

An investigation into the feasibility of thorium fuels utilization in seed-blanket configurations for TRIGA PUSPATI Reactor (RTP)

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Abstract. Thorium is one of the elements that needs to be explored for nuclear fuel research and development. One of the popular core configurations of thorium fuel is seed-blanket configuration or also known as Radkowsky Thorium Fuel concept. The seed will act as a supplier of neutrons, which will be placed inside of the core. The blanket, on the other hand, is the consumer of neutrons that is located at outermost of the core. In this work, a neutronic analysis of seed-blanket configuration for the TRIGA PUSPATI Reactor (RTP) is carried out using Monte Carlo method. The reactor, which has been operated since 1982 use uranium zirconium hydride (U-ZrH_{1.6}) as the fuel and have multiple uranium weight which are 8.5, 12 and 20 wt.%. The pool type reactor is one and only research reactor that located in Malaysia. The design of core included the Uranium Zirconium Hydride located at the centre of the core that will act as the seed to supply neutron. The thorium oxide that will act as blanket situated outside of seed region will receive neutron to transmute ²³²Th to ²³³U. The neutron multiplication factor or criticality of each configuration is estimated. Results show that the highest initial criticality achieved is 1.30153.

1. Introduction

Thorium is an element that occurs naturally in the world, mostly in Canada, Kazakhstan and Australia. Thorium offers several potential advantages, which include a higher abundance in nature compared to uranium, improved proliferation resistance and lower waste radiotoxicity [1]. Thorium-based fuels have excellent neutronic properties during irradiation process [2]. Nonetheless, one of the disadvantages of thorium is in the bred ²³³U, which is a high-energy gamma emitter that requires well-shielded facilities.

The main thorium isotope is ²³²Th, which occurs about 99.98% in natural. Unlike ²³⁵U, thorium is a fertile material that can be transmuted to the fissile uranium isotope, ²³³U. A thorium fuel cycle consists of four stages, in which the first stage is the production of ²³³Th from ²³²Th by a neutron capture. The second stage is the change from ²³³Th to ²³³Pa thru beta decay and within a long period of



time, ^{233}Pa eventually becomes ^{233}U . More fission reactions will then take place when ^{233}U exists in a reactor.

Studies on thorium fuel cycle have been limited to few reactors such as molten salt and light water reactors. For light water reactors, thorium fuels are mixed with either uranium or plutonium. As for molten salt reactor, there are two types, in which the first type is thorium in a solid form, surrounded by molten salt [3]. The second type is when thorium is homogeneously mixed with molten salt in a liquid form, increasing the heat transfer capability.

One of the commonly studied configurations for thorium reactors is the seed-blanket configuration, which is also known as Radkowsky Thorium Fuel concept. The concept was proposed by Professor Radkowski and it is one of the Thorium Seed-Blanket design. Radkowski thorium reactor (RTR) is the design of core reactor based on the arrangement of the core of pressurized water reactor. Design of RTR involves the process of seed-blanket configuration. The elements that are situated in the seed are usually metal element or oxide element. As for RTR, the seed element is UO_2 . For the blanket, the element is ThO_2 . The designs are focusing more on heterogeneous configuration seed-blanket unit (SBU) fuel assembly. The blanket part is separate with the seed part to allow fuel independent with the seed while the seed part is supplying neutrons for the blanket.

While in this study the configuration contains thorium and a fissile material, either uranium or plutonium, in a single core. The seed is usually represented by uranium that provides neutrons to a blanket of thorium. The thorium blanket acts as a neutron receiver from the seed. Figure 1 below shows the seed-blanket configuration in a reactor core. As displayed in the figure, fuels that are situated inside and outside of the rectangle are typically filled with uranium and thorium, respectively.

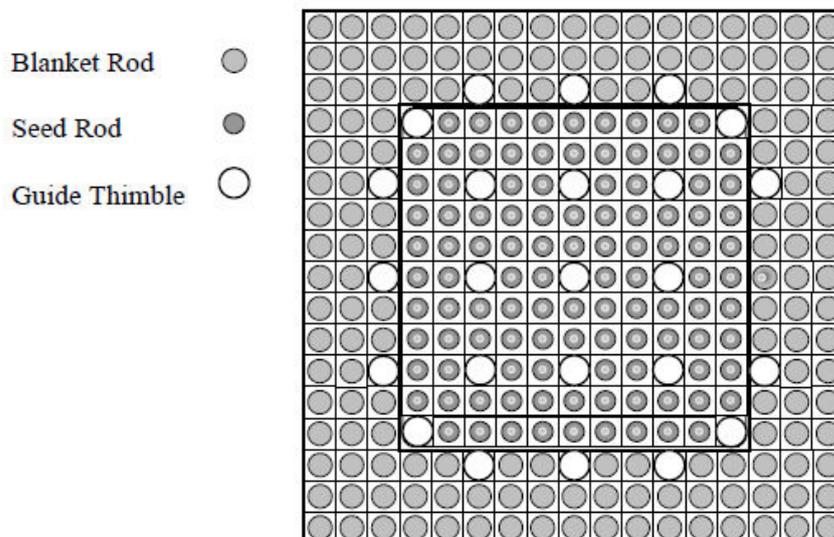


Figure 1. An example of seed-blanket configuration. Reproduced from Ref. [5].

One known advantage of the configuration is that the quantity of ‘weapon quality’ plutonium produced in a pressurized water reactor can be potentially reduced by a factor of 3 to 5 [4]. As for this research, the seed-blanket configuration is implemented in the TRIGA PUSPATI Reactor (RTP), a research reactor that has been operated by Malaysian Nuclear Agency since 1982. The reactor is a pool-type reactor that uses uranium zirconium hydride, $\text{U-ZrH}_{1.6}$, as the main fuel with 8.5, 12 and 20 wt.% of total U [6]. The production of $\text{U-ZrH}_{1.6}$ fuel for this reactor, however, has been discontinued. Nonetheless, there is an ongoing initiative to replace the $\text{U-ZrH}_{1.6}$ with thorium. Hence, this project investigates the neutronic behavior of thorium fuel as a potential substitute for the RTP, by comparing

the initial multiplication factors or criticality, k , of the core with and without thorium. The core that contains thorium is modeled based on the seed-blanket concept.

Rector TRIGA Puspati (RTP) is the only research reactor in Malaysia. It has been operated for almost 35 years of ages. The reactor achieved its criticality on 28 June 1982. The reactor was constructed to fulfill various nuclear applications such as for research, education and services for companies. There are several facilities that are available in the reactor such as neutron activation analysis (NAA), small angles neutron scattering (SANS) and neutron radiography (NR). Besides, there is also prompt gamma neutron activation analysis (PGNAA) and boron neutron capture therapy (BNCT).

The model of reactor TRIGA Puspati is TRIGA Mark II Pool-Type Reactor with its maximum power is 1MW thermal. The fuel of the reactor is Uranium Zirconium Hydrate $U-ZrH_{1.6}$ with three different weight percentages which are 8.5, 12 and 20 wt.% of ^{235}U . The reflector of the reactor is graphite which is to reflect the neutron in the reactor to prevent it escaping from the core. The flux RTP is at the rotary rack and the control material is boron carbide and there are 4 types of control rods. Besides, the coolant for the reactor is light water that had been undergoes demineralized process.

2. Methodology

The RTP core consists of 6 rings that encircle the central timber beginning from ring B, which is the nearest ring to the central timber, to ring G that is located at the outermost ring of the core. The number of fuel rods of each ring is not similar as the size of the ring becomes larger when going from the innermost ring B (6 fuel rods) to ring G (36 fuel rods). The core with a seed-blanket configuration is modeled in a 2D structure using MCNPX as shown in Figure 2.

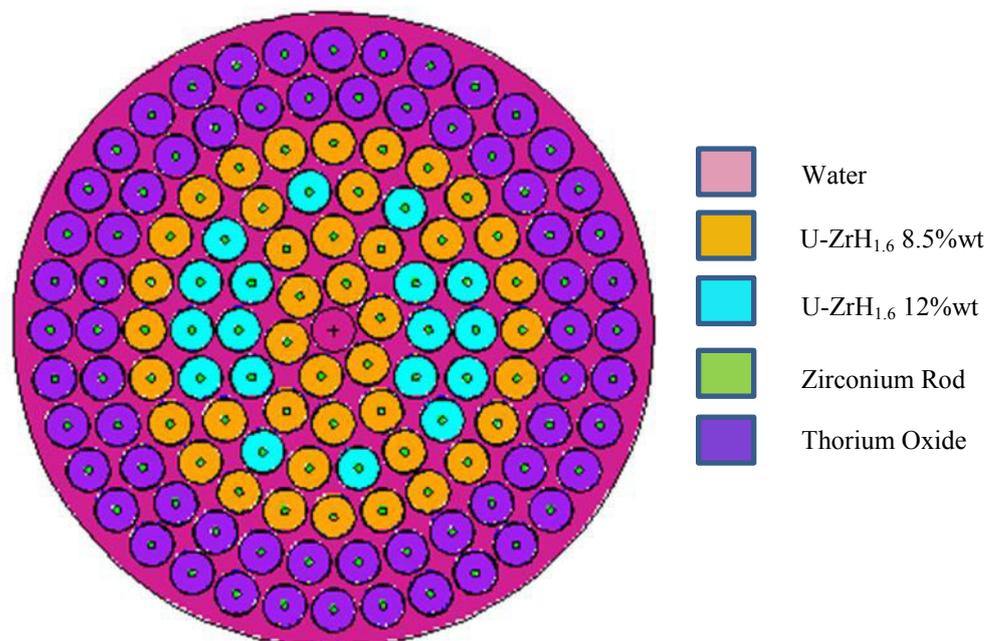


Figure 2. Seed-Blanket Configuration for RTP.

By using KCODE with 10000 neutron per second (NPS) and 5000 active cycles, the initial criticality, k , of the core was determined. The criticality of the core, k , is 1.0 when the number of neutron produced is the same as the neutron loss. If the criticality is lower than 1.0, the reactor system is considered subcritical due to the number of neutron loss is higher than the number of neutron gain. To achieve supercritical state, the number of neutron produced needs to be higher than that of neutron

loss. For a fast breeder reactor, the supercritical condition is essential because thorium in the reactor needs more neutrons to transmute it to ^{233}U for fission to occur.

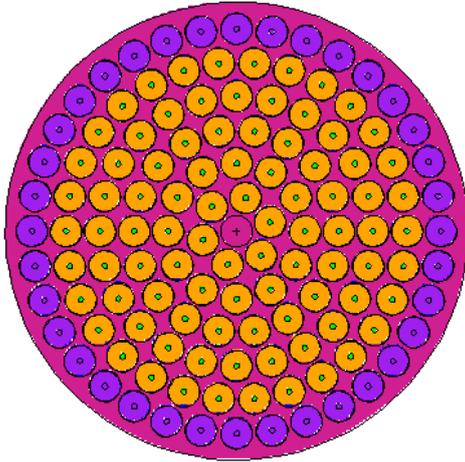


Figure 3. Configuration 1

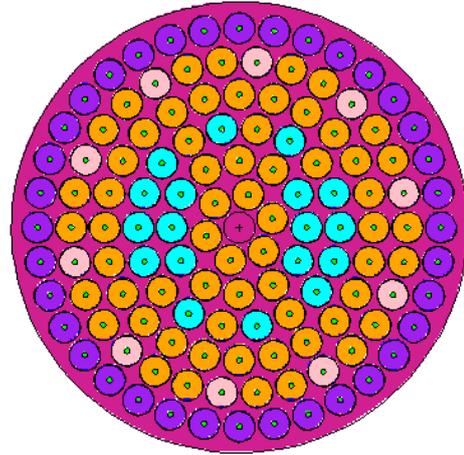


Figure 4. Configuration 2

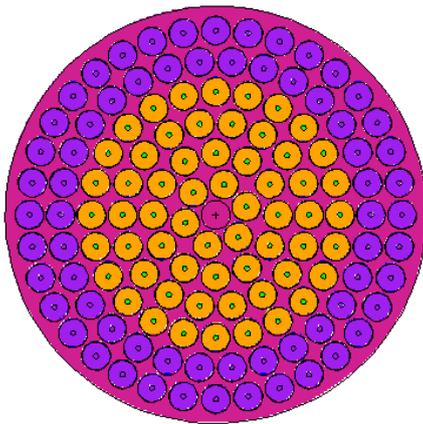


Figure 5. Configuration 3

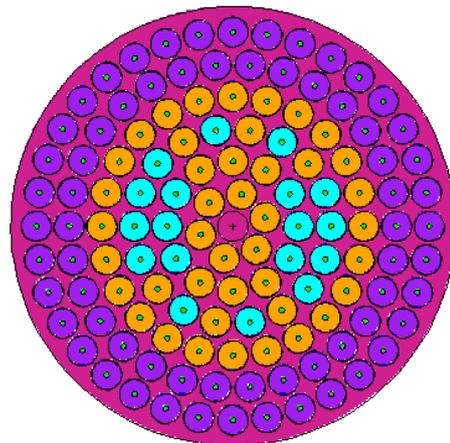


Figure 6. Configuration 4

Four seed-blanket configurations with various thorium and uranium compositions have been modeled and analyzed in this work, as displayed in Figure 3 to Figure 6. For Configurations 1 and 3, both cores contain thorium oxide (ThO_2) and $\text{U-ZrH}_{1.6}$ fuels with 8.5 wt.% only. Whereas, Configuration 2 has ThO_2 and $\text{U-ZrH}_{1.6}$ fuels at 8.5, 12 and 20 wt.%. Lastly, Configuration 4 comprises of ThO_2 and $\text{U-ZrH}_{1.6}$ fuels with 8.5 and 12 wt.%. The initial k of each analyzed seed-blanket configuration was obtained using MCNPX. Additionally, the reactivity difference between each configuration and the original core without thorium was calculated using Equation 1 below,

$$\Delta\rho = \frac{k_1 - k_2}{k_1 \times k_2} \times 10^5 \text{ pcm}, \quad (1)$$

where k_1 is the criticality of the seed-blanket configuration and k_2 is that of the core without thorium, which is approximately 1.388 as reported by Ref. [6].

3. Result and discussion

There are four seed-blanket configurations that have been analyzed for this study and the results are shown in Table 1.

Table 1. Results from MCNPX

Configuration	Criticality, k	Reactivity difference (pcm) from configuration without thorium fuel
1	1.26483	-7015
2	1.30153	-4787
3	1.16882	-13510
4	1.19247	-11813

Based from the result above, criticality k of the core that contains more thorium oxide seems to be smaller than that of the core that holds less thorium oxide, as observed from Configurations 1 and 2 criticalities that are higher than Configurations 3 and 4. This happens because thorium fuels in the core might have captured neutrons that being released from uranium during the initial state, before having more neutrons to be generated by breeding ^{233}U .

In addition, results show that the criticality of the core that contains all uranium enrichments is higher than that of the core that contains U-ZrH_{1.6} with a single 8.5 wt.%. It is also observed that the configuration that has the smallest k value is Configuration 3 with 1.16882 compared to all other variations.

As for reactivity difference, the smallest difference that was estimated is obtained from Configuration 2 (-4787 pcm). This finding seems reasonable since Configuration 2 has the closest look and fuel composition as the original core without thorium. On the other hand, Configurations 3 and 4 have quite large differences, namely -13510 and 11813 pcm, due to their very distinct fuel compositions compared to the original U-ZrH_{1.6} only core.

The study is only at a preliminary stage, the criticality that have been archive was only in early stage. The thorium fuel need more time to be self-sustainable for fission reaction. This is because the thorium fuels need to be transmute first before it begin the process of fission reaction. Besides, the configurations are in 2D infinite configuration. There might be some small leakage probability occur. The reactor are design with slightly different from the original reactor design, the outer part of the reactor such as the concrete and reflector are not included in the design. Thus, it might have different result from the original 3D design.

4. Conclusion

From the study, it shows that all seed-blanket configurations can achieve supercritical condition. The core that contains only uranium zirconium hydride with 8.5 wt.% has a small criticality compared to the core that contains all uranium total U weight values, namely 8.5, 12 and 20 wt.%. Criticality, k , for the core that contains less thorium is higher than the core that has more thorium because of the absorption of neutrons in thorium oxide fuel, before uranium can be bred.

5. References

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Acknowledgements

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