EVALUATION OF HIGHER K-MODES OF AHWR-LEU CORE AND ESTIMATION OF NEUTRON FLUX AT IN-CORE DETECTOR LOCATIONS

Sudipta Samanta\textsuperscript{a*}, K.P. Singh\textsuperscript{b} and Umasankari Kannan\textsuperscript{a}

\textsuperscript{a}Reactor Physics Design Division, Bhabha Atomic Research Centre, Trombay, Mumbai–400085, India
\textsuperscript{b}MP&RThS, Bhabha Atomic Research Centre, Trombay, Mumbai–400085, India

Email: sudiptas@barc.gov.in
Email: kpsingh@barc.gov.in

ABSTRACT

The Advanced Heavy Water Reactor LEU (AHWR-LEU) is a boiling light water cooled heavy water moderated reactor utilizing thorium based fuel. It has several passive safety features such as negative coolant void coefficient of reactivity and passive decay heat removal. The neutronic and thermal hydraulics is expected to be strongly coupled in the reactor core. A perturbation in the coolant conditions can give rise to power oscillations. Also the AHWR-LEU reactor core has a very large diameter. Slow xenon induced oscillations are possible in AHWR-LEU due to perturbation in reactor operation. The neutronic de-coupling of the reactor could lead to excitation of higher harmonics. It is very important to monitor the detailed spatial neutron fluxes. On-line flux mapping through SPNDs is one such measurement approach in power reactors. In an earlier simulation the fluxes at the detector locations were calculated for the AHWR reference core. Presently, the core had been redesigned with (Th-LEU) MOX fuel. In this simulation, the positions of the in-core instrumentation have not been changed. The LEU variant of the Advanced Heavy Water Reactor called AHWR-LEU has been designed to have on-line flux monitoring with the help of SPNDs using 59-Co, 51-V or Platinum clad Inconel as the sensor. The neutron flux at those detector locations were calculated using the Transport Theory Code ATES3.

Keywords: AHWR-LEU, SPND, K-modes, Flux Mapping System

INTRODUCTION

The Advanced Heavy Water Reactor is a thorium fuelled boiling light water cooled vertical pressure tube type of reactor using natural convection for heat removal [1]. AHWR is designed to monitor the space dependent neutron flux profile in the core by means of several self-powered neutron detectors (SPNDs) of the on-line flux mapping system. It is possible to get a fairly good estimate of 3-D core neutron flux distribution or flux map from these in-core SPNDs in order to provide control function. The neutron flux at the detector locations were estimated for the AHWR core fuelled with (Th, LEU) core from transport theory Code ATES3 [2]. It is seen that AHWR-LEU core exhibits a slightly bottom peaked flux distribution. For development of mode based on-line flux mapping system it is imperative to compute the higher harmonics of the Neutron Diffusion Equation. The equilibrium core has been simulated by Neutron Diffusion Theory code KINFIN to find the higher K-modes. Ten k-modes and corresponding eigen-values were estimated with Subtraction Technique. These simulations will be used to optimize the detector locations and also provide basic inputs for design of the detectors. AHWR-LEU is a large core with H/D ratio of about 0.72. Linear stability analysis was done and it was found that the eigen-value separation of the first azimuthal mode is about 15mk. This would in turn generate higher harmonics of the flux which require monitoring and controlling. The fundamental eigenvalue and eigenfunction have been evaluated by Power Iteration method. For obtaining the successive higher modes, the contribution of already determined modes is eliminated one by one using the subtraction technique. The bi-orthogonality relations between the direct and adjoint eigenvectors are used for this purpose.
DESCRIPTION OF AHWR-LEU CORE

The AHWR-LEU core consists of 513 lattice locations in a square lattice pitch of 22.5 cm with 444 occupied by fuel locations. The reactivity devices are housed in 69 locations. Among the 69 locations for the reactivity devices, 45 locations are used for locating Shutoff Rods (SORs). The equilibrium core is fuelled with fuel assemblies designated as composite clusters or D5 clusters. This cluster consists of a circular array of 54 fuel pins. The inner and intermediate array of 12 and 18 pins contain of 30% and 24% LEU content weight in the (Th,LEU)MOX fuel. The outer array of (Th, LEU) MOX pins have average of 16% by weight of total LEU (the lower half of the active fuel will have 18 % LEU and the upper part will have 14 % LEU). The equilibrium cluster fuel has 5 % Gd in the two fuel pins of the innermost ring mixed with the (Th, LEU) MOX. The core is being designed with 32 intra-lattice locations (between 4 channels) for housing the in-core detectors. Six SPNDs are provided at each of these locations [3].

SIMULATION OF AHWR-LEU CORE

The AHWR-LEU equilibrium core has been modelled as a two region core shown in figure-1. The equilibrium core has been simulated by computer code KINF [4]. Two group lattice cell data have been generated using transport theory code WIMSD and its associated 69-group nuclear data library. The reactor core along with the surrounding radial and axial reflector was represented using more than 24090 mesh points. While in the X-Y plane 803 mesh points (lattice pitch=22.5 cm) were used to represent the core and radial reflector, 30 meshes were used to represent the core in axial directions. The equilibrium core has been simulated with 4 different burn-up zones. In total 10 k-modes and corresponding eigenvalues have been estimated with subtraction technique.

Fig-1: Layout of the AHWR-LEU core
RESULTS AND DISCUSSIONS

The flux at the in-core detector locations estimated from ATES3 shown in Fig.2. The AHWR-LEU core exhibits a slightly bottom peaked flux distribution. The fundamental and up to 10th higher eigen-values of the AHWR-LEU equilibrium core were calculated by the KINFIN code. The eigen-value separation between the fundamental and the first azimuthal mode was found to be 15.82mK. This is relatively smaller and could give rise to spatially tilted flux profiles. The Flux profile for the first azimuthal mode at radial mid-plane plotted along the axis in Fig.3. The 2nd \(\lambda\)-mode is an axial mode since it varies from a negative value to a positive value along the axial direction. Similarly 3rd \(\lambda\)-mode is a radial mode. Also the variation of the 4th \(\lambda\)-mode is an axial mode. The AHWR-LEU core was also simulated with Diffusion Code FEMINA and agreed with the transport simulations.

CONCLUSIONS

The AHWR-LEU core has a provision of about 160 SPNDs [5]. It is expected that these will be able to capture the perturbed 3D flux shape. A detailed flux synthesis exercise will be taken up to optimize the actual positions of the detectors.

REFERENCES