Thorium Utilization in Heavy Water Moderated Accelerator Driven System

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Abstract. This Paper discuss our studies on Th utilization in heavy water moderated ADSs. The once through and self sustaining Th-U cycle are studied. The former is more attractive but has a rather low gain. The recycling option is more realistic due to its much better gain. The study is carried out at lattice level using the code DTF as modified for lattice and burn-up calculations (BURNTRAN).

Keywords: Accelerator Driven system, Th-U cycle, Transport theory, Burn-up, Monte-carlo

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INTRODUCTION

In recent years there is considerable interest in accelerator driven sub-critical systems (ADSs) [1]. Reactor operation in subcritical mode possesses extra safety features, provides better breeding (due to extra neutrons from the source) and extended burn-up. Research on Accelerator Driven Systems (ADSs) is being carried out around the world primarily with the objective of waste transmutation [2]. Presently, the volume of waste in India is small and therefore there is little incentive to develop ADS based waste transmutation technology immediately.

With limited indigenous U availability and the presence of large Th deposits in the country, there is a clear incentive to develop Th related technologies. India also has vast experience in design, construction and operation of heavy water moderated reactors. These reactors have a good neutron economy; and permit continuous fuelling. Heavy water moderated reactors employing solid Th^{232}-U^{233} fuels can be self sustaining, but the discharge burn-ups are too low to be economical. A possible way to improve the performance with regard to burn-up and / or breeding of such reactors is to use an external neutron source as is done in ADSs. This paper discusses our studies on Th utilization in heavy water moderated ADSs.

The study aims to investigate following two options.

1. The feasibility of the once through Th cycle, without the use of any extraneous fissile material (either enriched U or Pu at any stage).
2. In case of the recycling option, whether the system can operate in a self sustaining mode with reasonably high K_{eff} and discharge burn-up. The minimum value for the burn-up has been pegged at 30,000 MWD/ tonne.

METHOD OF CALCULATION

The study is carried out at the lattice level using the code BURNTRAN [3]. The code, developed in Theoretical Physics Division of BARC, is an extended version of the one and two dimensional transport theory codes - DTF [4] and ATRAN [5]. The code has been coupled with the ENDF-6 based WIMS-172 cross section and burn-up data library [6]. Dancoff correction for treatment of resonances in fuel consisting of 7, 19, 37 and 54 rod clusters, typical of heavy water lattices has been incorporated in the code. A burn-up routine has also been added. The code has been validated by comparing against published results and also with the Monte Carlo based burn-up code McBURN [7]. The average K_∞ of a bundle from zero to discharge burn-up is assumed as the average core K_∞. It is also assumed that the core is fully surrounded with a blanket so that the net neutron loss due to leakage is practically zero.

SUB-CRITICAL SYSTEMS STUDIED

The Once Through Cycle

The once through cycle is an attractive option as it does away with reprocessing or enrichment facilities and can be started with naturally occurring fuels viz., natural U and Th. The natural U acts as initial seed and is slowly removed and subsequently the system is fed only with Th with in-situ production of U^{233} which is burnt in the system. This was studied for the 37 rod clusters typical of PHWRs with D_2O coolant. Several parameters such as V_m/V_f ratio, specific power and moderator purity were varied.

U^{233} Recycling in Sub-critical Systems

We have studied 37 rod fuel clusters, typical of PHWRs with H_2O, boiling H_2O and D_2O coolants. We have analyzed Th fuel assemblies with U^{233} content up to 5% in the recycling mode. Light water is preferred as coolant over D_2O due to lower operating costs and reduced tritium activity in the primary coolant circuit.

RESULTS AND DISCUSSIONS

The Once Through Cycle

A typical result for the equilibrium situation is shown in Fig.1. The maximum average K_∞ achievable is about 0.9 The gain at such a low K_∞ is rather low (< 20). Various ways to increase gain are possible such as reducing parasitic absorption in the core (say by using denatured Zr, and maintaining a higher purity of the moderator), use of a fast booster or use of target materials with higher spallation yields. Each of these has its own associated problems and complicates the scheme.

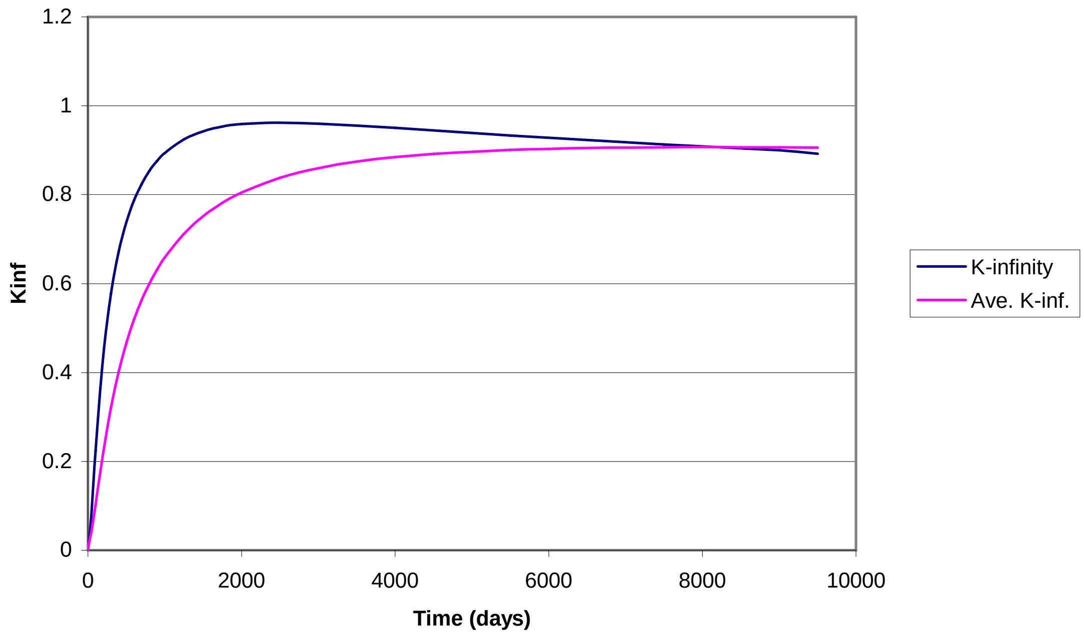

FIGURE 1. Variation of K_∞ for a Th bundle as a function of exposure

Results with Recycling of U^{233}

The cases studied with PHWR 37 rod clusters are summarized in Table 1. We see that with D_2O coolant, we get an average K_∞ in the range of 0.97-0.98 and high burn-up reaching up to 50000 MWD/T. The average K_∞ is fairly constant over a long range of discharge burn-up. With light water coolant, both burn-up and K_∞ are somewhat lower. Fig. 2 shows the variation of the K_∞ as a function of irradiation for 1.25% U^{233} in Th. More details are given in [8].

TABLE 1. Summary of results for the 37 fuel rod cluster PHWR lattice. The table shows the average K_∞ and discharge burn-up for selected cases.

S.No.	Coolant	U^{233} in recycled fuel	Net U^{233} produced (Kg/y)	Average k_∞	Pitch (cm)	Discharge burn-up (MWd/t)
1.	Boiling H_2O	1.33	0	~ 0.96	28.5	30000
2.	H_2O	1.33	0	~ 0.95	28.5	30000
3.	D_2O	1.25	9	~ 0.97	28.5	50000
4.	D_2O	1.33	0	~ 0.97	28.5	60000

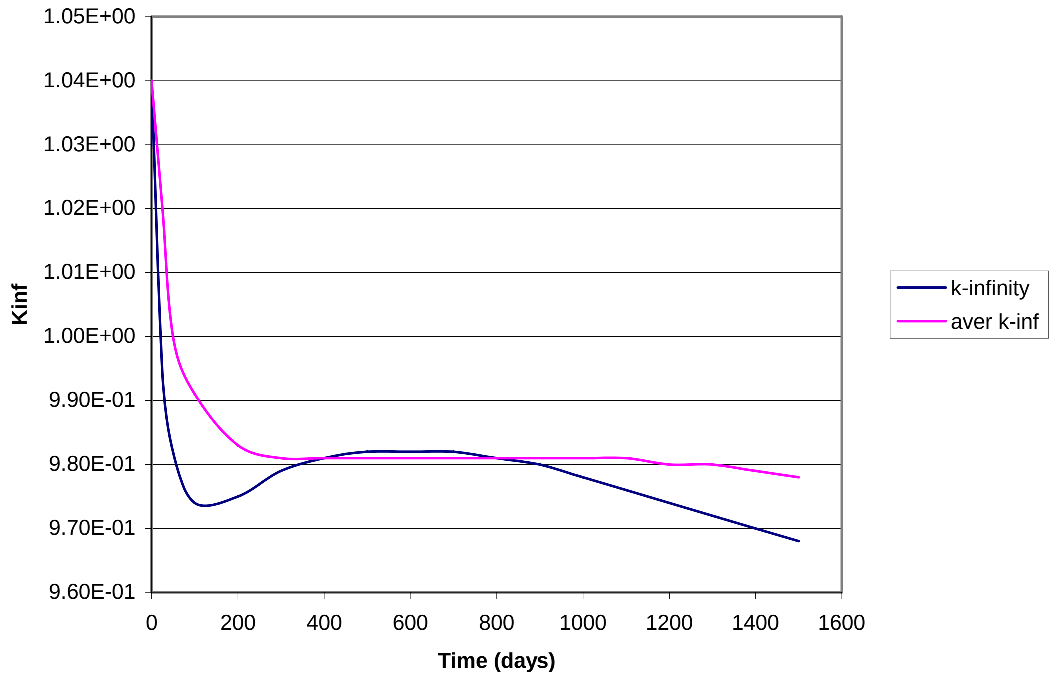

FIGURE 2. Variation of K-inf of PHWR lattice cell for 37 fuel rod clusters fuel with 1.25% U^{233} in Th and D_2O coolant (1 day corresponds to 19.4 MWD/ t)

CONCLUSION

Our study shows that in a heavy moderated ADS, the once through Th-U cycle gives an energy gain that is too low to be practical or economical. However with recycling, the ADS can be operated at a reasonably high gain to be practical and results in a self sustaining cycle.

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