Transport Lattice Code KARMA 1.1

Kang-Seog Kim*, Ser Gi Hong, Jin Young Cho, and Jae Seung Song
Korea Atomic Energy Research Institute P.O. Box 105, Yuseong, Daejon, 305-333 Korea

**Corresponding author: kimks@kaeri.re.kr*

1. Introduction

Korea Atomic Energy Research Institute (KAERI) is developing a transport lattice code called KARMA (Kernel Analyzer by Ray-tracing Method for fuel Assembly) to be used in the nuclear design for the operating domestic PWRs. This program adopts MOC (Method Of Characteristics)[1] for the spatial discretization, a subgroup method[2] and a direct resonance table method for the resonance treatment, B1 method for the criticality spectrum, and exponential matrix method with Krylov subspace method for the burnup calculation. Multigroup libraries are provided by the KAERI library processing system. Although this program is based on LIBERTE[3] developed at KAERI, KARMA has been restructured and modularized for the future maintenance and code verification and validation. This code has been developed to satisfy all the requirements needed by the nuclear regulatory commission to be used in the operating PWR's. These requirements include the functional requirements, software design description, test plan, test report and user's manual.

2. Methods and Results

2.1 Library

Figure 1 shows the overall flow chart of KAERI library processing system to generate the KARMA library. Multi-group microscopic cross sections for all the nuclides are processed through the NJOY[4] code developed by Los Alamos national laboratory. These cross sections are reformulated to be used in the transport lattice code by GREIDT. Intermediate resonance parameters (λ) called hydrogen equivalent parameters and the resonance integral tables are generated by the MERIT code[5]. This code includes a solver for the ultra fine group slowing down calculation in the homogeneous and the heterogeneous 1-dimensional cylindrical geometries to obtain an effective resonance cross section from the fine group BROADR cross sections. This code also involves a solver to obtain the corresponding background cross sections to the effective resonance integral by using the method of characteristics and the interface current method. This code also includes a functionality to generate the hydrogen-equivalent parameters to be used in the resonance treatment. SUBDATA is to generate the subgroup data. The LIBGEN program is to assemble all the prepared data in a specified format, and to collapse the multi-group data into a smaller number of group data by using the given neutron spectra. The formatted KARMA library is converted into the binary one through the LIBFORM program.

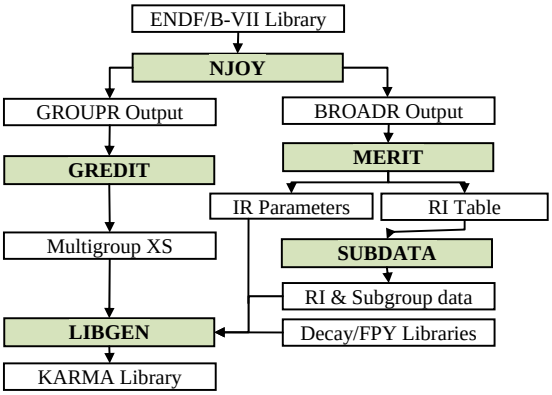

Figure 1. Flow chart for the library generation

2.2 Modules

KARMA is composed of 12 modules in which each module is working and being maintained independently. Commonly used variables and local variables used only in each module are separated and interface between modules are done only through the common variables. Figure 2 provides the flow chart of modules. INPT module is for the input processing, LIBR for reading library, GEOM for the geometry construction and ray tracking, MACR for the particle number densities and macroscopic XS, RESO to estimate the self-shielded XS, TRPT for the MOC transport calculation, CRIT for the criticality spectra, REFL for the reflector XS, BURN for the burnup calculation, EDIT to edit HGC file, and CASE for the branch calculations.

2.3 Methods

The KARMA code adopts MOC for the spatial discretization. This MOC is used for the resonance transport calculation to obtain the background cross sections to estimate the effective self-shielded cross sections, and for the transport eigenvalue calculations.

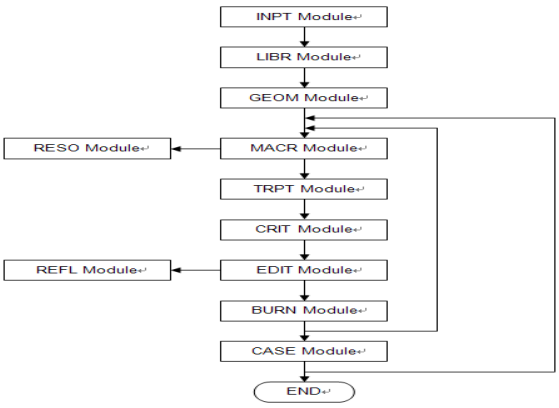

Figure 2. Flow Chart of Modules

The conventional coarse mesh finite difference (CMFD) acceleration is used to enhance the rapid convergence in the eigenvalue calculation by conserving the reaction rates in a coarse mesh. KARMA code can handle any type of PWR fuel assemblies and geometrical symmetries such as 1/1, 1/2, 1/4 and 1/8 symmetries.

Effective self-shielded cross sections are estimated by the subgroup method through the MOC transport calculation for the whole domain. Recently a new method has been implemented to estimate the self-shielded cross sections directly from the resonance integral tables.

Criticality spectra can be obtained through the B_1 method by homogenizing the whole domain. Local scalar fluxes are modified by the criticality spectra to consider the neutron leakage effect. The criticality spectra are used in obtaining few group constants and 1-g cross sections to be used in the burnup calculations.

Burnup calculations are performed by the exponential matrix method for which solution is obtained by the Krylov subspace method. Since the KARMA library includes the burnup chain and other data required for the burnup calculation, modification and improvement can be easily achieved without modifying the program source.

Typically the effective reflector cross sections are obtained from the transport calculation for the 1-D pin array core including fuel pin and reflector cell arrays. And the corresponding diffusion calculations are performed to obtain the discontinuity factors, and then the equivalence theory is applied. This procedure had been implemented in the REFL module.

KARMA provides the HGC (Homogenized Group Constants) file, which will be used to edit few group constants, power distributions and various data required for multi-dimensional diffusion core calculation.

2.4 Code Package

Figure 3 shows the nuclear design code package under development, in which the HGC file is reprocessed by PROLOG or XFORM to generate the group constant tablesets and the heterogeneous formfunctions. These tablesets and heterogeneous formfunctions will be used in the core calculation by using MASTER at KAERI or ASTRA at KNF.

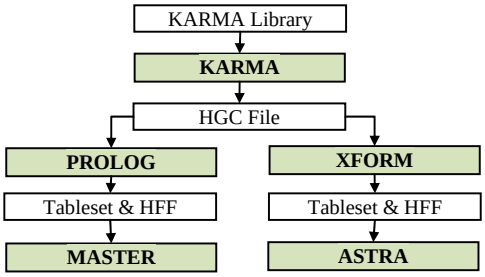

Figure 3. Nuclear Design Code Package

2.5 Verification and Validation

Other than programming design, test plans were established and tests have been performed for each module. Benchmark matrix has been setup and currently benchmark calculations are performed, which includes critical experiment, a comparison with the Monte Carlo calculations, and the world-widely well known benchmark problems. In parallel, core-follow calculations are being performed for the nuclear design license for the KARMA/XFORM/ASTRA code package at KNF.

3. Conclusion

A new transport lattice KARMA is under development according to the required procedures from the nuclear regulatory commissions. The KARMA program itself has been completed. However, since KARMA is strongly inter-related with the library and the core calculation codes, this program will be finalized after completing all the related verification calculations.

REFERENCES

[1] J. R. Askew and et al., "A general description of the lattice code WIMS," *J. British nucl. Energy Soc.* 5, 564-585 (1966)
[2] A. Khairallah and J. Recolin, "Calcul de l'autoprotection résonnante dans les cellules complexes par la méthode des sous-groupes," *Proc. Seminar IAEA-SM-154 on Numerical Reactor Calculations*, pp 305-317, I.A.E.A., Vienna (1972)
[3] Kang-Seog Kim and et al., "LIBERTE methodology," KAERI/TR-2304/02 (2002)
[4] R. E. MacFarlane, et al, "The NJOY Nuclear Data Processing System Version 91," LA-12740-M (1994)
[5] Kang-seog Kim, *et al.*, "MERIT Code Development for Generation of Intermediate Resonance Parameters and Resonance Integral Tables," (Submitted to 2006 KNS Spring Meeting)