BR2 REACTOR CORE STEADY STATE AND TRANSIENT MODELING

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ABSTRACT

A coupled neutronics/hydraulics/heat-conduction model of the BR2 reactor core is under development at SCK • CEN. The neutron transport phenomenon has been implemented as steady state and time dependent nodal diffusion. The non linear heat conduction equation inside fuel elements is solved with a time dependent finite element method. To allow coupling between functional modules and to simulate subcooled regimes, a simple single-phase hydraulics has been introduced, while the two-phase hydraulics is under development. Multiple tests, general benchmark cases as well as calculation/experiment comparisons demonstrated a good accuracy of both neutronic and thermal hydraulic models, numerical reliability and full code portability. A refinement methodology has been developed and tested for better neutronic representation in hexagonal geometry. Much effort is still needed to complete the development - extended cross section library with kinetic data and two-phase flow representation.

1 Introduction

The BR2 reactor is the most important SCK•CEN's facility. It was operated during the past 35 years in the framework of many international programs concerning the development of structure materials and nuclear fuels for the various types of nuclear fission reactors and for fusion reactors. The qualities and particular performances of the reactor also designated it for performing experiments aiming to demonstrate the safety of nuclear cores.

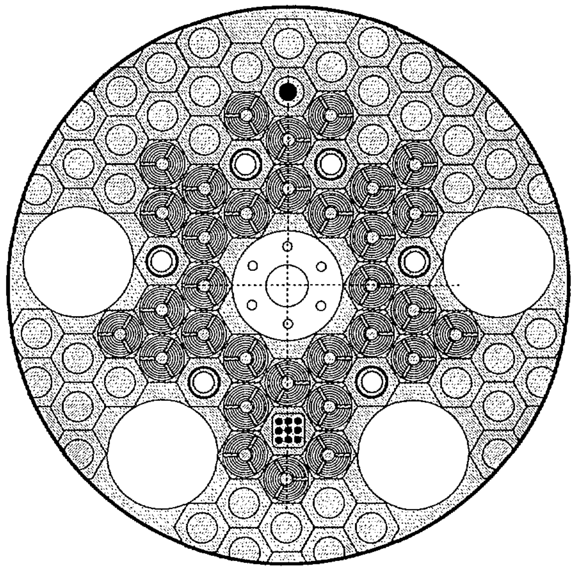

Figure 1: BR2 core cross section at mid plane

During a reactor installation life there is always a need to be able on the one hand to predict global reactor behavior to ensure the safe operation and on the other hand to go deeper in details and look for subtle characteristics. To fulfill these requirements we develop an analysis tool dedicated to BR2 both for daily routine and studying of particular parameters of interest.

This BR2 model is based on advanced mathematical approaches and in conjunction with carefully prepared data of nuclear, thermal and hydraulic characteristics covers: i) normal operational and accidental regimes, ii) classical BR2 assemblies and new type fuel under development, iii) startup homogeneous and burnt heterogeneous core loads.

2 BR2 home code

Globally the model consists of following modules:

Neutronic calculation - nodal 3D diffusion, multigroup, perturbation theory, direct implicit and improved quasi static kinetics. The calculations of the macroscopic cross-sections have been carried out using the MULCOS [9] and SCALE [10] systems. Fuel elements and control rods are represented in one-dimensional cylindrical geometry with taking into account neighboring elements. For a while all calculations have been performed for fresh fuel at 323 ^{o}K. Collapsing has been done from 40 to 2 energy groups (MULCOS) and from 238 to 2 groups (SCALE).

Heat conduction - 3D Cartesian and cylindrical finite element, implicit kinetics.

Hydraulics - axial channel-by-channel description, today: single phase, future: two-phase flow six-equation model with near implicit scheme.

Coupling aspects.

Native integration, modularity, adequate representation of physical phenomena with internal feedback reduce uncertainties in our model. Three dimensions, near implicit time integration yield high fidelity results.

Programming.

Single code, special reactor description language and autonomous output plotting make it friendly and independent in use. The code is written in Fortran 90 and demonstrated full portability on personal computers, work stations and super calculators.

3 Results

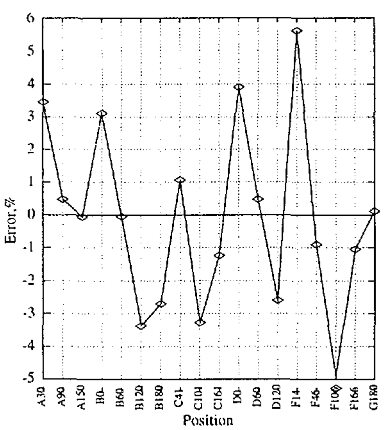

Figure 2: Subassembly power relative error. Reference - MCNP.

The functional modules have been tested separately and in coupled mode on a wide range of problems. Neutronic model comparisons where produced against BR2 monte-carlo simulation (Fig.2) and WWER-1000 validated codes.

To test the implementation of the method we made run different known benchmark cases and simplified BR2 models. Some results are reproduced in Table 1.

The heat conduction calculations have been compared with available analytical solutions and the HEATIG7.2 code results. Fully coupled model produces values close to experiment and independent numerical estimates (Fig.3).

Case	Takeda			SNR	WWER-1000
	rod-in	rod half-in	rod-out	HEX-3D	HEX-2D
code/source	HEXNOD	HEXNOD	HEXNOD	DIF3D-N	NSE Reference
K_{eff}	0.85425	0.96305	1.07792	1.01151	1.11226
BR2 Homecode	0.86155	0.96842	1.07767	1.01766	1.11067

Table 1: K_{eff} benchmarks

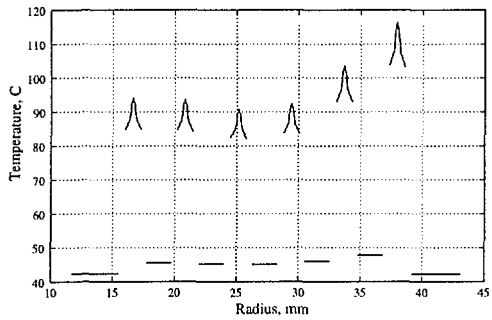

Figure 3: Example of radial temperature distribution in a BR2 fuel element.

4 Quasi refinement - new approach

In classical deterministic reactor core modeling every hexagonal element is often represented as a radially homogeneous prism. The internal heterogeneous structure and the element neighborhood are treated during macroscopic cross section calculation. To include the heterogeneity in the entire core model we need to apply either an extremely fine mesh grid all over the reactor or to refine the region of interest. While in academic geometry $(x, y, z \,/\, r, \theta, z \,/\, r, \theta, \phi)$ the refinement is quite straight forward, in hexagonal geometry it requires an additional mathematical methodology (triangular subgrid, conform transformations, ...). Moreover, new cross sections must be introduced into fine meshes.

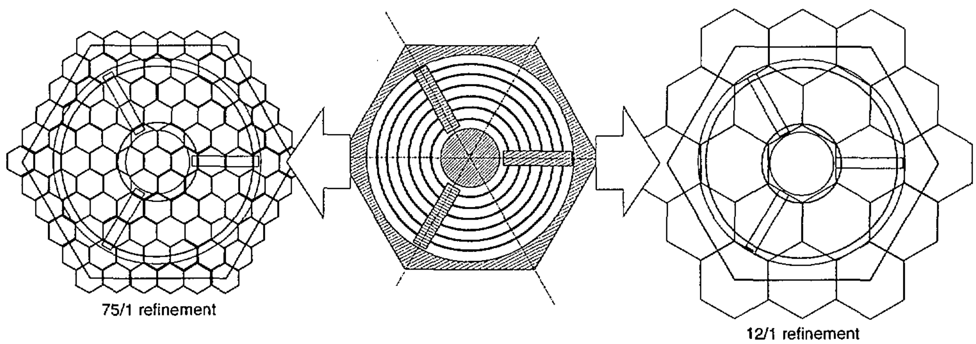

Figure 4: 75/1 and 12/1 quasi refinements.

Taking into account the particular BR2 nature we developed a quasi refined model. The idea is to apply the regular hexagonal grid with finer lattice pitch and to make cover each cell more or less homogeneous region (Fig.4). We tested two grids 12/1 and 75/1, (number of fine hexagons equivalent to 1 coarse area). Both of those models demonstrated excellent numerical stability and physical results. For example, the

75/1 refinement yields peak thermal and fast fluxes surprisingly close to measurements (see flux shapes Fig.5).

Refinement	Rings	Plane nodes	K_{eff}
1/1 (no refinement)	7	127	1.086
12/1	22	1387	1.096
75/1	59	9919	1.126

Table 2: Plane nodes number (42 axial planes) and K_{eff} from quasi refinement tests.

This approach has a number of advantages and disadvantages. The positive point is that it allows to go to a detail level close to the realistic without modification of neither method nor code. Since the fine hexagons cover almost homogeneous regions, the procedure of homogenization is of less importance for macroscopic cross section calculation. The negative point is that it can be applied only to the entire core leading to an important number of nodes (Table.2) even in homogeneous regions where it may be not required.

The results of such a refinement will depend on the reactor type and on the numerical method. The tests prove that for BR2 the nodal hexagonal diffusion is suitable approximation.

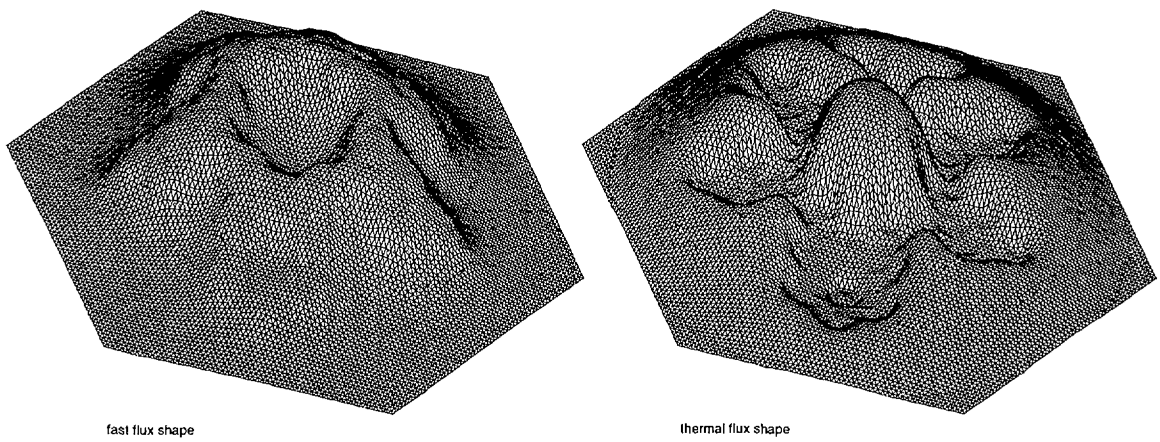

Figure 5: BR2 flux shape at hot plane

5 Conclusions

Such a tool offers to the BR2 analysis group a high flexibility in the reactor core management and studying of physical parameters.

The actual activities are concentrated on the two-phase hydraulics and development of extended cross section library both for refined and non refined models. To complete this tool we will need also to include the isotopic evolution - fuel burnup and poison. Advanced computing may be required to achieve a fine level of numerical simulation.

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