ANALYSIS ON K_{eff} FUEL ARRANGEMENT OF PUSPATI TRIGA REACTOR CORE WITH DIFFERENT POWER OF REACTOR CORE

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ABSTRACT

This paper simulated different powers of nuclear reactor to analyse the k_{eff} and the production of uranium-233. The research use thorium fuel in form of thorium zirconium hydride fuel rod and simulated with different arrangement of core configuration and reactor power, namely 750 kW, 1 MW and 3 MW. The configuration are simulated using Monte Carlo n-Particle eXtended (MCNPX) with 1000 neutron per seconds with 550 cycle for each configuration. Results from the simulation show that higher reactor power gives the steepest pattern for k_{eff}. Besides, it also affects the production of uranium-233 as the higher reactor power provides the highest output for uranium-233 buildup.

ABSTRAK

Kertas kajian ini mensimulasikan kuasa berlainan reaktor nuklear untuk menganalisis keffs dan pengeluaran uranium-233. Penyelidikan menggunakan bahan api torium dalam bentuk torium zirkonium hidrida torium dan disimulasikan dengan susunan konfigurasi teras dan reaktor teras yang berbeza iaitu 750 kW, 1 MW dan 3 MW. Konfigurasi disimulasikan menggunakan Monte Carlo n-Zarah eXtended (MCNPX) dengan 1000 neutron setiap saat dengan 550 kitaran untuk setiap konfigurasi. Keputusan dari simulasi menunjukkan bahawa kuasa reaktor yang lebih tinggi memberi corak yang paling curam untuk keff. Selain itu, ia juga memberi kesan kepada pengeluaran uranium-233 sebagai kuasa reaktor yang lebih tinggi menyediakan keluaran tertinggi untuk penambahan uranium-233.

Keywords: RTP, thorium, uranium, hydride, MCNP, reactor core configuration

Introduction

PUSPATI TRIGA Reactor (RTP) use uranium zirconium hydride (U-$ZrH_{1.6}$) fuel that consists of 8.5 w.t.%, 12w.t.% and 20 w.t.% uranium, which has 20% uranium-235 [1_ENREF_2, 2_ENREF_3]. It is the only research reactor in Malaysia that has been operated since 1982. The 1MW pool-type reactor achieved its criticality since 28th June 1982 and has been the platform to conduct research related with neutron applications [3].

There are studies of thorium fuel cycle that have been carried out on to replace uranium as nuclear fuel. However, some areas of research on thorium still need to be explored especially thorium nuclear reactor. One of the potential use of thorium as nuclear fuel is low actinide production in nuclear reactor [4-6_ENREF_2_ENREF_3]. In 2013, Malaysia had started a committee on research and development of thorium for future fuel. The program name Thorium Flagship Project is one of the project to utilize the usage of thorium in Malaysia [7_ENREF_2_ENREF_3].

METHODOLOGY

PUSPATI TRIGA Reactor core was designed according to original core as shown in Figure 1 below [8]. Then, five different configurations have been designed with each of the configuration has different variations as shown in Figure 2. Configuration A shows the core with 86 number of U-ZrH1.6, which has the same number of rods with the real core of RTP, Core 0. Core 0 is the first core that reached the criticality with the number of keff 1.05261 and it consists of 82 full solid U-ZrH1.6 fuel, and 4 control rod which 3 of the rods are fuel follower control rods and 1 of it is air follower control rods. The core is filled with water, which also acts as a moderator.

For configuration B, the blank space in the core is filled with thorium fuels. The thorium fuels are arranged at the outermost and second outermost rings of the core as an imitation of a seed-blanket configuration. 86 rods of U-ZrH1.6 are arranged in the middle of the core surrounded by 39 numbers of thorium fuels. Configuration C shows the arrangement of RTP core with a checker configuration. Thorium fuels are arranged in the middle of the core with 3 of the thorium fuels placed in ring B, 6 in ring C, 9 in ring D, 12 in ring E and 9 in ring F. Thorium fuels are arranged in a checker box-like configuration.

Next one is configuration D, which has thorium fuels arranged only in specific rings of the core. The fuel is arranged alternately with UZrH1.6. 11 thorium fuel rods are arranged in ring C, 24 rods in ring E and another 4 rods are in ring G. Lastly, for configuration E, the thorium fuel rods are arranged in the middle of the core with a diamond shape arrangement. Most of the rods are situated in ring B, C, D and 4 of the rods in ring E.

15 configurations were designed and simulated with each main configuration has different arrangements but the same amount of thorium fuel which are 39 thorium fuels except configuration A that does not consist any of thorium fuels. All configuration were simulated with different level of power reactor which are 0.75kW, 1MW and 3MW.

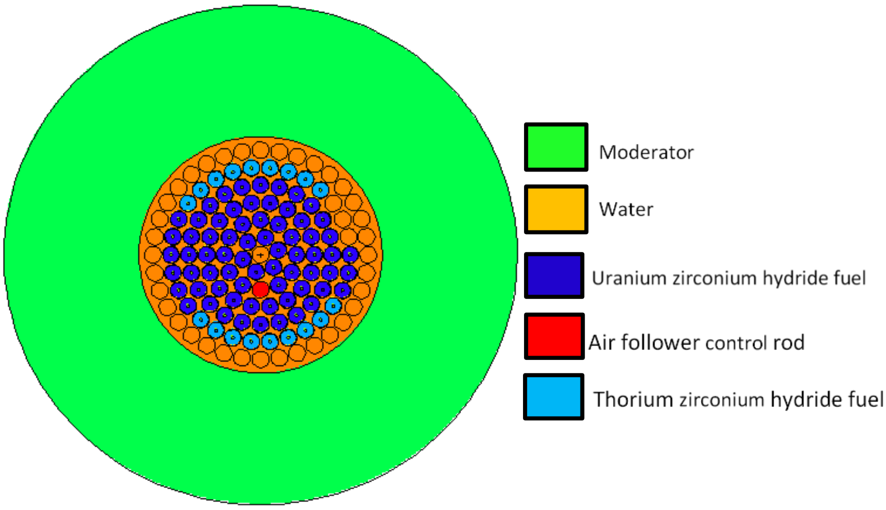
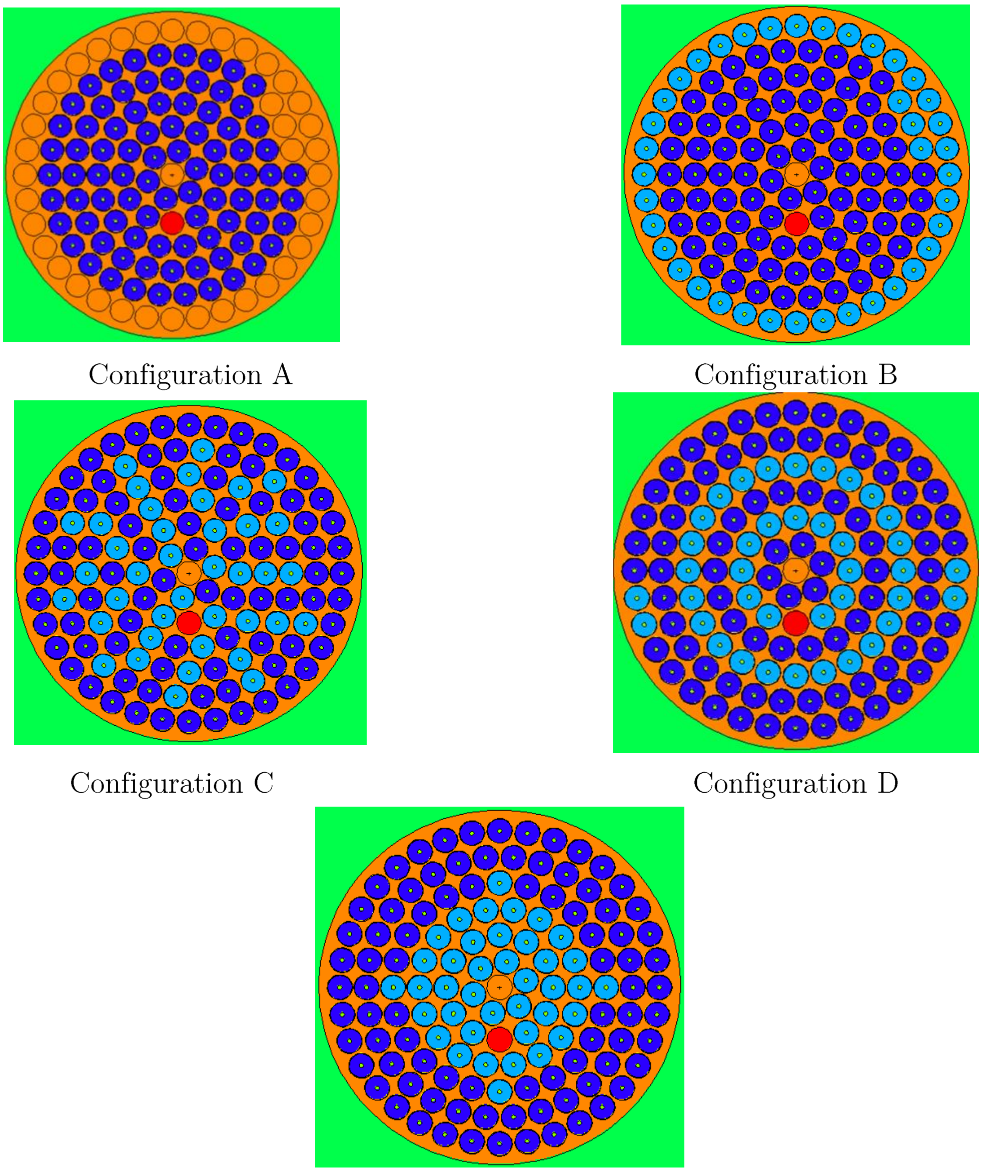


Figure 1: Arrangement of thorium fuel in RTP core



Configuration A

Configuration B

Configuration C

Configuration D

Configuration E

Figure 2: Arrangement of configuration core

RESULT AND DISCUSSION

There are 39 thorium zirconium hydride (Th-ZrH_2) fuel rods were placed on the core beginning from configuration B to configuration E. Meanwhile, there is no thorium fuel rod placed in configuration A. All 15 configuration as shown in Figure 3 were simulated using Monte Carlo n-Particle eXtended (MCNPX) with 1000 neutron per seconds with 550 cycles. The results from the simulation are shown in Table 4.

Table 3: Configuration label for different reactor powers

Configuration	750 Kw	1 MW	3 MW
A	A0.75	A1	A3
B	B0.75	B1	B3
C	C0.75	C1	C3
D	D0.75	D1	D3
E	E0.75	E1	E3

Table 4: Simulation result fuel arrangement at various reactor powers

Configuration	k_{eff}			Buildup uranium-233 at the EOC (g)
	Beginning of cycle (BOC)	Lifecycle (days)	Slope	
A0.75	1.05133	547	-0.00011	0
B0.75	1.04934	531	-0.00011	24.05
C0.75	0.86618	-	-0.00009	45.53
D0.75	0.86149	-	-0.00008	46.46
E0.75	0.87679	-	-0.00009	34.44
A1	1.05246	289.5	-0.00016	0
B1	1.04942	276.5	-0.00015	31.4
C1	0.86591	-	-0.00012	56.74
D1	0.86051	-	-0.00012	57.62
E1	0.87721	-	-0.00013	43.96
A3	1.05122	158.6	-0.00088	0
B3	1.04941	165.1	-0.00083	78.09
C3	0.86643	-	-0.00062	87.13
D3	0.86091	-	-0.00061	87.07
E3	0.87626	-	-0.00065	83.2

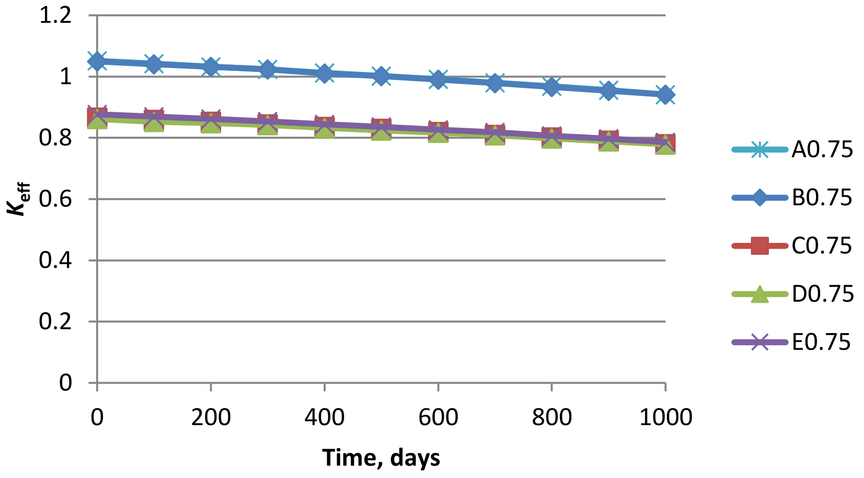


Figure 5: k_{eff} of 750 kW power.

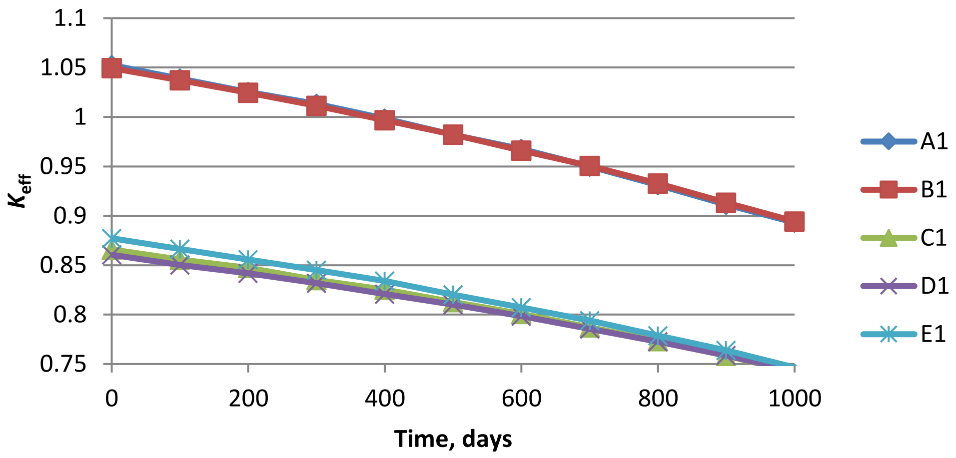


Figure 6: k_{eff} of 1 MW power.

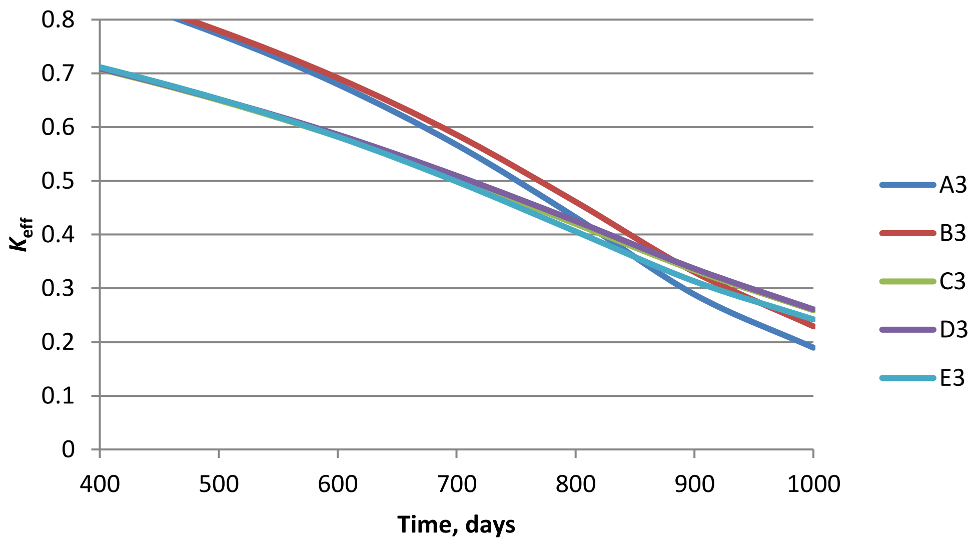


Figure 7: k_{eff} of 3 MW power.

In Figure 5, it shows that the configuration A0.75 and B0.75 have the highest values of k_{eff} until at the middle of the cycle before dropping down to subcritical. As for C0.75, D0.75 and E0.75, the slope of the plots is quite similar and the values of the k_{eff} are under 1.000 from BOC until EOC. This might be due to the distribution of neutron flux that prevents the successful fission of U-$ZrH_{1.6}$ fuels

As for Figure 6, only configuration A1 and B1 achieved criticality and after 400 days, the k_{eff} goes down to subcritical state. Meanwhile, for configuration C1, D1 and E1, all three configurations do not achieve critical state at the beginning of cycle. Among all three configurations, configuration E has the highest value throughout the cycle.

For Figure 7 above, it shows that C3, D3 and E3 lines are overlapping each other. Although the values of k_{eff} for all configurations are below than 1.000, it shows that at the end of the cycle, there is an effect of uranium-233 taking place in the core. The graph shows that the k_{eff} values of C3, D3 and E3 remain steady at the time of 800 days instead of going down like A3 and B3 lines. The value of k_{eff} also due to the higher power of the reactor and the thermal flux is low at the BOC.

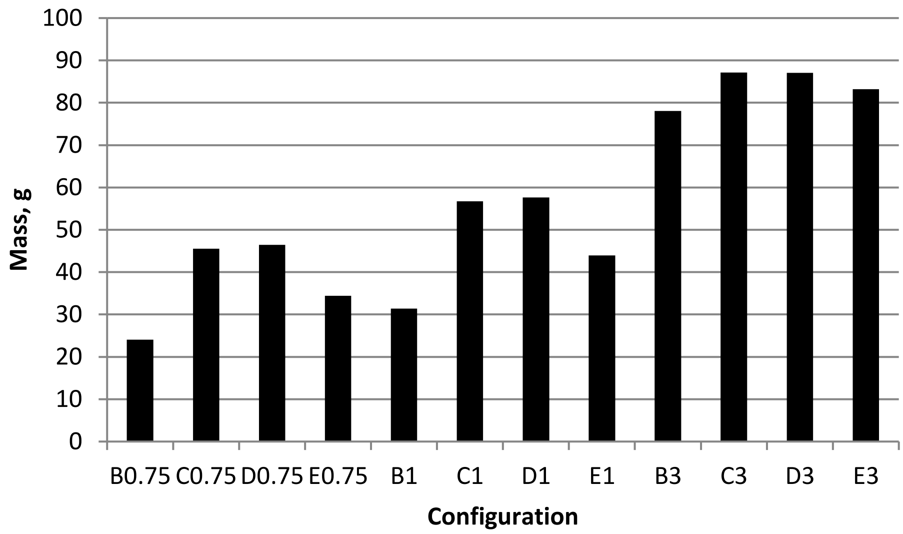


Figure 8: Uranium-233 buildup in gram

Figure 8 above shows that the mass of uranium-233 at the end of the cycle. The mass of uranium-233 increases when the power of the reactor increases. The highest reactor power that has been simulated is 3 MW that has the highest mass of uranium-233, which undergoes transmutation process. The increasing result for 3 MW power reactor might have slightly changed the pattern of k_{eff} in the graph.

CONCLUSION

In conclusion, the slope for criticality become steeper when the power of reactor increases. based on all different simulated power reactors, configuration A and configuration B remain at the top of the chart for it value of k_{eff} except for 3 MW reactor power. In 3 MW power reactor simulation, configuration A and configuration B become steeper after 800^{th} days of simulation. As for the buildup uranium-233, reactor power at 3 MW give the highest result with the production above 80 gram from configuration C3, D3 and E3.

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