Validation of Ultra-Fine Group Library Generation of Lead-cooled Fast Reactor for STREAM code

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1. Introduction

STREAM (Steady state and Transient REactor Analysis code with Method of characteristics) is a high-accuracy neutron transport analysis code for light water reactors. However, STREAM has a problem to analyze non-light water reactors, such as a fast reactor. Because of the differences of a light water reactor and a fast reactor, the MOC code for fast reactors requires different nuclear cross-section data considering the reactor characteristics, such as a spectrum shape and spectrum weight. To enhance the accuracy of STREAM for fast reactor analysis, a new nuclear cross-section library for Fast reactors was tested for LFR pin and assembly problems in this literature.

2. Methods and Model Problem

Before starting this research, STREAM code had difficulty for the application of a LFR problem because of low accuracy of the upscattering calculation in a high-energy region. STREAM for LWR applications calculates the problem with a Hydrogen-based nuclear cross-section library and in order to improve the calculation speed, the nuclear cross-section resonance treatment processing in STREAM is performed only in the resonance energy region. Therefore, the deterministic code requires calculation of many energy groups considering upscattering for fast reactor core analysis. In addition, it is necessary to confirm the energy group structure for the fast reactor neutron spectrum and to newly produce upscattering correction factors for precise upscattering calculation.

In this research, the STREAM code for fast reactor analysis does not use resonance treatment, unlike for LWR cases. Since there is importance in the fast spectrum, and the energy group is ultra-fine in a fast reactor test, the resonance treatment is not necessary. PSM (Pin-based pointwise energy Slowing-down Method) for multi-group cross-section calculation is used in this research.

The STREAM cross-section library for the fast reactor case was constructed through the NJOY/NTOS code, in accordance with the ANL 1041 group structure and the ANL 2082 group structure used in the MC2-3, developed by the US Argonne National Laboratory, and the ECCO 1968 group structure used in the ERANOS 2.3 (instead of the 40-200 group structure generally used in the light water reactor analysis).

Each of the ANL 1041 and ANL 2082 group structures are divided into the same lethargy energy grid over the whole energy region. Nuclear data used for library generation was obtained from the ENDF/B-VII.0 library, and a sensitivity analysis was performed according to the group structure of the nuclear cross-section library.

For the sensitivity analysis, the design of the PASCAR (Proliferation-resistant Accident-tolerant Self-supported, Capsular and Assured Reactor) reactor, developed by Seoul National University, was adopted in the pin-cell problem. PASCAR reactors consist of rectangular fuel assemblies, unlike usual fast reactors which consist of hexagonal fuel assemblies. For the pin-cell case, the test was conducted by changing the enrichment degree of the nuclear fuel in the same geometry. The boundary condition is reflective and the pin pitch is 1.26 cm. For this analysis, the inner, middle, and outer pins have different fuel enrichments.

Table 1: LFR Pin-cell problem Specification

Pin	Material	Radius[cm]	Nuclide
Inner	Fuel	0.32606	U,Np,Pu,Am,Cm,Zr (U-Pu 3.33 w/o)
	Pb	0.36384	Pb
	Zr	0.37399	Zr
	HT9	0.45000	Cr,Mn,Fe,Ni,Mo
	LBE	-	Pb,Bi
Middle	Fuel	0.32606	U,Np,Pu,Am,Cm,Zr (U-Pu 6.35 w/o)
	Pb	0.36384	Pb
	Zr	0.37399	Zr
	HT9	0.45000	Cr,Mn,Fe,Ni,Mo
	LBE	-	Pb,Bi
Outer	Fuel	0.32606	U,Np,Pu,Am,Cm,Zr (U-Pu 9.37 w/o)
	Pb	0.36384	Pb
	Zr	0.37399	Zr
	HT9	0.45000	Cr,Mn,Fe,Ni,Mo
	LBE	-	Pb,Bi

Table 2: LFR Pin-cell problem calculation results comparison (STREAM 72, ANL 1041, ECCO 1968, ANL 2082)

LFR Pin	MCS		STREAM 72G(for LWR)		STREAM 1041G		STREAM 1968G		STREAM 2082G	
	k_{eff}	STD	k_{eff}	Diff. [pcm]	k_{eff}	Diff. [pcm]	k_{eff}	Diff. [pcm]	k_{eff}	Diff. [pcm]
Inner	0.95759	0.00004	0.99110	-3351	0.95559	-200	0.95695	-64	0.95672	-87
Middle	1.16190	0.00004	1.19004	–2814	1.15706	-484	1.15865	-325	1.15863	-327
Outer	1.33610	0.00004	1.35896	-2286	1.32934	-676	1.33103	-570	1.33099	-511

Table 3: LFR Pin-cell problem average calculation times comparison (STREAM 72, ANL 1041, ECCO 1968, ANL 2082)

LFR Pin	MCS		STREAM 72G(for LWR)		STREAM 1041G		STREAM 1968G		STREAM 2082G	
	time[sec]	core	time[sec]	core	time[sec]	core	time[sec]	core	time[sec]	core
Time	598	133	11	1	552	1	2046	1	2034	1
Total time with 1 core	79534		11		552		2046		2034	

The effective multiplication factors of the STREAM LFR nuclear cross-section library of ANL 1041, ANL 2082, and ECCO 1968 group are compared with the Monte Carlo core analysis code MCS. MCS is Monte Carlo code developed by UNIST. MCS can solve whole core depletion calculations and use a continuous energy, probability table method and S($\boldsymbol{\alpha}$,$\boldsymbol{\beta}$) for high accuracy of results. MCS shows high accuracy for both thermal reactors and fast reactors in various benchmark tests. In this research, 30 inactive cycles, 300 active cycles, and 300000 histories are used.

3. Results

3.1 Pin-cell problem

Table 2 compares the STREAM results with the MCS results. The scattering matrices of the 1041 and 2082 family libraries were all stored up to the P1 scattering cross-section matrix. As a result, the data size of the scattering matrix increases exponentially with the increase of the group structure. Therefore, even if only the scattering cross-section matrix is stored up to the P1 scattering matrix, the total data size of 50 nuclides of the 2082G library is 24 GB, and the time required to calculate the neutron transport equation is increased.

As shown in Table 2 and Table 3, the effective multiplication factor difference between MCS and STREAM is small for the inner pin (with the lowest enrichment), and the difference is largest for the outer pin (with high enrichment). The STREAM 72 group structure for LWR shows high accuracy for LWR applications, however it is not appropriate in for LFR applications. In comparison, the ANL 1041 group structure has a calculation time which is about 4 times faster, but it is less accurate (as much as 100~150pcm in comparison to the ANL 2082 group structure and ECCO 1968 group structure). Table 3 shows the average calculation time required for each problem. In MCS, it takes about 80000 seconds to calculate one core, and 552 seconds and 2034 seconds for 1041G and 2082G in STREAM, respectively.

Figure 1 shows the comparison of absorption reaction rate difference of the LFR pin problem results between STREAM (using the 1041G library) and MCS. The reaction rate in STREAM and MCS is low and the difference in reactivity is also 0pcm in the thermal energy region because the internal reaction rate of the LFR in the fast energy region is high. The difference in reactivity in the resonance region is very small, and overall, in the high energy region, the reactivity difference is due to a large difference in the effective multiplication factor. There is no large reactivity difference value (such as 100pcm) in the graph. However, since there are many energy groups having small reactivity difference, the total reactivity difference in the fast energy region is 460pcm when all reactivity differences are added.

As shown in figure 2, the overall reactivity difference from the STREAM 2082G library result is smaller than the overall reactivity difference from the STREAM 1041G library result. The reactivity difference between STREAM 1041G library and MCS is -484pcm while the reactivity difference between STREAM 2082G library and MCS is -327pcm.

Table 4: LFR assmebly problem calculation results comparison (STREAM 72, ANL 1041, ECCO 1968, ANL 2082)

LFR Assembly	MCS		STREAM 72G(for LWR)		STREAM 1041G		STREAM 1968G		STREAM 2082G	
	k_{eff}	STD	k_{eff}	Diff. [pcm]	k_{eff}	Diff. [pcm]	k_{eff}	Diff. [pcm]	k_{eff}	Diff. [pcm]
Assembly	1.14870	0.00004	1.17813	-2943	1.14412	-458	1.14560	-310	1.14565	-305

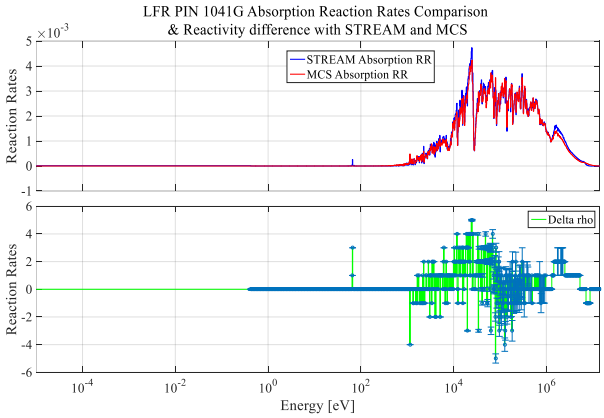

Fig. 1. Absorption Reaction Rates & Reactivity difference comparison of the middle pin-cell problem test results of STREAM(1041G Library) and MCS.(Whole energy region)

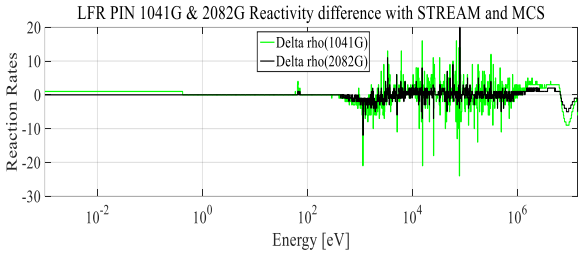

Fig. 2. Reactivity difference comparison of the middle pin-cell problem test results of STREAM(1041G Library & 2082G Library) and MCS.(Whole energy region)

3.2 Assembly problem

Figure 3 shows the assembly problem geometry for this research. In the assembly, the middle pin of chapter 3.1 is chosen as the fuel pin. The assembly contains a total of 7 control rods consisting of lead and zirconium. Coolant material is LBE. The assembly problem specification is below.

Table 5: LFR Assembly problem Specification

Assembly	Material	Radius[cm]	Nuclide
Fuel pin	Fuel	0.32606	U,Np,Pu,Am,Cm,Zr (U-Pu 6.35 w/o)
	Pb	0.36384	Pb
	Zr	0.37399	Zr
	HT9	0.45000	Cr,Mn,Fe,Ni,Mo
	LBE	-	Pb,Bi
Control rod	Pb	0.40500	Pb
	Zr	0.45500	Zr

As shown in table 5, the assembly problem shows a similar tendency as the pin-cell problem. The ANL 2082 and ECCO 1968 group structure results show higher accuracy than the ANL 1041 group structure results. The reactivity difference between STREAM 1041G library and MCS is -454pcm while the reactivity difference between STREAM 2082G library and MCS is -305pcm.

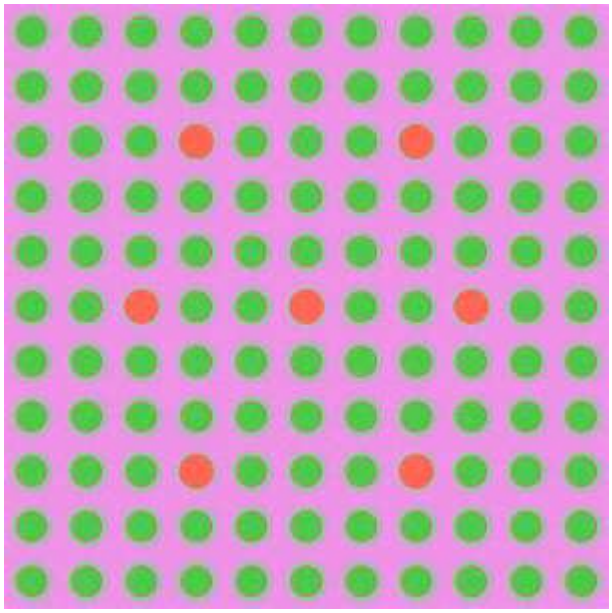

Fig. 3. Assembly Problem Geometry for the fast reactor

3. Conclusions

In this study, a pin-cell problem is analyzed by STREAM code and the nuclear reaction rates are compared by changing the group structure of the nuclear multi-group cross-section library of STREAM. The differences in the changes of the group structure are confirmed and the denser fine group structure has more accurate multiplication factor results. When the energy grid of the resonance energy region is miss-divided, the difference of the effective multiplication factor of the Monte Carlo code and the deterministic code can be large. Also, the accuracy of the effective multiplication factor changes, depending on the degree of enrichment, is a big problem. Therefore, it seems it would be necessary to apply an appropriate methodology and energy group for fast reactor analysis on STREAM code.

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