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XENON DYNAMICS OF AHWR

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ABSTRACT

Large core reactors where the core dimension is significantly large compared to the migration length of neutron are more susceptible to xenon instability due to local perturbations. Advanced Heavy Water Reactor (AHWR) is being designed for on-power refueling. Therefore, refueling or movement of control devices in AHWR causes local perturbation. Preliminary modal analysis of AHWR equilibrium core also showed that the eigenvalue separation between fundamental mode and 1st azimuthal mode is small indicating its susceptibility to xenon oscillation in azimuthal plane. Therefore, xenon dynamic studies for AHWR with explicit xenon calculations were carried out using diffusion theory based computer code and the gain in reactivity due to on-power refueling was compensated by suitable movement of control devices. The reactivity feedback due to coolant density and fuel temperature variations were also duly accounted. The paper describes about behavior of AHWR core due to introduction of different reactivity perturbations.

INTRODUCTION

The susceptibility to xenon oscillation comes from the out-of-phase interaction between the positive and negative reactivity feedback due to the destruction of ^{135}Xe by neutron capture and its formation by the decay of the fission product ^{135}I. Advance heavy water reactor (AHWR) [1, 2] has core height of 350 cm and core diameter of 690 cm. The diameter of the reactor core is much larger compared to the migration length (14 cm). Therefore xenon instability is expected in the azimuthal plane.

Preliminary modal analysis of AHWR equilibrium core showed that the eigenvalue separation between fundamental mode and 1st azimuthal mode is small indicating its susceptibility to xenon oscillation in azimuthal plane. Therefore, detailed xenon dynamics studies of AHWR operational transients were carried out with diffusion theory based code FEMFOLXe [3]. Fuel temperature feedback and coolant density feedback were also considered in the study. To simulate the actual operating condition during the operational transients, it is imperative to introduce the reactivity compensation by suitable movement of the regulating rods (RR) / shim rods (SR) / adjuster rods (AR) in accordance to the control logics of reactor regulating system (RRS). The following operational transients were studied with reactivity compensation along with reactivity feedbacks arising due to fuel temperature and coolant density.

1. Refuelling of four channels in four quadrants simultaneously
2. Refuelling of four channels successively with certain time interval between two refueling
3. Refuelling of single channel

As AHWR design is first of a kind, there is a possibility that some of the reactivity loads might not have accounted, therefore, reactivity margin of ~30 mk (k-effective = 1.03152) has been assumed in the design calculations. However, if this margin is not used till the finalization of design, the excess reactivity of 30 mk can translate to higher design discharge burnup. This paper gives the details of xenon dynamic studies for the equilibrium core of AHWR.

AHWR CORE CONFIGURATION

AHWR is a vertical pressure tube type heavy water moderated and light water cooled thermal reactor. It has been designed to use (Th, U-Pu) MOX as fuel. The AHWR core consists of total 513 lattice locations out of which the 452 locations are occupied by fuel clusters and remaining 61 locations for housing different reactivity devices. Each fuel cluster is divided into 24 meshes axially. Doppler coefficient and void reactivity coefficient of AHWR are negative. AHWR is designed to have online refueling. Whole core of AHWR has been divided into four radial zones and two axial zones along its height for convenience. Four radial zones and two axial zones of AHWR core is shown in figure-1a and figure-1b respectively.

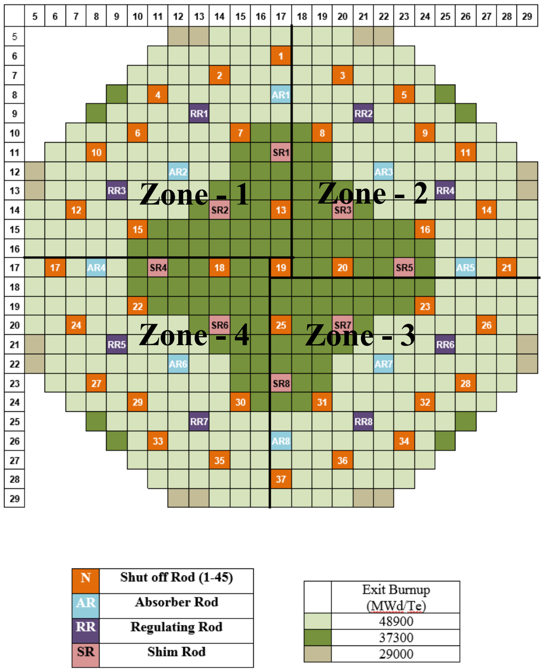


Figure-1a. Four radial zones of AHWR core

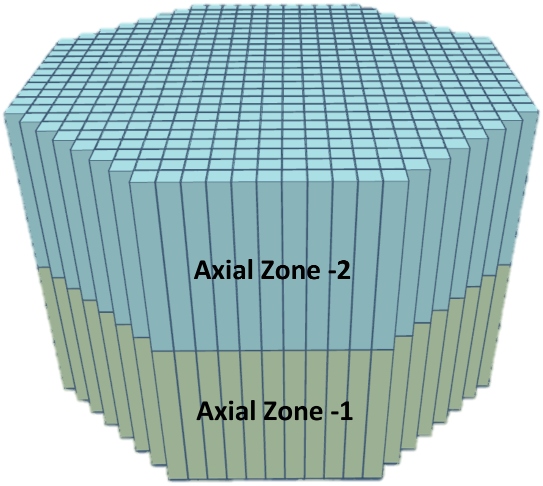


Figure-1b. Two axial zones in AHWR core

REFUELING OF AHWR

On power refueling demands replacement of highest burn-up fuel with fresh fuel and it leads to local flux / power peaking. A special scheme named as mini batch refueling scheme was devised to control such peaking. The mini batch is set of 4 (or multiple of 4) symmetric channels from four quadrants of the core. The mini batch of 4 channels is refueled in sequential manner (one after another) at reduced power to control the power peaking. The reactor power is gradually raised after the completion of refueling of 4 channels of mini batch. The calculations have showed that refueling requirement is merely 4 channels per month.

As the actual refueling operation is expected to have some time interval between two successive channels, therefore, refueling of the four channels was simulated at certain time intervals and the time interval has been assumed to be 3 hrs, 6 hrs and 9 hrs.

CALCULATION METHODOLOGY

In this calculation, nodal flux expansion method was used for solution of static diffusion equation. First space dependent static reactor problem is solved for initial conditions. The iodine and xenon behavior in AHWR for specified time interval is calculated and represented as a change in absorption cross-section. Subsequently a new static problem is solved with new parameters. The time dependent behavior is determined by comparing successive solutions. Feedbacks due to coolant density and fuel temperature are also included [4].

The simulation of refueling of one channel or a mini batch of four channels introduces positive reactivity in the core; the positive reactivity is immediately compensated by the inward movement of one bank of RRs as per the control logics. The reactivity calibration of each bank of RRs with their position in the core as shown in figure-2 was incorporated to compensate the change in reactivity. Based on the amount of reactivity change due to operational transient (on-power refueling), new position of the RRs banks in the core is estimated and core is simulated with new position of RRs banks. The flow chart of the core simulation is described in the figure-3.

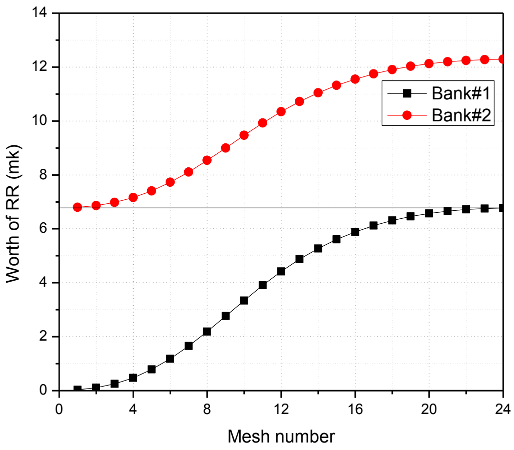


Figure-2. Worth of RR with mesh number

A few eigen modes were also estimated for AHWR equilibrium core using the code NDIFF3D [5] and they are given in table-1. Figure-4 gives the flux distribution for different eigenmodes in the two axial halves of the core. The saturated xenon load of AHWR is 19.6 mk and the eigenvalue separation between fundamental mode and first azimuthal mode is merely 8.75 mk. Therefore, xenon instability in azimuthal plane can be easily excited due to reactivity perturbation. But the eigenvalue separation of first axial mode with fundamental mode is 45.7 mk. It is highly unlikely to excite axial eigenmode.

Table - 1

Mode	**λ- Eigenvalues**	**Eigenvalue separation (mk)**	**Remarks**
1	1.03152		Fundamental
2	1.02229	8.75	1st Azimuthal-1
3	1.02229	8.75	1st Azimuthal-2
4	1.00889	21.75	2nd Azimuthal-1
5	1.00360	26.97	2nd Azimuthal-2
6	0.99390	36.69	1st Radial
7	0.98510	45.68	1st Axial
8	0.98474	46.06	3rd Azimuthal-1
9	0.98474	46.06	3rd Azimuthal-2
10	0.97549	55.68	1st Azimuthal-1 + 1st Axial

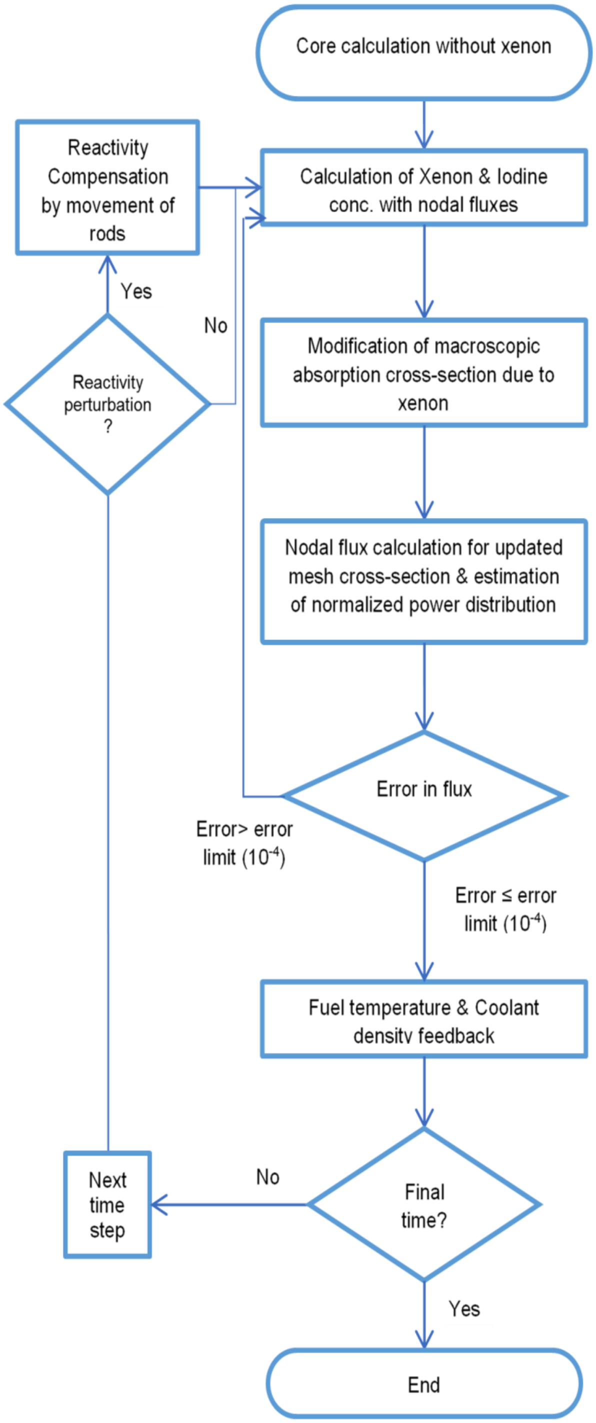
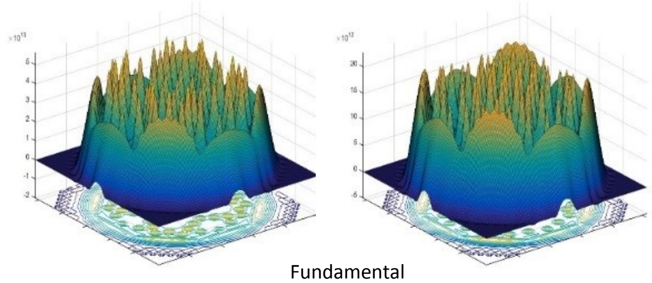
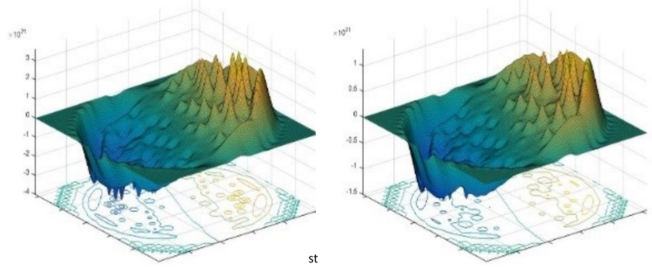


Figure-3. Flowchart for explicit xenon calculation with feedbacks and reactivity compensation

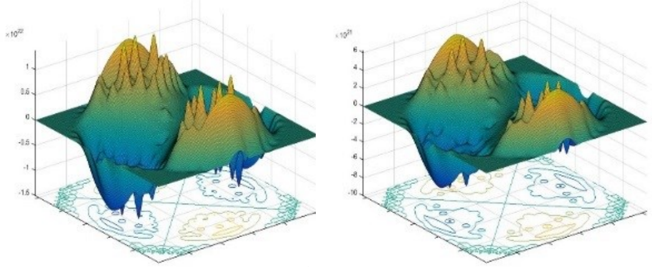
Z = 65.4 cm Z =284.4cm



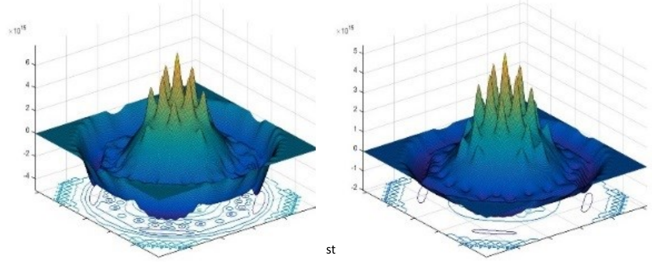
Fundamental



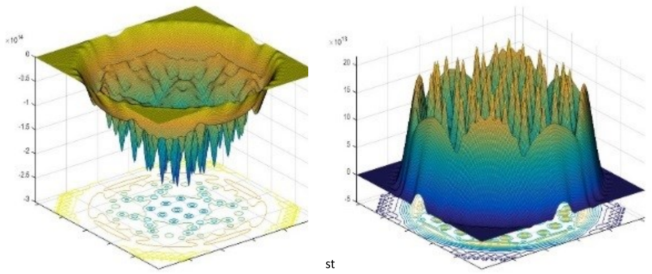
1st Azimuthal



2nd Azimuthal



1st Radial



1st Axial

Figure – 4. Flux plot at two different elevation

RESULTS AND DISCUSSIONS

Refueling of four channels in four quadrants simultaneously

Xenon dynamic behavior of the core after simultaneous refueling a mini batch of four channels (one each in four quadrants) was studied. Locations of four channels belonging to a mini batch are (16,24), (24,18), (18,10) and (10,16). The core excess reactivity due to refueling of the mini batch was compensated by suitable movement of RRs. The figure-5 shows that simultaneous refueling of four channels in four different quadrants of AHWR do not lead to any significant variation of spatial power distribution with respect to time.

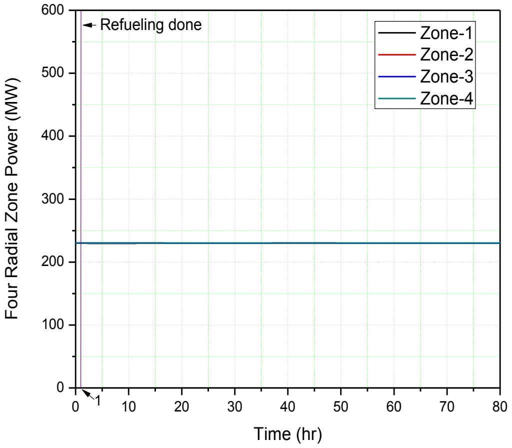


Figure 5a. Quadrant power variation with time

However, practically it is not possible to refuel four channels with one fuelling machine. Therefore, the four channels of the mini batch needs to be refuelled successively with some time interval between two successive fuelling.

Refueling of four channels successively with certain time interval between two fueling

The actual refueling operation is expected to have some time interval between two successive refueling operations. Therefore, refueling of the four channels of AHWR was simulated by refueling one channel after another with certain time intervals and three cases with different time intervals of 3 hours, 6 hours and 9 hours were considered. The choice of time interval between two successive refueling has been considered based on the experiences of the on-power refueling of PHWRs. For all the cases, same sequence of channels located at (16,24), (24,18), (18,10) and (10,16) during refueling was assumed. The core excess reactivity due to refueling was compensated by inward movement of RRs. Each of the three cases was analysed without reactivity feedback and with reactivity feedback due to fuel temperature and coolant density. For the first case where the time interval between two successive refueling is 3 hours, the refueling operation begins at time equal to 1 hour and it ends at time equal to 10 hrs. The quarter core (quadrant power) variation without and with reactivity feedback is given in the figure 6a and figure 6b respectively.

For the second case where the time interval between two successive refueling is 6 hours, the refueling operation begins at time equal to 1 hour and it ends at time equal to 19 hrs. The quarter core (quadrant power) variation without and with reactivity feedback is given in the figure 7a and figure 7b respectively.

Similarly for the third case where the time interval between two successive refueling is 9 hours, the refueling operation begins at time equal to 1 hour and it ends at time equal to 28 hrs. The quarter core (quadrant power) variation without and with reactivity feedback is given in the figure 8a and figure 8b respectively.

It has been observed that as the time interval between two successive channels increases from 3 hours to 9 hours, the range of the maximum and minimum quadrant power increases from 350-105 MW(th) to 380-100 MW(th) for the case where the reactivity feedbacks are not considered.

The comparison shows that the quarter core power variations due to successive refueling of a mini batch of four channels after certain time interval converges and damps substantially after taking the credit of negative reactivity feedbacks due to fuel temperature and coolant density. The minor variations in the quadrant power can be corrected by reactor control system.

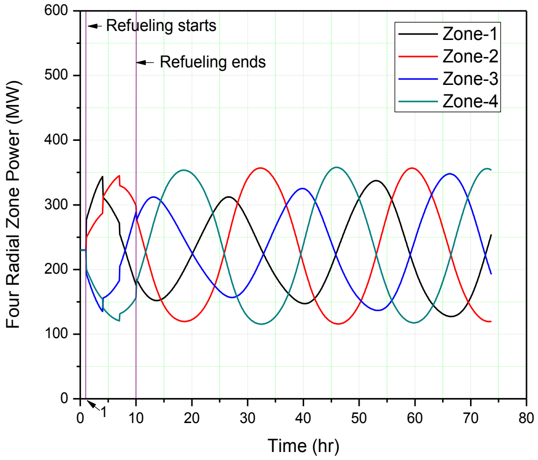


Figure 6a. Quadrant power variation with time (without reactivity feedbacks)

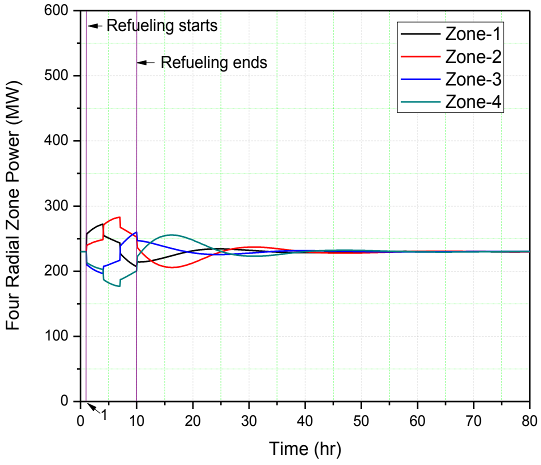


Figure 6b. Quadrant power variation with time

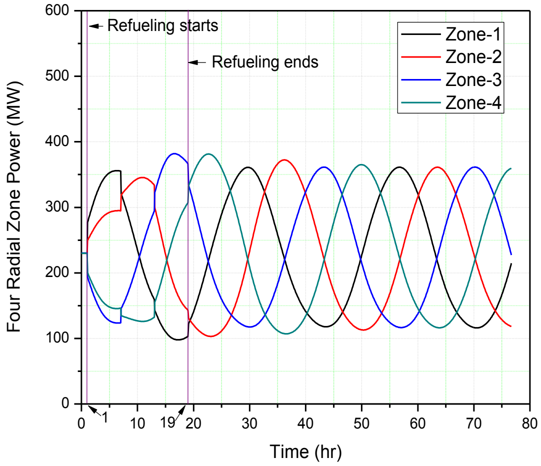


Figure 7a. Quadrant power variation with time (without reactivity feedbacks)

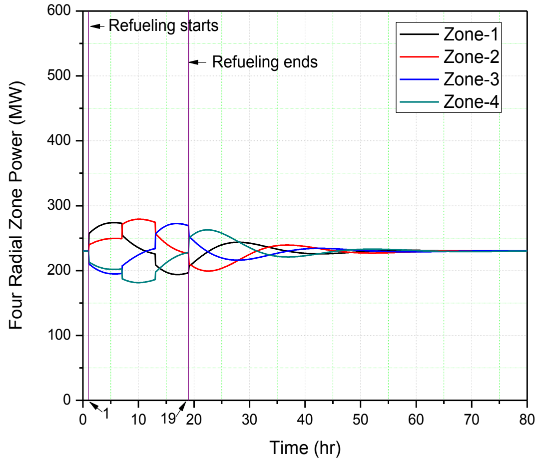


Figure 7b. Quadrant power variation with time

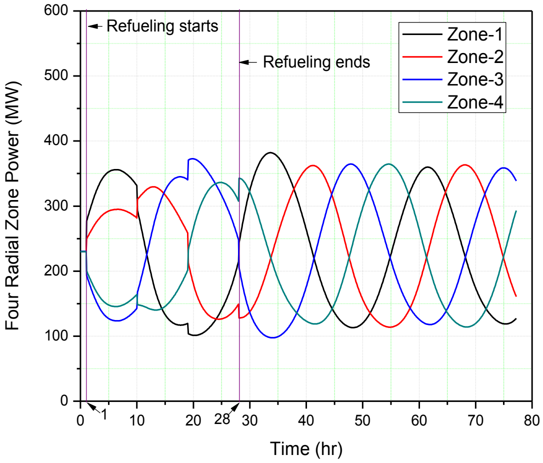


Figure 8a. Quadrant power variation with time (without reactivity feedbacks)

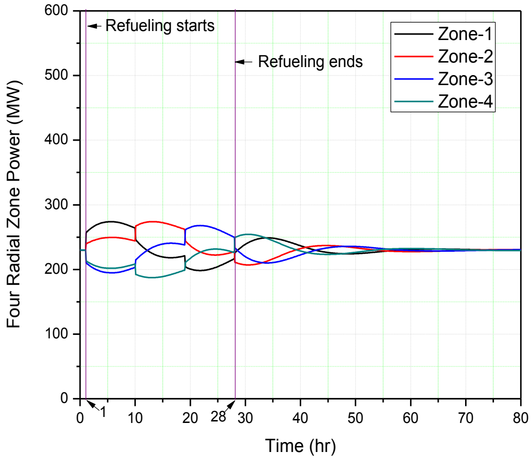


Figure8b. Quadrant power variation with time

Refueling of single channel

In order to understand the effect on xenon dynamics due to refueling of single channel, a channel was selected for refueling at the location (16, 24) by following standard refueling rules. Due to refueling of the channel, the reactor power in the corresponding quadrant of the core is perturbed. The increase in core excess reactivity due to refueling of a channel was compensated by movement of the RR banks. Variation of power in all the four quadrants with time was estimated for period of about 80 hrs. The variation in power without reactivity feedbacks was compared with the results obtained with reactivity feedbacks and it is shown in figure – 9(a) & 9(b). The variation of power in the two axial zones of the core was also estimated and compared in figure – 9(c) & 9(d).

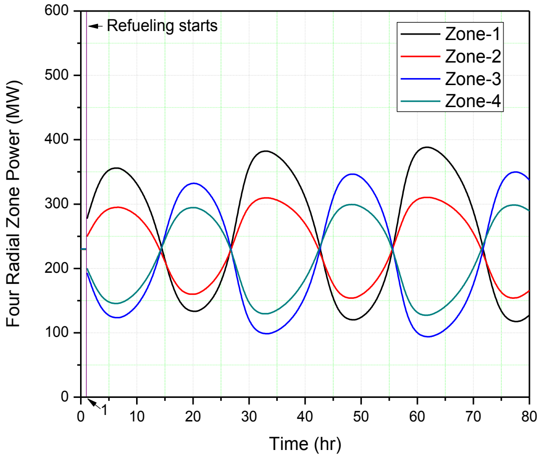


Figure 9a. Quadrant power variation with time (without reactivity feedbacks)

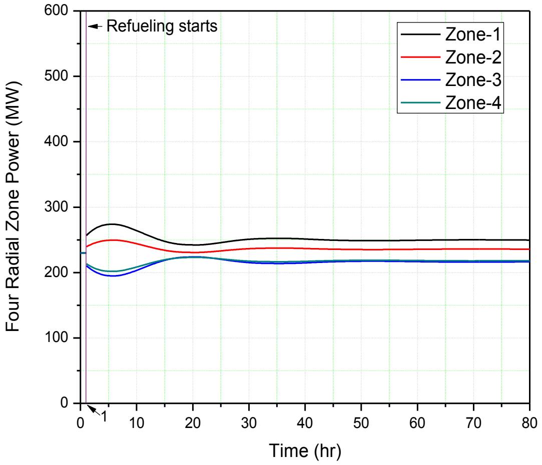


Figure 9b. Quadrant power variation with time

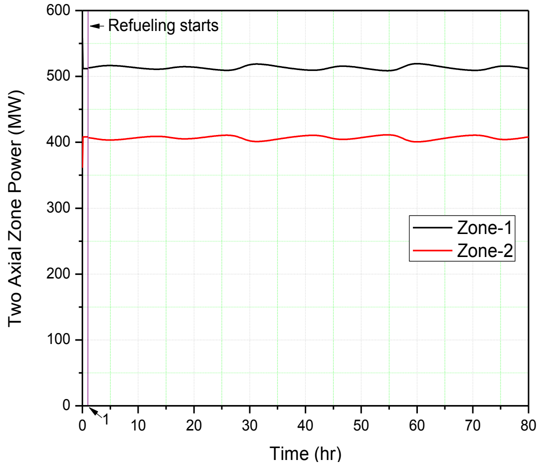


Figure 9c. Axial power variation with time (without reactivity feedbacks)

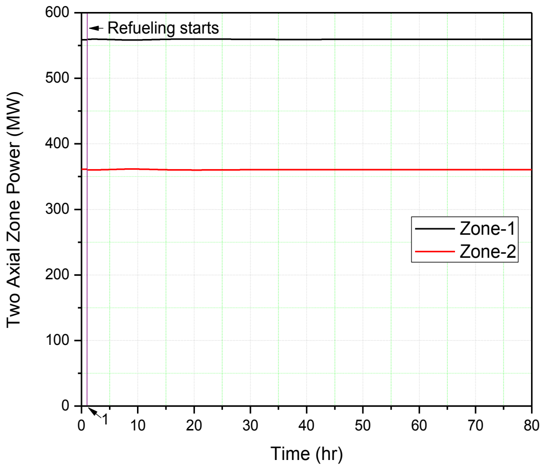


Figure 9d. Axial power variation with time

CONCLUSION

The preliminary modal analysis indicates that local perturbations like on-power refueling can easily excite first azimuthal eigenmode in the equilibrium core of AHWR. Similar observations were made during the study of xenon dynamics of AHWR due to on-power refueling of single channel or successive refueling of mini-batch of four channels after some interval of time. However, the studies have showed that due to strong negative feedback of fuel temperature and coolant density, the quarter core power variations converges and damps substantially such that reactor regulating system can easily take care of variations in quadrant power. Moreover, the calculations have also shown that the axial power distribution remains unaffected due to the refueling of the core. In all three cases movement of RRs is enough to compensate all reactivity changes.

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