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Sensitivity Analysis of Criticality for Different Nuclear Fuel Shapes

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1. Introduction

Rod-type nuclear fuel was mainly developed in the past, but recent study has been extended to plate-type nuclear fuel. The Plate-type fuel is popular in research reactors due to their outstanding thermo-hydraulic characteristics[1].

Therefore, this paper reviews the sensitivity of criticality according to different shapes of nuclear fuel types. Criticality analysis was performed using MCNP5. MCNP5 is well-known Monte Carlo codes for criticality analysis and a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron or coupled neutron / photon / electron transport, including the capability to calculate eigenvalues for critical systems[2].

2. Assumptions and Results

2.1 Statistical reliability

In this criticality analysis, the number of source histories per cycle is used 10,000. This value was determined to ensure uniform distribution of the sources sampled from one cycle of criticality analysis throughout the calculation area and to decrease the calculation variation.

The number of active cycle was 100 and the number of inactive cycle was 50. One million sources, which are 10,000 (number of source histories per cycle) times 100 (number of active cycle), would give the statistically enough reliability on criticality analysis results.

2.2 Sensitivity analysis

We performed the sensitivity analysis of criticality for different shapes of nuclear fuel using MCNP5. Followings are assumed and considered in the sensitivity analysis.

- Flooding.
- Different shapes but same volume, density and mass.
- Different shapes but Same nuclide component.
- Fuel shape : Sphere, Cube, Rod and Cuboid
- Fuel assembly shape : Rod-type assembly and Plate-type assembly

2.2.1 Fuel shape

Followings are assumptions of the fuel shape.

- Sphere diameter is equal to Cuboid height.
- Bottom of the Cuboid is square.
- Height of Cube and Cylinder are same.
- Bottom area of Cube is equal to that of Cylinder.

The details of fuel shape are summarized in Table 1.

Table 2 shows the results of sensitivity analysis. The maximum criticality (k_{eff}+2σ) is 0.44622 for Cube and it is higher than that of other shapes.

Table 1: Details of fuel shape model

Shape	Size (cm)				Surface Area (cm^2)
	r	h	w	l	
Sphere	7.21	-	-	-	652.80
Cylinder	6.56	11.62	-	-	748.50
Cube	-	11.62	11.62	11.62	809.93
Cuboid	-	14.21	10.43	10.43	819.04

Table 2: Criticality analysis results

Shape	k_{eff}	σ	k_{eff} + 2σ
Sphere	0.42498	0.00078	0.42654
Cylinder	0.43754	0.00092	0.43938
Cube	0.44428	0.00097	0.44622
Cuboid	0.44234	0.00093	0.44420

2.2.2 Fuel Assembly types

Followings are assumptions of the fuel assembly type.

- Rod-type fuel assembly is composed of 37 cylinder type rods.
- Height of Rod-type fuel assembly is equal to that of Cylinder.
- Plate-type fuel assembly is composed of 37 plates.
- Height of Plate-type fuel assembly is equal to that of Cube.
- Bottom area of Rod-type fuel assembly is equal to that of Plate-type fuel assembly.

The details of fuel assembly types are summarized in Table 3. Figure 1 shows Cross-section diagram of the two models.

The results of sensitivity analysis are summarized in Table 4 . The maximum criticality is 0.70911 for Rod-type fuel assembly and 0.59704 for Plate-type fuel assembly. The criticality for Rod-type fuel assembly is higher than Plate-type fuel assembly.

2.2.3 Interval between plates

Additionally, we performed sensitivity analysis on interval between plates for plate-type fuel assembly. The results of sensitivity analysis are summarized in Table 5. The criticality in case of 8mm interval is higher than that of other cases.

3. Conclusions

We performed the sensitivity analysis of criticality for different fuel shapes. In sensitivity analysis for simple fuel shapes, the criticality is proportional to the surface area. But for fuel Assembly types, it is not proportional to the surface area. In sensitivity analysis for intervals between plates, the criticality is greater as the interval increases, but if the interval is greater than 8mm, it showed an opposite trend that the criticality decrease by a larger interval.

As a result, it has failed to obtain the logical content to be described in common for all cases. However, criticality is obviously influenced by fuel shapes, interval between plates or rods, arrangement method, and etc. Therefore, the sensitivity analysis of Criticality would be always required whenever subject to be analyzed is changed.

Table 3: Details of fuel assembly model

	Length (cm)				Surface Area (cm^2)
	r	h	w	l	
Rod type assembly	8.23	11.62	-	-	3180.70
Plate type assembly	-	11.62	14.58	14.58	13021.00
Rod	1.08	11.62	-	-	85.96
Plate	-	11.62	0.25	14.58	351.92

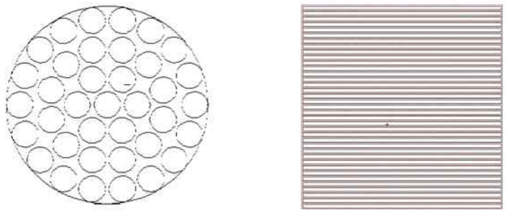

Figure 1. Cross-section diagrams of the two assemblies

Table 4: Criticality analysis results

Assembly	k_{eff}	σ	$k_{eff} + 2σ$
Rod type	0.70681	0.00115	0.70911
Plate type	0.59704	0.00112	0.59928

Table 5: Criticality analysis results

Interval (mm)	K_{eff}	σ	$k_{eff} + 2σ$
0	0.40865	0.00029	0.40923
1	0.47056	0.00034	0.47124
2	0.52327	0.00034	0.52395
3	0.56283	0.00035	0.56353
4	0.58916	0.00035	0.58986
5	0.60655	0.00034	0.60723
6	0.61669	0.00034	0.61737
7	0.62120	0.00036	0.62192
8	0.62167	0.00035	0.62237
9	0.62011	0.00032	0.62075
10	0.61557	0.00032	0.61621
15	0.57535	0.00032	0.57599
20	0.53654	0.00030	0.53714
25	0.47961	0.00026	0.48013

REFERENCES

[1] C.G.Seo, Y-G Cho, S-Y Oh, C. Park, Conceptual Code Design of a 20MW Research Reactor Using the HANATO Fuel Assembly, Transactions of Korean Nuclear Society Spring Meeting, 2006.

[2] X-5 Monte Carlo Team, LA-UR-03-1987/ LA-CP-03-0245, A general Monte Carlo N-Particle Transport Code, Version 5, Los Alamos National Laboratory, 2008.2.