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MASTER - An Indigenous Nuclear Design Code of KAERI

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Abstract

KAERI has recently developed the nuclear design code MASTER for the application to reactor physics analyses for pressurized water reactors. Its neutronics model solves the space-time dependent neutron diffusion equations with the advanced nodal methods. The major calculation categories of MASTER consist of microscopic depletion, steady-state and transient solution, xenon dynamics, adjoint solution and pin power and burnup reconstruction. The MASTER validation analyses, which are in progress aiming to submit the Uncertainty Topical Report to KINS in the first half of 1996, include global reactivity calculations and detailed pin-by-pin power distributions as well as in-core detector reaction rate calculations. The objective of this paper is to give an overall description of the CASMO/MASTER code system whose verification results are in details presented in the separate papers.

1. Introduction

Over the years a lot of nuclear design codes have been developed by venders around the world to estimate spatial power densities of nuclear reactors in various modes of normal reactor operations and abnormal conditions and have been applied to a great number of commercial reactors. For the purpose of nuclear design and analysis of PWR core, there are FASER/MEDIUM (Siemens)[1] DIT/ROCS (ABB-CE)[2] and PHOENIX/ANC (Westinghouse) code systems being used in Korea which have been provided in accordance with the technology transfer contracts associated with the localization program of fuel design and manufacturing. Although these code systems share the major features of solution methodology in common, they have some restrictions possibly leading to the code system modifications when they have to be applied to the core design of other vendor's reactors. It is, however, obviously difficult and inefficient that KAERI having little knowledge of detailed program structure and associated revision history makes independent revisions or updates of the code systems to fulfill new requirements. One of the new requirements, for example, is to respond the recent trends of software development characterized by multi-function software system with high accuracy, high speed and high versatility using consistent models derived from accurate first principles and a relational data base management system. Instead of building up maintenance capability for the existing code systems, KAERI has decided to develop an indigenous nuclear code system based on the accumulated reactor physics technology through the years of joint R&D program with leading vendors and more than ten years of experiences in nuclear design activities regarding WH, CE and FRAMATOM reactors. Due

to increasing uncertainty on the use of restricted computer codes such as ROCS and HERMITE after the expiration of Tech. Inducement Contract in May 1997, KAERI has recently put spurs to the development of indigenous design code systems, specially restricted codes, and has internally released the nuclear design code MASTER (Multi-purpose Analyzer for Static and Transient Effects of Reactor) to replace the nuclear code systems of ABB-CE being used in the pressurized water reactor (PWR) core design.

Prime functional and performance requirements of the MASTER code are to keep the prediction accuracy at least equivalent to existing code systems without using core dependent bias and to realize multi-function capability through integrating such functions as static core design, transient core analysis and operational support. The MASTER code also has to be applicable to all PWRs. For these requirements, the MASTER code employs advanced reactor physics methodologies, the state-of-the-art numerical solution methods and modern programming techniques.

2. MASTER Solution Methodology

MASTER is designed to calculate the steady-state and transient core behaviors in 3-dimensional full-, half- or quarter-core symmetric Cartesian geometry based on two-group diffusion theory. The major calculation categories for design application in MASTER consist of the calculation modules for depletion, steady-state flux, transient flux, pin power, pin burnup, xenon dynamics, adjoint flux, thermal hydraulics and design specific activities including fuel management. These modules are integrated to constitute the MASTER code package (see Fig. 1) so that the extra efforts usually required for interfacing or transferring data between different calculation modules are not necessary any more.

2.1 Neutronics Solution Methods

MASTER has three kinds of neutronic solution methods being most widely used: the nodal expansion method (NEM)[3], the nodal integration method (NIM)[4] and the coarse-mesh finite difference method (CFDM). It performs fuel depletion using microscopic cross sections produced by CASMO-3[5]. In order to preserve quantities of heterogeneous solution within assemblies it employs the simplified equivalence theory (SET)[6] introducing the heterogeneity factor. All constants required to deplete nuclides are fetched from CASMO-3 to keep consistency between the cell and dimensional codes. Exceptionally, however, the delta macroscopic cross section concept is used for control rods and the equivalent macroscopic cross section based on SET is provided for radial reflectors. The equivalent reflector cross sections[7] are provided beforehand through 1-dimensional modeling so that they can preserve all quantities of the response matrix elements in the heterogeneous geometry of the core-reflector interface region. This concept is extended to the L-shape reflectors by approximation of scattering cross sections. By using the flux-volume weighted cross sections the heterogeneous effects of partially inserted rod is considered to minimize the cusping effects in the axial direction.

2.2 Transient Module

The solution methods for the transient flux calculation module in MASTER are identical to those of steady-state flux calculation module except for the additional solution methods regarding time-discretization. For this purpose the implicit first order Euler method combined with frequency transformation is used. The transient flux calculation module predicts the core average power, T/H related quantities and detailed fuel pin powers for the rapid changes of reactor conditions such as control rod position, boron concentration, inlet mass flow, inlet temperature and pressure within a short time period. Any transient calculation can be started with an arbitrary convergent steady-state reactor core solution. In each time step, the sequence of neutronics followed by thermal hydraulics with the respective updating process is gone through once, then the transient time is advanced. Time step widths are automatically determined after checking of the behavior of relative changes of the neutronic and thermal-hydraulic solutions during time step.

2.3 Depletion Module

MASTER has the microscopic depletion module consistent to CASMO-3. It contains depletion modules[8] for fuel, burnable poison and fission product. MASTER uses the fully or semi weighted predictor-corrector method to minimize the errors coming from a relatively large time step. A constant predictor-corrector weighting factor is used for fuel and fission product. However, the weighting factor for burnable poison is internally determined considering thermal group microscopic absorption cross section behavior during depletion time step. Meanwhile, since the nodewise cross sections are generated through the flux and volume weighting with zero net current boundary condition, neglecting the large intranodal cross section gradients induced by depletion and thermal feedback leads to a deterioration of accuracy of the modern advanced nodal methods. Thus the burnup correction model is included to take into account the spatial dependence of the cross sections in solving the equivalent 1-dimensional diffusion equation for the transverse integrated flux.

2.4 Thermal Hydraulic Module

MASTER has two kinds of thermal hydraulic (T/H) calculation modules which can be switched on depending on problems: One is to use for simple T/H calculations the fuel temperature versus linear power density table. And the other is to apply the detailed T/H code, COBRA3-C/P[9], for steady-state and transient thermal analysis of rod bundle nuclear fuel elements which is intrinsically integrated in the code. Even though the simple table might be accurate enough to estimate T/H conditions for the normal steady-state operation, COBRA3-C/P can be used to simulate the more sophisticated transient reactor conditions in view of thermal hydraulics.

2.5 Pin Power Calculation Module

MASTER calculates the local heterogeneous fuel pin power distributions in each axial segment within

fuel assembly by modulation of the local homogeneous distributions based on the Method of the Successive Smoothing with Improved Analytic Solution (MSS-IAS)[10] and the heterogeneous power form factors. These pin power distributions are served to yield the axially integrated pin powers.

2.6 Pin Burnup Calculation Module

The detailed fuel pin burnup is accumulated using the pin powers in a similar fashion to the node burnups so that the burnup formfunction is not required. During depletion calculation the pin power from the previous case is weighted with the pin power from the present case to yield the average pin power for this depletion step. Since the burnup is proportional to the power integration over time, the pin burnup increase is directly calculated by multiplying the node average burnup increase by the pin-to-node power ratio. This change is then added to the existing pin burnup.

2.7 Xenon/Samarium Dynamics Module

During reactor operation the reactor core can be placed in a slow transient state induced by load follow operations. Using the xenon dynamics module in MASTER such a behavior can be traced by solving iteratively the time-dependent iodine/xenon and the promethium/samarium differential equations with the steady-state flux solution process. The iteration process is performed until the flux shapes and their concentrations are converged.

2.8 Adjoint Module

In addition to the steady-state solution an adjoint module has been included in MASTER. This module calculates the adjoint flux with the precalculated steady-state solution and the kinetic parameters such as effective delayed neutron fractions, delayed neutron precursor decay constants and prompt neutron life time.

2.9 Numerical Solution Methods

The vectorized Gauss-Seidel method is used to obtain the neutronic solution. The iterative process to obtain the solution is accelerated by the well-known multi-grid coarse mesh rebalancing (CMR) procedure. As an additional acceleration procedure the asymptotic extrapolation is employed for the acceleration of the neutronics solutions for the partial currents, the transverse leakages and the neutron fluxes.

2.10 Input/Output Structure

The input structure is implemented to realize an easy use and design automation. The input cards are identified by group and block names. The groups are classified depending on the characteristics of data. Each group has several blocks corresponding their functions. The output structure is designed

to generate the files and data for both CE and WH design procedures. The Input and output files are as follows:

Input Files	: MAS_INP	- Main Input
	MAS_XSL	- Microscopic Cross Section Library
	MAS_HFF	- Heterogeneous Formfunction Library
	MAS_RST	- Restart File
Output Files	: MAS_OUT	- Main Output
	MAS_SUM	- Output Summary
	MAS_RST	- Restart File
	MAS_PPI	- Pin-by-pin Information File

3. Summary

In response to the growing needs to have an indigenous code system in Korea, KAERI has developed a core simulator over the years which is aimed to be applicable not only to the conventional PWR core design but also to the on-line core supervisory system. The core simulator employed advanced reactor physics methodologies, the state-of-the-art numerical solution methods and modern programming techniques to realize 3-D on-line pin-by-pin power mapping with design quality accuracy. However, the development of indigenous nuclear design code system became more important for KAERI than the core simulator due in part to the controversy between ABB-CE and KAERI on the use of so-called "restricted computer codes" such as ROCS and HERMITE after the expiration of technology transfer contract in May 1997.

On the basis of the calculational models and program structure of core simulator, the indigenous nuclear code system MASTER was expeditiously developed by adding functional modules necessary for static core design. The indigenous code MASTER as is implied by the name is capable of performing multi-function such as static design and transient analysis by using the same calculational models and the consistent data base. CASMO-3 from Studsvik was selected as a cell code, and was linked with MASTER by the interface program XFORM. As a result of intensive efforts, alpha version of MASTER was internally released for the verification and validation in October 1995.

Since the internal release in KAERI, the validation of CASMO/MASTER has been performed for IAEA code benchmark problems and conducted with an emphasis on items related to the conventional design activities covering the predictions of low power physics test, boron letdown and reaction rate distributions for conventional PWRs. Those results will be in details presented in the separate papers[11,12,13,14] with their specific topics. The results to date indicate that the CASMO/MASTER system has a level of accuracy sufficient for the PWR core design and analysis without using any posterior bias. The whole spectrum of validation will be completed in the next months to submit the Uncertainty Topical Report to KINS in the first half of 1996.

References

1. H. J. Winter, S. Merk, "Code Manual MEDIUM," SIEMENS/KWU Technical Report U6521/88/E331, December, 1988.
2. R. Loretz, et. at., "User's Manual for ROCS - Coarse Mesh Diffusion Theory Neutronics Code," CE-CES-4 Rev. 4-P, December, 1989.
3. H. Finnemann, H, Raum, "Nodal Expansion Method for the Analysis of Space-time Effects in LWRs," Proceedings of a Specialists' Meeting on Calculation of 3-Dimensional Rating Distributions in Operating Reactors, Paris, November, 1979.
4. H. D. Fischer, H. Finnemann, "The Nodal Integration Method - A Diverse Solver for Neutron Diffusion Problems," Atomkernenergie 39, 229, 1981.
5. M. Edenius, B. Forssen, "CASMO-3 User's Manual," STUDSVIK/NFA-89/3, November, 1989.
6. K. Koebke, "A New Approach to Homogenization and Group Condensation," IAEA Technical Committee Meeting on Homogenization Methods in Reactors Physics, IAEA-TECDOC-231, Lugano, 1978.
7. K. B. Lee, Y. J. Kim, B. O. Cho, C. O. Park, "Verification of Equivalent Radial Reflector Cross Sections by Using CASMO3 for PWR Core Design," CASMO User's Meeting, Feb. 22-24, 1995.
8. C. H. Lee, Y. J. Kim, "An Adaptation of the SAV Standard Nuclide Chain for the CASMO3/MEDIUM3 Procedure," Journal of the Korean Nuclear Society, Vol.26, No.2, June, 1994.
9. R. E. Masterson, L. Wolf, "COBRA III-P: An Improved Version of COBRA for Full Core Light Water Reactor Analysis," Nuclear Engineering and Design 48, 293, 1978.
10. R. Boeer, H. Finnemann, "Fast Analytical Flux Reconstruction Method for Nodal Space-time Nuclear Reactor Analysis," Ann. Nucl. Energy, Vol.19, No.10-12, 617-628, 1992.
11. J. S. Song, K. S. Kim, K. B. Lee, J. H. Park, S. Q. Zee, "Uncertainty Evaluations of CASMO-3/MASTER System for PWR Core Neutronics Calculations, " Proc. of the KNS Spring Mtg, Cheju, May 1996.
12. D. C. Jung, Y. S. Jung, B. O. Cho, J. H. Park, C. O. Park, "RIA 해석을 통한 MASTER 코드의 신뢰성 검증, " Proc. of the KNS Spring Mtg, Cheju, May 1996.
13. Y. S. Park, B. O. Cho, C. H. Lee, Y. S. Jung, C. O. Park, "Verification and Application of MASTER for Load Follow Operation, " Proc. of the KNS Spring Mtg, Cheju, May 1996.
14. K.S. Kim, J. S. Song, S. K. Zee, "CASMO-3/MASTER Pin Power Benchmarking for the B&W Critical Experiments, " Proc. of the KNS Spring Mtg, Cheju, May 1996.

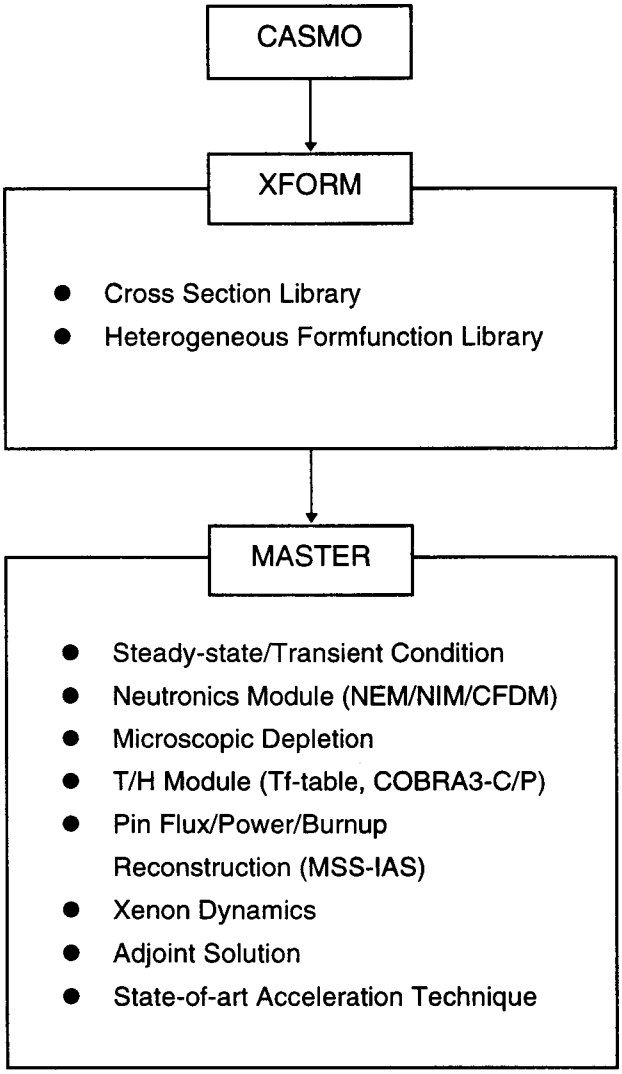

Figure 1 Overall Structure of CASMO/MASTER