

Simulation Of Fuel Ball Dimensional Size And Uranium Enhancement For High Temperature Reactor

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Abstract. The purpose of this study was to examine the combined effect of enriching U-235 fuel and fuel fingers (Kernell) to determine its criticality (K_{eff}). In this study, simulation of HTR (High Temperature Reactor) type reactors using MCNPX (Monte Carlo N eXtended Particles). The fuel used is UO_2 which has a density of 10.4 gr / cm^3 , with impurity using 4 ppm Boron atom with Atomic B-10 fraction of 80.1% and B-11 of 19.9%. The variation of enrichment used is 7% to 15% and the fuel radius (Kernell) ranges from $160 \mu\text{m}$ to $340 \mu\text{m}$. From the results, it was obtained that the optimum K_{eff} occurs at 7% enrichment and the radius of the fuel of $310 \mu\text{m}$ was 1.01236.

1 Introduction

Electrical energy is a vital need for economic development and social development. Until now, most power plants in Indonesia still use fossil fuels. Therefore, energy diversification must be done to reduce dependence on oil. One of the efforts that will be carried out to meet the electricity needs is to build a Nuclear Power Plant (NPP). Nuclear reactors are the most needed thing in building the plant.

High Temperature Reactor (HTR) is a gasses cooled high temperature reactor type [1, 2, 3]. Graphite in this HTR was utilized as a moderator as well as a reflector and spherical particle fuel with the composition of UO_2 as a neutron generator. In this research, pebble bed was used in HTR which composed of UO_2 Kernel particles (TRISO) in a graphite metric [4, 5]. TRISO particles (tri structural isotropic) are composed of several layers with a radius of $175\text{-}300 \mu\text{m}$

Uranium Oxide (UO_2) is the key parameter in design HTR. This parameter can be freely chosen to determine the expected value of HTR criticality. Reactor criticality is a variable that express the state of the reactor to get optimum operation [6, 7]. Hence, it is important to simulate the reactor state at different variation of kernel radii and UO_2 enrichment before conduct the operation in order to produce the expected criticality value [8, 9]. This simulation aims to examine

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the effect of the combination of U-235 fuel enrichment and fuel fingers (Kernell) to determine the criticality (K_{eff}).

2 Simulation Method

The first step before reconstructing the HTR-10 terrace is to determine the atomic density of the components of reactor . Atomic density is an MCNPX input [10] which states the number of material atoms in each cell in a particular geometry. It is known that the element Boron is composed of 0.99% Boron-10 and 80.1% Boron-11. Calculation of atomic density is done using the equation.

$$N_i = a_f N_B \tag{1}$$

With the atomic density of Boron-10 or Boron-11 (atom / barn-cm), it is an atomic fraction (a_f) and is the density of the Boron atom (atom / barn-cm).

The next step is to determine atomic density in moderator balls and graphite metrics. Moderator ball and graphite metric composed of elements of carbon with 4 ppm natural Boron impurity. The density of the carbon atom is obtained using equation (2) and the density of the Boron atom with equation (3).

$$N_K = \rho_K \frac{N_A}{A_r} \tag{2}$$

$$N_B = \text{impurity} \times N_K \tag{3}$$

with N_k the density of the Carbon atom (atom/barn-cm), ρ_k is the density of Carbon (gram /cm³), N_A is the Avogadro number (0.6022 cm³ atom/barn-mole), is the relative atomic mass of Carbon (12 grams / mol), and N_b is Boron atom density (atom/bar-cm). Boron-10 or Boron-11 atomic density is obtained from equation (1) before.

The next step is to determine the density of the atom making up the fuel and the control rod. The fuel is composed of UO_2 with impurity the natural Boron in Uranium at 4 ppm. Relative atomic mass (A_U) Certain uranium elements in enrichment (W_{u235}) are obtained by equation (4) and the relative molecular mass (Mr) UO_2 is obtained by adding up the relative atomic mass of Uranium and Oxygen (equation 5).

$$A_U = \left(\frac{w_{f_{U235}}}{A_{U235}} + \frac{(1-w_{f_{U235}})}{A_{U238}} \right)^{-1} \tag{4}$$

$$A_{UO_2} = (\text{amount of atoms} \times A_U) + (\text{amount of atoms} \times A_O) \tag{5}$$

Substitution of the molecular density of UO_2 (N_{UO_2}) from equation (2) produces the atomic density of Uranium and Oxygen using equation (6)

$$N_i = \text{amount of atoms} \times N_{UO_2} \tag{6}$$

If the number of Uranium atoms is equal to one, then it is the density of the Uranium (N_U) atom and if the number of oxygen atoms is equal to two, then N_O the density of the oxygen

atom (N_U). The atomic density of Uranium-235 and Uranium-238 is obtained by determining the atomic fraction of Uranium-235 ($a_{f_{U235}}$) and the atomic fraction of Uranium-238 ($a_{f_{U238}}$) from equation (7) and equation (8) below,

$$a_{f_{U235}} = w_{f_{U235}} \left(\frac{A_U}{A_{U235}} \right) \tag{7}$$

$$N_{U235} = a_{f_{U235}} \times N_U \tag{8}$$

Boron-10 and Boron-11 atomic densities are obtained from equations (3) and (1) with N_K the density of the Uranium (N_U) atom. Density of Boron and Carbon in the control rod is obtained from the B4C molecule which is the constituent of the control rod. The molecular density value of B4C (N_{B4C}) can be obtained from equation (2) with the substitution of equation (6) obtained by the density of Boron and Carbon atoms. Boron-10 and Boron-11 atomic density values obtained from the equation (1).

The process of calculating the reactor criticality value uses the MCNPX program with a fuel radius variation (Triso) of 160 μm to 340 μm , with a multiple of 30 μm and a variation of UO2 fuel enrichment of 7% to 15%, with a 1% increase. After the reactor core design was inputted in the MCNPX program, the reactor criticality calculation process was carried out with the number of neutrons simulated in the KCODE card and neutron source in the SDEF card that was specified based on the reactor core design. A total of 5000 neutrons per cycle were simulated with a criticality value estimate (Keff) of 1.0 which was chosen so that the final accumulation results were expected to approach the critical condition of a reactor. The use of Skipping 10 cycles was done before the accumulation of criticality data (Keff) of a total of 210 cycles to prevent the convergence of the source and so that the fission source can stabilize before Keff values are used to average the final criticality value (Keff) [3, 11, 12].

3 Results and Discussion

Many parameters affect the reactor criticality value (Keff), including fuel enrichment, fuel radius, control rod length and so on. In this study, the value of criticality of the reactor is influenced by the factors of fuel radius and fuel enrichment.

As is known to get optimum enrichment must be fulfilled the Keff value > 1. But this Keff value should not be far from 1. If this happens, the reactor will shut down. In this study the enrichment range was 7% to 15%. Optimal enrichment is also affected by the presence of the Kernel radius.

Table 1 shows the simulation results of reactor criticality values as a result of the influence of the fuel radius (Kernel) and fuel enrichment . It can be seen that the 7% enrichment of the kernel radius for the optimum Keff value is 310 μm , as well as 8% enrichment . At 9% and 10% enrichment the Keff value reaches optimum at a Kernel radius of 280 μm . At enrichment of 11%, 12%, 13% and 14%, the Keff value reaches optimum at a Kernel radius of 250 μm . The optimum value of Keff at 15% enrichment is achieved when the kernel radius is around 220 μm . Of the several percentages of enrichment given the most optimum Keff value owned by 7% enrichment.

Table-1. Simulation results of reactor critically values as a result of the influence of fuel radius (Kernell) and fuel enrichment

radius Kernell (μm)	k_{eff} U-235								
	7%	8%	9%	10%	11%	12%	13%	14%	15%
160	0,46	0,50	0,54	0,57	0,61	0,64	0,67	0,69	
	152	272	185	932	143	089	055	697	0,72196
190	0,62	0,67	0,71	0,74	0,78	0,81	0,84	0,86	
	444	017	189	781	32	592	332	947	0,89112
220	0,76	0,80	0,84	0,88	0,92	0,94	0,97	0,99	
	436	933	946	279	054	669	253	793	1,01591
250	0,87	0,91	0,95	0,98	1,01	1,04	1,06	1,08	
	341	573	292	622	57	043	108	21	1,09848
280	0,95	0,99	1,02	1,05	1,08	1,10	1,12	1,13	
	591	326	87	568	111	052	428	713	1,15148
310	1,01	1,04	1,07	1,10	1,12	1,14	1,16	1,16	
	236	523	668	157	355	245	008	978	1,18725
341 0	1,05	1,08	1,10	1,12	1,14	1,16	1,18	1,19	
	005	089	797	962	689	276	236	312	1,20186

All the sifting shows the same optimization trend. Figure 1 shows the relationship between the fuel radius (Kernell) and the criticality value of the reactor in some fuel enrichment as the optimization trend. Increasing the kernel radius value, the K_{eff} value increases. These results indicate that the HTR fueled pebble bed reactor [12, 13, 14] to achieve criticality requires fuel enrichment between 7% and 15%

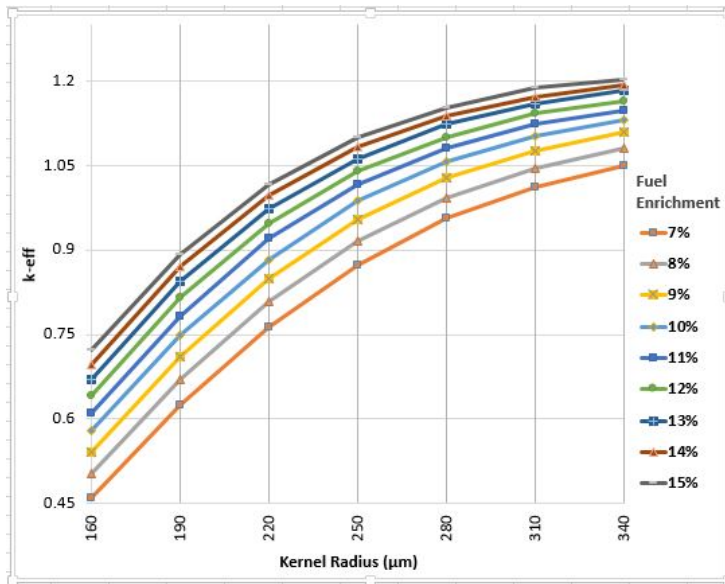


Fig. 1. Simulation results of reactor criticality values as a result of the influence of fuel radius (Kernel) and fuel enrichment

4 Conclusions

In this paper, a combination of U235 and fuel-fuel fingers (Kernel) enrichment effects is used to determine the criticality (Keff). In this study simulation of HTR (High Temperature Reactor) type reactors using MCNPX (Monte Carlo N eXtended Particles) was carried out. The fuel used is UO₂ which has a density of 10.4 gr / cm³, with impurity using 4 ppm Boron atom with Atomik B-10 fraction of 80.1% and B-11 of 19.9%. Variations of enrichment used in this study range from 7% to 15%. While the fuel radius (Kernel) ranges from 160 μm to 340 μm. From the simulation results, it was found that the optimum keff of 1.01236 occurred at 7% enrichment and the radius of the fuel was 310 μm.

Acknowledgment

The authors thank to the Directorate of Research and Community Service Directorate General of Strengthening Research and Development of the Ministry of Research, Technology and Higher Education which has funded this research.

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