for Nuclear Power 2014. GOV/INF/2014/13-GC(58)/INF/6.

International Journal of Scientific Engineering and Science
Volume 4, Issue 8, pp. 4-8, 2020. ISSN (Online): 2456-7361

[6] K. Okumura, T. Kugo, K.Kaneko and K. Tsuchihashi: *SRAC2006: A Comprehensive Neutronic Calculation Code System, JAEA-Data/Code 2007-004*, Reactor Physics Group, Nuclear Science and Engineering Directorate, Japan Atomic Energy Agency (2007).
[7] Novalianda,Sari., Menik Ariani., Fiber Monado, Zaki Su'ud. *Neutronic Design Of Plutonium Uranium Fuel-Based Gas-Cooled Fast Reactor*. Jurnal Pendidikan Fisika Indonnesia 14 (2) (2018).
[8] Novalianda,Sari., Menik Ariani., Fiber Monado, Zaki Su'ud . Studi Awal {erhitungan Sel Bahan Bakar Berbasis Uranium Oksida (UO_2) Pada Reaktor Cepat Berpendingin Helium. Jurnal Lingkungan dan Pembangunan Volume 2, Nomor 1, 2016.
[9] Solly Aryza et al A Novelty Design Of Minimization Of Electrical Losses In A Vector Controlled Induction Machine Drive, 2019
[10] Zaki Su'ud and Hiroshi Sekimoto. *The Prospect of Gas-cooled Fast Reactors For Long Life Reactors With Natural Uranium As Fuel Cycle Input*. Annals of Nuclear Energy 54:58–66 · (2013)