

MHTGR-350 Benchmark Calculation with ENDF/B-VIII.1 Multi-Group Cross Section Library using Library Correction System based on Various Correction Options

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) developed the DeCART2D/CAPP code system to perform nuclear core design for the high temperature gas-cooled reactor (HTGR) system using a two-step core analysis procedure [1–2]. The DeCART2D code conducts neutron transport calculations requiring a multi-group cross section library, which can be produced by the KAERI library generation system [3]. In this code system, a multi-group cross-section library is produced using ENDF/B-format evaluated nuclear data files, while resonance treatment is performed based on the resonance integral table (RIT) and the subgroup method.

However, the initially generated library contains errors compared to actual reactor core parameters because it assumes a typical neutron spectrum for multi-group collapsing. To reduce these errors and efficiently enhance the accuracy of the library, Kim and Park developed a library correction system [4]. The library correction system has been verified for conventional pressurized water reactors (PWRs); however, verification for HTGR systems has not yet been conducted. Due to the distinctive characteristics of the multi-group library for HTGR systems compared to PWR systems, such as group structure and temperature range, the performance of the library correction system needs to be verified for HTGR systems.

Meanwhile, the conventional KAERI library generation system is partially incompatible with ENDF/B-VIII.0 and ENDF/B-VIII.1 due to diversification of nuclear data and changes in data format. Since the Korea licensing authority recommends using the latest evaluated nuclear data, applying ENDF/B-VIII.1 to multi-group cross section generation is essential for future reactor core designs.

In this study, improvement of the conventional KAERI library generation system is conducted to apply ENDF/B-VIII.1. Afterwards, a 190-group cross section library is initially generated using the improved library generation system. Subsequently, library correction is conducted using MHTGR-350 fuel compact and fuel block problems as reference models, and the performance of the correction system for HTGR systems is verified. DeCART2D calculations for the MHTGR-350 benchmark problems using variously corrected libraries are also included to compare the effect of the reference model in library correction.

2. Methodology

2.1 Conventional KAERI Library Generation System

Fig. 1 illustrates the conventional KAERI library generation system. With this code system, a multi-group cross-section library for lattice transport calculations can be generated from ENDF/B-formatted raw data.

The ANJOY and ANJOYG codes generate NJOY input files for all user-defined nuclides, as well as batch scripts for automatic NJOY execution. The GREDIT and GREDITG codes read GROUPL and GAMINR output files from the NJOY code and produce multi-group cross-section files as a function of temperature and background cross section. The MERIT code reads BROADR output from NJOY to generate RIT as a function of temperature and background cross section. The SUBDATA code generates subgroup data to reproduce the resonance integral accurately.

Consequently, the LIBGEN code combines all data including decay, fission yield and delayed gamma production data for multi-group cross-section library generation.

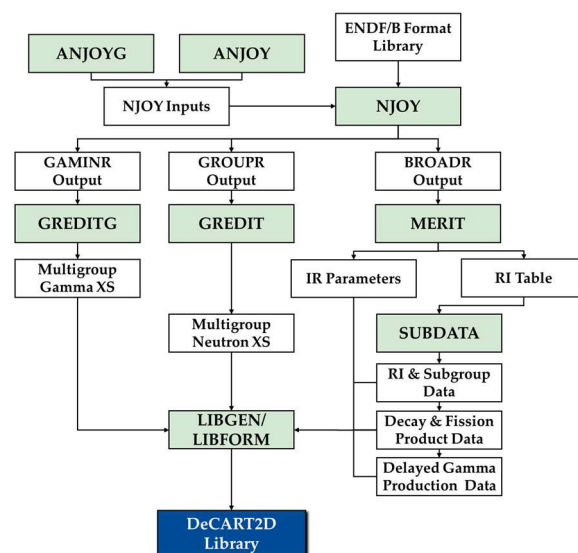


Fig. 1. The conventional KAERI library generation system

2.2 Library Correction System

The library correction system developed by Kim and Park performs library correction using group-wise correction factors shown by Equation (1).

$$f_{x,g,i}(T) = \frac{\sigma_{x,g,i}^{MC} \cdot \phi_g^{MC}(T)}{\sigma_{x,g,i}^{Lattice} \cdot \phi_g^{Lattice}(T)} \quad (1)$$

where $f_{x,g,i}(T)$ represents the correction factor as a function of temperature T , according to the reaction type x , the energy group g , and the nuclide index i . σ^{MC} and ϕ^{MC} represent the microscopic cross section and flux calculated by the Monte Carlo code, while $\sigma^{Lattice}$ and $\phi^{Lattice}$ are calculated by lattice code. In this code system, the McCARD code and the DeCART2D code are utilized as the Monte Carlo code and the lattice transport code, respectively.

The multi-group neutron cross section data and RIT are corrected using group-wise correction factors for all user-defined nuclides and neutron reactions. This correction procedure is performed repeatedly to ensure convergence of the correction factors. Consequently, high-fidelity Monte Carlo reaction rates can be reproduced in neutron transport calculations.

The library correction system includes CORRA, CORRXS, and CORRIT. The CORRA code calculates correction factors using the McCARD and DeCART2D calculation results. The CORRXS and CORRIT codes modify multi-group neutron cross-section data and RIT, respectively. This code system is incorporated into the conventional library generation system, as shown in Fig. 2.

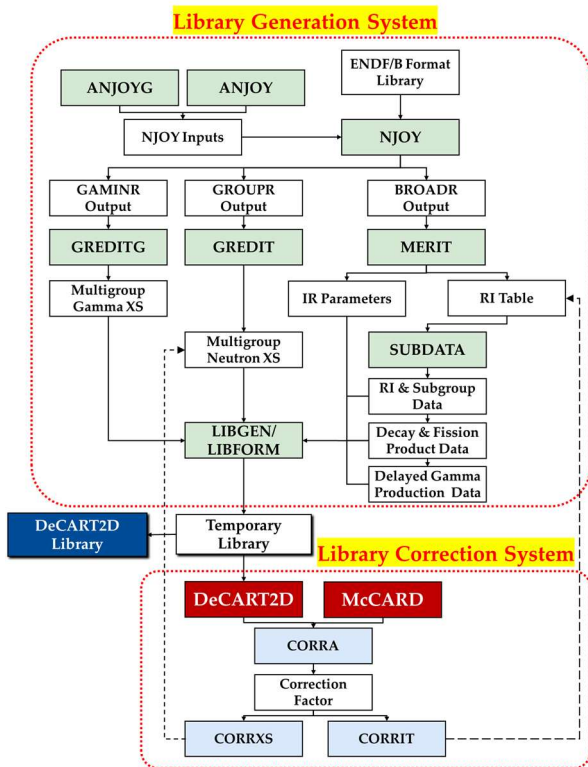


Fig. 2. Library generation system including library correction system

3. Generation of ENDF/B-VIII.1 Multi-group Cross Section Library

3.1 Improvement of KAERI Library Generation System for ENDF/B-VIII.1

To apply ENDF/B-VIII.1 to the KAERI library generation system, ANJOY and LIBGEN are improved in this study. As the NJOY code was updated to NJOY2016 to support ENDF/B-VIII.0 and later versions, the format of the NJOY input also changed. The improvement focuses on the ANJOY code to produce proper NJOY input files.

ENDF/B-VIII.1 also provides diverse formats of scattering radius data, which are used to calculate the potential cross section in LIBGEN. The improvement is conducted to properly read scattering radius data in diverse formats. Additionally, the FORTRAN formats are modified to properly read fission yield and decay data provided in ENDF/B-VIII.1.

3.2 Library Correction with Various Correction Options

The initial multi-group cross section library based on ENDF/B-VIII.1 is generated by the improved KAERI library generation system and is then corrected using the MHTGR-350 fuel compact and fuel block problems [7].

The fuel compact problem consists of UCO TRISO fuel particles which are packed with a packing fraction of 35%. Fig. 3 shows the configuration of the fuel compact problem.

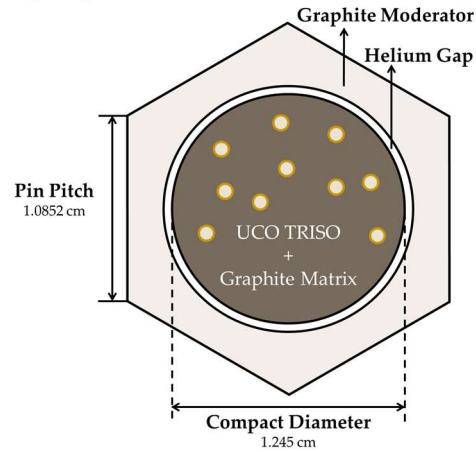


Fig. 3. Configuration of MHTGR-350 fuel compact problem

The fuel block problem consists of 210 fuel compacts and 6 burnable poison compacts. In the burnable poison compacts, B₄C BISO particles are packed with a packing fraction of 10.9%. The original MHTGR-350 benchmark problems consist of standard fuel blocks and fuel blocks with a reserved shut-down control hole. In this study, however, the fuel block problems are simplified to the FB35 and FB30 problems, which consist of fuel compacts with packing fractions of 35% and 30%, respectively. Fig. 4 shows the configuration of the fuel block problem.

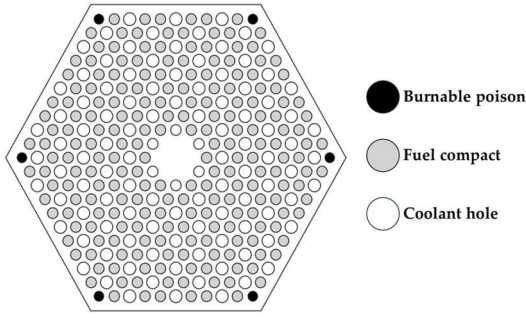


Fig. 4. Configuration of MHTGR-350 fuel block problem

With these reference models, library corrections were performed for five rounds of iterations and for six temperature points for uranium and boron: 300 K, 700 K, 1000 K, 1200 K, 1600 K, and 2000 K. Table I summarizes the correction options for each library correction. The UCR library indicates the uncorrected library, which is directly generated by the KAERI library generation system.

Table I: Summary of library correction options

Library ID	Correction Options	
	Reference model	Corrected nuclides
UCR	Uncorrected library	
LIB-COMP	Fuel compact	^{235}U , ^{238}U
LIB-FB35	FB35	^{235}U , ^{238}U , ^{10}B , ^{11}B
LIB-FB30	FB30	^{235}U , ^{238}U , ^{10}B , ^{11}B

Table II shows the changes in RMS errors of reactivity in each correction round for LIB-COMP, LIB-FB35 and LIB-FB30, which represent the library corrected using fuel compact, FB35 and FB30, respectively. The McCARD Monte Carlo code is used as a reference solution with less than 10 pcm of stochastic uncertainty in k_{eff} . The RMS errors are calculated as 1023 pcm, 1301 pcm and 1225 pcm with uncorrected library for fuel compact, FB35 and FB30 reference model, respectively.

Table II: RMS errors of reactivity for each round

Correction round	RMS errors in reactivity [pcm]		
	LIB-COMP	LIB-FB35	LIB-FB30
Uncorrected	1023	1301	1225
Round 1	162	59	35
Round 2	15	76	71
Round 3	30	33	54
Round 4	28	17	29
Round 5	25	37	27

The RMS error of reactivity is reduced to 25 pcm, 37 pcm and 27 pcm when the library corrections are performed for fuel compact, FB35 and FB30 problems, respectively. This suggests that the library correction system can improve the library that has a 190-group structure with wide temperature ranges for each reference model.

4. Benchmark Calculation Results

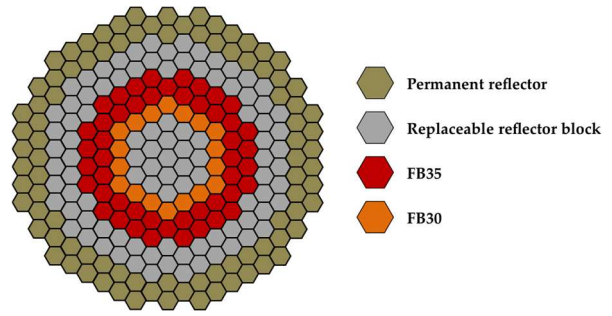


Fig. 5. MHTGR-350 2D core configuration

In this benchmark calculation, DeCART2D calculations for fuel compact, FB35, FB30 and 2D core problems are performed using LIB-COMP, LIB-FB35, and LIB-FB30. These results are compared with the McCARD Monte Carlo calculation results with less than 10 pcm of stochastic uncertainty in k_{eff} . The benchmark calculation is performed using 10 temperature points: 300 K, 400 K, 500 K, 600 K, 700 K, 800 K, 1000 K, 1200 K, 1600 K, and 2000 K, which include the temperature points used in library correction.

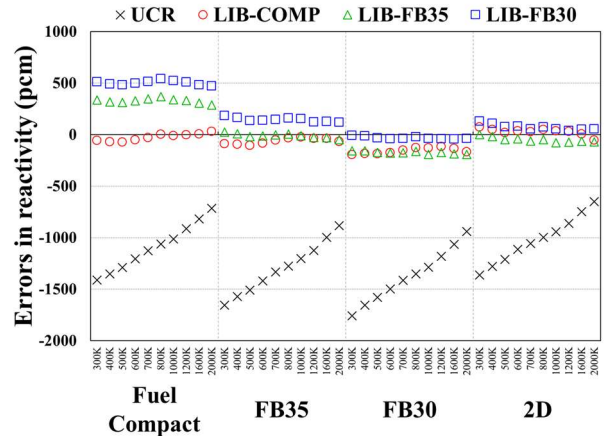


Fig. 6. Comparison of benchmark calculation results

Table III: RMS errors in reactivity of each benchmark results

Benchmark problem	RMS errors in reactivity [pcm]			
	UCR	LIB-COMP	LIB-FB35	LIB-FB30
Fuel compact	1113	42	328	502
FB35	1319	69	23	146
FB30	1395	159	176	34
2D core	1045	42	56	77

Fig. 6 and Table III compare the DeCART2D calculation results for each benchmark problem using the uncorrected and corrected library.

In the fuel compact problems, the RMS error in reactivity is 1113 pcm with the uncorrected library, while it is reduced to 328 pcm and 502 pcm with LIB-FB35

and LIB-FB30, respectively. With the LIB-COMP, the RMS error is reduced to 42 pcm. In the FB35 and FB30 benchmark problems, RMS errors in reactivity of 1319 pcm and 1395 pcm are calculated with the uncorrected library. The minimum RMS errors were calculated as 23 pcm for FB35 and 34 pcm for FB30 which are calculated using libraries corrected with same reference model. In the 2D core benchmark problems, the RMS error of 1045 pcm is reduced to 42 pcm, 56 pcm, and, 77 pcm for LIB-COMP, LIB-FB35 and LIB-FB30, respectively.

In these results, each benchmark problem corresponding to its reference model shows the minimum RMS error of reactivity while LIB-COMP shows generally accurate result for all benchmark problems. Also, all the corrected libraries show improved results in the 2D core problem.

5. Conclusion

In this study, a multi-group cross section library for the MHTGR-350 system is generated using the improved library processing system. The conventional library generation system is improved for ENDF/B-VIII.1 application. The initially generated 190-group ENDF/B-VIII.1 library is corrected using the library correction system with the MHTGR-350 system as a reference model. Consequently, the performance of the library correction system is confirmed, and the reactivity error is efficiently reduced for the reference model.

DeCART2D calculation results for the MHTGR-350 benchmark problems are also compared to the McCARD reference solution using the uncorrected library and the corrected libraries with various correction options. Each corrected library shows the improved results compared to uncorrected library. However, overfitting problems are observed, as each library shows the minimized errors for its corresponding benchmark problems compared to the other libraries.

From this perspective, optimization of the correction options and the reference model will be performed in future work. Furthermore, additional HTGR benchmark problems will be included in the library optimization to produce a library that can be applied to broader HTGR systems.

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