Physics study of D-D/D-T neutron driven experimental subcritical assembly

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Abstract

An experimental program to design and study external source driven subcritical assembly has been initiated at BARC. This program is aimed at understanding neutronic characteristics of accelerator driven system at low power level. In this series, a zero-power, sub-critical assembly driven by a D-D/D-T neutron generator has been developed. This system is modular in design and it is first in the series of subcritical assemblies being designed. The subcritical core consists of natural uranium fuel with high density polyethylene as moderator and beryllium oxide as reflector. The subcritical core is coupled to Purnima Neutron Generator. Preliminary experiments have been carried out for spatial flux measurement and reactivity estimation using pulsed neutron source (PNS) techniques. Further experiments are being planned to measure the reactivity and other kinetic parameters using noise methods. This facility would also be used for carrying out studies on effect of source importance and measurement of source multiplication factor k_s and external neutron source efficiency φ^* in great details. Some experiments with D-D and D-T neutrons have been presented.

Introduction

Accelerator driven subcritical systems (ADS) [1-3] have sparked interest in scientists worldwide due to their potential for burning actinides and long-lived fission products as well as their superior inherent safety characteristics in terms of avoiding any criticality related (runaway) incidents. ADS can primarily be used for waste transmutation of long-lived fission products and also for power generation. Indian interest in ADS has an additional dimension, which is related to the planned utilization of our large thorium reserves for future nuclear energy generation.

An ADS is basically a subcritical reactor which produces fission without achieving criticality; it uses additional neutrons from an external source – an accelerator producing neutrons by spallation.

The physics of ADS is quite different from that of critical reactors and it needs to be studied before such systems are put into operation. For example, subcritical neutrons have additional source neutrons (unlike critical reactor where the source is fission neutron only) which have different spatial and energy distribution. This distribution changes from generation to generation which gives rise to the concept of source multiplication factor k_s. Also, the power in an ADS is very sensitive to the value of k_{eff} and it is essential to accurately predict this parameter over the entire length of the burnup cycle. In addition to these, the stationary spatial flux distribution and neutron energy spectrum in ADS is different from critical reactor. Similarly, the dynamic response of ADS to transients and perturbations are also quite different from that of the critical reactors. As high energy accelerator suitable for ADS are yet to be developed, the physics of ADS is generally studied using neutrons produced either by D-D / D-T reaction or by other low energy accelerators.

A zero power subcritical assembly driven by D-D/D-T neutron generator has been developed at Purnima, BARC. The subcritical system BRAHMMA (**B**eO **R**eflected **A**nd **H**DPe **M**oderated **M**ultiplying **A**ssembly) [4] is aimed at understanding neutronic characteristics of accelerator driven system at low power level.

BRAHMMA Subcritical Core

The modular subcritical assembly consists of metallic natural uranium as fuel and high density polyethylene (HDPe) as moderator in a 13 X 13 square lattice configuration followed by 200 mm of beryllium oxide (BeO) as reflector. The fuel is embedded in high density polyethylene moderator matrix. The whole assembly is surrounded by an outer layer of borated polyethylene and cadmium to isolate the system from scattered neutrons. The central 3X3 positions of the lattice are empty and serve as the cavity for inserting neutron source. The target end of the neutron generator is inserted in this cavity such that the target is located at the centre of the core. Fig.1 shows the subcritical core.

One of the unique features of subcritical core is the use of Beryllium oxide (BeO) as reflector and HDPE as moderator making the assembly a compact and modular system.

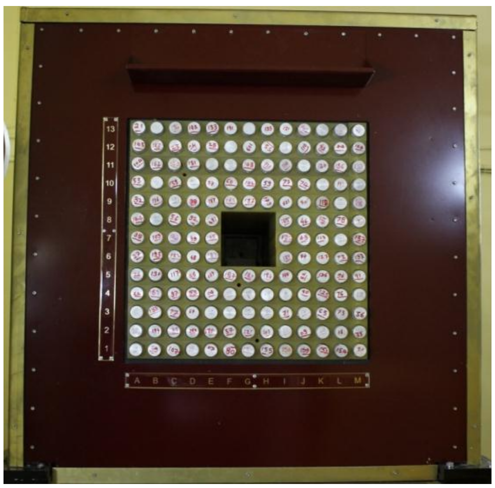


Fig.1. BRAHMMA Subcritical

Fig.2. Subcritical core being coupled to neutron generator

Purnima Neutron Generator

The coupling with the subcritical core is provided by deuteron accelerator based neutron generator (Fig.2). It is a 300 kV deuteron accelerator. The D+ ions are produced in an RF ion source, which are extracted, focused, accelerated and bombarded on the target. The target is maintained at ground potential. The deuteron ions impinge on titanium-tritium (TiT) or titanium-deuterium (TiD) targets (with copper backing), providing 14.1 MeV or 2.45 MeV neutrons via $T(d,n)^4He$ or $D(d,n)^3He$ reactions respectively.

The neutron generator has both DC and pulsed operation. It has facility for online source strength monitoring using neutron tagging and programmable source modulation.

Pulsed Neutron Source Techniques

A. Area Ratio (Sjöstrand)

In this method [5], a series of neutron pulses are injected in the system. The decay of neutrons is observed and a histogram (Fig.3(a)) is plotted. Reactivity is obtained by the ratio of the prompt and delayed areas as

$$\rho \text{ (in \$)} = -A_{prompt} / A_{delayed}$$

where A_{prompt} is the prompt area and $A_{delayed}$ is the delayed area in the PNS histogram.

B. Slope Fit

The prompt neutron decay constant α may be obtained from the slope of the prompt part in the PNS histogram as

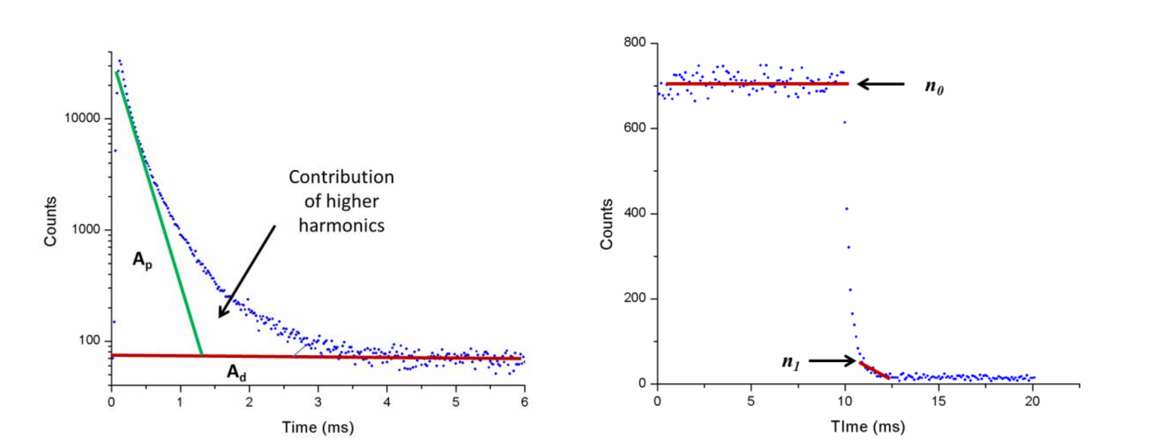
$$\alpha = (\rho - \beta_{eff})/\Lambda$$

where Λ is the mean neutron generation time.

C. Source Jerk

In this method, the source is operated in a steady state - steady state flux, say n_0. The source is then switched off (Beam Trip) and the prompt jump of the flux to lower level n_1 is recorded (Fig.3(b)). The reactivity is then obtained as

$$\rho \text{ (in \$)} = (n_1 - n_0)/n_1$$



(a) (b)

Fig.3. (a) PNS histogram (b) Source-Jerk

Experimental Results

Experiments were carried out for measurement of reactivity using PNS techniques. The neutron counts were measured with a miniature ^3He detector (Active length: 70 mm, diameter: 6.5mm).

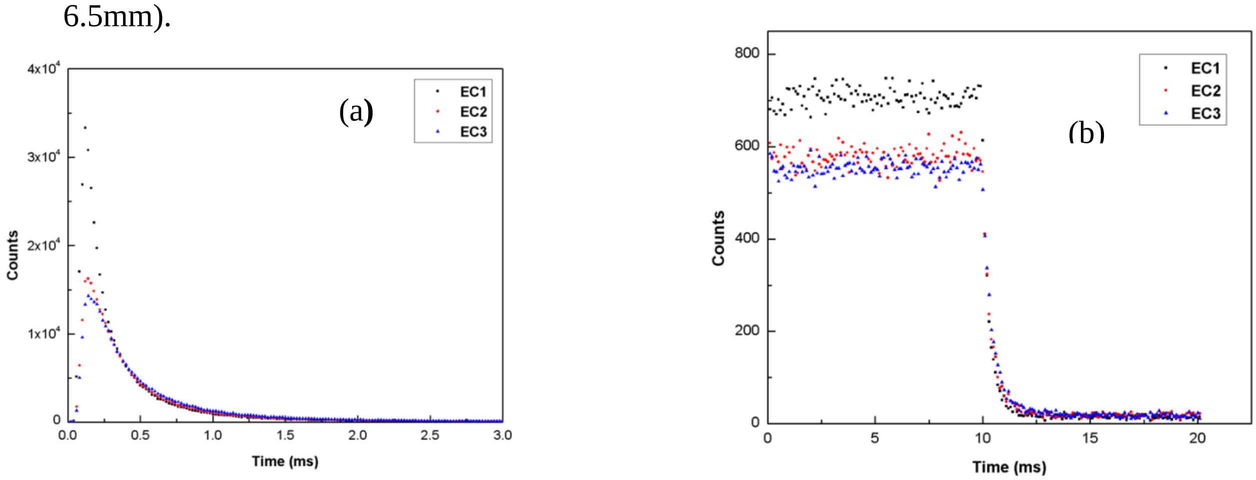


Fig.4. (a) PNS histogram (b) Source-Jerk

Measurements were carried out in axial experimental channels EC1, EC2 and EC3. Fig. 4(a) shows the PNS histogram. This histogram is used to obtain reactivity value using Area Ratio method and slope fit method as discussed above. The values of β_{eff} and Λ are obtained theoretically using Monte Carlo simulations. Fig.4 (b) shows the experimental plot for source jerk method. The reactivity is obtained from the prompt jump data as discussed above. Table 1 summarizes the experimental values obtained.

Table 1. Experimental results for reactivity measurement

Experimental channel	Area Ratio	Slope Fit	Source Jerk
Theoretical		**0.890**	
EC1	**0.898 ± 0.002**	**0.887 ± 0.002**	**0.902 ± 0.005**
EC2	**0.902** ± 0.002	**0.884** ± 0.002	**0.890** ± 0.005
EC3	**0.893** ± 0.002	**0.883** ± 0.002	**0.902** ± 0.005

Conclusion

A zero power experimental subcritical facility has been developed to study the physics and neutronics of accelerator driven subcritical systems. Preliminary experiments have been carried out and results are in good agreement with theoretically estimated values. This experimental facility is expected to provide new data and would be used as a test bed for testing of new theoretical and experimental concepts. Future plan for upgradation of this facility to higher k_{eff} value and design of next generation of zero power fast experimental ADS facility are underway.

Acknowledgement

The author would like to acknowledge the team members involved in this work, in particular, Mr. Tushar Roy, Dr. Yogesh Kashyap, Dr. Mayank Shukla, Mr. Tarun Patel, Mr. P. S. Srakar, Mr. Nirmal Ray and Ms. Shefali Bajpai.

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