PRELIMINARY ANALYSIS ON UTILIZATION OF THORIUM AND U-ZRH$_{1.6}$ IN PUSPATI TRIGA REACTOR CORE

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ABSTRACT

Thorium is one of the potential elements for becoming a nuclear fuel for various types of nuclear power plants such as Molten Salt Reactor (MSR), High-temperature Gas-Cooled Reactor (HTR) and Fast Neutron Reactor (FNR). This paper proposes to use thorium and uranium zirconium hydride (U-ZrH$_{1.6}$) as fuels for the PUSPATI TRIGA Reactor (RTP), which is currently operated by the Malaysian Nuclear Agency (MNA). The work was carried out using the Monte Carlo N-Particle (MCNP) Transport code. In the simulation, thorium fuel rods were placed together with U-ZrH$_{1.6}$ fuel rods in 11 different variations, which have a different thorium mass. Results, such as, effective criticality k_{eff}, neutron flux, and cycle length were estimated and compared to those of the experimental and simulation of the original core RTP. The neutron flux of each core with thorium displays hardly any differences when thorium is added. Similarly, from the criticality and burnup calculations, these cores show minimal increase in criticality and cycle length.

ABSTRAK

Thorium adalah salah satu elemen yang berpotensi menjadi bahan bakar nuklear bagi pelbagai jenis loji kuasa nuklear seperti Reaktor Salt Molten (MSR), Reaktor Gas Bercahaya Tinggi (HTR) dan Reaktor Fast Neutron (FNR). Kertas ini bercadang untuk menggunakan torium dan uranium zirkonium hidrida (U-ZrH1.6) sebagai bahan api untuk PUSPATI TRIGA Reactor (RTP), yang kini dikendalikan oleh Agensi Nuklear Malaysia (MNA). Kerja-kerja ini dijalankan menggunakan kod Pengangkutan Monte Carlo N-Zarah (MCNP). Dalam simulasi, rod bahan api torium diletakkan bersama-sama dengan rod bahan api U-ZrH1.6 dalam 11 variasi yang berbeza, yang mempunyai massa torium yang berbeza. Hasilnya, seperti keefektifan kritikal yang berkesan, fluks neutron, dan panjang kitaran dianggarkan dan dibandingkan dengan kajian eksperimen dan simulasi RTP teras asal. Fluks neutron setiap teras dengan torium menunjukkan hampir tidak ada perbezaan apabila torium ditambah. Begitu juga, dari pengiraan kritikal dan pembakaran, teras ini menunjukkan peningkatan yang minimum dalam kritikal dan panjang kitaran.

Keywords: MCNP, TRIGA Reactor, Molten Salt Reactor, thorium

INTRODUCTION

PUSPATI TRIGA Reactor (RTP) 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 [1]. The TRIGA mark II reactor 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 [2, 3].

Under thorium flagship program that was launched in 2014 and, Malaysian government is interested to utilize thorium as an economic, clean and sustainable nuclear fuel through research and development program [4]. Thorium is another solution to replace uranium as the source of nuclear fuel. It is however, a fertile material that needs to be transmuted from thorium-232 to uranium-233 [5]. The combination of thorium with uranium in RTP might be as the solution for this issue. The uranium in RTP can act as neutron source to thorium which absorb neutron for transmutation process to be occur [6] which is why the combination of thorium and uranium in the core very significant in this study. Figure 1 shows the configuration of thorium in RTP core. Thorium can act as blanket that receive neutron from uranium while uranium provide neutron for thorium (seed).

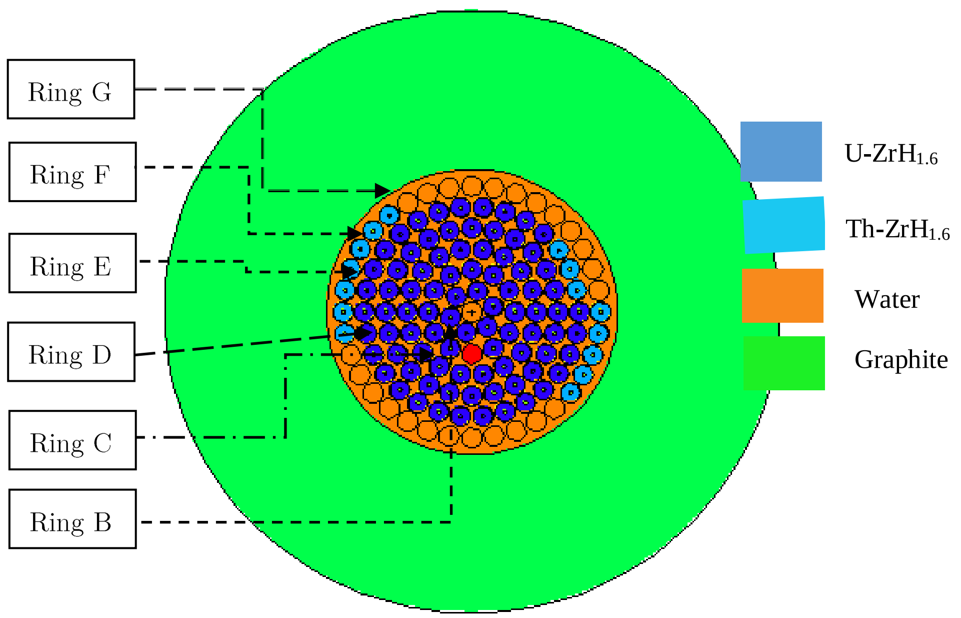

Figure 1: Top view of the RTP core with thorium and uranium fuel rods, which is modeled using the MCNP code.

METHODOLOGY

The core was designed and simulated using MCNPX code and the arrangement as followed from Core 1 of RTP [10]. The core consists of 86 rods of uranium zirconium hydride (U-$ZrH_{1.6}$) with weight percentage of w.t.8.5% for each rod. The core was arranged with increasing number of thorium zirconium hydride (Th-$ZrH_{1.6}$) for each core. Figure 2 shows the number of rods for each configuration of the core.

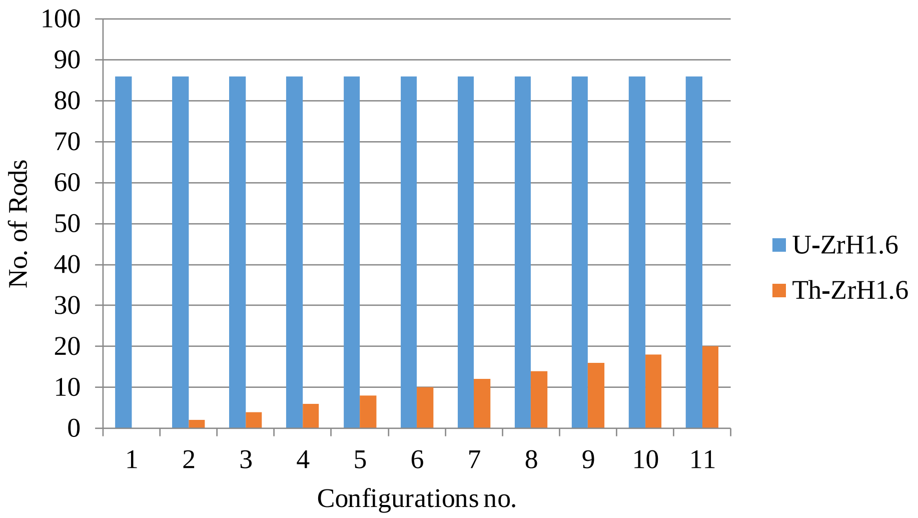

Figure 2: Configurations with number of uranium and thorium fuel rods.

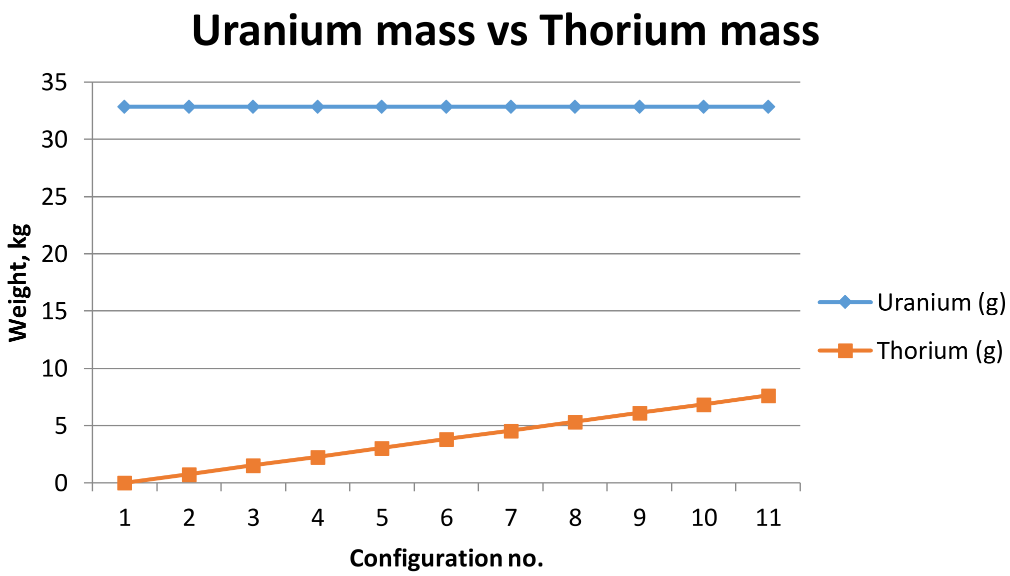

Figure 3: Mass comparison between Uranium and Thorium.

Th-$ZrH_{1.6}$ is arranged at the outermost and second outermost ring of the core, which are ring F and ring G. To differentiate from each type of configuration, two rods are added for each configuration until 20 rods of Th-$ZrH_{1.6}$ are all together in the last configuration. The rods added are arranged with one of the rod position is opposite with another rod in the same ring. Figure 1 shows the arrangement for the rods in configuration no 7.

Preliminary simulation has been carried out for configuration no. 1 to determine and validate the value of effective criticality, keff, at the beginning of cycle (BOC). The result shows that k_{eff} obtained for the configuration is 1.05139. Table 1 shows the comparison of our k_{eff} at BOC with previous study [7-9]. According to the table, it shows that the designed core has almost the same as the core-1 k_{eff} obtained from Ref. 7 with an acceptable difference of -484 pcm. Nonetheless, the criticality differences are slightly large when compared to the other two studies [8, 9] because those studies analysed Core-11 and Core-15, which have a different number of fuel rods and composition. Therefore, it can be accepted with the real core of RTP.

Table 1: Simulated k_{eff} of RTP

k_{eff} simulated (Core-1)	k_{eff} Core-1	k_{eff} Core-11	k_{eff} Core-15
1.05139	1.05677[7]	1.07517 [8]	1.0364 [9]
PCM	-484	-2103	1375

All the 11 configurations are simulated with MCNPX to determine k_{eff} at the BOC until the end of cycle (EOC) by carrying out the burnup calculation. Additionally, the neutron flux and uranium-233 buildup were also determined. The burnup time was set to 500 days with an interval of 100 days. The power was set to 1 MW, which is the maximum power that can be operated by RTP. In a real practice, the reactor is operated about 1 to 6 hours per day and it is operated normally from Monday to Thursday. By excluding Friday to Sunday and four weeks of maintenance, it is estimated that RTP can run for 175 days continuously. If RTP is operated for about 4 hours daily, the total hours of operation RTP yearly will be 700 hours. Therefore, the 500 days burnup period for the simulation is considered sufficient as it equals to 17 years of real operational time for RTP.

RESULT AND DISCUSSION

Figure 4 shows the k_{eff} of different configurations variations of the cores from the burnup calculation. The criticality lines of all configurations show the same trend with a very minimal difference. This shows that the values of k_{eff} are not significantly affected by the increasing number of Th-$ZrH_{1.6}$ fuel rods. Further detail can be seen in Figure 5 which shows the closer view of the graph. It shows that the configuration 1 is situated at the center of all configurations. All other configurations take around 385 to 392 days of burnup time or equivalent to 13 years of RTP operational time to achieve 1.0 criticality.

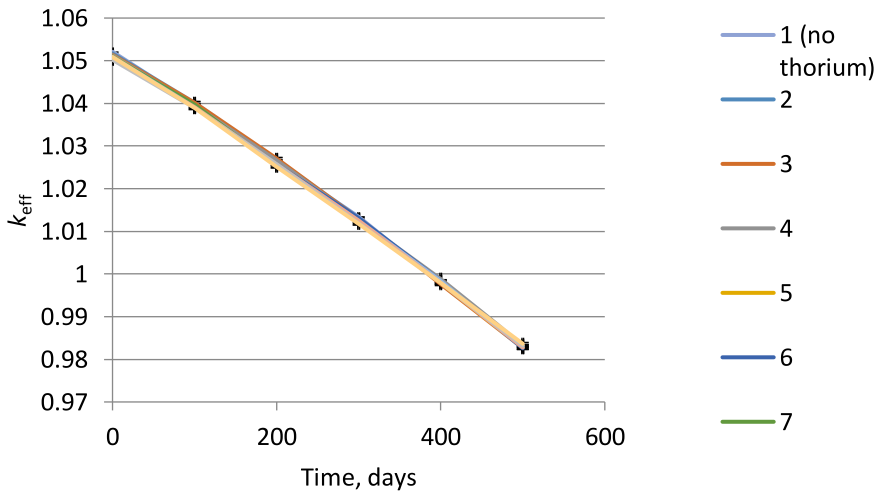

Figure 4: Keff of burnup calculation configuration 1 to 11

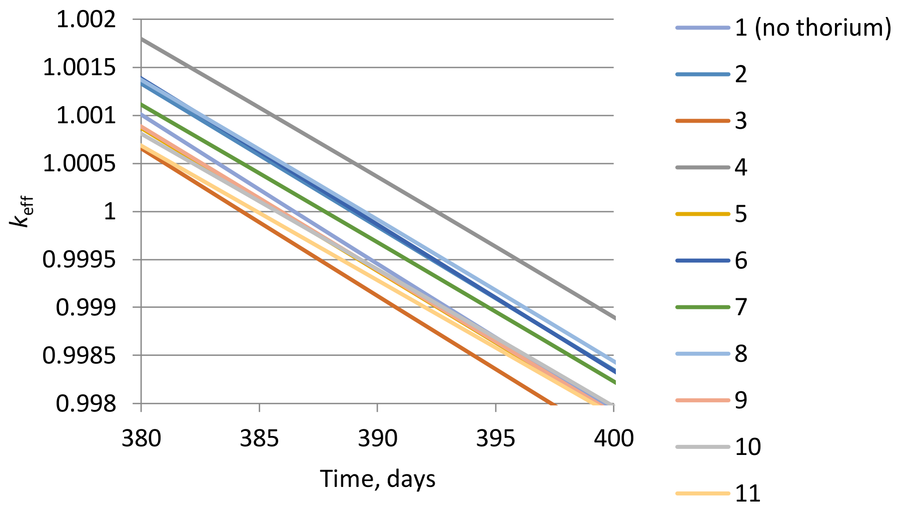

Figure 5: Close up view k_{eff} of burnup calculation configuration 1 to 11

Figure 6 shows that the result of uranium-233 buildup from the burnup process of Th-$ZrH_{1.6}$ in the core. By the end of burnup time, configuration 11 has built the highest uranium-233. This is because the amount of thorium mass situated in configuration no 11 are higher in comparison to other variations. Figure 7 shows the relationship between number of thorium fuel mass added at BOC with the mass of uranium-233 produced at EOC.

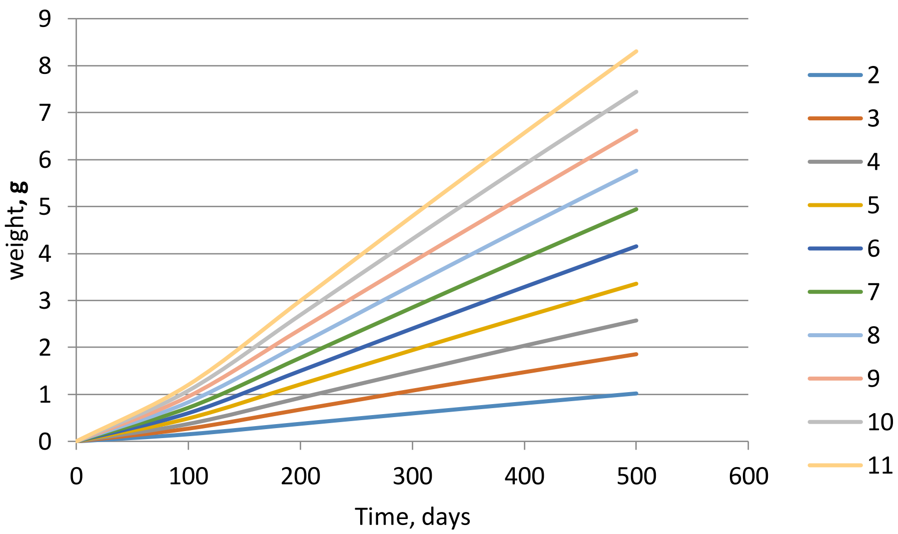

Figure 6: Uranium-233 buildup in gram.

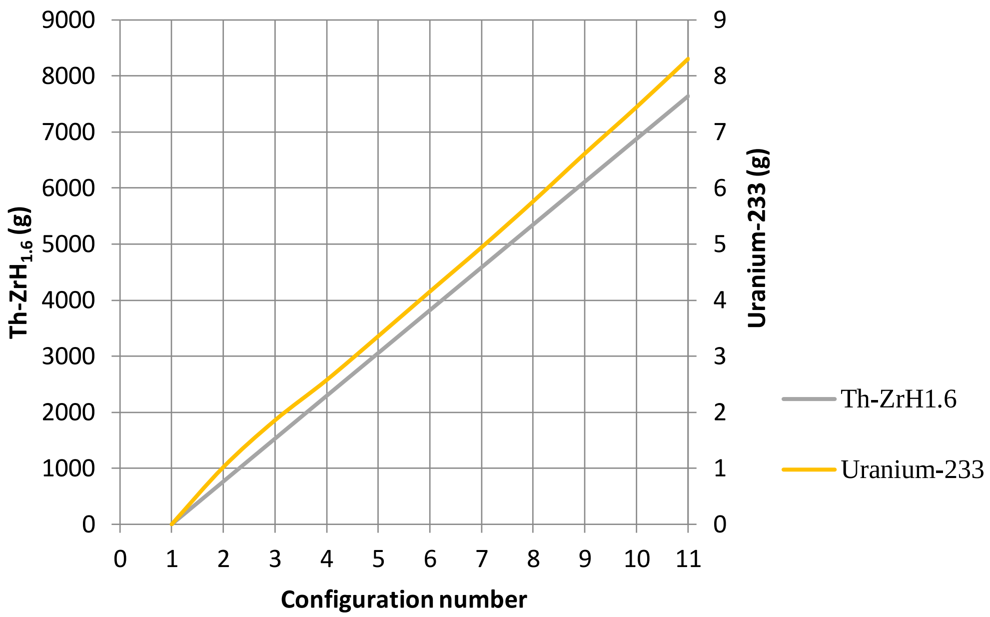

Figure 7: Number of uranium-233 produce at EOC vs initial number of thorium added in gram.

Another parameter that was determined is the neutron flux for each configuration. Figure 8 and 9 shows the result of neutron flux at the beginning of cycle for each configuration. Five critical points were identified for the neutron flux reading which are fuel rod ring B, ring C, ring D, ring E and ring F. Results show that neutron flux is the highest at the centre of the core and it decreases when moving to the outer part of core.

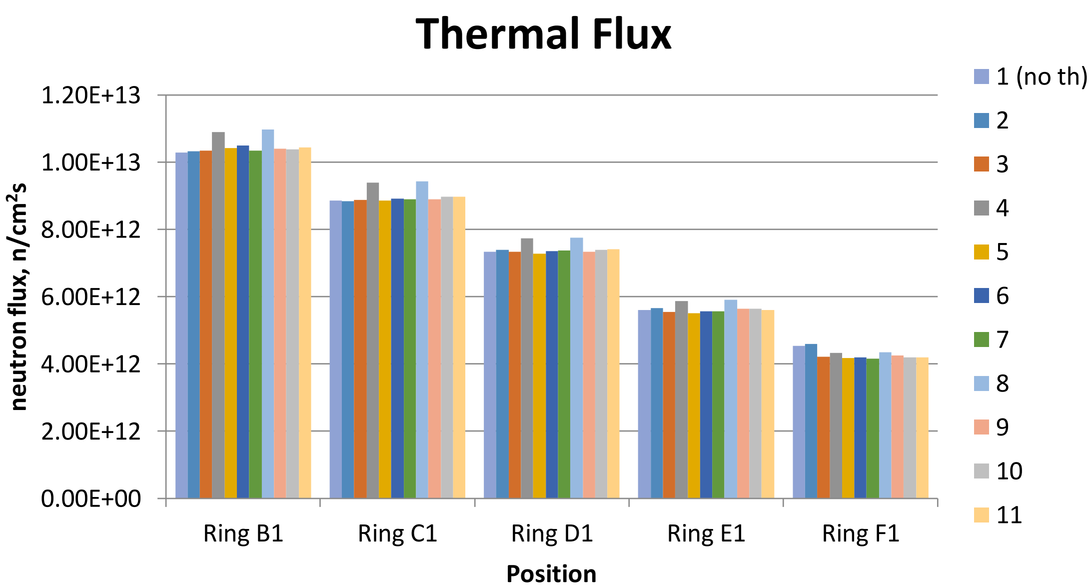

Figure 8: Thermal neutron flux for all configurations.

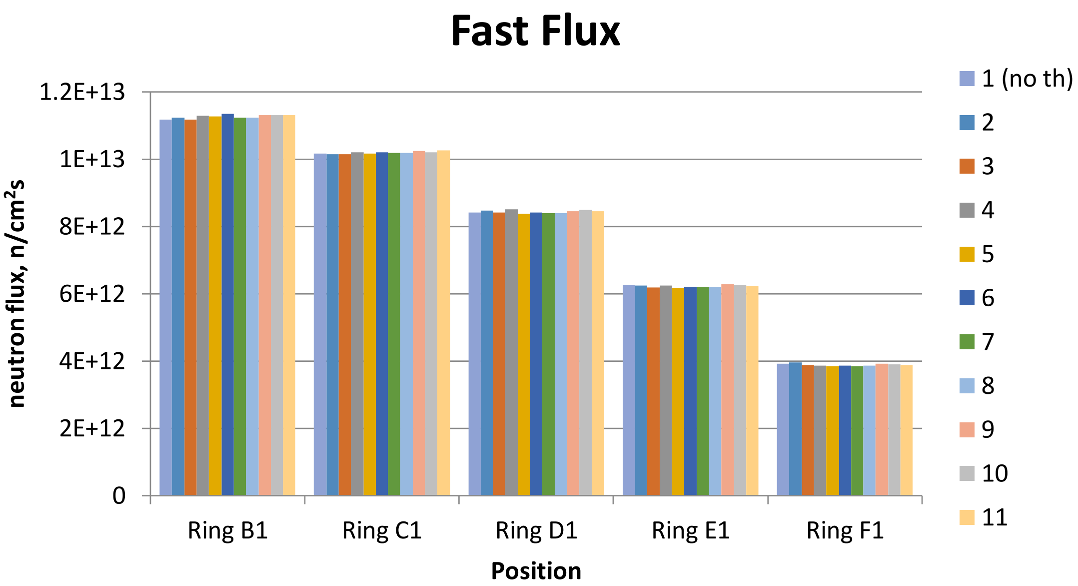

Figure 9: Fast Neutron Flux for all configurations

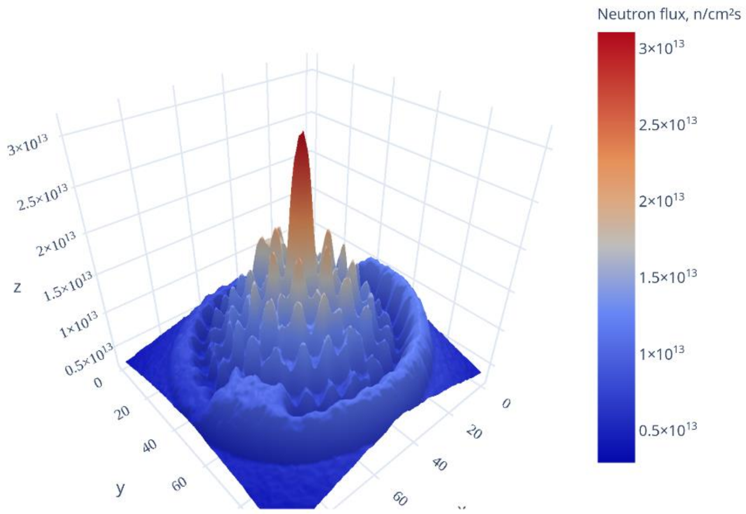

Figure 10: Thermal neutron mesh for configuration 11 BOC

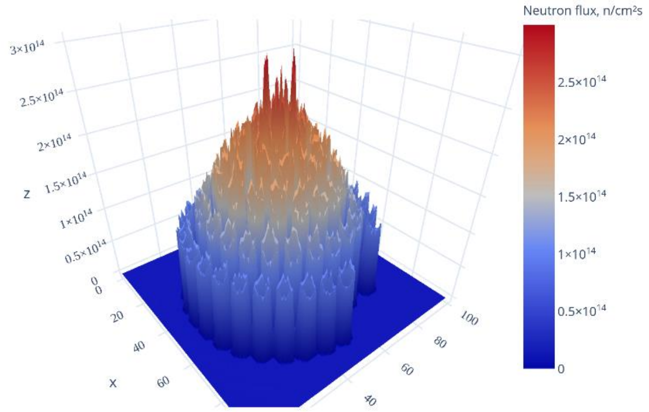

Figure 11: Fast Neutron Mesh for configuration 11 BOC

Figures 10 and 11 show the three-dimensional views of the thermal and fast neutron fluxes. Similar to Figure 8 and 9, the flux is the highest at the centre of the core. This is because the number of uranium at the center of the core is much higher compared to the thorium situated at the outermost side of the core. Uranium is a fissile material that provides neutron for enabling the chain reactions. As for the outer part of the core, it is filled with thorium that is a fertile material that absorb neutron in order to initiate the process of transmutation that convert thorium to uranium-233.

CONCLUSION

As conclusion, the increasing number of Th-$ZrH_{1.6}$ in RTP does not delay the time taken for burnup process of the fuel. The time taken in order to achieve 1.0 criticality is almost the same for each configuration, which is 385 to 392 days of burnup time or 13 years of RTP operational time. However, the build-up for uranium-233 has a very significant value because of the increasing number of thorium for each configuration. Lastly, neutron flux for all of the configuration has almost the same pattern.

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ACKNOWLEDGEMENT

Special thanks to Malaysian Nuclear Agency for supporting this work and Universiti Tenaga Nasional for sponsoring the research project under the UNITEN Start-up grant Bold 2025 project code RJO10289176/B/1/2017/20