Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Monte Carlo Simulation of a Perturbed Subcritical Core

Mustafa K. Jaradat[a,b]*, Chang Je Park[b]
[a]*University of Science and Technology, KAERI campus, 217 Gajeong-ro, Yuseong-gu, Daejeon, 305-350, Korea*
[b]*Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea*
[*]*Corresponding author: jaradat@kaeri.re.kr*

1. Introduction

Jordan Subcritical Assembly (JSA) is designed for the purpose of education, training, and experiment research. Jordan subcritical assembly is considered Jordan's First Nuclear Facility Moving Jordan into the nuclear age. It is a teaching and training experimental facility that is designed to stay in a subcriticality.

A subcritical assembly is a multiplying system of nuclear fuel and moderator whose effective multiplication factor is less than unity. An extraneous source of neutron is required for the steady state operation in order to compensate for the difference between the production rate of fission neutrons in the fuel and the rate of loss caused by absorption and leakage. [1]

2. Description of JSA

Jordan subcritical assembly consist of 301 fuel rods, the length of the fuel rod is 55cm and diameter of 1cm, loaded vertically into a distilled light water filled tank in a square lattice with 1.91cm pitch. Each fuel rod contains 43 cylindrical pellets of uranium oxide (UO_2) with 3.4wt% 235U enrichment. The dimensions of each cylindrical pellet are 1cm in height and 0.843cm in diameter. The density of the uranium oxide is 10.4215g/cm^3, so each fuel rod contains 7.496 gram of ^{235}U. Five insulator pellets made of aluminum trioxide (Al_2O_3) are added to the top and bottom of the fuel pellets with same dimensions as the fuel pellet, and is plugged with a spring and upper end plug on the top, and a lower end plug at the bottom. The cladding tube is made of zirconium alloy (Zr-4) with outer diameter of 1cm and inner diameter 0.86cm. Helium gas is filled the gap between the fuel pellets and the cladding, the thickness of the gap is 0.0085cm. Fuel rods positioned by two grids square lattice. The upper grid is made of organic glass (Plexiglas) with 1cm thick and 53cm in diameter. The lower grid is made of aluminum alloy with 1.5cm in thickness and 53cm diameter. JSA uses light water as a moderator and reflector and Pu-Be start up source with neutron emission rate 1x10^{6}n/s. [2]

3. MCNP Simulation of JSA

The simulation model of JSA is a three-dimensional MCNP model that reflects the fuel rods arrangement of this facility. This model uses continuous energy neutron cross-section data libraries ENDF/B-VI cross-section data libraries and was developed as a nuclear analysis computational tool for calculations using version 5 of MCNP [3]. This simulation models the fuel pellets, aluminum pellets, helium gap, pressure spring, zirconium alloy tubes, water moderator, the upper and the lower grid plates. The material compositions of the assembly were taken from the preliminary design documents for JSA. Figure 1 shows a cross-sectional view of the JSA core via MCNP visual editor.

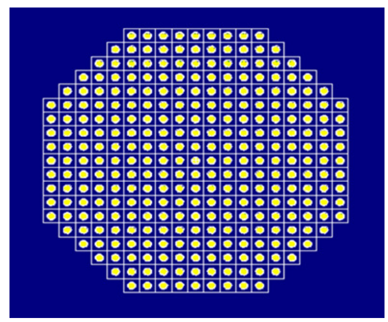

Fig. 1. A cross-section view of the JSA core (the reactor assembly) via MCNP visual editor.

The pressure spring was made from AISI Type 302 The spring has a total volume is 0.6338cm^3 with typical density about 8 g/cm^3 was homogenized with the helium gas about the volume contains the spring and the gas which is 1.74cm^3. The new density of the mixture is 2.91 g/cm^3.

4. Results and Discussion

The multiplication factor of the JSA was calculated using the MCNP model with MCNP 5. Table 1 shows the subcritical parameters. Figure 2 shows the shape of the radial flux in the core.

Table (1) Subcritical Parameters Calculated by MCNP

1	Final estimated combined k-effective (collision/ absorption/ track-length)	0.95779 ± 0.00021
2	Estimated 68% k-effective confidence interval	0.95758 to 0.95799
3	Estimated 95% k-effective confidence intervals	0.95737 to 0.9582
4	Estimated 99% k-effective confidence intervals	0.95724 to 0.95833
5	Percentage of fissions caused by thermal neutrons of energies <0.625 eV	92.83%
6	The average number of neutrons produced per fission	2.448

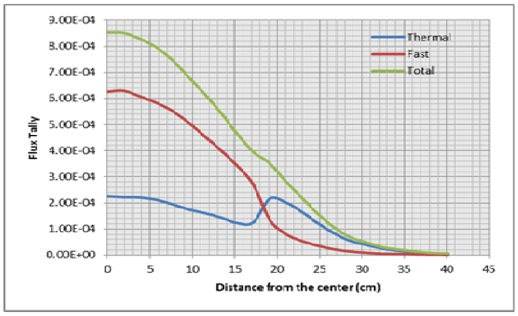

Fig. 2. Radial flux shape in the subcritical core

5. Perturbed core effects on k_{eff}

Many cases had been studied on subcritical core to show how the small perturbations effect on k_{eff} and the flux of the subcritical assembly.

5.1 Changing pitch between fuel rods

The pitch between the fuel rods is 19.1 mm, which is the value at which the k_{eff} of the assembly is maximal. The maximum k_{eff} value reaches 0.95779 which in fact is a slight overestimation (k_{eff}=0.94851 by the designer) because of some approximations in the calculations such as the omission of some structural materials, the homogenization of the spring material and the impurities of the fuel rod materials also are not included. Figure 3 shows the how k_{eff} changes with pitch various values.

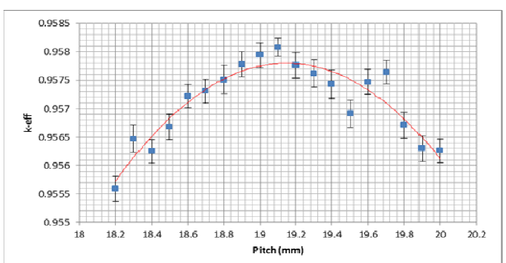

Fig. 3. The effect of pitch changing on k_{eff}.

5.2 Changing reflector material

The MCNP model that has been developed can be used to simulate the effect of reflector material on the multiplication factor of subcritical assembly. Four types of reflector have been light water, heavy water, graphite and beryllium. As it is shown in Table 2 the best material as a reflector is beryllium which gives the highest value of k_{eff} for the same arrangement which is 1.08274.

Table 2 k_{eff} with Different Reflector Materials

	Moderator	Reflector	k_{eff}	Std
1	Light water	Bare	0.86215	0.00021
2	Light water	Light water	0.95779	0.00021
3	Light water	Heavy water	1.03161	0.00015
4	Light water	Graphite	1.03164	0.00015
5	Light water	Beryllium	1.08274	0.00014

5.3 Adding material different than fuel in the center of the core

The effect of adding a material other than the fuel in the middle of the core is also modeled. Table 3 shows different these cases. The shape of the radial thermal flux in the core for some cases is shown in figure 4.

Table 3 k_{eff} with Materials other than fuel in the center

	Case	k_{eff}	Std
1	Unvoided core (301 rod)	0.95779	0.00021
2	Water void (1 fuel rod removed from the center)	0.95746	0.00015
3	Beryllium reflector (1fuel rod removed from the center)	0.95742	0.00015
4	Control absorber B_4C (1fuel rod removed from the center)	0.94032	0.00021

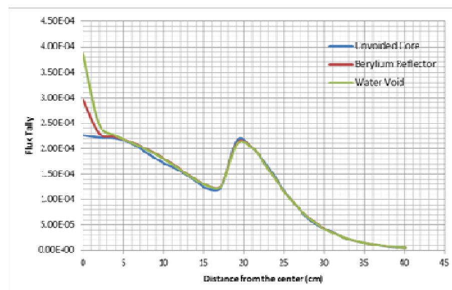

Fig. 4. Thermal flux shape in the core with one rod removed from the core

6. Conclusions

MCNP model is very helpful to study the effect of perturbations on the core of a subcritical core. The optimum pitch was determined using this model. Also the reflector material has huge effect on the multiplication factor; we realize that beryllium is the best among all reflector materials. The shape of the thermal flux in the core varies by changing the central rod of the core and it has the highest value when the central rod is water.

REFERENCES

[1] E. McDaniel, T. Elliott, Design and Uses of Light Water Moderated Subcritical Assembly, Georgia Institute of Technology, Georgia, 1957.

[2] Preliminary Design Documents for Jordan Subcritical Assembly, Zahang Jin shan, Rang Chun fang , JD. SA. SY. 01-RD, Revision A, 2009-05-05.

[3] X-5 MONTE CARLO TEAM, 2003. MCNP – A General Monte Carlo N-Particle Transport Code, Version 5, LA-CP-03-0245, LANL.