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Measurement of control rod reactivity and shut down margin of 3 MW TRIGA Mark-II research reactor using analogue and digital I&C system

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ABSTRACT

Measurement of reactor safety parameters is essential for reactor safety, operation and experimental research. Reactor control rod reactivity has been measured by the positive period method using analogue and digital instrumentation & control (I&C) system of the 3 MW TRIGA Mark-II research reactor of Bangladesh Atomic Energy Commission (BAEC). The BAEC research reactor had been operating with the analogue I&C system since September 1986–July 2011. The analogue I&C system has been replaced by a new digital I&C system on June 2012 and the reactor is now operating with the PC based digital I&C system. In the newly installed digital I&C system several modifications, upgradations and replacement tasks were carried out including control rod drive systems. After the installation of the digital I&C system, some nuclear safety parameters (e.g., control rod worth, core excess reactivity and shut down margin) were measured to ensure the safe operation of the reactor. In this study, the measured control rod reactivity, core excess reactivity and shut down margin were also compared with the previous measured (analogue system) values for the validation of the digital I&C system of the reactor. The measured safety parameters were found within the safety limit as mentioned in the safety analysis report (SAR) of the BAEC research reactor.

1. Introduction

The BAEC 3 MW TRIGA Mark-II research reactor achieved its first criticality on 14 September 1986. The BAEC research reactor had been operated about 26 years with the analogue I&C system. Analogue based instrumentation and control (I&C) system as well as the associated systems of the reactor got obsolete day by day because of the advent of PC based digital I&C system. Considering these facts, installation of a digital I&C system based on the state-of-the-art digital technology became necessary. A new digital I&C system has been procured and installed in the BAEC research reactor on June, 2012. Several modifications, upgradations and replacement of I&C systems were carried out which includes: safety power channels, fuel temperature measuring instruments, water temperature monitoring systems, wide range log power channel, multi range linear power channel, thermal power calculator (TPC), reactor protection system and control rod drive systems, etc. (Haque et al., 2012). During the installation of new control rod (CR) drive system, 25 fuel elements have been removed from the reactor core to maintain the subcritical mass in the reactor core. These fuel elements were kept in the fuel storage rack in the reactor pool. After installation of the CR drive systems, 25 fuel elements put back into the core in the same position. The reactor core configuration was changed due to the orientation change of 25 fuel elements and CR. Therefore, it was necessary to estimate safety parameters (such as CR reactivity, core excess reactivity, and shut down margin) and validate digital I&C system of the reactor.

The BAEC research reactor has six control rods designated as Transient, Shim-1, Shim-2, Shim-3, Shim-4 and Regulating. The reactivity control is performed by control rods of Boron Carbide (B_4C). The control rods are positioned at different locations of D-ring in the reactor core (Fig. 1). The standard 5 control rods have electrically driven rack and pinion drives, and 1transient rod has a pneumatic electromechanical drive system. The control rods travel vertically a distance of approximately 38.1 cm (15 in.) between their fully withdrawn and inserted positions (GA, MOMM, 1984).

In small research reactors, reactivities and reactivity increments play an important role in reactor physics, safety, control and operational schedules (Tombakoglu and Cecen, 2001). Reactor control rod reactivity measurement is necessary to assure the performance of control rods. Nuclear reactors must have sufficient excess

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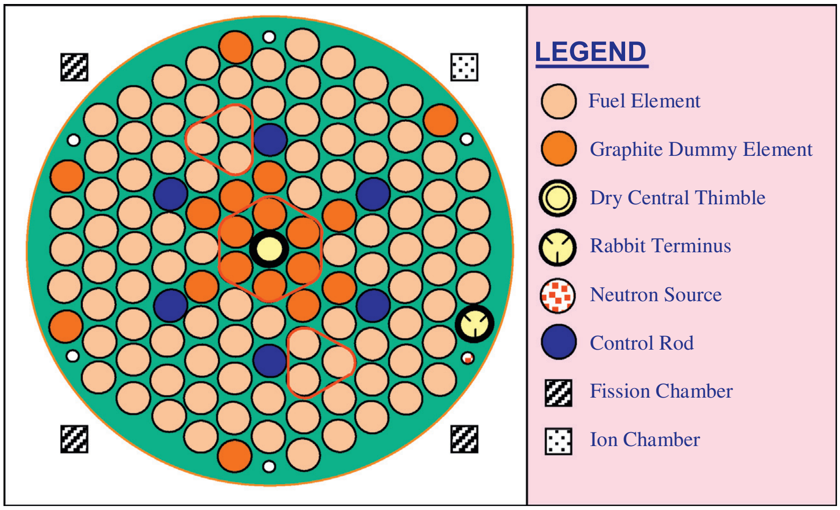

Fig. 1. Core configuration of the BAEC research reactor.

reactivity to compensate the negative reactivity feedback effects such as those caused by the fuel temperature and power defects of reactivity, fuel burn-up, fission product poison and also to allow full power operation for predetermined period of time (Mesquita and Souza, 2010; Souza and Mesquita, 2009). In the BAEC research reactor, if the initial core excess reactivity in the core is large enough to allow 4% burn-up reactivity loss, then the core life is about 1600 Mega Watt days (MWds) before the first refueling is necessary (GA, SAR, 1984). The total burn-up of the reactor is about 700 MWds up to June 2012. In this study, the reactor safety parameters were measured using analogue and digital I&C system in presence of dry central thimble (DCT) in the reactor core. It is to be mentioned here that a wet central thimble (WCT) was replaced by a DCT in the reactor core on October 1988. This paper presents the control rod worth, core excess reactivity and reactor shut down margin of the reactor after 10 MWds (1988) and 700 MWds core burn-up (2011). It also compared these safety parameters measured by analogue and digital I&C system of the BAEC research reactor.

2. Brief description of the reactor

The TRIGA Mark-II research reactor of BAEC is a light water cooled, graphite reflected reactor, designed for steady state and square wave operation up to a power level of 3 MW (thermal) and for pulsing operation with a maximum pulse power of 852 MW. The reactor is designed for multipurpose uses like training, education, radioisotope production and various R&D activities in the field of nuclear science and technology, such as neutron activation analysis (NAA), neutron radiography (NR) and neutron scattering (NS). The reactor uses Low Enriched Uranium (LEU) fuel with enrichment of 19.70% U-235, $ZrH_{1.6}$ (prime moderator) and burnable poison Er^{167}. The fuel material is housed in a 0.5 mm thick stainless steel (Type 304) cladding. The important safety feature of the TRIGA fuel is the Prompt Negative Temperature Coefficient of Reactivity (PNTCR). The nominal value of the PNTCR is about $1.1 \times 10^{-4}\%\ \Delta k/k/^{\circ}C$ (GA, SAR, 1984). Because of this characteristic of fuel, the reactor can be operated in pulse mode (with peak power of 852 MW and half maximum pulse width of about 18.6 ms).

The reactor core consists of 100 fuel elements (93 standard fuel elements, 5 fuel follower control rods (FFCR) and 2 instrumented fuel elements), 6 control rods (5 FFCR and 1 air follower control rod), 18 graphite dummy elements, 1 Dry Central Thimble, 1 pneumatic transfer system irradiation terminus and 1 neutron source. The control rods are positioned in the D-ring. Fig. 1 shows the geometrical configuration of the fuel elements, graphite dummy elements and control rods loaded in the core.

3. Experimental measurement

3.1. Control rod reactivity

The control rod reactivity was measured by the positive period method that consists of withdrawing the control rod from a known critical position through a small distance, and then to measure the stable period of the resultant reactor transient. Prior to measurement the control rod reactivity, the reactor was kept shut down position for about four days to make the reactor xenon free condition. The reactivity measurements were performed at low power so that the increase in temperature during the experiment was negligible.

The following steps were followed for the measurement of the control rod reactivity:

1. The reactor was made critical at low power (40 W) by raising and banking all control rods except the test rod. The test rod was fully down position and power range switch was set at AUTO.
2. The test rod was withdrawn (about 50–100 units) until it started to increase the reactor power.
3. Stop the rod withdrawal and noted the rod position.
4. The time were measured by two digital stop watches for the change of reactor power from 60 W to 90 W and 120 W to 180 W (on the scale of multi range linear power channel NMP 1000 of the reactor digital console). The average of these two values (t) were determined.
5. Down the other control rods except the test rod to make the reactor critical at 40 W again.
6. Steps 1 through 5 were repeated until the test rod is fully up (999) position.
7. Following equation is used to calculate the reactor period, T for each withdrawal (Shaw, 1969)

$$P = P_0 e^{\frac{t}{T}} \tag{1}$$

Here,

$$\frac{P}{P_o} = \frac{90}{60} or \frac{180}{120}$$