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Parametric study of the heterogeneous assembly with Thorium applied to NuScale

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1 Introduction

According [1], the indicator there is an estimated global on-demand energy and demand growth of around 1.5% each year until 2030, with a 25% reduction in carbon dioxide. In this scenario, nuclear energy will assume this increasing importance, in the global energy matrix, as it is clean and sustainable. Most of the 440 existing nuclear power plants are the second generation, are of the light water (LW) and Pressurized Water Reactor (PWR) type, are already in the decommissioning phase. The nuclear plants in the world are as fuel Uranium, which can make the reactors unfeasible. The high cycle cost of uranium is about $600/kg, [2] therefore new alternatives like thorium are needed, much cheaper.

Thorium can revolutionize the world in many aspects, especially when compared to Uranium. When Thorium is radiated by thermal neutrons by the 233U. The process is completely analogous to 238U and 239Pu. It is estimated that uranium reserves still have 70 years of useful life, with thorium this time would be extended. Thorium is much more concentrated in the earth's crust compared to Uranium, as Thorium reserves are about 3 to 4 times larger than that of Uranium [3]. Which generates an enormous production potential during the mining process. Comparatively safer and more efficient, it is also beneficial from an energy point of view.
Thorium nuclear fuel reactors are in a good position to take their position on greenhouse gas emissions. Compared to current reactors, it results in much less radioactive waste and less fuel usage. They are safe fuels and important in the matter of non-proliferation of nuclear weapons. The closed thorium cycle with less nuclear fuel produces less plutonium and other actinides and significantly reduces the long-term radio toxicity of nuclear fuel waste. In practice, this reduction leads to a significant change in radioactive waste management, in addition to being more advantageous compared to MOX/UOX, as shown in the study [4].

The Concept was developed by Radkowsky y [5], [6] [7] [8] [9]where the reactor consisted of a region with Seed(UO2), fissile material, into the core, it is a Blanket (U-Th)O2 region, with fertile material. The defined proportions for the seed region are 20%wt 235U enriched with the Blanket part with 90%wt ThO2+10%wt UO2 [5]. The regions are based on the moderator volume ratio over the fuel volume ratio, for the seed region (Vm/Vf=3.2) and Blanket (Vm/Vf=1.9). These works [10] [11] [4] demonstrated the high capacity of burning fuel with less production of radioactive products and being more advantageous. In the closed cycle of thorium, the seed is recharged, which brings total savings in fuel consumption, from the second refuel.

That is why the third generation Small Modular Reactors (SMR) will have their relevance in the energy matrix of countries. SMRs are PWR-type reactors with capacity from 10MW to 400MW and have several advantages over conventional reactors, such as shorter construction time, modularity, scalability, location flexibility, diverse applications, mass production economy [12] [13]. The SMR of the research was the NuScale, due to its passive cooling system, being safer, smaller in dimension, thus not exceeding the thermal-hydraulic and neutronic parameters [14]. In addition, it has a lower power density linear and longer cycle length about 24 months. In the opinion of [15] the high reflection of modularity, translates into an overall design savings, about 60% cheaper than conventional PWR reactors. The total result represents overall savings in design, simplification, modularity, at 37% of direct costs and 80% of indirect costs.

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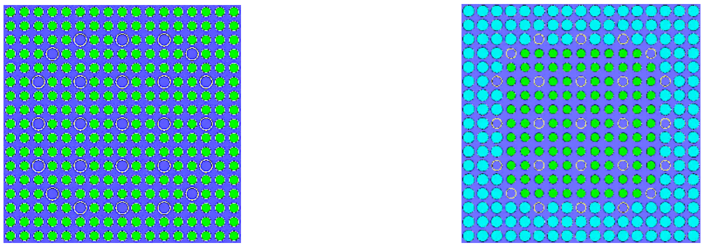
We will discuss the design features of the NuScale reactor, reactor simulations compared to the original reactor in the SERPENT program developed by [16] [17] which allegedly demonstrates its effectiveness in the nuclear neutron calculation with Monte Carlo Method (MMC), have been proven as an excellent tool for simulations with several applications in industry and academia, being 5 times faster than MNCP and with an error of 0.2-1%. Despite being very costly from a computational point of view. We will use the Lobo Carneiro cluster from NACAD-UFRJ. Later we will make a simulation of a reactor with thorium against NuScale and make the comparison.

The study was carried out by the computational model used in SERPENT are Monte Carlo Method (MMC) codes applied to reactor physics and used in several research centers, universities and companies. The code is capable of "burning", that is, it calculates the change in the composition of nuclear fuel and reactor materials, as well as neutronic factors over time as a function of power. SERPENT uses data in ACE format from cross section libraries based on ENDF/B-VII. All results were obtained with a neutron population of 20000 per cycle, for 2000 active cycles, with 200 inactive cycles, ensuring reliability with a standard deviation of ~2E-04.

2 Methodology

The use of thorium in PWR reactors is a design concept for fuels. The heterogeneous and the homogeneous. The heterogeneous design is much better and more effective for converting 232Th into 233U. This is considered a seed region (fissile) closer to the inner core of the fuel element, and an outer region composed of the blanket (fertile), called Seed-Blanket-Unit (SBU). The method was approached by Radkowsky Thorium Fuel (RTF). The parametric study with the following proportions for the seed region (20%wt 235U) enriched and (20%wt UO2+ 90%ThO2) for the blanket region. It considers a reactor model as a homogeneous mixture of water with fissile material, in order to determine the best ratio of the Vseed/Vtotal and Vblanket/Vtotal ratio as a function of the conversion rate and K-infinity. From the best proportion of volumes, two regions are applied, one with a seed (Vm/Vf = 3.2) and another with a blanket region (Vm/Vf=2.0), according to the literature obtain the best and most effective values for LWR reactors. This way we will be able to obtain the maximum conversion rate and maintain the reactor's criticality condition. Afterward, it carries out a study to determine the best pitch/diameter ratio for the seed and blanket regions independently. Faced with the volume obtained by the parametric study of the anterior. An approach will be made to examine which configuration is better, following the same materials and power density and number of rods of NuScale (17x17). It is expected to obtain different diameters and pitches for seed and blanket regions.

The study determined the best proportion of Blanket Volume 41.53% and Seed Volume 58.47%, totaling 90393 cm^3. The same number of rods as NuScale was selected. The blanket pitch calculation was performed from the total volume divided by the active height of 200 cm of the fuel element. When opting for the study with the fixed pitch, only the diameter of the blanket and seed rod varies, as otherwise the engineering and dimensional characteristics of the reactor would be lost. The calculation of the pitch is obtained by dividing the side of the blanket area by the number of sticks, therefore the 1.2506 cm pitch, for the blanket region. The same reasoning was used to calculate the pitch ratio of the seed region, whose value is 1.245455 cm. Finally, performing an isolated study of each cell, with the concept exposed by Radkowsky applied to the rod. The rod with the best pitch/diameter ratio consequently, Seed ratio (Vm/Vf=3.362) with (pitch/diameter=1.63) and Blanket (Vm/Vf=1.989) with (pitch/diameter =1.25). The main parameters analyzed in this work were the K-inf, conversion rate (CR), fuel burning in a total period of 720 days, with 18 steps, called SBU-B will be compared to the Small Modular Reactor (NuScale) for the same power density of 0.004903kW/g. The K-infinity, as it determines how sustainable the chain reaction in the nucleus will be, (K-infinity>=1) indicates that each fission is capable of generating another during the study period. The conversion rate (CR) determines the amount of fertile material capable of generating fission is defined by the fissile material over the absorbed.



(a) (b)

Figure 1-(a) NuScale reactor model with 4.6%wt 235U. (b) Reactor Model Seed-Blanket-Unit (20%wt 235U+ 90%wt232Th), (green) seed region and (cyan) blanket region (SBU-B)

3 Results and Discussion

The results obtained in K-infinity and the conversion rate showed that the same power density can have a criticality of the reactor for a period of 720 days, at the end of the cycle, as shown in fig.1. From the point of view of conversion rate, the NuScale reactor presented a higher conversion rate, which implies greater fuel combustion and, consequently, greater production of plutonium. The result of k-infinity indicates an extended fuel cycle. Other parameters were also studied, such as effectively delayed neutron fraction and prompt generation time, but it's not in this article.

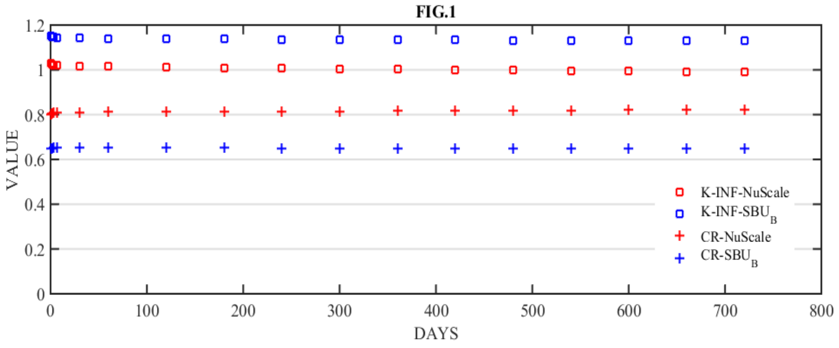


Figure 2- Comparison of K-infinity and conversion rate.

The study demonstrates that the SBU, despite use more nuclear fuel in the first recharge, it produces less plutonium, as shown in fig.3. closed thorium may reduce 20-48% the amount of uranium, according to [4]. See Figure 3, an important point to mention, SBU-B has a lower plutonium production compared to NuScale. 239Pu production is around 16-14% reduction at the end of 720 days.

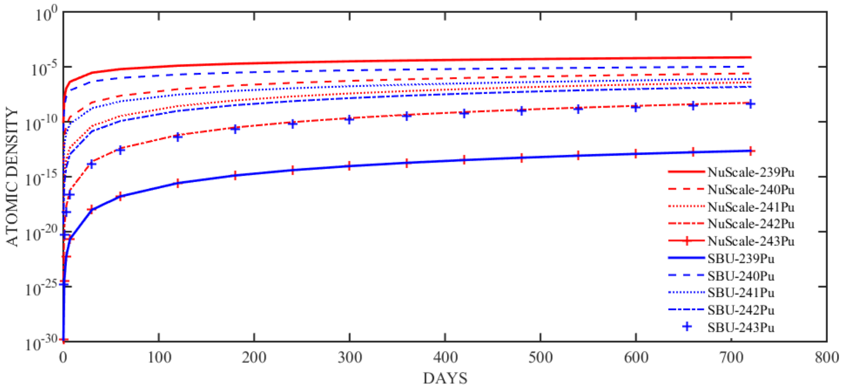


Figure 3- Comparison of Plutonium Production

The fuel temperature coefficient, (FTC or DTC), defined in Fig.4, as the change in reactivity as a function of temperature (DTC) when varying the temperature from 900ºK to 1800ºK in pcm. All accidents the positive reactivity reactor delimits the response to reactivity insertion. The SBU-B showed a satisfactory result within the range of 2 to 4.5 pcm. It's obvious that NuScale has better response than the reactivity insert. The value grows with increasing temperature. It also shows that control within neutron parameters is possible.

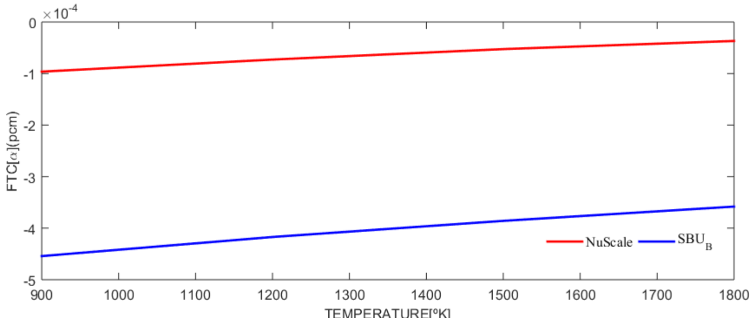


Figure 4- Comparison of Doppler Effect (FTC/DTC) SBU-B (Blue) vs NuScale (Red)

4 Conclusions

In conclusion, he notes that the study is in agreement with the references. On the first recharge, although the SBU-B fuel mass is higher than NuScale, it produces less plutonium. However, the fuel mass tends to reduce from the 2nd recharges to a closed thorium cycle, with the reduction of plutonium production. So, maintain criticality conditions and neutronic parameters. Represent a radionuclide minimization of 14% to 73% reduction in total enriched plutonium production. Be in line with the nuclear products mitigation thesis. Consequently, producing less plutonium implies lower costs for storing nuclear waste and lower storage facilities in case of application in a real nuclear plant. Demonstrates effectiveness of SBU-B compared to NuScale.

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