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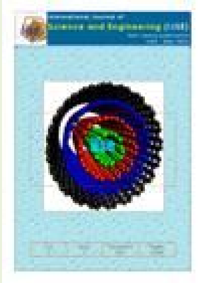

Analysis Loading Height of HTR (High Temperature Reactor) Core to Obtain Criticlity of Reactor

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Abstract *- High temperatur reactor (HTR) attract to be studied due to it has inherent safety characteristics and capabilities to produce energy economically. Design of reactor core in this study is a blend HTR 10 in China with HTR pebble-bed. The reactor has thermal power of 10 MW with inlet and outlet helium temperatures of 250°C and 700°C. HTR design is a cylindrical with helium gas as a coolant and graphite as a moderator. The HTR uses pebble-bed fuel composed a large amount of particles of TRISO in graphite metrics. Kernel radius used to analyse reactor core height in this research is 225 μm with enrichment of 16% in order to achieve critical condition. Reactor criticality is also influenced by the height of active reactor core where pebble-bed fuel is distributed. Calculation of the reactor criticality at any height variations active core is done with MCNP5 modelling techniques. The modelling is done by making the geometry of reactor and pebble-bed which is distributed by using body-centred cubic lattice in the reactor core. From the MCNP5 calculation, the first criticality of HTR can be achieved on the active core height of 150.9012 cm calculated from the bottom active core with criticality value of 1.00312±0.00090. The higher active reactor core is, the more increasing the reactor criticality is. This is occured due to there are many fuel balls of pebble-bed used, so that activity of fission in reactor increases. However, reactor criticality is still in stable condition in each the rise of active core height from critical core height even though reactor reactivity increases 0.01 Δk/k. The minimum of fuel needed to achieve initial criticality (critical core height) is 11,805 pebbles and 8,906 moderators.*

Keywords— *HTR, kernel radius, active core, reactor criticality, MCNP5*

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I. Introduction

Attention scientist of reactor technology and nuclear energy in the world against the High Temperature Reactor (HTR) has increased in the past decade. Inherent safety characteristics and capabilities to produce energy economically are the main factors that attract many people to study and develop HTR. The HTR utilizes graphite as the moderator at the same reflector and the fuel is a spherical particle (pebble-bed) with UO_2 composition as a neutron generator (Holbrook, 2008).

HTR is the types of gas-cooled high temperature reaktor. HTR core design in this study is a blend HTR 10 in China with HTR pebble-bed. Thermal reactor power is 10 MW with inlet and outlet helium temperatures of 250°C and 700°C. HTR design is a cylindrical with helium gas as a coolant and graphite as a moderator. In addition, the HTR uses pebble-bed fuel composed a large amount of particles of TRISO in graphite metrics. The TRISO particle is coated fuel particles by a radius of 175-300 µm. According to Hammam, kernel radius of 225 µm with enrichment of 16% can use in HTR due to reactor has been critical (IAEA, 2003; G. Hosking, 2007; Zuhair, 2012; Croff, A., 2009; O. Hammam, 2014).

Reactor criticality is also influenced by the height of active reactor core where pebble-bed fuel is distributed. The reactor criticality will increase with the increasing number of pebble-bed in the reactor core. The criticality of reactor is a variabel that describes the state of the reactor in order to operate optimally. Therefore, it is needed to determine the height of active core and the minimum of pebble-bed so that reactor is in critical condition (S. Volkan, 2002).

Calculation of the reactor criticality at any height variations active core done with modelling techniques of MCNP5 which is a software that can simulate the interaction of particles in a reactor with a Monte Carlo approach. The modelling is done by making the geometry of reactor and pebble-bed which is distributed by using body-centred cubic lattice in the reactor core.

II. Material and Method

Materials used in this research were HTR10, HTR pebble bed database and continous energy nuclear data library ENDF/B-VII. Modelling of HTR uses the Monte Carlo code

MCNP5. MCNP (Monte Carlo N-particle) is a general-purpose, continuos-energy, generalized-geometry, time-dependent, coupled neutron, photon and electron Monte Carlo transport code. MCNP is also capable of calculating the multiplication factor (criticality) of fissile systems. A system is defined by generating cells bounded by surfaces in three dimensions. Any kind of geometry can be defined as a cell and this cell can be rotated and moved to anywhere in the space. MCNP can simulate particle transport. Monte Carlo simulates individual particles and recording some aspects (tallies) of their average behaviour (J.F. Briesmeister, 1992).

Criticality evaluations are done based on the principle of neutron balance. The number of neutrons in each generation is taken into account and comparison is made with the number of neutrons in the consequent generation. All possible mechanisms for the birth and loss of neutrons are accounted in bookkeeping. Thus, effective multiplication factor is evaluated for a given cycle. Each fission neutron is generated randomly out of possible locations containing fissile material. In order to generate statistical basis, simulations are repeated as many times as desired (S. Volkan, 2002).

The initial step is to calculate atom density from reaktor and fuel, then to model the reactor core with diameter of 180 cm and height of 197 cm. Reactor core is surrounded by a graphite reflector, while the graphite reflector is surrounded by layer of boronated carbon bricks and core is filled by pebble bed and moderator balls. On the side reflectors near the active core there are ten boreholes with 130 mm diameter for the insertion of control rods and three boreholes of 130 mm diameter for irradiation. On the side of the reflector there are twenty flow channels in the form borehole with 80 mm diameter for helium inlet. Pebble-bed is distributed in the reactor core which is composed of many triso particles. Triso is a fuel that is composed of Uranium Dioxide coated by four outer layers: Carbon, IpyC (Inner Pyrolytic Coating), SiC (Silicon Carbides) and OpyC (Outer Pyrolytic Coating). Both of PyC have density differences. The first layer next to kernel (UO_2) has lower density than others that is functioning to intercept gas of fissile product. SiC layer serves as a barrier to the production of fissile active movement like Cs, Sr and Ag. SiC is also a mechanical and chemical barrier at high temperatures (R. Didiek, 2007). The key design parameters of the HTR and the basic characteristics of the fuel elements are shown in Table 1 and 2.

Pebble-bed and moderator balls is distributed in the core zone of the HTR using a body-centred cubic (BCC) lattice by packing fraction and the percentages of the pebble and moderator balls of 0.61 and 57:43. BBC lattice modelling in MCNP uses lattice option at any active core height variation. MCNP model for BBC lattice, pebble-bed and TRISO is shown in Figure 1 and 2, while MCNP reactor model is shown in Figure 3.

After reactor core has been modelled, the next process is calculation of reactor criticality done in each additional active core height of 13.7544 cm from initial core height of 54.6204 cm until maximum height of 205.9188 cm with the number of neutrons simulated in KCODE card and neutron source in SDEF card which are specified by reactor core design. 5000 neutrons in each cycle are simulated by estimation criticality value (K_{eff}) of 1.0 selected in order that the final accumulation results are expected nearly equal to the critical condition. Using skipping 10 cycles is done before data accumulation of criticality value from a total of 210 cycles to prevent convergence of the source and that the fission sources can be stable before criticality values are used to average its final estimation. SDEF card is utilized to specify fission source distributions in reactor core and S(α,β) graph.01t of thermal neutron scattering data is applied in all materials containing graphite to consider binding effect at thermal neutron and graphite moderator under energy of 4 ev.

Table 1.Key design parameters of the HTR

Core	
Reactor thermal power (MW)	10
Average core height (m)	1.97
Reactor core diameter (m)	1.80
Pebble packing fraction	0.61
Materials	
Nuclear fuel	UO_2
Coolant	He
Reflector	Graphite
Coolant	
Temperature at reactor inlet/outlet (°C)	250/700
Primary helium pressure (MPa)	250

Table 2. Fuel element characteristics

Fuel kernel	
Diameter of ball (cm)	6.0
Diameter of fuelled region (cm)	5.0
Density of graphite in matrix and outer shell (g/cm^3)	1.73
Enrichment of 235U (w%)	16
Equivalent natural boron content of impurities in uranium (ppm)	4.0
Equivalent natural boron content of impurities in graphite (ppm)	1.3
Radius of the kernel (µm)	225
UO_2 density (g/cm^3)	10.4
Coatings	
Coating layer materials (starting from kernel)	C/IPyC/SiC/OPyC
Coating layer thickness (mm)	0.09/0.04/0.035/0.04
Coating layer density (g/cm^3)	1.1/1.9/3.18/1.9
Dummy (no fuel) elements	
Diameter of ball (cm)	6.0
Density of graphite (g/cm^3)	1.73
Equivalent natural boron content of impurities in graphite (ppm)	1.3

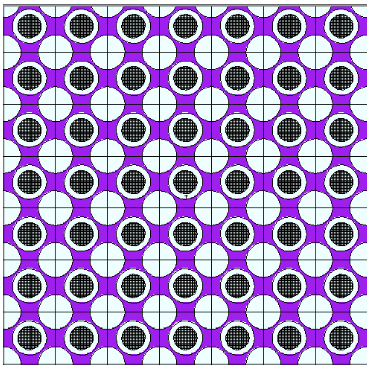

Figure 1. Pebble-bed and Moderator ball is in BCC lattice in reactor core

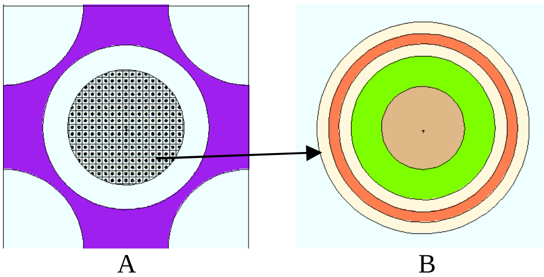

Figure 2. Pebble-bed with Moderator ball in every corner (A) and Triso coated by UO_2, Carbon, IPyC, SiC and OPyC (B).

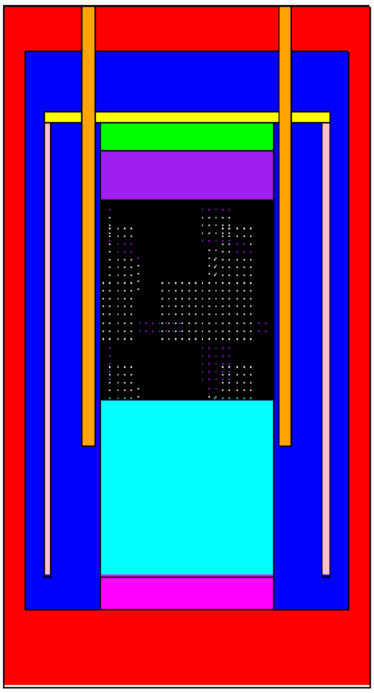

Figure 3. MCNP model of HTR geometry at XZ coordinate with black region as active core

III. RESULT AND DISCUSSION

In MCNP In the calculation of HTR pebble-bed, pebble-bed core model is approximated by utilizing a BCC lattice. Repeating structure of MCNP leads to the emergence of partial pebble around the core which can add extra fuel into the core. Excess fuel contributed by this partial pebble is eliminated by reducing the volume of the core where a pebble packing fraction is maintained unchanged. This approach relies on an exclusion zone which compensates contribution of partial pebble. The size of the exclusion zone is given by the pebble radius determined by the ratio of the number of fuel pebble with the number of pebble in unit cells, thus obtained exclusion zone thick is 1.71 cm around the core with fuel pebble and moderator ratio is 57:43.

All of MCNP5 calculations utilize the continous energy nuclear data library ENDF/B-VII with a temperature of 27^{o}C without control rods. The results of HTR criticality calculation in each core height is shown in Table 3 and the results are plotted in graph and are shown in Figure 4.

Table 3. The results of criticality (K_{eff}) in each active core height

Active core height (cm)	K_{eff}	Deviation
205.9188	1.10810	0.00086
192.1644	1.08452	0.00086
178.4100	1.06156	0.00087
164.6556	1.03510	0.00091
150.9012	1.00312	0.00090
137.1468	0.96741	0.00094
123.3924	0.92405	0.00085
109.638	0.87353	0.00080
95.8836	0.81498	0.00083
82.1292	0.74400	0.00083
68.3748	0.65867	0.00088
54.6204	0.55870	0.00072

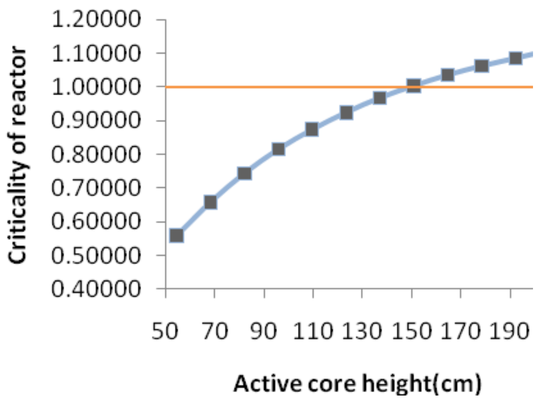

Figure 4. The results of criticality reactor (K_{eff}) in each active core height

From the MCNP5 calculation, the first criticality HTR can be achieved on the active core height of 150.9012 cm calculated from the bottom active core. Active core height to achieve the first criticality is called critical core height describing the minimum of core height to achieve critical condition. The higher active reactor core is, the more increasing the reactor criticality is. This is occured due to there are many fuel balls of pebble-bed used, so that activity of fission in reactor increases. However, reactor criticality is still in stable condition in each the rise of active core height from critical core height even though reactor reactivity increases 0.01 Δk/k shown in Figure 5.

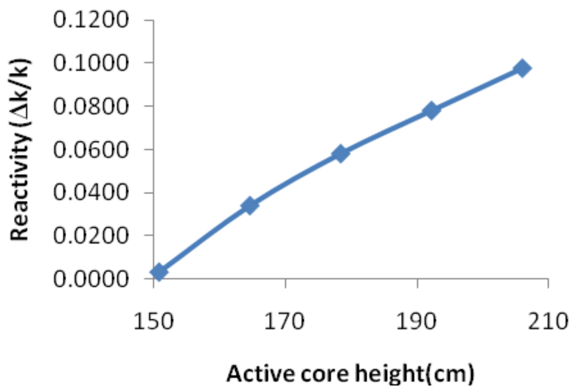

Figure 5. Reactor reactivity in each active core height

The minimum of fuel needed to achieve initial criticality (critical core height) is obtained by dividing the volume of active core with the volume of pebble-bed. The volume of active core is obtained by multiply pebble packing fraction in core of 0.61 about the core volume which is cylinder with radius of 90 cm and core height of 150.9012 cm. Using pebble-bed and moderator ratio it can be obtained the number of pebble-beds and moderators of 11,805 and 8,906.

IV. CONLUSIONS

From the results explaned above can be concluded that from the results of MCNP5 calculations the first criticality of HTR can be achieved at 150.9012 cm active core height calculated from the bottom active core, the higher active reactor core is, the more increasing the reactor criticality is. This is occured due to there are many fuel balls of pebble-bed used so activity of fission in reactor increases. However, reactor criticality is still in stable condition in each the rise of active core height from critical core height even though reactor reactivity increases 0.01 $\Delta k/k$ and the minimum of pebble-bed and moderator needed to obtain critical condition is 11,805 pebbles and 8,906 moderators.

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