Generation of 3-D Power Distribution Synthesis Library for SMART Core Monitoring System

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) has developed a System-integrated Modular Advanced ReacTor (SMART) for a seawater desalination and electricity generation. Online digital core monitoring system for SMART was developed as a part of plant monitoring system. The system is called SMART Core Monitoring System (SCOMS). SCOMS is one of the application programs executed in the information processing system. It calculates the Limiting Condition for Operation (LCO) with measurable process variables and provides related information to the operator.

A Power Connection Method (PCM3D) for 3-D power distribution synthesis was developed, and its implementation to SMART core was evaluated [1, 2].

In this paper, SCOMS library was newly generated with 365MWh core power, and the library was verified with reference power distributions.

2. Methodology and Library Generation

The two-step procedure based on DeCART2D [3] and MASTER4.0 [4] code system for the nuclear design has been developed by KAERI. The transport lattice calculations are performed by DeCART2D code to generate few-group cross sections appropriately averaged over a fuel assembly through flux volume weighting and heterogeneous form functions for the reconstruction of pin information. The cross sections are tabularized as a function of burnup, soluble boron concentration, fuel temperature and moderator density. The nodal diffusion calculations are performed by MASTER code with the tabularized cross sections. In this section, methodology and library generation are described.

2.1 3-D Power Synthesis

This study aims to generate 3-D power distribution library for SCOMS. This library contains Power Sharing Factor (PSF), Power Connection Factor (PCF), etc. Instrumented node power is determined by using a power sharing factor and power connection factors are used for calculating the undetected node power. Instrumented node means a neutronics node of assembly where an in-core detector is installed. A detected node power can be calculated as shown in Eq. 1. k' and k are axial indices for the detector and the neutronics node, and l is the radial index for neutronics node. Furthermore, the superscript "d" means the detected power.

$$P^d_{l,k} = \frac{1}{w_k}\sum_{k'} F_{l,kk'} P^d_{l,k'} \tag{1}$$

where,

$P^d_{l,k}$ = Detected node power at node (l,k)

$P^d_{l,k'}$ = In-core detector power of detector unit k'

$F_{l,kk'}$ = PSF from detector k' to node k $\left(\approx \frac{w_{kk'} P^C_{l,k}}{P^C_{l,k'}}\right)$

w_k = $\sum_{k'} w_{kk'} \quad (w_{kk'} = h_{kk'}/h_k)$

h_k = height of detector unit k'

$h_{kk'}$ = height of plane k included in detector unit k'

The relation between the in-core detector node and neutronics node and the weighting factor are used for the calculation of power sharing factor. The exact power sharing factor cannot be determined if all neutronics power are not directly detected by using in-core detectors. Therefore, an approximated power sharing factor ($F^C_{l,kk'}$) was used. Here, the superscript C means the calculated value by neutronics code.

An undetected node power can be determined using the neighboring powers and 3-D power connection factor is defined by the ratio of the power of a node (l,k) to the power average of the neighboring nodes as in Eq. 2. The exact 3-D power connection factor cannot be determined for the same reason as power sharing factor. So, an approximated 3-D power connection factor ($C^C_{l,k}$) was used as follow:

$$C_{l,k} \approx C^C_{l,k} = \frac{1}{P^C_{l,k}(N_l + N_k)}\left(\sum_{j=1}^{N_l} P^C_{j,k} + \sum_{j=1}^{N_k} P^C_{l,j}\right) \tag{2}$$

A node power is determined from the neighboring node powers using the 3-D power connection factors.

$$C^C_{l,k}(N_l + N_k)P_{l,k} - \sum_{j\in U} P_{j,k} - \sum_{j\in U} P_{l,j} = \sum_{j\in I} P^d_{j,k} + \sum_{j\in I} P^d_{l,j} \tag{3}$$

Where, groups U and I mean the un-instrumented and instrumented node groups, respectively. N_l and N_k are the number of neighboring nodes in the radial and the axial directions. This equation can be solved by an iterative scheme and then 3-D power distribution can be determined [2].

2.2 PREPCM3D

MASTER and PREPCM3D codes are used to 3-D power distribution library. As shown in Fig. 1, MASTER code is used as a function of burnup, core power and control rod position. Cross section library, heterogeneous form function library and MASTER's input files are used in MASTER code to generate MASTER's output file which will be used in PREPCM3D code.

PREPCM3D is a preparation code to generate 3-D power distribution library for SCOMS. The output files required by SCOMS contain information of neutronics, detector signal of core and reference power distribution.

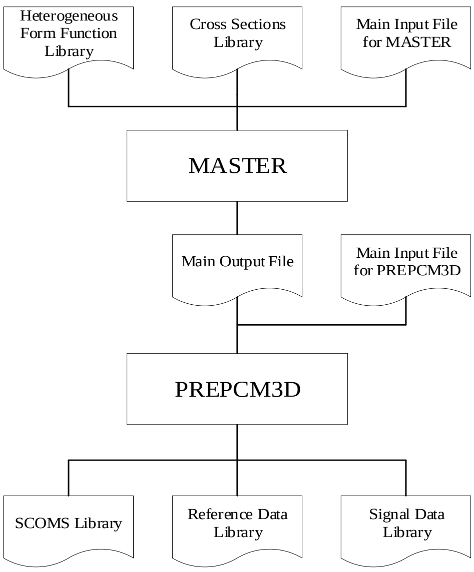

Fig. 1. SCOMS 3-D power distribution library flowchart

2.3 PCM3D

Verification used to ensure SCOMS library is valid. The program code used in this verification is called PCM3D code. As shown in Fig. 2, flowchart for PCM3D code contains configuration of core file, information of neutronics file, detector signal of core file and reference power distribution file. PCM3D code generates output files which contain comparison between MASTER and 3-D method of synthesis [2].

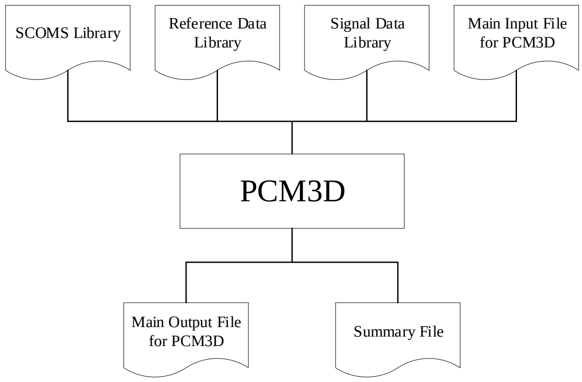

Fig. 2. PCM3D flow chart

3. Verification

In this section, library generation and results are introduced as follow:

3.1 Library Generation

Coefficients for 3-D power synthesis are provided in the form of library (look-up table) and those are generated as a function of burnup, core power, and total travel length. As to the reference 1, 2-power points (100% and 30%) are selected in generation of library. Burnup interval is determined based on the depletion step of neutronics code. The Total Travel Length (TTL) is defined as Eq. 4, and summation of total movement of regulating groups which are moved in a programmed sequential pattern. About more than 4,000 cases for library are generated. If core power, burnup, and TTR are determined, coefficients are automatically searched from library with linear interpolation method in SCOMS.

$$TTL = \sum_{l=1}^{NREG} R(l) \qquad (4)$$

where,

TTL	=	Total travel length (cm)
l	=	Regulating group index
$R(l)$	=	Regulating group position (cm)
$NREG$	=	Number of regulating group

3.2 Results

Fig. 3 and Fig. 4 show node power errors results from PCM3D code. Burnup, core power and total travel length play major factors to calculate node power error. The results are reference node power compared with calculated node power. There is no differences node power error at 30% core power. The maximum node power error is 0.03%.

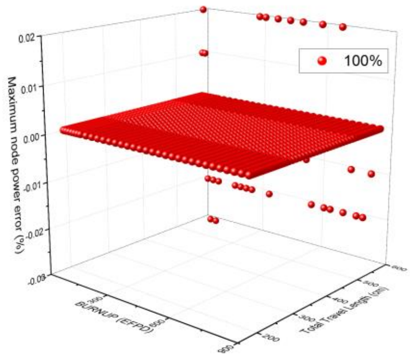

Fig. 3. Maximum node power error versus burnup and total travel length at core power 100%

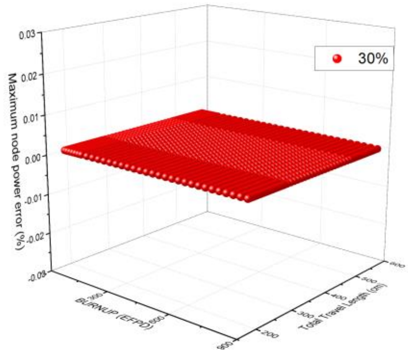

Fig. 4. Maximum node power error versus burnup and total travel length at core power 30%

4. Conclusions

Library of 3-D power distribution synthesis was generated for SCOMS in this study. From the result of MASTER code, the library data for 3-D power distribution synthesis were generated by using PREPCM3D code. The output of MASTER code should contain in-core signals and 3-D power distribution. If it doesn't contain in-core signals, it will be generated by using power distribution in PREPCM3D code. The library test was performed by using PCM3D program that synthesized 3-D power distribution. At the test result, PCM3D program was judged to have similar results as the reference solutions at all base points in the library. Also, it is judged that results for generating PSF, PCF, etc. will be implemented in SCOMS. Therefore, the library produced and properly verified to synthesize the 3-D power distribution.

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REFERENCES

[1] J. Y. Cho, et al., "3D Power Synthesis Methodology for SMART Core Monitoring System", KAERI/TR-3399, 2007.
[2] B. S. Koo, et al., "Evaluation of 3-D Power Distribution Synthesis Method for SMART Core Monitoring System", Transactions of KNS Autumn Meeting, Gyeonju, Oct. 27, 2011
[3] J. Y. Cho, et al., "DeCART2D v1.1 User's Manual," KAERI/UM-40/2016, 2016.
[4] J. Y. Cho, et al., "MASTER v4.0 User's Manual," KAERI/UM-41/2016, 2016