Gamma Energy Production Analysis in KALIMER-600 Core

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1. Introduction

Korea Atomic Energy research Institute (KAERI) has been developing the sodium cooling fast demonstration reactor(KALIMER-600) to burn the TRU from LWR. A low enriched uranium fuel will be used until a qualified TRU fuel is ready.

A fast reactor core is divided into several flow groups based on the power distribution. A different flow group has a different flow rate. A flow rate assigned to each flow group is not changed for the core life time. Most of the heat produced in the non-fuel assembly and structural materials is from gamma ray reaction. A gamma heating analysis is performed to estimate the flow rates for the non-fuel assembly groups. All the analyses are based on the uranium core.

2. Methods and Results

The Monte carlo MCNP and TRANSX-DANTSYS code systems are adopted for the analysis. In addition to a heterogeneous MCNP model, a homogeneous model in which each assembly is homogenized was developed for the estimation of rod heterogeneity effects. The R-Z and Trigonal TRANSX-DANTSYS models were developed for the region-wise and assembly-wise gamma heating calculations, respectively.

2.1 Calculational Model

Gamma heating analyses are done for the full core and unit fuel rod. A unit rod calculation is performed to investigate the basic characteristics of gamma heat deposition. A Uranium core and ENDF/B-VI are the references for the core model and cross section library. A few comparative studies are done to check the sensitivity of the cross section library and fuel composition.

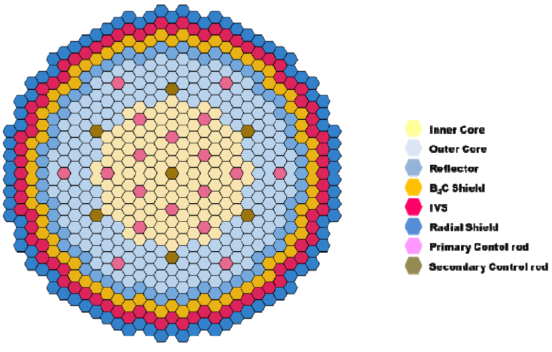

Fig. I: KALIMER-600 Core Configuration

Fig. I shows the cross-sectional view of the uranium core. It 20% and 16% the enriched uranium fuels are charged in the outer and inner core regions, respectively[1]. All full core analyses are done for BOL with ARO condition.

2.2 Unit Fuel Rod Analysis

Gamma heating is analyzed for 20% enriched unit fuel rod with a reflective boundary condition.

Table I. Results of Heating Analysis for unit rod

	MCNP			TRANSX-DANTSYS		
(%)	Neutron heating	Gamma heating	Total	Neutron heating	Gamma heating	Total
Fuel	92.86	5.85	98.71	93.17	5.56	98.73
Fuel gap	0.04	0.05	0.09	0.04	0.06	0.1
Cladding	0.09	0.76	0.84	0.10	0.78	0.88
Coolant	0.13	0.23	0.36	0.11	0.18	0.29
Total	93.11	6.89	100	93.42	6.58	100

The results of TRANSX-DANTSYS are in good agreement with those of MCNP. More than 98% of heat is deposited in the fuel region. About 7% of heat is from gamma ray in this calculation. In general, 13% of total fission heat is expected to be from gamma. The differences are due to the lack of the delayed gamma and relatively high enriched uranium. The less of U-238 there is in the concentration results the less there is in the (n, ɣ) reaction.

2.3 Full Core Analysis

The core is divided into several regions in radial and axial directions as in Table II. The heat energies deposited by neutrons and gamma rays are estimated separately.

(%)	Code	Active core		Lower part (Lower shield)		Upper part (Sodium bond, Gas plenum)		Total
		Neutron	Gamma	Neutron	Gamma	Neutron	Gamma	
Inner core	MCNP	43.216	3.492	0.025	0.151	0.028	0.206	47.117
	DANT	43.169	3.140	0.029	0.128	0.032	0.195	46.693
Outer core	MCNP	47.880	3.542	0.024	0.106	0.024	0.160	51.736
	DANT	48.696	3.296	0.029	0.130	0.031	0.184	52.367
Radial reflector	MCNP	0.020	0.120	0.004	0.073	0.004	0.078	0.300
	DANT	0.026	0.111	0.006	0.057	0.006	0.088	0.295
B4C shield	MCNP	0.213	0.002	0.067	0.012	0.074	0.012	0.381
	DANT	0.239	0.021	0.083	0.009	0.093	0.011	0.457
IVS	MCNP	0.000	0.002	0.000	0.001	0.000	0.001	0.005
	DANT	0.000	0.001	0.000	0.000	0.000	0.001	0.002
Radial shield	MCNP	0.000	0.002	0.000	0.001	0.006	0.002	0.010
	DANT	0.000	0.001	0.000	0.000	0.000	0.000	0.001
Primary C.R.	MCNP	0.022	0.107	0.004	0.043	0.004	0.060	0.240
	DANT	0.027	0.060	0.005	0.013	0.005	0.023	0.131
Secondary C.R.	MCNP	0.017	0.083	0.003	0.033	0.003	0.044	0.183
	DANT	0.011	0.024	0.002	0.005	0.002	0.009	0.053
Total	MCNP	91.368	7.351	0.127	0.419	0.143	0.564	100
	DANT	92.168	6.655	0.153	0.343	0.170	0.511	100

Table II: Results of Heating Analysis for Full core

The results of MCNP and TRANSX-DANTSYS calculations are almost the same. The difference of k_{eff}-value between two code systems is 53pcm. The heat distribution of MCNP shows a trend very similar to that of TRANSX-DANTSYS. As expected, the gamma becomes a dominant heat source in the non-fuel regions. However, the B_4C region has a different behavior because of boron's (n,α) reaction. Thanks to the B_4C shield assemblies, the neutrons make almost zero heating effects on the regions beyond B_4C shield assemblies. The total gamma heat is about ~7% in core and most of the gamma heat is deposited in the fuel region.

2.4 Fuel Composition Effects

KALIMER-600 is for TRU burning. The effects on gamma heating due to the fuel change from uranium to TRU are investigated. 27%TRU-63%U(238)-10%Zr fuel with TRU obtained from LWR spent fuel discharged at the burn-up of 33,000MWD/MTU is assumed.

Table III: Effect of gamma followed fuel composition
(unit : Mev/Fission Neutron)

		20% Uranium	TRU (27%)	Rel. Dif (%)
Fuel Zone	Bottom	0.456	0.417	9.3
	Active	6.122	6.258	-2.2
	Upper	0.353	0.315	11.8
Flow Tube		0.608	0.587	3.6
Total		7.539	7.578	-0.5

Insignificant differences are found between uranium and TRU fuel. TRU fuel produces a harder neutron energy spectrum so that less of the neutron capture reactions are observed in non-fuel assemblies and structural materials.

2.5 Cross Section Library Sensitivity

Cross section library sensitivity is studied by using 20% enriched uranium fuel model.

Table IV: Result of analysis for library sensitivity
(unit : Mev/Fission Neutron)

		ENDF/B-VI	JEFF-3.1	JENDL-3.3
Fuel Zone	Bottom	0.456	0.435	0.448
	Active	6.122	6.143	6.611
	Upper	0.353	0.333	0.348
Flow Tube		0.608	0.594	0.633
Total		7.539	7.506	8.041

ENDF/B-VI and JEFF-3.1 show very good agreement. However, JENDLE-3.3 shows relatively high gamma heating values. The reason is that JENDLE-3.3 is evaluated to have a high U-235 capture cross section.

3. Conclusions

In general, about 13% of fission energy in the fast reactor is produced by gamma reaction. Prompt gamma covers 25% of the total gamma energy and 50% of the total gamma comes from (n,ɣ) reaction. A delayed gamma accounts for the rest of the 25%.

The calculation shows that the gamma energy is about ~7% of the total energy produced in the KALIMER-600. Although no delayed gamma is considered in this study, the value of 7% is generally less than expected. A harder neutron energy spectrum and relatively low U-238 inventory are intended to make that difference. The energy deposited in the non-fuel assemblies of KALIMER-600 is expected to be no more than 2% of total energy. The fuel change from a low enriched uranium to TRU would not make any considerable difference in terms of gamma energy deposited in non-fuel assemblies.

The amount of delayed gamma energy is almost equivalent to that of the prompt gamma energy. Further investigation should be given to evaluate the delayed gamma energy in detail.

REFERENCES

[1] W. S. Park, M. H. Baek, J. W. Yoo, and S. J. Kim, Gamma Heating Analysis for Sodium-cooled Fast Reactor, KAERI/TR-4273/2011.

[2] A. Luthi, "DEVELOPMENT AND VALIDATION OF GAMMA-HEATING CALCULATIONAL METHODS FOR PLUTONIUM-BURNING FAST REACTORS", Doctor Dissertation. EPFL, 1999