The prospect of uranium nitride (UN-PuN) fuel for 25-100MWe gas cooled fast reactor long life without refuelling

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Abstract. The prospect of uranium nitride (UN-PuN) fuel for 25-100MWe Gas Cooled Fast Reactor has been done. This research use helium coolant which has low neutron moderation, chemical inert and single phase. This study use natural uranium and plutonium. Plutonium taken from spent fuel of LWR (Light Water Reactor). So, it can reduced spent fuel in the world. The calculation use SRAC2006 and JENDL 4.0 for the data libraries. First, we calculate PIJ for fuel pin cell calculation and CITATION for core calculation. The reflector radial-axial width is 50 cm. The variation of fuel fraction is 40% until 65%, cladding 10%, and moderator 25% up to 50%. The variation of the power is 75-300 MWth (25-100 MWe). The calculation of survey parameter has been done. The variation of percentage plutonium is 7% up to 13%. We have optimum k-eff value in percentage of plutonium 11%. The high powers cause k-eff value high too. Second, the core configuration divided by three variation fuel (F1, F2, and F3). F1 is located in the central core, F2 middle core and F3 outer core. The variation percentage Plutonium for fuel F1:F2:F3 = 8%:10%:12%. The increasing power level make the burn up level increase. All case can reach burn up time plus than 20 years. The thermal powers increase cause the peak power density increase. The power 150 MWth, 225 MWth, and 300 MWth have excess reactivity (%Δk/k) less than 2%.

1. Introduction

Nuclear power plant has been characterized by substantial growth not only in numbers but also in plant sizes, with economies of scale favouring the large plants [1]. According to the IAEA (International Atomic Energy Agency) definition an SMPR is an electricity producing nuclear power plant in the capacity range of 100 to 500 MWe (bellow 600MWe) [1,2]. In response to important commercial developments, the energy range of small and medium reactors is now taken as being up to around 700 MW [3]. These guidelines are mainly intended for decision makers in developing countries interested in embarking on a nuclear power programme [2]. The main incentives for these designs have been improvements in safety, reliability and economics [3]. Also proposed for use in a relatively isolated area, however, should satisfy some very important requirements such as easy operation, easy maintenance, easy construction and decommissioning, inherent/passive safety, and proliferation resistance [4].

Since June 1990 there is a team for small nuclear electricity reactor has been performed. It is responsible for assessment and design of a small reactor for electricity and/or sea-water desalination

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for small islands and isolated in Indonesia [5,6]. This research the reactor is designed without on-site refuelling, its means it has a capability to operate long life consistent with the plant economics and energy security [7]. The design of small fast reactor has been design with higher fuel volume fraction [8-11]. Beforehand, small and medium GFR with modified CANDLE burn up scheme with uranium natural has been analyze before [12-15]. In this research, In this research The prospect of uranium nitride (UN-PuN) fuel for 25-100MWe Gas Cooled Fast Reactor long life without refuelling has been done.

2. Design Concept and Calculation Methods

Table 1 shows parameter design of fuel pin in the reactor. The fuel use uranium plutonium nitride fuel. Silicon carbide for the cladding is good choice to material cladding because it has high melting point, low chemical activity, no appreciable creep at high temperature, and low neutron absorption cross section.

Table 1. Parameter design of fuel pin in the reactor

Parameter	Specification
Fuel material	UN-PuN
Cladding material	SiC
Coolant material	Helium
Fuel volume fraction	40% - 65%
Cladding volume fraction	10%
Coolant volume fraction	30% - 50%
Pin pitch	1.45 cm

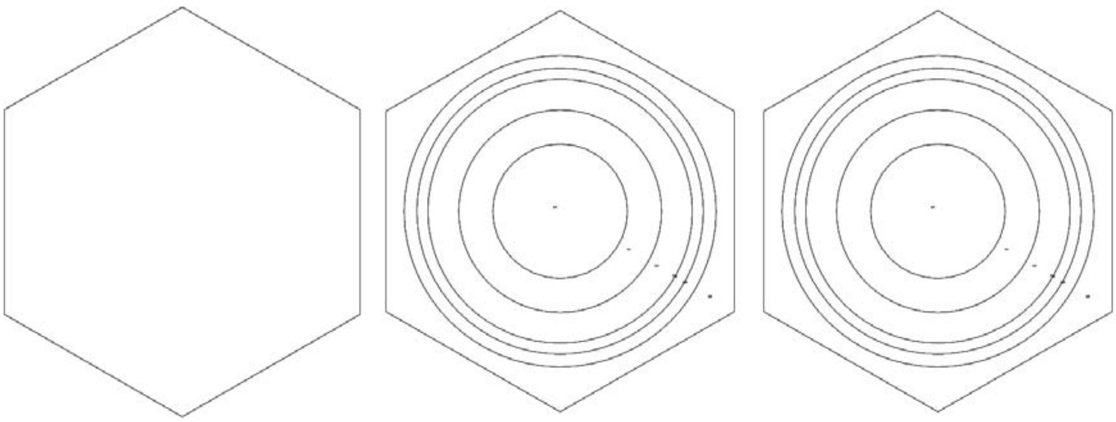

Figure 1. Hexagonal geometries for fuel pin calculation (PIJ) by SRAC2006 results calculation

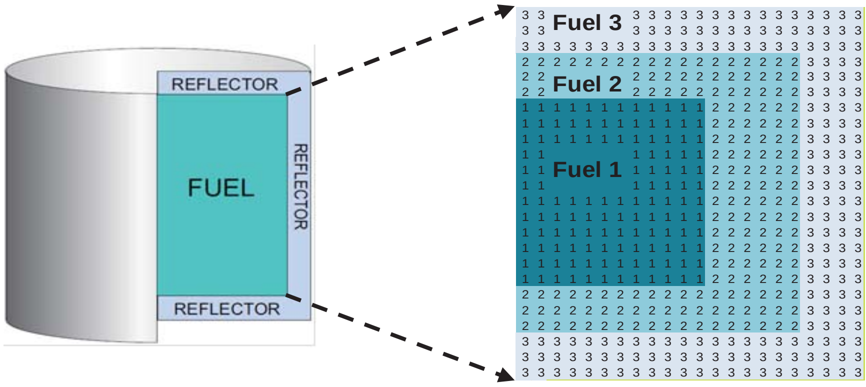

Figure 2. Half heterogeneous core configuration with different width in variation fuel

Fig. 1 show hexagonal geometries for fuel pin calculation (PIJ) by SRAC2006 results calculation. Fig. 2 show half heterogeneous core configuration with different width in variation fuel. There is three variation fuel, F1, F2 and F3 which F1 is in the center, F2 in the middle and F3 in periphery, and after that there is a reflector. Percentage F1:F2:F3 = 8%:10%:12%.

The calculation method use SRAC 2006 and libraries JENDL 4.0. It is designed to permit neutronics calculation for various type reactors. SRAC covers production of effective microscopic and macroscopic group cross section, and static cell and core calculation including burn-up analysis. First, it calculate fuel pin cell PIJ with Collision Probability Method (CPM). In PIJ calculation, we get k-inf, burn-up analysis and more. After that, it continues to calculate core reactor with CITATION, with various core configuration [16].

3. Results and Discussion

Table 2 show the results of parameter optimization UN-PuN fuel in GFR use SRAC calculation. The power of the reactors is varied from 75-300 MWth (25-100 MWe). The core geometry design is set to be pancake geometry, means the diameter width is greater than the height (D>H). The width of reflector is set same for all case i.e. 50 cm. The enrichment variation for F1 : F2 : F3 = 8% : 10% : 12%. The optimum results can be reach if the reactor have effective multiplication factor (k_{eff}) around one ($k_{eff} \geq 1$), means has excess reactivity less than 2% %Δk/k. Multiplication factor is number of fission in one generation divide by number of fission in preceding generation.

$$excess.reactivity(\%) = \frac{(k_{eff} - 1)}{k_{eff}} x100\% \quad (1)$$

All case constrained to have maximum excess reactivity less or around 2% %Δk/k. The burn up level is increases as the power level is increase. For 225MWth the burn up level is less than 150MWth due to the addition of width and height active core. The addition is to find the optimum excess reactivity value (2% %Δk/k).

Table 2. Result of parameter optimization of UN-PuN fuel in GFR

Thermal power (MWt)	Width active core	Height active core	Volume fraction (%)			Burnup level (MWd/ton)	
			Fuel	Cladding	Coolant	Average	Peak
75	175	100	60.5	10	29.5	1.37E+04	2.75E+04
150	175	100	57.5	10	32.5	2.90E+04	5.80E+04
225	195	125	58	10	32	2.64E+04	5.27E+04
300	195	125	55	10	35	3.51E+04	7.03E+04

Table 3 shows the main results or performance UN-PuN fuel in gas cooled fast reactor without refueling. This result was obtained after we calculate the reactor core (CITATION calculation) with all results parameter in Table 2. All case can reach burn up time plus than 20 years. The breeding ratio for 75MWth is largest than the others, due to the thermal power is smallest than the others. When the thermal powers increase cause the peak power density increase. The range of power density is 25 until 114 Watt/cc. For case 2 until 4 has excess reactivity (%Δk/k) less than 2%.

Table 3. Performance of UN-PuN fueled gas cooled fast reactors without refueling

Thermal power (MWt)	Breeding / convertion ratio	Peak power density (W/cc)	%Δk/k
75	1.325	25	2.04
150	1.244	53.5	1.53
225	1.268	77	1.89
300	1.231	114	1.78

Figure 3 show effective multiplication factor (k_{eff}) value of gas cooled fast reactor with various power. The trend of the graph is similar for 150-300MWth. The trend of the graph of 75MWth different because the power is too small, so the number of fission is less than the others cause the graph is decrease until 14 years burn up time after that it increase. The declining graph explains that it is burning and the rising graphs explain breeding. So for 150MWth until 300MWth after the fifth burn up time the reactor is breeding.

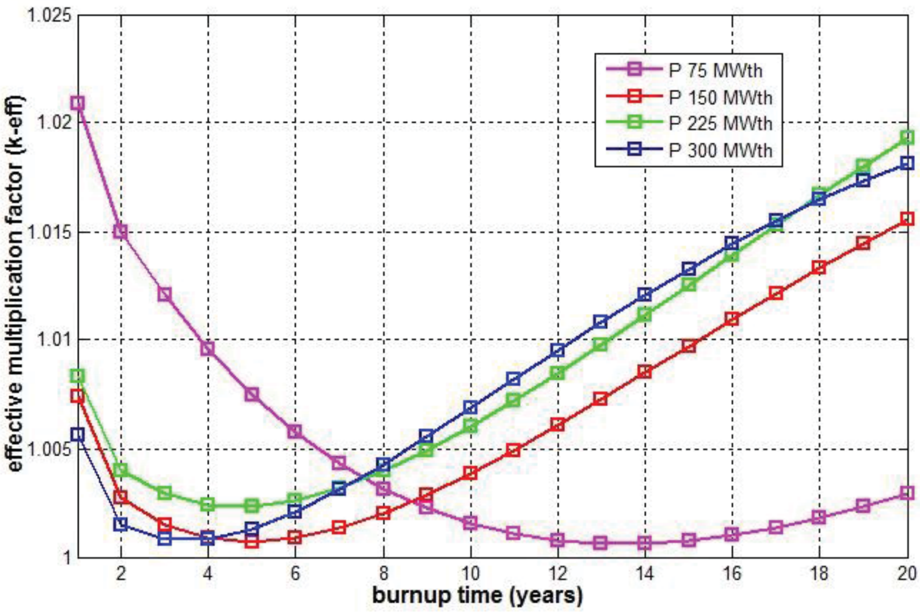

Figure 3. Effective multiplication factor (k-eff) value of gas cooled fast reactor with various power

4. Conclusion

The prospect of uranium nitride (UN-PuN) fuel for 25-100MWe Gas Cooled Fast Reactor has been done. The variation percentage Plutonium for fuel F1:F2:F3 = 8%:10%:12%. The increasing power level make the burn up level increase. All case can reach burn up time plus than 20 years. The thermal powers increase cause the peak power density increase. For all power have similar trend of k-eff value except 75MWth because of the power is too small, but all power experienced two phases of burning and breeding.

5. Acknowledgment
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References

[1] IAEA-TECDOC-347 1985 *Small and medium power reactors : Project initiation study phase I* (International Atomic Energy Agency) p 7
[2] IAEA-TECDOC-445 1987 *Small and Medium power reactors 1987* (International Atomic Energy Agency) p 9
[3] IAEA-TECDOC-881 1996 *Design and development status of small and medium reactors system 1995* (International Atomic Energy Agency) p 7
[4] Hiroshi S and Zaki S 1995 *Nuclear Technology* **109** pp 307-313
[5] M Nurdin 1992 Proc. Int. Specialists Mtg. Potential of Small Nuclear Reactors for Future Clean and Safe Energy Sources *Elsevier* pp 145
[6] Zaki S 2006 Strategi pengembangan riset dalam bidang iptek nuklir dalam rangka penyiapan SDM yang berkualitas tinggi *Seminar nasional II SDM Teknologi Nuklir* **ISSN 1978-0176** pp 1-8
[7] IAEA-TECDOC-1536 2007 *Status of Small reactors design without on-site refueling* (International Atomic Energy Agency) p 9
[8] Zaki S 2008 *Progress in Nuclear Energy* **50** pp 276-278
[9] Zaki S 2008 *Progress in Nuclear Energy* **50** pp 157-162
[10] Zaki S Bakrie A and Sedyartomo S 2005 *Progress in nuclear energy* **47** pp. 212-221
[11] Zaki S and Hiroshi S 1993 *Nuclear engineering and design* **140** pp 251-260
[12] Fiber M Zaki S Abdul W Khairul B Menik A and Hiroshi S 2013 *Advanced Material Research* **772** pp 501-506
[13] Menik A M Ali S Ade G A and Zaki S 2010 *Proceeding Seminar dan Workshop Nasional Pendidikan Teknik Elektro (SWNE)* pp 93-98
[14] Menik A Zaki S and Fiber M 2013 *Jurnal Ilmu dasar* **14** pp 11-15
[15] Zaki S and Hiroshi S 2013 *Annals of Nuclear Energy* **54** pp 58-66
[16] Okumura K 2002 *SRACPP version 2002* (Japan Atomic Energy Research Institute) p 1-28