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Utilization of the BARC critical facility for ADS related experiments

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Abstract. The paper discusses the basic design of the critical facility, whose main purpose is the physics validation of AHWR. Apart from moderator level control, the facility will have shutdown systems based on shutoff rods and multiple ranges of neutron detection systems. In addition, it will have a flux mapping system based on 25 fission chambers, distributed in the core. We are planning to use this reactor for experiments with a suitable source to simulate an ADS system. Any desired sub-criticality can be achieved by adjusting the moderator level. Apart from perfecting our experimental techniques, in simple configurations, we intend to study the one-way coupled core in this facility. Preliminary calculations, employing a Monte Carlo code TRIPOLI, are presented.

Keywords. Critical facility; moderator level; accelerator driven systems; shutdown system; fission chamber; detector; sub-criticality.

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1. Introduction

A 100 W critical facility (CF) is being constructed in BARC. The purpose of this facility is physics design validation of Advanced Heavy Water Reactor (AHWR). It consists of three core configurations: reference core, AHWR core and PHWR core. In reference core of critical facility, there are 19-pin natural uranium metal clusters. It has been proposed to utilize the CF for ADSS experiments also, with some appropriate neutron source at the center. Recently BARC has proposed a one way coupled core configuration for ADSS application. This coupled core consists of a fast core around the source and a thermal core separated by a buffer zone [1]. We have chosen the mixed carbide Mark-II FBTR fuel for the fast zone with the reference core of CF as thermal zone. Monte Carlo simulation of this critical facility was done by TRIPOLI code [2] and the critical height was found to be 200 cm. Any desired sub-criticality can be achieved by adjusting the moderator level, 200 cm moderator height was taken in this study. Dimensional descriptions of these two cores are given below.

2. Monte Carlo simulation

Monte Carlo simulation of a composite core has been done by code TRIPOLI 4.0 in this paper. Accelerator driven sub-critical system (ADSS) is a different system from critical system. In the critical system, only fundamental mode of neutron flux distribution exists, all other higher harmonics die out with time. So we have to deal with only fundamental mode. But in the case of ADSS, the presence of external neutron source leads to peaked flux distribution exciting other higher harmonic modes of neutron flux distribution

Apart from the presence of higher harmonics in ADSS, the geometry and material composition is complicated and different from conventional reactor core. For example, in this paper two kinds of clusters have been simulated. One is a 19-pin natural uranium cluster of critical facility and the other is a hexagonal cluster for fast fuel sub-assemblies with mixed carbide fuel.

Because of the above-mentioned reasons, Monte Carlo simulation is the preferred tool to deal with neutronics of ADSS. In Monte Carlo simulation, we can model the exact geometry and also use point energy nuclear data instead of multigroup nuclear data set. Hence it will be an exact simulation of neutron transport problem in spatial as well as energy domains.

3. TRIPOLI 4.0 code

The TRIPOLI-4.0 is a three-dimensional, polykinetic computer code for particle transport, based on the Monte Carlo method. The particles covered are, neutrons, photons, electrons and positrons. It is designed for two major classes of problems, those relating to shielding and neutronics.

We can define any arbitrary three-dimensional geometry in terms of the given first- and second-order surfaces and the given standard volumes. In this calculation JEF2 point nuclear data library was used.

4. Simulation details and results

4.1 *Geometry*

The composite core consists of two sub-critical cores. One of these is made of fast fuel sub-assemblies while the other is the reference core of the critical facility. In the critical facility, 19-pin (aluminum clad) natural uranium cluster and in fast fuel sub-assembly, 61-pin (SS clad) cluster were modeled, pin by pin (figure 1). In the center of the core there is a source region of diameter 30 cm, surrounded by two rows of hexagonal fast fuel sub-assemblies (figure 2). The fast assembly is chosen as the Mark II mixed carbide fuel of the FBTR at IGCAR, Kalpakkam. This combination is enclosed in a cadmium shell to prevent the thermal flux from entering the fast core region. This cadmium shell is surrounded by critical facility reference core with heavy water. This complete configuration is contained in a cylindrical calandria vessel. The radius of calandria vessel is 165 cm. For simplicity

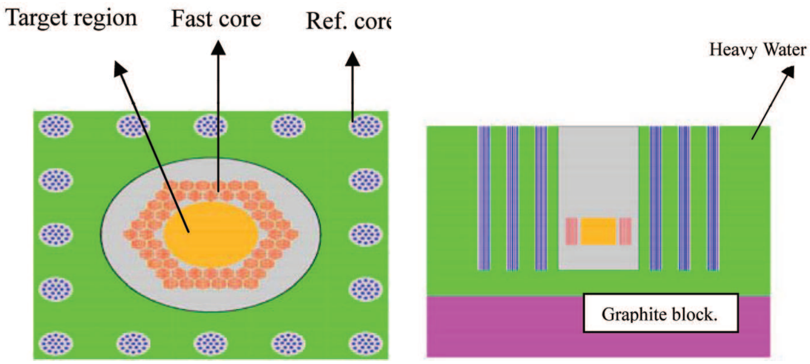

Figure 1. Top (left) and side (right) view of the composite core.

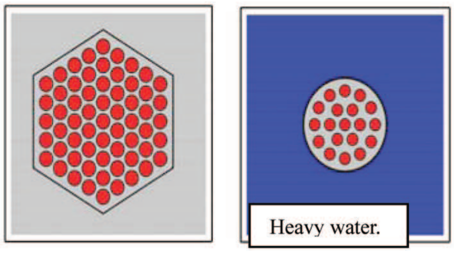

Figure 2. Fast fuel hexagonal sub-assembly (left) and 19-pin natural uranium cluster.

Table 1. Details of the reference core of the critical facility [3].

Radius of calandria vessel	165.0 cm
Height of moderator level including bottom reflector	200.0 cm
Radius of natural uranium fuel pin	0.6 cm
Clad thickness of fuel pin	0.135 cm
OD of fuel channel	10.94 cm
ID of fuel channel	10.34 cm
Pitch of ref. core of critical facility	24.5 cm

of calculation, the cross-section of calandria vessel has been taken as a square of equivalent area instead of cylinder. There are 46 lattice locations and six shutoff rod locations in reference core. In the calandria vessel, following the active fuel region, there is 30 cm heavy water as a bottom reflector, followed by 72 cm bottom graphite reflector block. All other related data are given in tables 1 and 2.

4.2 *Estimation of K_{eff}*

The following five configurations were studied and K_{eff} was calculated.

Table 2. Details of the hexagonal fast fuel sub-assemblies [4].

Fuel composition	55% PuC +45% UC
Radius of fuel pin	2.18 mm–0.37 mm
Pitch of fuel pin	0.592 cm
No. of fuel pin in one sub-assembly	61
Distance from flat to flat surface of sub-assemblies	50.75 cm
Clad thickness of sub-assemblies	0.475 mm
Length of fast fuel sub-assemblies	32 cm
Diameter of source region	30 cm
Thickness of cadmium shell	5 mm

Table 3. Effective multiplication factor (K_{eff}) for the various configurations simulated with TRIPOLI.

Various configurations	K_{eff}
Mark-II MC core	0.5760
Mark-II MC core and heavy water	1.2269
Mark-II MC core in cadmium/boron shell and water	0.7354/0.6809
Ref. core with cadmium/boron	0.9190/0.9118
Composite core with cadmium/boron	0.9276/0.9124

(i) Only Mark-II mixed carbide (MC) fast fuel sub-assemblies, consisting of two rows surrounding the target region.
(ii) Mark-II MC fast fuel sub-assemblies, surrounded by heavy water.
(iii) Mark-II MC fast fuel sub-assemblies, enclosed in cadmium shell and surrounded by heavy water.
(iv) Only reference core.
(v) Reference core and Mark-II MC core separated by cadmium shell (composite core).

Thousand batches were used in the simulation, each batch containing 1000 particles. K_{eff} of all these configurations are being given here. The statistical error is 0.3% in each case. The results are displayed in table 3.

5. Conclusions

The conclusions are as follows:

1. It can be seen that higher K_{eff} can be achieved, if the sub-critical core is made by combining the two different sub-critical cores with lower K_{eff}.
2. Boron shell is more effective in cutting the contribution of thermal neutron than cadmium shell.

This study is basically a feasibility analysis to confirm that such cores can be assembled in the critical facility. No optimization with regard to the amount of fuel in different zones etc. has been done. Further studies are required to assess the boosting effect of the source by the fast core, neutron economy and safety.

References

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