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EFFECT OF F / M RATIO AGAINST NEUTRON FLUX DISTRIBUTION ON THE HTGR-10 MWth PEBBLE BED CORE

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ABSTRACT

EFFECT OF F/M RATIO AGAINST OF NEUTRON FLUX DISTRIBUTION ON THE HTGR-10 MWTH PEBBLE BED CORE. The research on the effect of F/M ratio on neutron flux distribution in the HTGR-10 MWth pebble bed core has been done. The goal of this research is to know the effect caused by variations of pebble fuel ratio with pebble moderator (F/M) on neutron flux distribution at HTGR-10 MWth core and to obtain optimal F/M ratio to be applied in the HTGR- 10 MWth core. In this research, the first step is completed modeling of HTGR-10 MWt then calculation of the neutron energy spectrum and neutron flux calculation, with variations F/M = 100: 0, 80:20, 60:40, 57; 43, 52; 48, 50 : 50, 40.60, and 20:80. Modeling and calculation are performed using the program package EGS99304 with 36 group vitamin C, MCNP6.1 and VisEd. The calculation results have shown that the resulting neutron spectrum is identical to the neutron spectrum that occurs on the core of the nuclear reactor. The highest neutron flux distribution of 1.32E + 14 n/cm^2 sec occurred at F: M = 40:60 with the position at the center of the reactor core. The fuel ratio is also in the range of 40% to 60% to apply to the HTGR10 MWth core with multiplication factor value is in the range of 1.08 to 1.16. From the results of calculation, it can be concluded that highest flux the HTGR-10 MWth is 1.32 E+14 n/cm^2 sec with F/M ratio is 40:60, while the variation F/M ratio which can be used on HTGR-10 MWth is from the ratio of 40:60 to 60:40.
Keywords: neutron flux, neutron spectrum, HTGR-10 MWth, pebble bed core, F/M ratio

ABSTRAK

PENGARUH RASIO F/M TERHADAP DISTRIBUSI FLUKS NEUTRON PADA TERAS HTGR-10 MWTH PEBBLE BED. *Telah dilakukan penelitian mengenai Pengaruh rasio F/M terhadap distribusi fluks neutron pada teras HTGR-10 MWth pebble bed. Penelitian ini dilakukan bertujuan untuk mengetahui pengaruh yang ditimbulkan akibat variasi rasio bahan bakar pebble dengan moderator pebble (F/M) terhadap distribusi fluks neutron pada teras HTGR-10 MWth dan untuk mendapatkan rasio F/M yang optimal untuk diaplikasikan di dalam teras HTGR-10 MWth. Dalam penelitian ini terlebih dahulu dilakukan pemodelanHTGR-10 MWth secara lengkap kemudian dilakukan perhitungan spektrum energi neutron dan fluks neutron dengan variasi F/M = 100:0, 80:20, 60:40, 57;43, 52;48, 50:50, 40,60, dan 20:80. Pemodelan dan Perhitungan dilakukan dengan menggunakan paket program EGS99304 dengan menggunakan 36 group vitamin C , MCNP6.1 dan VisEd. Hasil perhitungan menunjukkan spektrum neutron yang dihasilkan identik dengan spektrum neutron yang terjadi pada teras reaktor nuklir. Distribusi fluks neutron tertinggi sebesar 1.32E+14 n/cm^2 det terjadi pada F:M = 40:60 dengan posisi berada di tengah-tengah teras reaktor. Didapat pula rasio bahan bakar dalam kisaran 40 % sampai 60 % untuk dapat aplikasikan ke dalam teras HTGR10 MWth dengan nilai faktor multiplikasi berada pada kisaran 1,08 sampai 1,16. Dari hasil perhitungan yang dilakukan dapat disimpulkan bahwa pada HTGR-10 MWth fluks tertinggi dapat mencapai nilai 1.32E+14 n/cm^2 det dengan F/M rasio = 40:60 sedangkan variasi F/M rasio yang dapat digunakan pada HTGR-10 MWth adalah dari rasio 40:60 sampai 60:40.*
Kata kunci: fluks neutron, spectrum neutron, HTGR-10 MWth, pebble bed, F/M rasio

INTRODUCTION

HTGR-10 MWth is one of the pebble bed reactor design based on the concept of Generation IV nuclear reactor that emphasizes the increasing role of sustainability (sustainable) so that it can extend the life of the fuel supply, minimize the quality and quantity of nuclear material waste, and improve the reliability and nuclear safety. To ensure the reactor concept Generation IV in terms of increased reliability and nuclear safety met HTGR-10 MWth then the HTGR-10 MWth reactor should have a safety feature that is very special (excellent), which has a great margin of fuel temperature and the large coefficient of reactivity temperature to accommodate the insertion of reactivity [1-3]. Meanwhile, to support the concept of inherent safety materials used for construction and the HTGR pebble bed fuel and moderator pebble is very dominated by the element carbon (graphite), so that the negative reactivity will be achieved. The other of HTGR pebble bed characteristics is fuel loading can be done directly (on-line) this makes HTGR 10 MWth very economical [4-6].

With regards to graphite material dominance in the structure of the HTGR 10 MWth including in the pebble fuel and moderator so condition ratio of pebble fuel to the moderator will greatly influence neutron moderation factors and neutron flux that occur in the reactor core of HTGR 10 MWth. The research on the effect of the graphite material to the performance of neutronic HTGR pebble bed has been carried out by other researchers, such as optimization studies on neutron moderation in the core HTR pebble bed [7-8]. Analysis of calculation reactivity coefficient of fuel and moderator on RGTT200K core [9]. etc. Therefore, to the complement and increase and fulfill the knowledge of the graphite material effect on the performance of neutronic on the HTGR pebble bed core, a study entitled Effect of Ratio F / M Against the neutron flux distribution in HTGR-10 MWT pebble bed core is conducted. The purpose of this study is to obtain the F / M ratio that is optimal to be applied in all HTGR-10 MWth core based on the neutron flux distribution in the HTGR pebble bed core. Research carried out by using a Monte Carlo program package transport MCNP6 [10-11].

BASIC THEORY

Description HTGR-10 MWth

HTGR-10MWth pebble-bed is a high-temperature nuclear reactor designed to operate in input temperatures of approximately 250 °C and have output temperature of around 700 °C and a thermal power of 10 MW. Coolant fluid of HTGR-10 MWth is an inert helium gas which is directly forwarded to the heat exchanger system (HE). The operational pressure within HTGR-10 MWth pebble-bed core is 3 MPa in which the mass flow rate of the cooling fluid helium for full power is 4.3 kg/s. To realize the concept of inherent safety, then the construction materials of HTGR-10 MWth is very dominated by the carbon element (graphite) which will produce a negative reactivity[12].

HTGR-10 MWth is constructed to have the active core of 197 cm height with a radius of 90 cm. Reflectors are made of the graphite material which surrounds the core of HTGR-10 MWth with axial thick of 100 cm. In the reflector area within 5 cm from the edge of the reflector, there are the 10 holes arrangement of the control rods each with a diameter of 13.0 cm and an interval of 36o angle. There are also 7 small balls holes absorber as well as 3-holes-irradiation shaped of ellips with diameter of 13 cm. Small absorber ball diameter is 5 mm. Additionally, along with a distance of 50 cm from the edge of the reflector, there are 20 holes helium cooling with a diameter of 4.0 cm. Reflectors are then coated with a core barrel which made of stainless steel with a thickness of 5 cm. The upper reflector with a thickness of 130 cm which is also made of graphite, placed at 41 cm higher than the upper limit active core. Space with thickness is 41 cm between active high and the upper reflector left empty (void). bottom of the core on HTGR-10MWth pebble-bed which funnel-shaped is useful for driving out the former pebble caused of burning result. At the initial of criticality condition, the funnel is filled by pebbles moderator with a diameter of 3 cm which made of graphite. To achieve the equilibrium core condition, then moderator pebble will be issued slowly. At the bottom of the core on HTGR-10MWth pebble-bed is also contained a reflector made of graphite. At a distance of 210 cm from the center of the core is placed tube press (pressure vessel) made of stainless steel with a thickness of 8 cm so can be shackle of HTGR-10 MWth pebble-bed reactor. The Biological shielding with the thickness of 2 m which made of regular concrete with a density of 2.3 g / cm3 is placed 10 cm in the pressure vessel.

A space with a thickness of 10 cm between the vessel pressure and the biological shield which containing dry air is the RCCS room (Reactor Cavity Cooling System) which is used to cool the reactor HTGR-10MWth pebble-bed. Fuel and moderator of HTGR-10MWth pebble-bed is pebble-shaped with a diameter of 6 cm. The fuel pebble is divided into a fuel zone with a radius of 2.5 cm and thickness of a wrapper graphite matrix of 0.5 cm. In the fuel zone is spread of 8335 kernels coated by layers of TRISO particles (TRI structure ISOmaterial). The kernel contains UO2 fuel with a density of 10.4 gr/cc. The total mass of UO2 fuel in one pebble is 5 grams. TRISO layers lining the kernel which composed of layers are A porous carbon buffer layer that serves to collect fission gases [8], the inner pyrolytic carbon layer (IPyC), the silicon carbide layer (SiC), the outer pyrolytic carbon layer (OPyC).

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While the moderator pebble is made of solid graphite material. Illustrations and completed pebble fuel data are shown in Table 1 and Figure 1.

Table 1. Characteristic of Pebble Fuel and Moderator Ball [13-14]

PEBBLE					
Specification of KERNEL and TRISO					
Specification of KERNEL			**Specification of TRISO Layer:**		
Kernel	UO_2	-	TRISO LAYER	Outer Diameter (cm)	Density (g/cm^3)
Enrichment (U-235)	17	%	Buffer	0,0340	1,05
Diameter of kernel	0,050	cm	IPyC	0,0385	1,90
Density of UO_2	10,40	g/cm^3	SiC	0,0420	3,18
			OPyC	0,0460	1,90
Specification of Pebble Fuel bed and moderator pebble					
Specification of Pebble Fuel bed			**Specification of Moderator (dummy ball):**		
	Outer Diameter (cm)	Unit		Outer Diameter (cm)	Unit
Diameter of *pebble* ball	6,00	cm	Diameter of *moderator* ball	6,00	cm
Diameter of fuel active zone	5,00	cm	Material of Matrix	Graphite	-
Thickness of outer shell of graphite matrix	0,5	cm	Density	1,75	g/cm^3
Density of *outer shel* graphite matrix	1,75	g/cm^3			

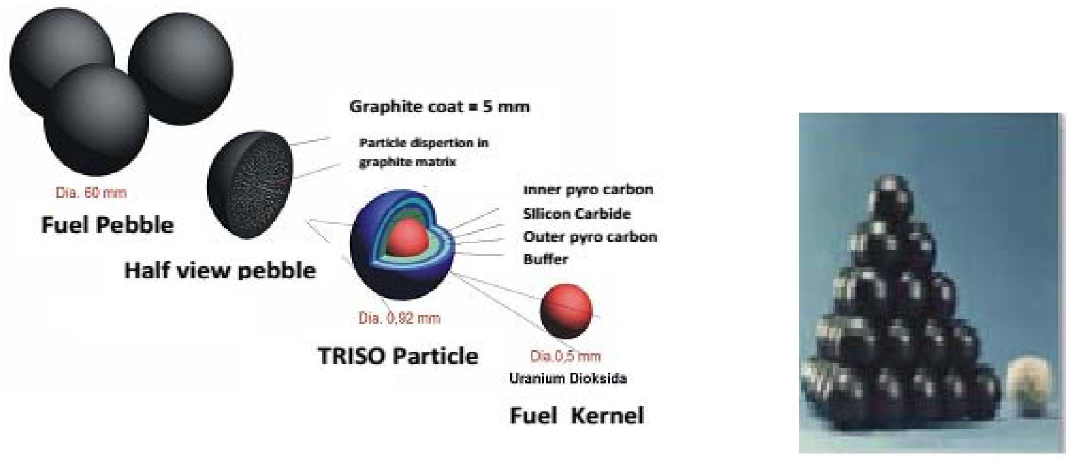

Figure 1. Fuel and moderator pebble construction

In the reactor core, the ratio of the fuel pebble to the moderator on the core has a certain comparison. In this study, variations in ratio of the number fuel pebble to moderator: are: 100: 0, 80:20, 60:40, 57:43, 52:48, 50:50, 40:60 and 20:80. While pebble fuel and moderators are arranged in the form of a lattice BCC (Body Centered Cubic). The variation of the F: M ratio was performed to consider the effective moderation ratio in the reactor core

MCNP Program Packages

MCNP is a widely used program package for calculating transport phenomena in neutrons, photons, electrons, or a combination. The MCNP was designed and developed by the Monte Carlo X-5 team since 2003 on the Manhattan project at Los Alamos National Laboratory. In simulating the life journey of a neutron from birth until absorbed by the

material making up of the reactor, the MCNP uses a process of probabilistic statistical duplication. Therefore the MCNP program package
can be used to solve complex problems in three-dimensional form and Complicated issues that can not be done by modeling using deterministic methods

In its development to date, MCNP has launched the MCNP6.1 program package. In the MCNP6.1 program package, users can perform neutronic calculations up to the calculation of burn-up. The MCNP6.1 program package utilizes a continuous energy cross-profile derived from the ENDF / B-VII.1 nuclear data library file[15-16] and features a burn-up calculation facility using the CINDER-90 depletion program[17-18]. Cinder 90 is a unique transmutation program package that has libraries of 63 cross section group consisting of 3400 nuclides, 1325 fission products, and more than 30 actinides in the atomic number range of 1≤ Z ≤103.

METHODOLOGY

Research in this paper is done by using MCNP6.1 program package. The Research begins with modeling of HTGR-10MWth construction using MCNP6.1 program package. Data used in accordance with the description that has been described. The modeled HTGR-10MWt construction includes a diameter reactor core of 90 cm surrounded by a reflector made of graphite material for radial, top and bottom directions. Modeling is also done for the cone where fuel and moderator released, control rod channels, helium cooling channels and canals of small balls absorber, irradiation channels, RSCC space and biological shields as thick as 200 cm. The atomic density data of each HTGR-10MWt zone follows the existing atomic zone density data in HTR-10 that has been modified in accordance with the cross-profile library ENDF / B-VII. These data are used as input parameters in the MCNP6.1 program package. Description of each zone on HTGR-10Mwt can be seen in Table 2.

Table 2. Atomic zone density at HTGR-10MWth [19]

No	No. zone	Atomic density of carbon (atom/barn-cm)	Atomic density of boron Natural (atom/barn-cm)	Description
1.	83-90	0.851047E-01	0.456926E-06	Bottom reflector with hot helium flow borings
2.	1	0.729410E-01	0.329811E-02	Boronated carbon bricks
3.	2	0.851462E-01	0.457148E-06	Top graphite reflector
4.	3	0.145350E-01	0.780384E-07	Cold helium chamber
5.	4	0.802916E-01	0.431084E-06	Top reflector
6.	6,7,91-97	0.572501E-01	0.277884E-08	Dummy balls, simplified as graphite of lower density
7.	8	0.781408E-01	0.419537E-06	Bottom reflector structures
8.	9	0.823751E-01	0.442271E-06	Bottom reflector structures
9.	10	0.843647E-01	0.298504E-03	Bottom reflector structures
10.	11	0.817101E-01	0.156416E-03	Bottom reflector structures
11.	12	0.850790E-01	0.209092E-03	Bottom reflector structures
12.	13	0.819167E-01	0.358529E-04	Bottom reflector structures
13.	14	0.541118E-01	0.577456E-04	Bottom reflector structures
14.	15	0.332110E-01	0.178309E-06	Bottom reflector structures
15.	16	0.881811E-01	0.358866E-04	Bottom reflector structures
16.	17,55,72, 74,75,76, 78,79	0.765984E-01	0.346349E-02	Boronated carbon bricks
17.	18,56,73	0.797184E-01	0.000000E+00	Carbon bricks
18.	19	0.761157E-01	0.344166E-02	Boronated carbon bricks
19.	20	0.878374E-01	0.471597E-06	Graphite reflector structure
20.	21	0.579696E-01	0.311238E-06	Graphite reflector structure
21.	22,23,25, 49,50,52, 54,66,67, 69,71,80	0.882418E-01	0.473769E-06	Graphite reflector structure
22.	24,51,68	0.879541E-01	0.168369E-03	Graphite reflector structure

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23.	26	0.846754E-01	0.454621E-06	Graphite reflector structure
24.	27	0.589319E-01	0.266468E-02	Boronated carbon bricks
25.	28,82	0.678899E-01	1.400000E-05	Graphite reflector structure
26.	29	0.403794E-01	1.400000E-05	Graphite reflector structure
27.	30,41	0.678899E-01	0.364500E-06	Graphite reflector structure
28.	31-40	0.634459E-01	0.340640E-06	Graphite reflector, control rod borings region
29.	42	0.676758E-01	0.125331E-03	Graphite reflector structure
30.	43,45	0.861476E-01	0.462525E-06	Graphite reflector structure
31.	44	0.829066E-01	0.445124E-06	Graphite reflector structure
32.	46	0.747805E-01	0.338129E-02	Boronated carbon bricks
33.	47	0.778265E-01	0.000000E+00	Carbon bricks
34.	48	0.582699E-01	0.312850E-06	Graphite reflector structure
35.	53	0.855860E-01	0.459510E-06	Graphite reflector structure
36.	57	0.728262E-01	0.391003E-06	Graphite reflector structure
37.	58,59,61, 63	0.760368E-01	0.408240E-06	Graphite reflector, cold helium flow region
38.	60	0.757889E-01	0.145082E-03	Graphite reflector, cold helium flow region
39.	62	0.737484E-01	0.395954E-06	Graphite reflector, cold helium flow region
40.	64	0.660039E-01	0.298444E-02	Boronated carbon bricks
41.	65	0.686924E-01	0.000000E+00	Carbon bricks
42.	70	0.861500E-01	0.861500E-01	Graphite reflector structure
43.	77	0.749927E-01	0.339088E-02	Boronated carbon bricks
44.	81	0.847872E-01	0.000000E+00	Dummy balls, but artificially taken as carbon bricks

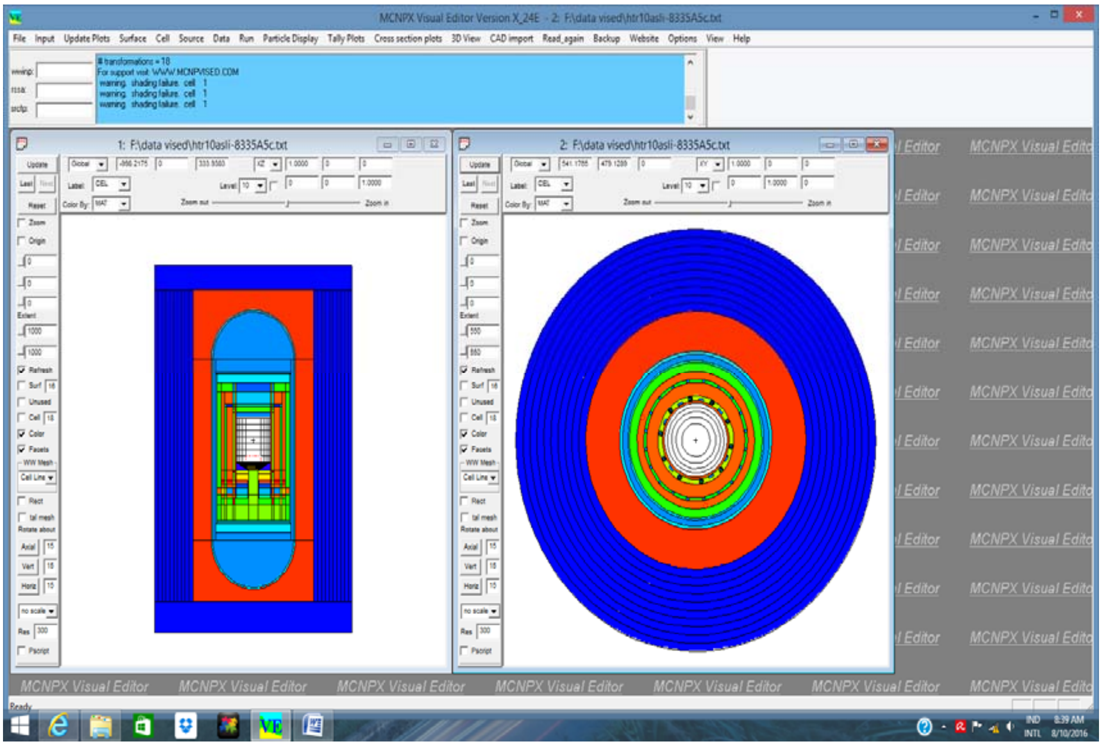

Figure 2. Results of HTGR-10MWt construction modeling using VISED program

Furthermore, HTGR-10MWth core is divided into 25 cells with the same volume, 5 axial lines, and 5 radial lines. The result of modeling can be seen using VISED program package. The results of the modeling illustration of the complete construction of HTGR-10WMth using the VISED program package shown in Figure 2.

The neutron energy distribution curve was obtained by determining the binary energy grid/group structure number in the EGS99304 program using 36 vitamin C groups. This distribution curve is needed to ensure that on the HTGR-10 MWt core there has been a nuclear reaction that transmits neutron particles. The neutron energy distribution curve for flux change per energy has a unique shape of the curve

The next stage was calculating neutron multiplication and neutron flux which had been normalized on every cell on HTGR-10 MWt core with 17% enrichment level and kernel amount at fuel pebble of 8335 curve shape. The ratio of pebble fuel to pebble moderator used is 100: 0, 80:20, 60:40, 57:43, 52:48, 50:50, 40:60 and 20:80. All calculations of neutron multiplication and neutron flux were conducted using MCNP6.1 with KCODE 2500 1.0 10 110 and KSRC 0.0 0.0 0.0 and Mode n p. Thus the calculation will follow 1000 total cycles with the first 10 cycles skipped and the source position lies on the coordinates (0,0,0). While the Tally which is used is the option Tally F4 and Tally En. Tally F4 serves to calculate the average flux in the cell while the En tally is used to obtain the flux distribution obtained by the desired energy bin.

RESULTS AND DISCUSSION

The results of the neutron energy distribution against the neutron spectrum on the HTGR-10 MWt core obtained are shown in Figure 3. This distribution curve is required to ensure that on the HTGR-10 MWt core has been a nuclear reaction with the neutron particle emitter.The resulting curve corresponds to the curves obtained by other researchers on the nuclear reactor core [20-21]. so it can be ascertained that on the HTGR- 10MWt has happened nuclear reaction.

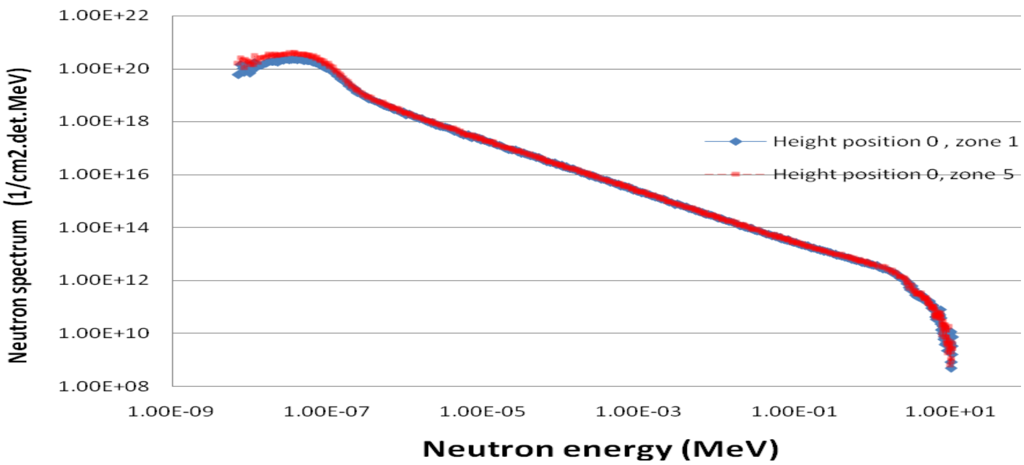

Figure 3. Neutron spectrum profile of neutron energy at center of HTGR-10MWth core

Figure 3 shows the characteristic neutron spectrum shape on HTGR 10 MWth core. In the rapid neutron region, there is a peak decline. This condition is due to the construction on HTGR 10 MWth core is dominated by carbon element. Accordingly, many fast neutrons are moderated.

In position height 0, zone 1 or altitude 0, zone 5 shows the same shape.The higher of the neutron energy than the lower the neutron spectrum. Figure 3 also shows that the maximum neutron spectrum occurs at low neutron energies within the thermal neutron energy group with an energy interval below 0.5 eV. From the neutron spectrum curve, it can be seen that the HTGR-10 MWt reactor core dominantly emits thermal neutrons.

From the results of normalized neutron flux calculations on the HTGR-10 MWt core that have been divided into 25 cells using MCNP6.1 as well as the F4 tally, option obtained results as shown in Table 3.

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Tabel 3. Results of MCNP 6.1 for neutron flux on HTGR-10 MWth core

Position of core height	F:M=100:0 Neutron flux				
	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	5.12E+13	4.73E+13	4.39E+13	4.12E+13	3.84E+13
39.30	7.76E+13	7.15E+13	6.54E+13	5.98E+13	5.44E+13
0.00	9.03E+13	8.22E+13	7.54E+13	6.87E+13	6.22E+13
-39.30	8.86E+13	8.11E+13	7.38E+13	6.69E+13	6.06E+13
-78.60	7.47E+13	6.77E+13	6.12E+13	5.51E+13	4.96E+13
Position of core height	F:M=80:20 Neutron flux				
	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	5.30E+13	4.97E+13	4.61E+13	4.25E+13	3.91E+13
39.30	8.50E+13	7.85E+13	7.06E+13	6.33E+13	5.70E+13
0.00	1.02E+14	9.26E+13	8.31E+13	7.42E+13	6.64E+13
-39.30	9.89E+13	8.97E+13	8.09E+13	7.22E+13	6.45E+13
-78.60	7.87E+13	7.20E+13	6.51E+13	5.85E+13	5.20E+13
Position of core height	F:M=60:40 Neutron flux				
	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	5.91E+13	5.44E+13	5.04E+13	4.66E+13	4.28E+13
39.30	9.46E+13	8.62E+13	7.80E+13	7.03E+13	6.26E+13
0.00	1.12E+14	1.01E+14	9.12E+13	8.11E+13	7.19E+13
-39.30	1.10E+14	9.86E+13	8.79E+13	7.86E+13	7.00E+13
-78.60	8.78E+13	7.91E+13	7.03E+13	6.29E+13	5.59E+13
Position of core height	F:M=57:43 Neutron flux				
	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	5.96E+13	5.55E+13	5.14E+13	4.72E+13	4.30E+13
39.30	9.62E+13	8.72E+13	7.85E+13	6.99E+13	6.22E+13
0.00	1.13E+14	1.02E+14	9.15E+13	8.19E+13	7.29E+13
-39.30	1.11E+14	1.00E+14	9.01E+13	8.01E+13	7.09E+13
-78.60	8.85E+13	8.02E+13	7.18E+13	6.44E+13	5.69E+13
Position of core height	F:M=52:48 Thermal neutron flux				

	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	6.29E+13	5.81E+13	5.31E+13	4.89E+13	4.49E+13
39.30	1.01E+14	9.13E+13	8.18E+13	7.38E+13	6.67E+13
0.00	1.20E+14	1.08E+14	9.74E+13	8.65E+13	7.68E+13
-39.30	1.16E+14	1.05E+14	9.43E+13	8.40E+13	7.43E+13
-78.60	9.14E+13	8.27E+13	7.38E+13	6.57E+13	5.80E+13
Position of core height	F:M=50:50 Thermal neutron flux				
	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	6.28E+13	5.75E+13	5.33E+13	4.90E+13	4.46E+13
39.30	1.04E+14	9.35E+13	8.32E+13	7.49E+13	6.65E+13
0.00	1.22E+14	1.10E+14	9.84E+13	8.74E+13	7.69E+13
-39.30	1.17E+14	1.06E+14	9.46E+13	8.44E+13	7.47E+13
-78.60	9.30E+13	8.44E+13	7.58E+13	6.71E+13	5.88E+13
Position of core height	F:M=40:60 Thermal neutron flux				
	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	6.98E+13	6.38E+13	5.86E+13	5.39E+13	4.89E+13
39.30	1.13E+14	1.02E+14	8.32E+13	8.24E+13	7.29E+13
0.00	1.32E+14	1.19E+14	1.07E+14	9.46E+13	8.37E+13
-39.30	1.25E+14	1.14E+14	1.02E+14	9.07E+13	7.98E+13
-78.60	9.79E+13	8.96E+13	8.02E+13	7.08E+13	6.20E+13
Position of core height	F:M=20:80 Thermal neutron flux				
	zone 1	zone 2	zone 3	zone 4	zone 5
	$R_{averate}$=20.12	$R_{averate}$ =48.59	$R_{averate}$=63.32	$R_{averate}$ =75.11	$R_{averate}$ =85.25
78.60	8.39E+13	7.69E+13	7.08E+13	6.52E+13	5.96E+13
39.30	1.39E+14	1.25E+14	1.12E+14	9.98E+13	8.84E+13
0.00	1.67E+14	1.50E+14	1.34E+14	1.18E+14	1.04E+14
-39.30	1.61E+14	1.44E+14	1.30E+14	1.15E+14	1.01E+13
-78.60	1.27E+14	1.14E+14	1.02E+14	9.05E+13	7.92E+13

As an illustration based on table 2, the 3-dimensional shape of the neutron flux on the HTGR-10 MWt core for F: M = 100: 0 can be seen in Figure 4. As an illustration based on table 2, the 3-dimensional shape of the neutron flux on the HTGR-10 MWt terraces for F: M = 100: 0 can be seen in Figure 4.

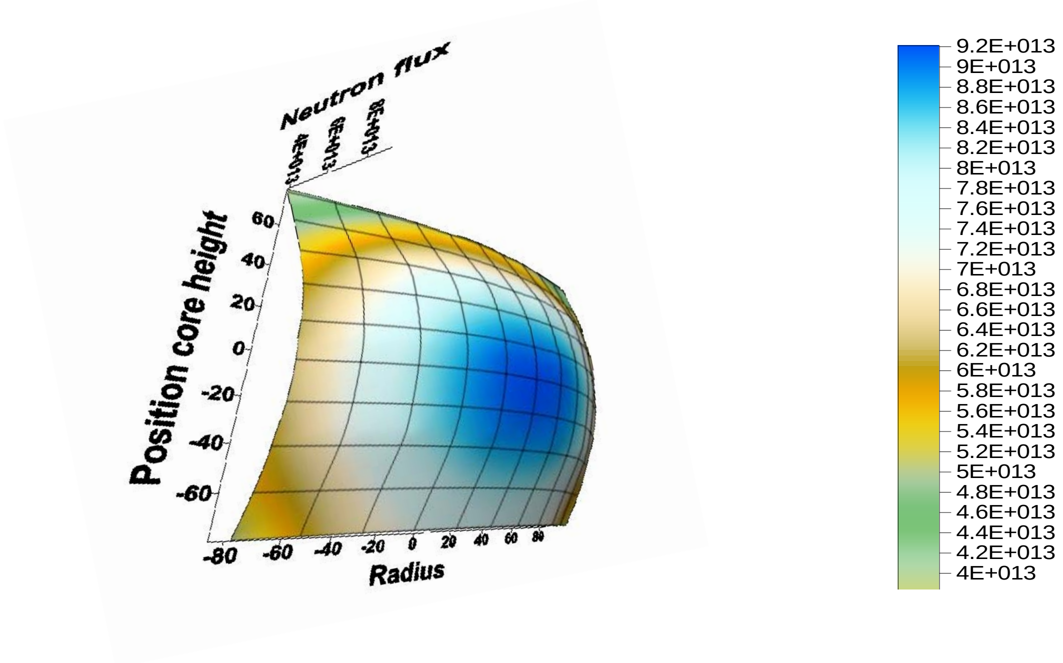

Figure 4. Profile of neutron flux on HTGR-10 MWt in 3-dimensional form F: M = 100: 0

Table 3 and Figure 4, shows that the largest neutron flux is in the middle of the HTGR-10 MWth core at height position of 0 cm and at an interval of 20.12 cm radius zone which is at the center of the terrace and the zone became the center of a nuclear reaction.

Description of the maximum neutron flux distribution based on F: M variation by using the 2-dimensional graph for axial neutron flux distribution can be seen in Figure 5 while for neutron flux radial distribution shown in Figure 6. From Figure 5 it can be seen that the highest neutron flux value occurs when the ratio F: M = 20: 80 while the smallest neutron flux occurs when the ratio F: M = 100: 0. This condition indicates that the more moderator balls that filled the HTGR-10 MWth core then the greater the neutron interaction. In addition from Figure 5 it also gives information that for all FM ratio, the neutron flux value will be lower when the position height of core is higher or lower altitude positions. While from Figure 6 shows that the greater the radius of the core (the more towards the reflector) the more decreasing the value of flux neutrons that occur. While based on the ratio F: M the highest neutron flux distribution value occurs at F: M = 20:80 and the lowest flux distribution value occurs at F: M = 100: 0.

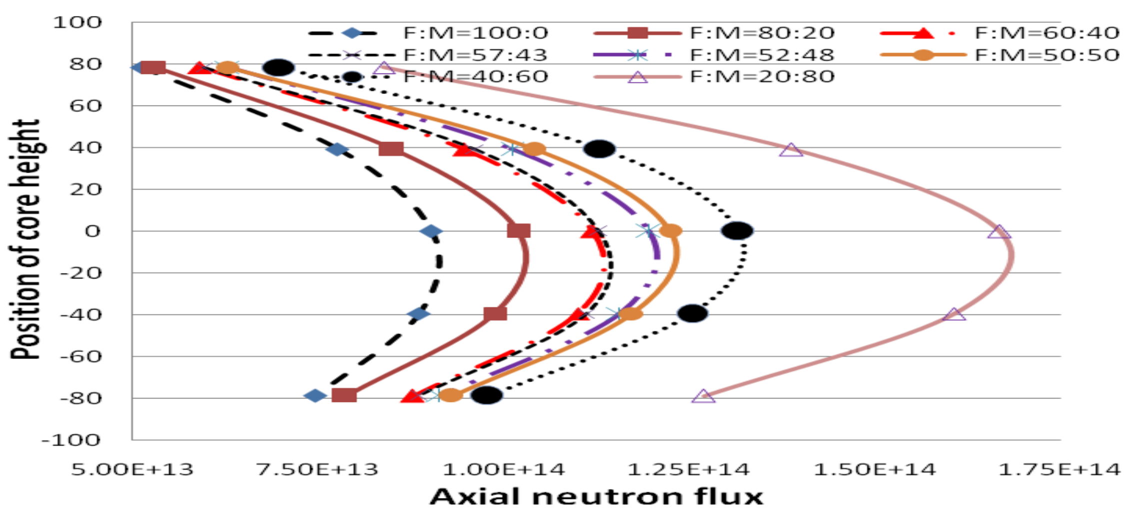

Figure 5. Axial neutron flux distribution for variation F: M at the center core of the radial direction (R radial) = 0

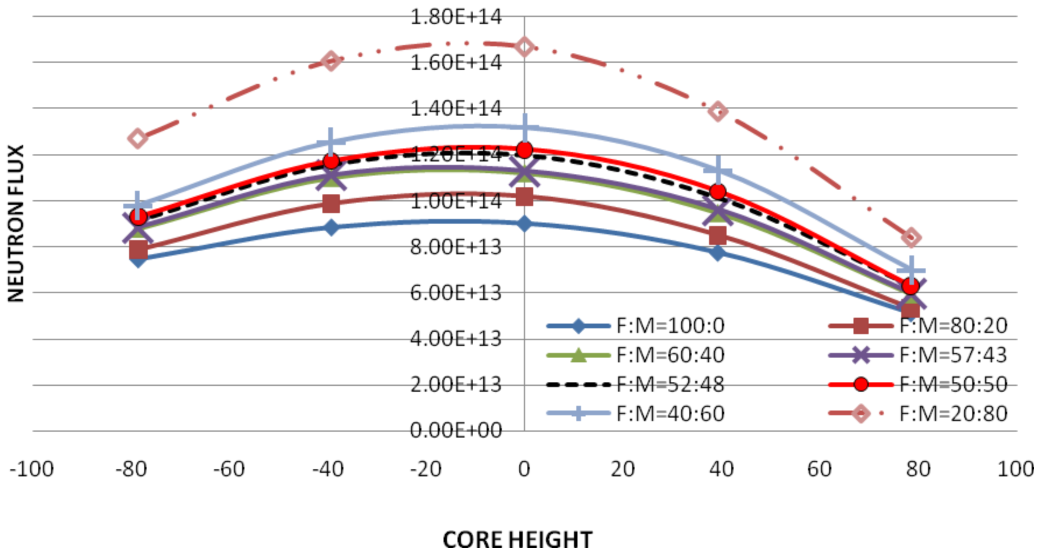

Figure 6. The radial neutron flux distribution for variation F: M at altitude 0

The relationship of neutron flux and the multiplication value against for fuel ratio can be seen in Figure 7. Figure 7, explains that the higher the fuel ratio to the moderator entering the reactor core will result in increased neutron multiplication value following the equation :

$$y = 0,000001\ x^3 + 0,022\ x + 0,1 \quad (1)$$

Where :
y : multiplication factor
x : fuel ratio (%)

This condition is caused by the more fuel the U-238 enriched or the more moderators inside the core will cause the larger the moderated neutrons so the more neutrons that pound the fuel kernel. Different is indicated by neutron flux, the higher the ratio of fuel to the moderator that goes into the reactor core will result in low flux value of neutrons following the equation :

$$y = -2,0\ 10^8 + 4,0\ 10^{10}\ x^2 + 2,0\ 10^{14} \quad (2)$$

where :
y : neutron flux
x : fuel ratio (%)

The more moderators that get into the core then its causing more fuel burning so that the higher the burnup happens. It is therefore necessary to find the optimal co nditions for the multiplication value to be in the range of values k_{eff} = 1.03 to accommodate the reactivity occurs while the flux value of neutrons remains high. Figure 7, shows that optimum conditions can be achieved when the ratio of fuel to the moderator is in the interval of 40% to 60%.

Figure 7 shows that optimum conditions can be achieved as the fuel ratio to the moderator is in the range of 40% to 60%. Table 2 shows that is the more moderator ratios put into the core will result in higher neutron flux values. This condition shows that the more a moderator in the core will lead to greater neutron moderated so that more neutrons pounding the fuel kernel.

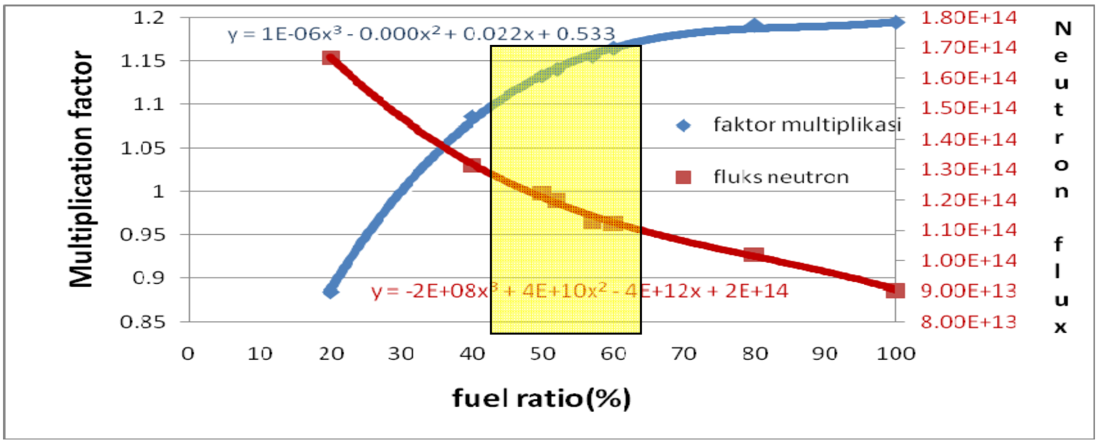

Figure 7. Multiplication factor curve and neutron flux on fuel ratio on HTGR-10MWth

CONCLUSION

From the calculation of neutron flux with all the control rods conditions fully lifted is in the middle of the HTGR-10 MWth core at a height of 0 cm and at a radius of 20.12 cm is the nuclear reaction center. The more moderator ratio put into the core will result in higher neutron flux values.

The highest neutron flux value can reach 1.32E + 14 n / cm2 det at F: M = 40:60 with height of 0 cm and radius 20,12 cm (zone 1)Optimal neutron flux conditions can be achieved when the ratio of fuel to the moderator is in the range of 40% to 60%.

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DISKUSI/TANYA JAWAB:

1. PERTANYAAN: Ihda Husnayani (PTKRN–BATAN)

- Kenapa bila F:M=100:0 nilai fluks nya lebih rendah dibandingkan yang lain?

JAWABAN: Hery Adrial (PTKRN - BATAN)

- *Pada kondisi F:M = 100: 0 maka pada teras reaktor tidak terdapat bola-bola moderator sehingga neutron yang brasal dari kernell hanya dimoderasi oleh unsur karbon yang terrdapat pada lapisan TRISO dan bahan matrik pada bola bahan bakar sehingga neuton yang termoderasi sangat sedikit. Kondisi ini akan menyebabkan fluks yang terjadi menjadi kecil.*