A Sensitivity Study of the HTGR PROTEUS Benchmark using the VSOP94 Code Package

Chang Je Park, Jae Man Noh, Hyung Kook Joo, Jonghwa Chang
Korea Atomic Energy Research Institute, P.O. Box 105, Yuseong, Daejeon, Korea, 305-600
cjpark@kaeri.re.kr

1. Introduction

Among the Generation-IV Reactors, the high temperature gas cooled reactor (HTGR) is attractive due to its high temperature heat source for hydrogen production. This study deals with some calculation results of the PROTUES benchmark problem of which the fuel is a pebble type. The PROTUEUS experiment was planned under the framework of an IAEA Coordinated Research Program (CRP) and started in January 1990.[1,2] The PROTEUS facility at the Paul Scherrer Institute (PSI) in Switzerland was composed of the low-enriched, fuel pebbles and reached its first criticality around July 1992. The VSOP94 code package is used to simulate the PROTEUS benchmark problem with various mesh sizes, energy groups, and streaming effect corrections of the pebble-bed fuel. The sensitivity analysis of the various calculation options of the VSOP94 code[3] is presented in this study.

2. Methods and Results

The detail parameters of the PROTEUS benchmark problem are well described in Ref. 2. The calculational meshes (batches, layers, and spectrum zones) are taken from the previous calculation done by Noh et al.[4]. The variations of the mesh size division are 2x2, 4x4, 6x6, 8x8 per core region (~ $10.5\times13.5cm^2$). The explored energy groups are the 2, 4, and 6 groups. The streaming effect of the pebble bed fuel[5] is also considered. In this section, some of the simulation results are described for the cases of various mesh sizes, energy groups, and streaming effect corrections.

2.1 Mesh Size

In the VSOP94, the 2-dimensional calculation is done by the CITATION subroutine which performs the finite difference diffusion calculation. Therefore, the effect of the mesh size is one of the important factors in the diffusion calculation. TABLE I shows the multiplication factors obtained by the VSOP94 code for the PROTEUS benchmark. As expected, the effective multiplication factors slightly increase as the mesh size becomes smaller. It also shows the convergence behavior of the effective multiplication for the mesh size. However, it has to be noted that the fine mesh calculation needs a long computing time and a huge computer memory. Thus, appropriate computational acceleration algorithms should be implemented for the future HTGR code systems.

2.2 Energy Group

The discretization of an energy group is another factor for the calculation accuracy in the HTGR calculation. If the homogenization is performed equivalently without any approximation, all the results of the diffusion calculations should be same. Unfortunately, the pebble-bed fuel has a naturally stochastic distribution and it is difficult to obtain the equivalent homogenized cross section. That is a main reason for the calculation difference for the various discrete energy groups as shown in TABLE I. As the energy group becomes fine, the multiplication factors slightly decrease.

2.3 Streaming Effect

To compensate for the existence of a vacancy around the pebbles in the fuel, the streaming effect is corrected by Liberoth and Stojadinovic[5]. If this streaming effect is not considered, the reactivity is overestimated because it is assumed that some material is filled around the pebbles. From the results, it is objerved that the streaming effect reduces the effective multiplication factors. Thus, the streaming effect should be considered for the pebble-bed type HTGR. It is also important that the upper cavity of reactor should be compensated by following the method of Gerwin and Scherer[6].

Figure 1 shows the power density distribution of the PROTREUS core with 4 energy groups with the mesh division of 8x8. Because there is no fuel shuffling, the power is high in the upper core and decreases almost linearly to the axial direction.

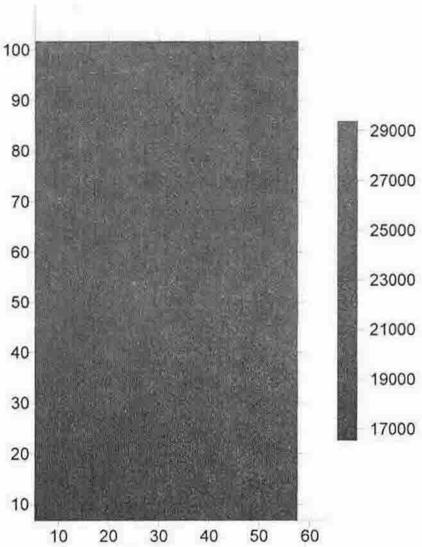
3. Conclusion

A simulation of the PROTEUS benchmark is performed with the VSOP94 code system. It is found that there are several parameters that have to be considered in the HTGR core calculation. The mesh size should be fine enough for the diffusion calculation. The discrete energy group also should be fine. However the computer memory and computing time should also be considered in choosing both parameters. The streaming effect should be considered to compensate for the effect of a vacancy around the pebbles in the HTGR core. It is expected to develop a more robust code system to provide a better accuracy for the HTGR core calculation.

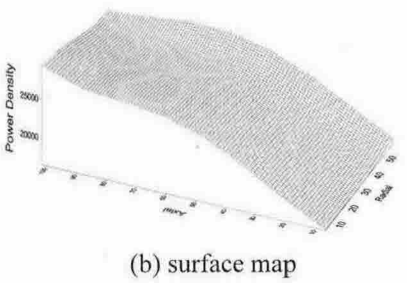
TABLE I. Effective Multiplication Factor

Energy Group	2x2 (5.3cm)[c]	4x4 (2.6cm)	6x6 (1.8cm)	8x8 (1.3cm)
2[a]	1.0372 (2.22 %)[d]	1.0401 (2.50 %)	1.0409 (2.58 %)	1.0416 (2.65 %)
4[a]	1.0145 (-0.02 %)	1.0177 (0.30 %)	1.0190 (0.42 %)	1.0199 (0.51 %)
6[a]	1.0071 (-0.75 %)	1.0106 (-0.40 %)	1.0118 (-0.29 %)	1.0128 (-0.19 %)
2[b]	1.0467 (3.15 %)	1.0484 (3.32 %)	1.0493 (3.41 %)	1.0498 (3.46 %)
4[b]	1.0230 (0.82 %)	1.0263 (1.14 %)	1.0270 (1.21 %)	1.0277 (1.28 %)
6[b]	1.0157 (0.10 %)	1.0189 (0.41 %)	1.0197 (0.49 %)	1.0205 (0.57 %)

[a] witht streaming effect, [b] without streaming effect
[c] radial mesh size, [d] relative error
* Multiplication factor of experiment results : 1.0147.



(a) contour map



(b) surface map

Figure 1. Distribution of the power density of the PROTEUS core.

REFERENCES

[1] Critical Experiments and Reactor Physics Calculations for Low-Enriched HTGRs, *IAEA TECDOC 1249*, 2001.

[2] D. Mathews, T. Williams, LEU-HTR PROTEUS System Component Description, PSI, *TM-41-93-43*, 1996.

[3] E. Teuchert et al., "VSOP('94) Computer Code System for Reactor Physics and Fuel Cycle Simulation," FZJ Internal Report, *Jul-2897*, 1994.

[4] J.M. Noh et al., "A Preliminary Conceptual Design for a 150 MWth Pebble Bed Reactor Core Using the VSOP94 Code Package," Korea Nuclear Society Spring Meeting, May 2003, Gyeong-ju, Korea, 2003.(CD-ROM)

[5] J. Lieberoth, A. Stojadinovic, "Neutron Streaming in Pebble Beds," *Nucl. Sci. Eng.*, **76**, 336, 1980.

[6] H. Gerwin, W. Scherer, "Treatment of the Upper Cavity in a Pebble-Bed High-Temperature Gas-Cooled Reactor by Diffusion Theory," *Nucl. Sci. Eng.*, **9**, 246, 1987.