CONTINUOUS IRRADIATION OF THORIUM IN EQUILIBRIUM CORE OF STANDARD PHWRs
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INTRODUCTION

In KAPS-1, for the first time in standard 220 MWe PHWRs flux flattening was achieved by loading 35 Thoria bundles (instead of depleted bundles) for initial flux flattening. Considering the requirement of U-233 for AHWR, a study was carried out for continuous irradiation of thorium bundles in few selected channels of equilibrium core of standard PHWRs. In order to arrive the loading scheme to obtain U-233 on regular basis objectives like Reduction in Allowed operating power should be less than 2 % FP, Reactivity load should be less than 2 mk and Burn up of Thoria bundles should be more than 1500 n/MB so that the production of U-233 from these bundles shall be more than 100 gram per bundle were fixed based on the operational and production of U-233 requirements. The proposed scheme was evolved using actual operation data of KAPS-2 core from 700 FPD to 2300 FPD and the fuel management code TRIVENI©. 12 Peripheral channels were selected for thorium loading at 2nd and 3rd string location to reduce the reactivity load keeping in mind that the softer neutron spectrum in the peripheral region helps in achieving cleaner U-233. It was established that the proposed loading scheme of Thorium Bundles into the core do not make any significant effect on the safety parameters like 1. Worth of shutdown system. 2. Void Coefficient & Power defect and 3. Kinetic parameters like delayed neutron fraction and prompt neutron life time.

EVOLUTION OF PROPOSED THORIUM LOADING SCHEME

The refuelling data of KAPS-2 from 700 FPD to 2300 FPD was used. 12 peripheral channels having the lowest Equilibrium channel power viz. A-08, A-13, B-06, B-15, C-04, C-17, D-03, D-18, R-03, R-18, T-06 and T-15 were identified for loading Thorium bundles. These channels were refuelled with Thorium (Th) bundles at string position 2 and 3 and rest with Natural Uranium (NU) bundles as and when they were refuelled during the actual KAPS-2 operation. These channels were refuelled again with another 2 Thorium bundles loaded at 2nd and 3rd location when they were next refuelled. By this process now these channels will have 4 Thorium bundles i.e. at 2nd, 3rd, 10th and 11th location. At the time of third refuelling again 2 Thorium bundles are loaded at 2nd and 3rd location maintaining 4 Thorium bundles in the channel and 2 Thorium bundles are discharged. Thus from 3rd refuelling onwards 2 thorium bundles from the selected channels will be regularly discharged. The reduction in allowed operating power with respect to the original NU core for the proposed Thorium loading core is shown in figure -1 and the reactivity load due to such loading along with number of Thoria bundles in the core is shown in figure-2 respectively.

Fig-1.Restriction on Operating power due to 48 Th bundles.
Fig-2.Reactivity load due 48 Th bundles loaded.
It can be seen from the above figures that both the criteria viz. reduction in Allowed operating power and Reactivity load are satisfying the desired criteria. It was observed that for this scheme Average Residence time of each Thorium bundle, Discharge burn up and the U-233 build up are 801 FPD, 1025 n/Mb and 80 gm repetitively. Thus for the normal residences time (as per KAPS-2 operating data) the Burn up of Thoria bundles is less and hence the production of U-233 is lower than the desired value. However, the burn up and U-233 production can be easily increased by suitably adjusting the residence time. To assess the overall effect of increasing the residence time, arbitrarily for all the 12 channels the residence time was made almost 1.5 times and the simulation was carried out again. The reduction in allowed operating power for this case is shown in figure -3 and the reactivity load along with number of Thoria bundles in the core is shown in figure-4 respectively.

| Fig-3. Restriction on Operating power due to 48 Th bundles in the scheme of increased residence time |
| Fig-4. Reactivity load due 48 Th bundles in the scheme of increased residence time |

It can be seen from the above figures that both the reduction in Allowed operating power and Reactivity load are still satisfying the desired criteria even though the residence time of Thoria loaded channels is increased. Average revised Residence time of each Thorium bundle, Discharge burn up and the U-233 build up during this period are 1190 FPD, 1505 n/Mb, and 105 gm respectively. It can be seen that the desired amount of U-233 can be obtained by adjusting the residence time suitably. The burn up of Thorium bundles may be considered as the simplest criteria for deciding the refuelling of the Thoria loaded channels. The effect of the proposed loading scheme of Thorium bundles into 12 channels on Safety parameters like Void Coefficient, Power defect, worth of shut down devices etc and the kinetic parameters was evaluated using ‘TRIVENI’ and ‘REFGAIN’ program and demonstrated to be equivalent or better than the original all Natural Uranium core.

CONCLUSION

The proposed scheme of Thorium irradiation in 12 peripheral channels in equilibrium core of 220 MWe PHWRs can be adopted to generate U-233 on regular basis. The reactivity load of about 2 mk and the operating reactor power restriction of about 2% FP can be taken care through proper fuel management. Safety parameters like Void Coefficient, Power defect, worth of shut down devices etc and the kinetic parameters are equivalent to the original all Natural Uranium core. By following this loading scheme U-233 can be obtain from the 4th year of Thoria bundle loading in the core and the expected U-233 production may be of the order of about 2 kg / year at 90 % capacity factor.

REFERENCES
3. M.P.S. Fernando et.al., REFGAIN_MANUAL. NPCIL.