INL/CON-06-11435
PREPRINT

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American Nuclear Society Annual Meeting

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June 2006

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U.S. Department of Energy
National Laboratory
operated by
Battelle Energy Alliance

Idaho National Laboratory

PBMR 400 COUPLED CODE BENCHMARK: CHALLENGES AND SUCCESSES WITH NEM-THERMIX

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INTRODUCTION

The Pebble Bed Modular Reactor (PBMR) is one of the High Temperature Gas-cooled Reactor (HTGR) concepts currently under analysis by various research groups. The Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) is supporting the development of a Coupled Code Benchmark for the PBMR 400 in order to promote the development of current analysis tools [1].

This paper discusses some of the benchmark results and the difficulties that arose during the analysis with the transient analysis code NEM-THERMIX [2]. On-going work and investigations are also outlined in the paper with a view to finally resolve some issues associated with the code modeling and to introduce several improvements in the code system.

THE NEM-THERMIX COUPLED code

Developed at Penn State, the code combines the nodal expansion 3-D diffusion solver NEM with the R-Z thermal-hydraulics code THERMIX-DIREKT. NEM is a 3-D multi-group nodal code used at PSU for modeling both steady state and transient core conditions. It utilizes a transverse integration procedure and is based on the partial current formulation of the nodal balance equations. The code has options for modeling of 3-D Cartesian, cylindrical and hexagonal geometry.

The Thermix-Direkt code calculates in cylindrical *(r,z)* co-ordinates, the temperature distribution in the pebble-bed due to heat transport by conduction, radiation and convection (natural and forced), given the power distribution and coolant flow conditions. The code can perform both steady-state and transient calculations. Relations for (for example) the conduction or heat transfer coefficients in the pebble-bed are partly empirical, partly exact with fitted parameters [3]. These relations have been validated by numerous experiments with the AVR test reactor which date back into the seventies. In addition, tests with non-nuclear pebble-beds in the seventies and eighties have also been utilized in order to validate the code. Over the years, Thermix-Direkt has been used and validated for core thermal hydraulics, and has been coupled with other neutronics codes such as Panther to perform transient analysis of a few HTR designs, e.g the Dutch ACACIA design, the German HTR-Modul [5,6] among others. Similarly, NEM has previously been coupled with other thermalhydraulics codes e.g. TRAC, but this was mainly for LWR analysis.

DESCRIPTION OF THE ACTUAL WORK

The PBMR 400MW OECD Benchmark Problem forms the basis of the work presented here. In the Benchmark definition as defined in [1], analysis of a steady-state standalone neutronics (referred to as Exercise 1) and steady-state standalone thermalhydraulics (referred to as Exercise 2) is required for all participants. A common set of cross sections is generated with the VSOP code [4] is also supplied to all participants. A joint effort by INL and PSU to analyze the benchmark problem employed the use of NEM-THERMIX code as described above.

During the analysis of the steady state stand-alone neutronics case several negative values of the fast flux were encountered in the top, bottom, and other peripheral locations of the side reflector region. The cause of the problem was initially attributed to the treatment of boundary conditions. Sensitivity studies to better understand these nodalization effects in the NEM code were performed and a full spectrum of the results of these sensitivity studies will be presented at the meeting in June.

Another effect currently under investigation is a significant increase in the k-eigenvalue observed when the helium channel and core barrel are modeled. The location of these interfaces suggests additional problems with NEM solutions in the peripheral locations.

The NEM-THERMIX code was originally used for the analysis of the PBMR268 MWth design. Several changes were necessary to model the PBMR 400MWth. The code was modified to ensure versatility in the future.

SOME RESULTS OF MODELLED CASES

The results from the nodalization sensitivity studies indicate that, for equally sized nodes in the side reflector, there is a transition node size between the very coarse and the finer node sizes for which the polynomial approximation of the transverse leakage generates non-physical solutions of the flux in the peripheral locations as shown in Table 1.

Table 1 Negative fast flux values appear in the bottom axial nodes after halving the last node

	100	106	119	200
100	8.565E+12	3.287E+12	1.497E+12	8.715E+10
131.8	1.437E+14	3.851E+13	1.375E+13	5.397E+11
163.6	1.579E+14	4.659E+13	1.697E+13	6.840E+11
195.4	1.440E+14	4.360E+13	1.604E+13	6.632E+11
227.2	1.223E+14	3.746E+13	1.380E+13	5.730E+11
259	9.921E+13	3.062E+13	1.129E+13	4.703E+11
290.8	7.849E+13	2.435E+13	8.992E+12	3.754E+11
322.6	6.185E+13	1.930E+13	7.137E+12	2.992E+11
354.4	4.943E+13	1.589E+13	5.893E+12	2.476E+11
386.2	4.018E+13	1.403E+13	5.133E+12	2.095E+11
418	2.963E+13	1.021E+13	3.663E+12	1.457E+11
468	3.383E+12	1.336E+12	6.146E+11	3.464E+10
518	-1.386E+15	-1.351E+15	-1.977E+15	-9.021E+14

The node size where the negative fluxes disappear has been linked to the fast diffusion coefficient in the reflector region. Because this is a two-group problem the fast diffusion coefficient was chosen as the most relevant parameter for the relationship since it governs the diffusivity of neutrons through the reflector region. The maximum node size in the reflector region for NEM was found to be thirteen times the fast diffusion coefficient. For unequally sized nodes in the side reflector, this issue is circumvented by making the size of the outermost node in the side reflector 2-3 times that of the adjacent node.
The value of keff increases from 1.00066 without the helium channel and the core barrel to 1.02629 when these peripheral locations are modeled. Figure 1 shows the shift in the axial fast flux profile that occurs when helium channel and without the core barrel are modeled.

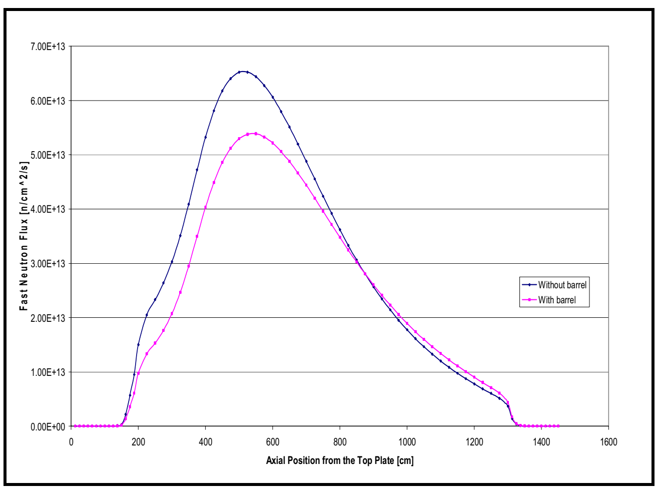

Figure 1 Axial fast flux profile with and without the helium channel and core barrel

It is suspected that the solution in the peripheral locations has not fully converged. How these solutions affect the fast flux profile is still being investigated.

Conclusions

The major objective of this paper is to present the challenges posed by certain features of the PBMR 400MWth design to the currently used nodal coupled code system NEM-THERMIX. Certain interesting physics challenges to the code are observed and the apparent deficiencies of the code in handling this reactor type are being addressed.

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