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Preliminary Evaluation of Nuclear Heating for KJRR Reference Core

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) has been developing KiJang Research Reactor(KJRR) for the RI production, NTD application and irradiation experiments[1,2]. The KJRR uses plate type fuel assemblies with low enriched U-Mo fuel meat and meets safety requirement with primary and secondary control rod assemblies. Plate type fuel assembly is widely used in research reactors.

In general, heating data is used in calculation of temperature distributions of specific core regions and knowing the exact temperature profile of core components is important in calculation of neutronics coefficients. The purpose of this calculation is to evaluate the nuclear heating of KJRR reference core at BOC condition. All the components of KJRR core were modelled for heating tally by Monte Carlo code.

2. Methods and Results

2.1 Computer Code

A preliminary heating calculation of KJRR was done by MCNP5 Monte Carlo code with ENDF/B-VII library[3]. Modified XS library for fuel meat region was used in order to consider delayed gamma effect (92235.62c & 13027.52c).

2.2 Methodology

In MCNP code, the F6 and F7 cell heating and energy deposition tallies are the following track length estimator.

$$F_{6,7} = \rho_a / \rho_g \int_V \int_t \int_E H(E)\Phi(\vec{r},E,t)\,dE\,dt\,\frac{dV}{V}$$

where,

ρ_a = atomic density (#/barn-cm)
ρ_a = gram density (g/cm^3)
H(E) = heating response

The unit of the heating tally is MeV/gram. The heating tally is merely flux tally multiplied by an energy-dependent multiplier (FM card). The F7 tally includes the gamma heating because the photons are deposited locally. The F6 tally deposits the photons elsewhere, so it does not include gamma heating. Thus for fissionable materials, the F7 result often will be greater than the F6 result even though F7 includes only fission and F6 includes all reactions. The true heating is found by summing the neutron and photon F6 tallies in a coupled neutron/photon calculation. Therefore, combination of neutron and photon F6 tallies is used in this heating calculation.

F6:N,P = F6:N + F6:P

The heating response *H(E)* for F6 neutrons and photons has different meanings, depending upon context as follows.

$$H(E) = \sigma_T(E)H_{avg}(E) \qquad (F_6)$$

$$H(E) = \sigma_f(E)Q \qquad (F_7)$$

$$H_{avg}(E) = E - \sum_i p_i(E)[\bar{E}_{out_i}(E) - Q_i + \bar{E}_{\gamma_i}(E)] \qquad (F_{6,N})$$

$$H_{avg}(E) = \sum_{i=1}^{3} p_i(E)\cdot(E - \bar{E}_{out}) \qquad (F_{6,P})$$

where,

H_{avg} = heating number
σ_T = total neutron cross section
σ_f = total fission cross section
$p_i(E)$ = probability of reaction *i* *(compton scattering, pair-production, photoelectric)*
E = incident neutron energy
$\bar{E}_{out_i}$ = avg. exiting neutron energy for reaction *i*
$\bar{E}_{\gamma_i}$ = avg. energy of exiting gammas for reaction *i*
Q_i = Q-value of reaction *i*
Q = fission Q-value (MeV)

All energy transferred to electron is assumed to be deposited locally in F6 tally. *H(E)*in F7 photon tally, is undefined because photo-fission is not included in MCNP.

2.3 Tallies

A criticality calculation was done with a nominal source size of 100,000 particles per cycle, an estimate of k_{eff} of 1.0, skip 25 cycles before averaging k_{eff} or tallying and run a total of 125 cycles. Tally normalization is done by tally multiplier (FM card). In addition, to normalize a criticality calculation by the steady-state power level of a reactor, following conversion procedure is used.

- Energy per fission (200MeV assumed)
- Number of fission per unit Watt
- Total number of fission per unit Watt
- Scaling factor for total power
- Scaling factor corrected with k_{eff}

Generally, a MCNP tally in a criticality calculation is for one fission neutron being born in the system at the start of a cycle. The tally results must be scaled either by the total number of neutrons in a burst or by the neutron birth rate to produce, respectively, either the total result or the result per unit time of the source. The scaling factor is entered on the FM card. If modeled system is not a critical condition, calculated tally results must be scaled as noted in above description.

In addition to FM card, segment divisor (SD) card is required to calculate heating tally. In F6 heating calculation, mass of each cell is inputted with tally card. Generally mass of a cell is calculated automatically. But MCNP can’t calculate the mass of a cell if the cell is composed with complex geometry. Thus, masses of all designated cells with F6 tally are inputted.

2.4 Analysis Results

The nuclear heating calculation of KJRR primary components was done by MCNP5 Monte Carlo code with ENDF/B-VII library. The delayed beta effects were considered with modified cross-section library. The heating data of each component are calculated and normalized to total power(15MW) as shown in Table 1. In addition, Table 2 shows heating data of the hottest Beryllium(Be) block per axial location. The IR0 Be block in Table 1 was the hottest Be block in the core.

Table 1. Summary of KJRR Heating Calculation.

Region	Heat(W)[a)]	%	Heat(W)[b)]	%
FA(22)	1.37E+07	91.08	1.43E+07	95.56
CE-SSR(2)	2.43E+04	0.16	2.14E+04	0.14
CE-CAR(6)	6.45E+04	0.43	5.86E+04	0.39
IR(1,10)	2.33E+04	0.16	2.17E+04	0.14
IR(0)	2.75E+04	0.18	2.59E+04	0.17
IR(2,3,5,6,8,9)	1.11E+05	0.74	1.04E+05	0.70
IR(4,7)	2.24E+04	0.15	2.08E+04	0.14
HTS, PTS	1.16E+04	0.08	1.08E+04	0.07
Half large Be blk(8)	3.41E+04	0.23	3.15E+04	0.21
Half std. Be blk(10)	2.26E+04	0.15	2.05E+04	0.14
OR(2,4,7,9)	1.68E+04	0.11	1.53E+04	0.10
OR(1,3,5,6,8,10)	2.99E+04	0.20	2.72E+04	0.18
Be bar(long, half)	1.12E+03	0.01	1.02E+03	0.01
Zr wall(water gap)	5.99E+04	0.40	5.64E+04	0.38
NTD(8)	3.44E+04	0.23	3.44E+04	0.23
ND(12)	8.65E-02	0.00	8.65E-02	0.00
Be block for NTD	7.73E+04	0.52	6.93E+04	0.46
Al block	5.12E+04	0.34	4.84E+04	0.32
Outer water(box)	2.76E+04	0.18	-	-
Coolant	-	-	9.78E+04	0.65
Others	6.99E+05	4.66	-	-
Total	1.50E+07	100.0	1.50E+07	100.0

a. top/bot/outer water included in each component
b. Others (including delayed effect) item included to FA item

Table 2. Heating of Hottest Be Block per Axial Location.

Axial Loc. (cm)	IR0-Be block-plane average			
	Heat(W/g)	Mass(g)	Heat(W)	%
-42.5 ~ -35.0	6.94E-01	5.82E+02	4.04E+02	2.75
-35.0 ~ -28.0	1.46E+00	5.43E+02	7.96E+02	5.42
-28.0 ~ -21.0	2.54E+00	5.43E+02	1.38E+03	9.39
-21.0 ~ -14.0	3.29E+00	5.43E+02	1.79E+03	12.20
-14.0 ~ -7.0	3.75E+00	5.43E+02	2.04E+03	13.87
-7.0 ~ 0.0	3.88E+00	5.43E+02	2.11E+03	14.38
0.0 ~ 7.0	3.66E+00	5.43E+02	1.99E+03	13.55
7.0 ~ 14.0	3.09E+00	5.43E+02	1.68E+03	11.45
14.0 ~ 21.0	2.28E+00	5.43E+02	1.24E+03	8.44
21.0 ~ 28.0	1.39E+00	5.43E+02	7.56E+02	5.15
28.0 ~ 35.0	6.47E-01	5.43E+02	3.51E+02	2.39
35.0 ~ 42.5	2.50E-01	5.82E+02	1.46E+02	0.99
Total			1.47E+04	100.0

3. Conclusions

The KAERI has been developing the KJRR research reactor with 15MW thermal power. To calculate the temperature distributions of core regions, preliminary evaluation of nuclear heating of KJRR was performed at BOC condition by using the MCNP5 Monte Carlo code with ENDF/B-VII library. All the components of KJRR core were modelled and calculated data were normalized to total power. Overall computational results are summarized in Table 1 and total heating ratio of fuel assemblies against entire core was approximately 95% including delayed effects.

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