8.1 ACCELERATOR DRIVEN REACTOR SYSTEMS

The Accelerator Driven System (ADS) is a new type of reactor which produces power even though it remains sub-critical throughout its life. All operating reactors in the world are " critical" reactors - which means that the number of neutrons produced by fission is exactly balanced by the number lost by leakage and absorption by various materials in the reactor. This balance is responsible for maintaining a constant reactor power at any desired level. Sub-critical reactors produce fewer neutrons by fission than are lost by absorption and leakage, and require an external supply of neutrons to maintain a constant reactor power. This external neutron supply comes from the interaction of a high energy proton beam with a heavy atom nucleus such as lead through what is known in nuclear physics as spallation. The power level in an ADS is greater for stronger external sources and for reactors which are closer to "critical".

Such reactors were conceived by the Nobel laureate physicist, Carlo Rubbia (Report CERN/AT 95-53) and his team at CERN, among others, for power generation, but have caught the attention of the world for an equally important role - that of burning nuclear waste. It is well known that nuclear reactors generate radioactive waste which retains its radio-toxicity for millions of years and disposal of this waste has been a major source of public concern. The new reactor is designed to safely transmute the waste into stable elements or those whose radio-activity is relatively short lived, while producing useful power.

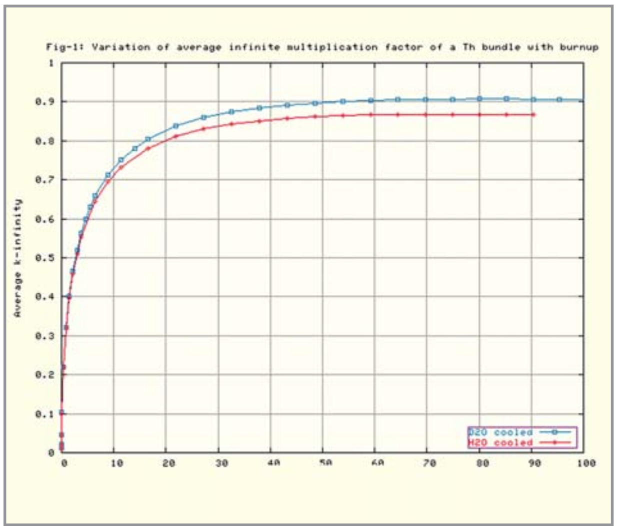
Indian interest in ADS has an additional dimension, which is related to the planned utilisation of its large thorium reserves for future nuclear energy generation. Thorium has the added advantage that it produces much less quantities of *long lived* radioactive wastes as compared to uranium. However, thorium by itself is not fissile and must be first converted to fissile U-233 by neutron irradiation, a process called breeding. In ADS, the accelerator delivers additional neutrons over and above those coming from fission. Moreover long term reactivity changes due to burnup are not controlled using parasitic absorber rods. The ADS is, therefore, expected to possess superior breeding characteristics as compared to critical reactors. Since ADS reactors are not required to maintain criticality, it is possible to increase burnup i.e. to extract more energy from a given mass of fuel. This effect is rather large for thorium based fuel. Being a new type of reactor, the ADS requires development of several technologies related to high power accelerators, removal of the intense heat generated by the interaction of the high power proton beam with the target, and associated materials development.

Accurate computer simulations play a very important role in determining the performance of the ADS reactor. The studies are geared to develop accurate computer simulation codes for ADS, compile necessary nuclear data for this purpose, carry out experimental and numerical tests regarding the adequacy of the simulations and finally to use these simulations to evaluate ADS performance with regard to the design objectives. The "state-of-the-art" codes have been developed for carrying out fuel burnup simulations based on the exact Monte Carlo method and the (accurate and quicker) multigroup transport theory method for this purpose. The codes are functional for fixed fuel ADS and are being put to use for evaluating some of the interesting ideas conceived for applications of ADS. Further development of these codes is being carried out to include fueling operations (insertion, removal, or shuffling) and it is expected to be completed within a year.

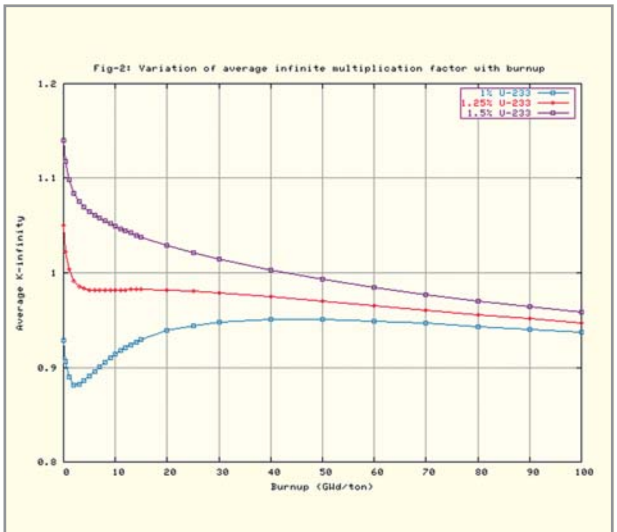
A facility for carrying out experiments on the Physics of ADS is being set up at Purnima labs, BARC. A report on the experimental program has been prepared and experiments will commence once the facility becomes operational. The experiments will serve the equally important purpose of testing the simulation methods under development. Measurement of the degree of sub-criticality is one such important experiment, as monitoring this parameter for ADS will be an important safety requirement. This can be done by pulsing the accelerator or by studying tiny fluctuations in the reactor power, called "noise". A new theory of Reactor Noise in ADS has been developed and is gaining international acceptance.

The Advanced Heavy Water Reactor (AHWR) is being designed and developed at BARC for the purpose of thorium utilization. In view of the remarks on thorium utilization in ADS made earlier, the following questions assume importance. What is the reduction in the annual fuel requirement of a thorium fuelled heavy water reactor if operated in the ADS mode? Is a self sustaining cycle possible? How much extra energy can be extracted from a given mass of fuel before it is discharged? What would be the accelerator power required to drive such a reactor?

Figures illustrate the use of the simulation codes for answering such questions. Figure shows the maximum multiplication factor that is possible in a heavy water reactor with thorium fuel in a once through cycle (i.e. one which does not require reprocessing of thorium for recycling in the reactor). The initial fissile seed could be natural uranium or even spent fuel from Pressurised Heavy Water Reactors (PHWRs).



Variation of average infinite multiplication factor of a Th bundle with burnup



Variation of average infinite multiplication factor with burnup

The scheme allows 10% thorium (1 GWd/t is equivalent to fission of 1% fuel mass) to be burnt before the fuel is discharged. However, the energy gain is small and hence, a large fraction of the reactor power (about 30%) would have to fed back to the accelerator. If light water is used as the coolant, the multiplication factor is lower and the ADS would require greater accelerator power.

Figure shows the effect of recycling U-233 produced in the reactor after mixing it with thorium in different proportions. Since the discharged fuel contains somewhat larger U-233 than what is required for recycling at 1.25% level, it is clear that a self sustaining cycle is comfortably possible with a multiplication factor of 0.95 at a discharge burnup of 4% fuel mass. Such a scheme requires about 15% of the produced energy to be fed back to the accelerator. Though this is a small fraction the corresponding accelerator power is still rather large for a commercial sized power producing reactor. As noted before, use of light water instead of heavy water as coolant requires more accelerator power. Clearly it is desirable to have some means to effect a further reduction.

The one-way coupled fast-thermal ADS reactor conceived at BARC can be used for this purpose. This is illustrated in Figure. The neutron source produced by the interaction of the proton beam with the target is first boosted in a small fast region (surrounding the target) having Pu as fissile material and a liquid metal coolant such as lead. These neutrons then enter the main thermal reactor region where most of the power is produced. The outer region will be a heavy water moderated reactor for which the technology is well established. Such an arrangement can considerably bring down the accelerator power requirements. It has the added advantage that the inner booster region can be used for burning long lived waste produced in our first and second generation reactors based on uranium and plutonium fuels.

Many such studies are required to evolve a suitable ADS design and the associated fuel cycle strategies for thorium utilization. The R&D program of the ThPD group on ADS is geared to provide the necessary simulation tools and the theoretical direction for this activity.

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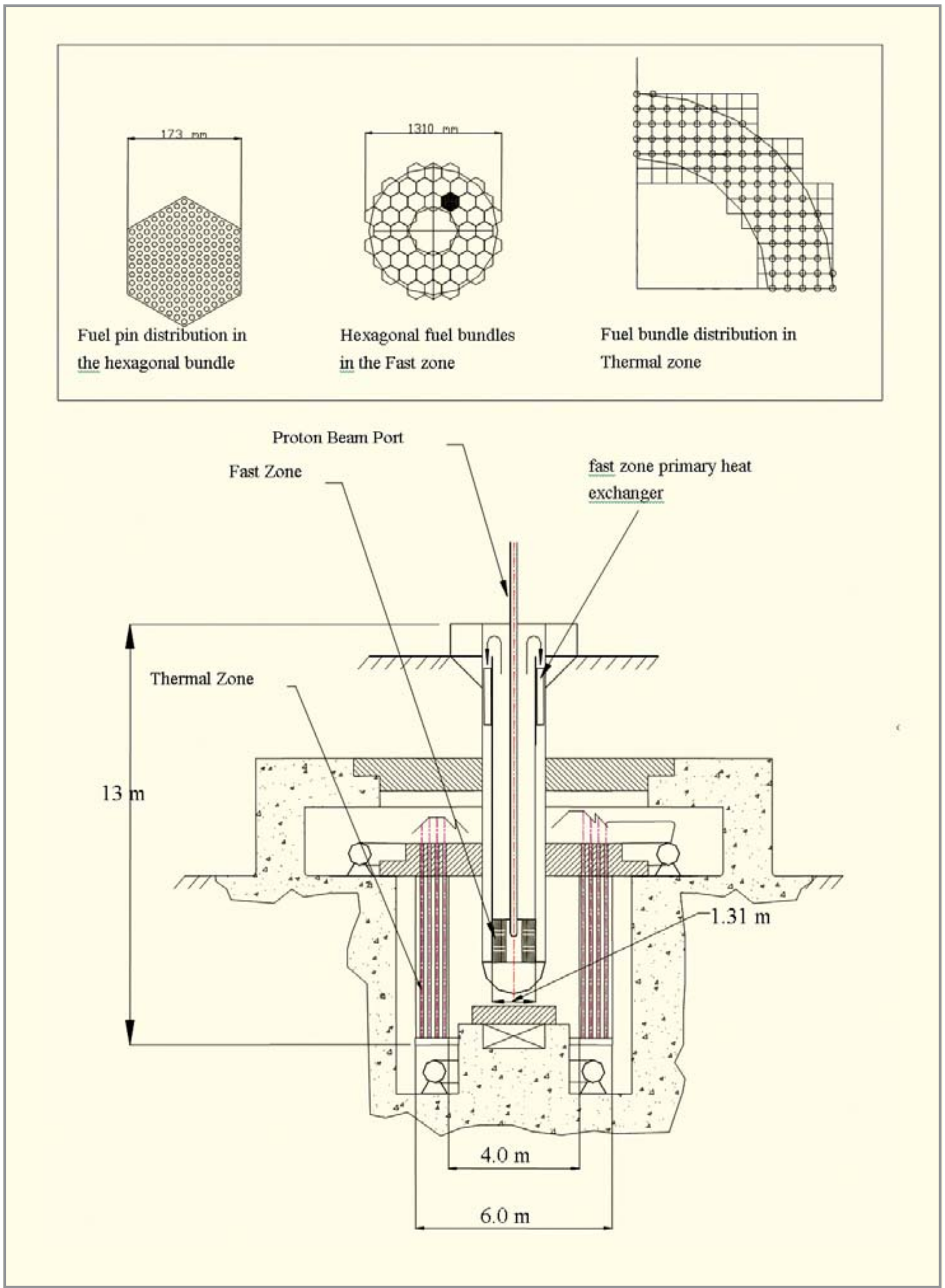

Schematic of fast-thermal ADS