Validation of Finite Difference Core Diffusion Calculation Methods with FEM and NEM for VVER-1000 Mwe Reactor

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ABSTRACT

India is developing several in-house fuel management codes for the design evaluation of VVER-1000 MWe reactors, being built at Kudankulam, Tamil Nadu in collaboration with Russian Federation. A lattice burnup code EXCEL provides the few group lattice parameters of various fuel assembly types constituting the core. The core diffusion analyses have been performed by two methods. In the first method the entire fuel assembly is treated as a single homogenized cell. Each fuel assembly cell is divided into $6n^2$ triangles, where 'n' is the number of uniform divisions on a side of the hexagon. Regular triangular meshes are used in the active core as well as in surrounding reflector regions. This method is incorporated in the code TRIHEXFA. In the second method a pin by pin description of the core is accomplished by considering the few group lattice parameters generated by EXCEL code for various fuel and non-fuel cells in each fuel assembly. Regular hexagonal cells of one pin pitch are considered in the core and reflector regions. This method is incorporated in HEXPIN code. Both these codes use centre mesh finite difference method (FDM) for regular triangular or hexagonal meshes. It is well known that the large size of the VVER fuel assembly, the zigzag structure of the core-baffle zone, the distribution of water tubes of different diameter in this baffle zone and the surrounding steel and water layers of different thickness, all lead to a very complex description of the core-reflector interface. We are analyzing the VVER core in fresh state by two other approaches to obtain independent benchmark reference solutions. They are finite element method (FEM) and nodal expansion method (NEM). The few group cross sections of EXCEL are used in the FEM and NEM analyses. The paper would present the comparison of the results of core followup simulations of FD codes with those of FEM and NEM analyses.

Key words: VVER core, pin by pin burnup code; finite element method, Nodal expansion method, validation.

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1. Introduction

The VVER-1000 Mwe reactor core of Kudankulam (KK) Project is a PWR of Russian design. Indigenous capability to perform incore fuel management of these reactors has been developed. This capability is also essential for an in-depth review of the physical characteristics under various steady state conditions and for analyses of slow (xenon) and fast transients of the KK core.

Indigenous lattice burnup code EXCEL [1] has been developed for homogenization of hexagonal fuel assembly cells as in the KK core. EXCEL uses the 172 group WIMS cross section library obtained as part of WIMS Library Update Project (WLUP) from IAEA [2]. It is based on a combination of one-d multigroup transport and 2-D diffusion methods. The transport simulations consists of one-d solutions for various pincell types, followed by supercell simulations for each of the heterogeneities like water cell, absorber cells of boron type, burnable absorber rods (BAR) or control cells. Few group lattice parameters in five or two energy groups are generated as a function of burnup, boron, coolant and fuel temperatures, xenon loads etc. They are available for assembly cell as well as individual pincell or other absorber cells of the assembly. Reflector material cross sections are also obtained by EXCEL code by auxiliary calculations.

Core diffusion analyses are performed by TRIHEXFA [3] or HEXPIN [4] codes. In TRIHEXFA analysis, each hexagonal assembly cell can be divided into small triangular meshes. An auto-triangularisation procedure allows $6n^2$ triangles to be considered in a hexagonal assembly cell, where 'n' is the number of uniform divisions on a side of the hexagon. Triangular centre mesh FD scheme is used for obtaining flux distribution. Power dependent feedback is applied to account for space-dependent xenon, coolant and fuel temperature loads.

The code ‘HEXPIN’ has been developed for core follow-up analysis using a pin-wise description of the entire core. The same regular hexagonal mesh grid expands into the reflector regions up to pressure vessel. The massive input to HEXPIN code has been simplified by superposition of fuel assembly layout description with the material specifications within each fuel type, as given to EXCEL code. The alternate ring layers of steel and water up to pressure vessel are treated as hexagonal cells within the annular radii of such regions and are automatically identified by the code.

2. Brief Description of the KK Core

The KK core consists of 163 FAs. Each fuel assembly has 331 locations. Of which 311 are fuel pins, 18 are locations for control or BARs or water cells and there are two water cells, one at the centre and another one for incore instrumentation thimble. Fig.1 gives a schematic diagram of KK fuel assembly. Fig.2 gives the schematic diagram of $1/4^{th}$ core and the surrounding reflector zones. The complex regions of core baffle, surveillance thimbles, core barrel, thermal shield and pressure vessel present a major problem in FD codes using regular meshes. At present they are accounted by some average steel-water fractions. It is planned to obtain a more precise value of steel water

fractions by rigorous analytical evaluations in every triangular/hexagonal mesh of these regions in TRIHEXFA/ HEXPIN simulations.

3. Solution by More Sophisticated Techniques

In order to obtain benchmark reference solutions for the design tools of KK core, we have undertaken analysis of the fresh VVER core with two other methods. One approach is three dimensional finite element method. In the FE code 'FINERC' [5, 6], it is possible to use a combination of rectangular and triangular meshes. There is a special feature simplifying the input for the active core region. The description of all the triangles as available from the TRIHEXFA code is readily processed to give the vertex coordinates of all the triangular elements in the active core. Subsequently, the core baffle, water tubes and annular rings of steel and water are described separately by suitable triangular elements. These two sets of information are then knit to get the data mapped on to a single global frame of reference. The geometrical description in FEM is superior to that of FD codes.

As a second approach, we have developed a code 'HEXNEM' based on the nodal expansion method proposed by Lawrence [7]. Fourth order polynomials in hexagonal right prismatic meshes are considered.

Few group cross sections generated using EXCEL code, are used in both FEM and NEM analyses.

4. Preliminary Results

In this abstract we present some of the results of analyses by FD codes. Detailed comparison with other sophisticated tools will be presented in the full paper.

The lattice parameter database was generated with EXCEL code for 11 fuel types considered in KK core up to eight fuel cycles. In TRIHEXFA analysis, each hexagonal assembly cell was divided into 24 triangular meshes. Power dependent feedback corrections are applied only in TRIHEXFA analysis. Eight fuel cycles have been analyzed. Plots of calculated critical soluble boron values and 3-D peaking factors are given in Figs. 3 and 4. The calculated critical boron was obtained with a uniform k_{eff} normalization of 0.996 for all eight fuel cycles. It is seen that the soluble boron is nearly zero at the end of every fuel cycle. Fig 5 gives the comparison of 2-D relative power distribution in $1/6^{th}$ core as obtained by TRIHEXFA and HEXPIN codes for KK Cycle-1 core at beginning of cycle. For this reactor state, the pin-wise peak factors obtained by HEXPIN code within each FA are given in Fig.6. Fig.7 depicts a picture of the fast flux distribution (E > 9.118keV) as calculated by HEXPIN.

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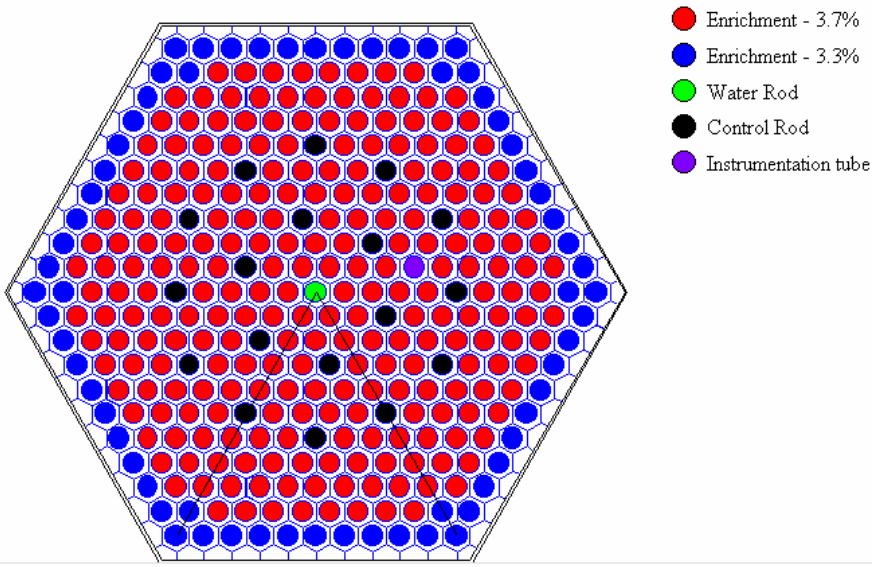

Fig.1 Schematic Diagram of Fuel Assembly of KK Core

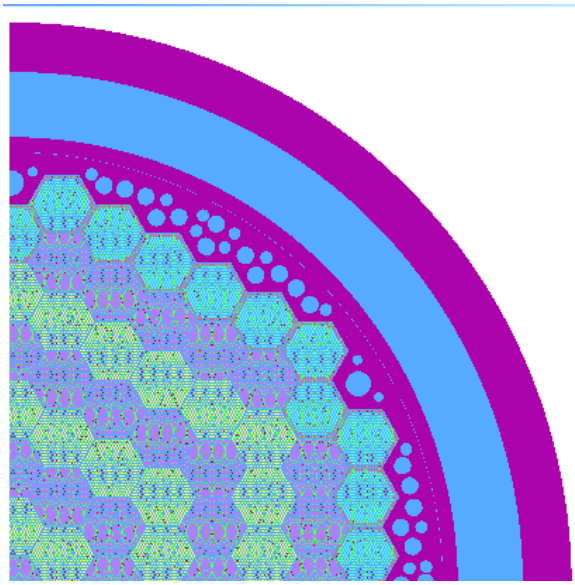

Fig.2 Schematic Diagram of 1/4th KK Core

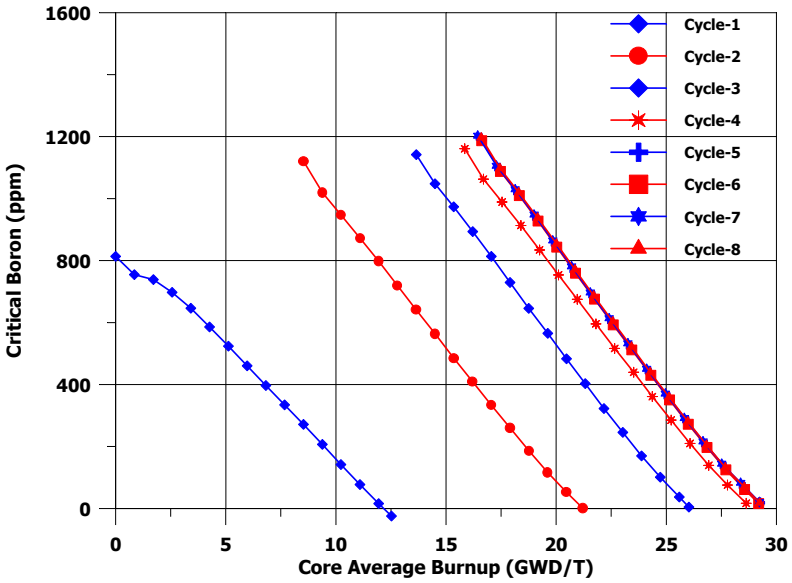

Fig.3 Critical Soluble Boron for 8 Fuel Cycles Calculated by TRIHEX-FA Code

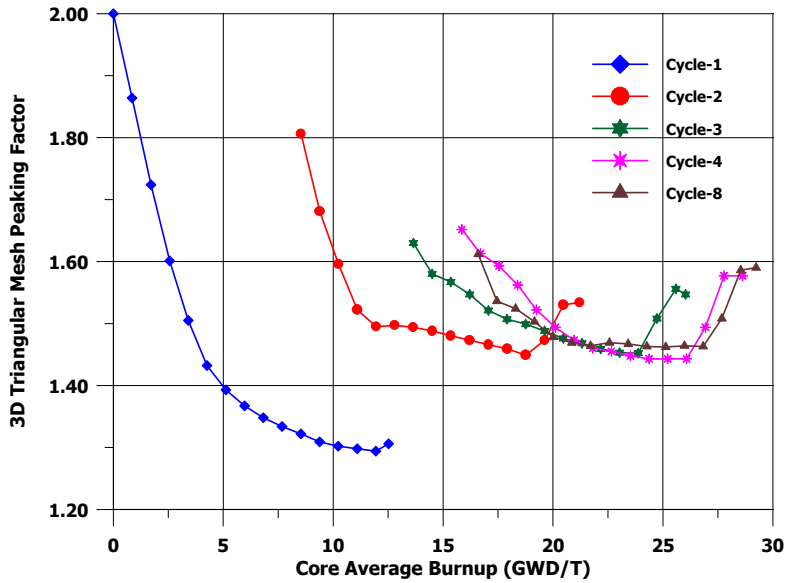

Fig.4 3D Triangular Peaking Factor Values for 8 Fuel Cycles Calculated by TRIHEX-FA Code

927 TRIHEXFA
849 HEXPIN
1181 1130
1162 1111
871 1054 1186
876 1042 1209
894 903 1242 1186
900 919 1275 1209
849 1075 903 1054 1130
875 1112 919 1042 1111
989 849 894 871 1181 927
1019 875 900 876 1162 848
1113 885 1090 810 872 909 1106
1173 924 1142 833 871 898 1037
Core
Centre

Fig.5 Comparison of Assembly Power Distribution in 1/6th Symmetric Core Calculated by TRIHEXFA (24 triangles/Hexagon) and HEXPIN Codes - KK Core Beginning of Cycle-1

1285
1264 1481
947 1283 1581
1147 984 1400 1581
928 1254 999 1283 1482
1237 939 1147 945 1285 1285
1272 986 1224 895 1127 964 1460
Core
Centre

Fig.6 Peak Pin Power (Relative) in 1/6th Symmetric Core Calculated by Pin by PIN Simulation Code HEXPIN – KK Core Beginning of Cycle-1

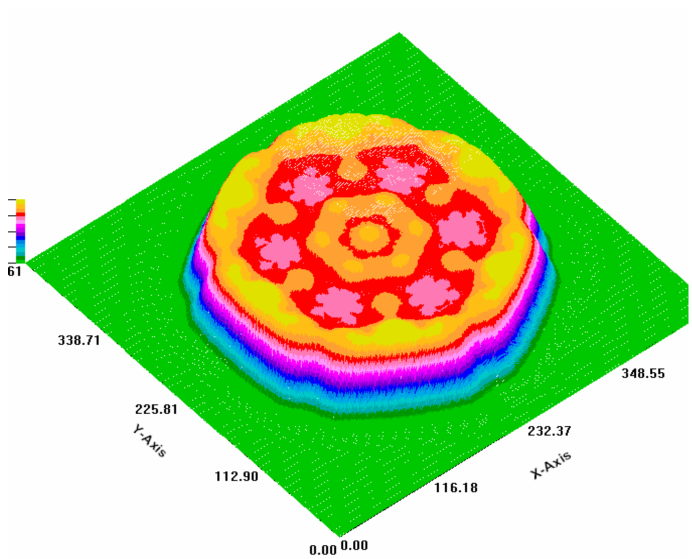

Fig.7 Fast Flux Distribution Calculated by Pin by PIN Simulation Code HEXPIN