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MEASUREMENT OF FEEDBACK REACTIVITY EFFECTS OF THE BAEC TRIGA REACTOR

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ABSTRACT

The aim of this study is to measure the feedback reactivity effects of the Bangladesh Atomic Energy Commission (BAEC) TRIGA Research Reactor (BTRR). Using digital instrumentation and control (I&C) system, feedback parameters such as reactivity coefficients of fuel, moderator and power effects are measured. At 300 kW reactor power, the obtained results for fuel temperature coefficient are 0.664 $^{¢}/_{°C}$ and 0.765 $^{¢}/_{°C}$ at C_1 and D_3 core positions respectively. The results for 100 kW to 400 kW reactor power show its increasing nature as the reactor power increases. The measured value of the moderator temperature coefficient is found to be 0.419 $^{¢}/_{°C}$ at 500 kW reactor power. The power coefficient of reactivity is measured for several power ranges from 50 kW to 2.5 MW and the average value is found to be 0.0757 $^{¢}/_{kW}$. The measured values of the reactivity coefficients are found to be in a good agreement with the GA Safety Analysis Report (SAR) provided for BTRR.

Keywords: TRIGA reactor, Reactivity, Fuel temperature coefficient, Moderator temperature coefficient, Power coefficient.

INTRODUCTION

The BAEC TRIGA Research Reactor (BTRR) is a light water cooled and moderated, tank type 3 MW thermal reactor which is used in different fields of science and technology since 1986. BAEC TRIGA reactor fuel is a solid homogeneous mixture of Erbium Uranium Zirconium Hydride (Er-U-ZrH) alloy containing about 20% by weight of uranium enriched to about 19.7% U-235 and about 0.47% by weight of erbium in a cylindrical rod with stainless steel (SS-304) cladding (GA Technologies, 1984). The use of Er-U-ZrH material for the fuel-moderator elements ensures the inherent safety features and gives the TRIGA core a large negative fuel temperature coefficient (Mesquita and Souza, 2008). As the temperature coefficient is negative, a significant amount of reactivity is required to compensate for the change in temperature (Lee *et al.* 2009; Mesquita and Souza, 2010). Light water is used as moderator in TRIGA research reactor and it is under moderated resulting a negative moderator temperature coefficient (DOE, 1993). Power coefficient of reactivity is the combined effect of all the parameters influenced by temperature. For TRIGA system, power coefficient is also

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negative because of its large negative fuel temperature coefficient and moderator temperature coefficient (Atomics General, 1967). Reactivity of a reactor core changes inherently with temperature, fuel burn up and core configuration, pressure and poisons (Hussain, 2011). Therefore, it is necessary to investigate the reactivity coefficients with operational time to ensure the operational safety of the reactor. The reactivity coefficients have been measured by various methodologies by various *rector* facilities (Kostić, 1997; Laggiard, & Runkel, 1997; Omar *et al.* 2012; Rahgoshay & Noori-Kalkhoran, 2013 Safarzadeh *et al.* 2015). Among them, noise analysis is an interesting way to measure the reactivity coefficients therefore several algorithms have been developed based on noise analysis technique (Shimazu, 1995; Demaziere *et al.* 2003, Andersson *et al.* 2003; Mori *et al.* 2003); Still, noise analysis technique shows some drawbacks because of the biasing nature of the estimated parameters from the true values (Mori, 2004). This paper represents the results of the research conducted to measure the feedback reactivity effects of the BTRR based on a simple methodology using NCCM and FCCM for different power levels.

METHODOLOGY

The change in reactivity for per degree change in temperature is termed generally as temperature reactivity coefficient (TRC); that is,

$$\alpha_x = \frac{d\rho}{dT_x} \quad (1)$$

where, $d\rho$ is the reactivity compensation due to temperature change, dT is the temperature change and α_x is the fuel temperature coefficient (FTC) when fuel temperature is changed and α_x is the moderator temperature coefficient (MTC) when moderator temperature is changed (Duderstadt and Hamilton, 1976). Fuel temperature coefficient is measured through the sequential ON and OFF of the primary coolant pump. Initially, the reactor is made critical at 100 kW using all the control rods. Recording all the control rod positions and the fuel temperatures of different fuel channels, the primary coolant pump is then turned ON to cool the fuel. Due to the decrease of fuel temperature, control rod positions changed that is recorded along with the new fuel temperatures. Fuel temperature change is obtained from the difference of two temperature recorded and the reactivity compensation is calculated using control rod calibration data.

To measure the MTC, reactor is made critical at 500 kW manually using all the control rods keeping the regulating rod at a desired position and the demand power is set at 500 kW. The operation mode of the reactor is set from manual to automatic and run for about half an hour to allow moderator temperature to increase within the safety limit (43 ºC) of the BTRR (GA SAR, 1986). The temperature effect of the moderator is compensated automatically by the regulating control rod to operate the reactor at a constant power. The final temperature of the moderator and position of regulating rod are recorded. The temperature difference of the moderator dT_M is determined from the thermocouple reading and the reactivity insertion for the corresponding control rod positions came from the control rod calibration data. Initial and final moderator temperature are found to be 28 ºC and 38 ºC respectively after half an hour operation. The reactor hall temperature was around 29 ºC during the measurement. At the fixed demanding power of 500 kW, the corresponding reactivity and the moderator temp eratures are shown in Table 1.

Table 1. Regulating rod positions, corresponding reactivity and moderator temperatures at 500 KW critical power.

Critical Power (kW)	Initial rod position	Final rod position	Initial reactivity(¢)	Final reactivity(¢)	Initial temp	Final temp
500 kW	498	508	918.318	922.512	28ºC	38ºC

Power coefficient of reactivity relates the change in reactivity when the reactor power is changed per kilo watt, that is,

$$\alpha_p = \frac{d\rho}{dp} \tag{2}$$

where, $d\rho$ indicates the change in reactivity; dp indicates change in reactor power (kW) and α_p stands for power coefficient of reactivity (Lewis and Elmer, 2008). Power coefficient of reactivity for various power ranges is calculated by increasing the reactor power (Rabir, 2013). The reactivity compensation along with reactor power is not absolutely linear but it may be considered as linear for smaller power levels (Souza and Mesquita, 2009, 2011). To determine the reactivity compensation due to power changes, the reactor is made critical manually at 50 kW under the FCCM inserting 834.008 ¢of reactivity. Then the critical power is shifted to 100 kW manually by all the control rods and the corresponding reactivity insertion is calculated using control rod calibration data. Control rods positions are recorded for several power ranges from 50 kW to 2.5 MW reactor power and the corresponding reactivity was obtained from reactivity data calculating the power coefficients of reactivity using equation (2). Table 2. Shows the several power ranges and the corresponding reactivity insertion in cents.

Table 2. Control rod positions and corresponding reactivity for several power levels

Reactor Power	Control rod positions						Reactivity insertion (¢)
	Transient	Shim1	Shim2	Shim3	Shim4	Regulating	
50 kW	458	457	457	455	456	451	833.008
100 kW	548	457	456	456	454	459	836.702
250 kW	459	462	462	460	456	466	846.765
500 kW	466	468	467	469	467	469	862.101
1 MW	479	484	486	485	487	489	901.796
1.5 MW	503	503	500	503	505	506	941.624
2 MW	527	522	526	519	521	530	986.186
2.5 MW	548	547	549	546	545	551	1035.873

[*] In Table 2, column 3 represents the control rod positions where, each rod length (15 inch) is represented by 1000 equal units from 0 to 999.

Updated reactivity data of control rod is essential to measure reactivity feedback parameters because of its changing nature with reactor operation period. Hence, control rod calibration of BTRR was done prior to the measurement of feedback parameters. The effective delayed neutron fraction of BTRR is 0.007 which is a dimensionless quantity (Lamarsh, 1966).

RESULTS AND DISCUSSIONS

Reactivity worth was measured using positive period method to get the control rod calibration data. The positive period method was used to measure the individual control rod worth and the total reactivity worth obtained for the BTRR control system was 14.75 $.

Figs. 1- 2 show the control rod calibration curves of all the six control rods of BAEC TRIGA reactor. From Fig. 1, it is observed that the change of reactivity is maximum at the center region of the core and decreases gradually towards the top and bottom region. This is because the neutron flux is higher at center region than the top and the bottom region (Hosan *et al.* 2015). It is also observed that worth of the six control rod is different from one another and the maximum worth was found to be 2.804 $ for regulating rod and the minimum worth was found to be 1.777 for transient rod.

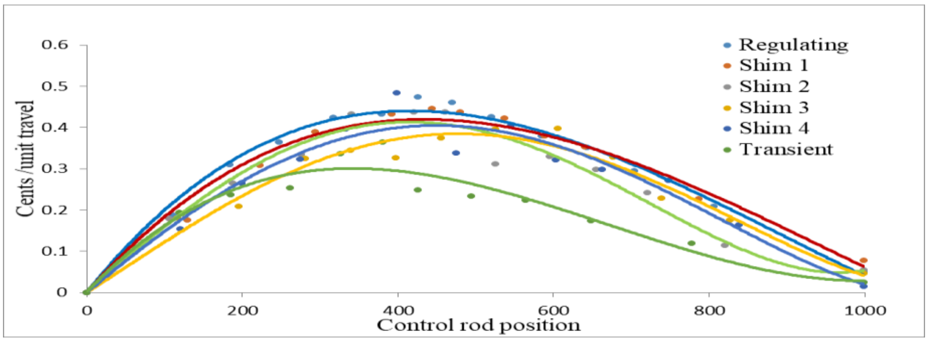

Fig. 1. Differential worth for each unit movement of control rods. The total length (15 inch) of each control rod is divided into 1000 equal units.

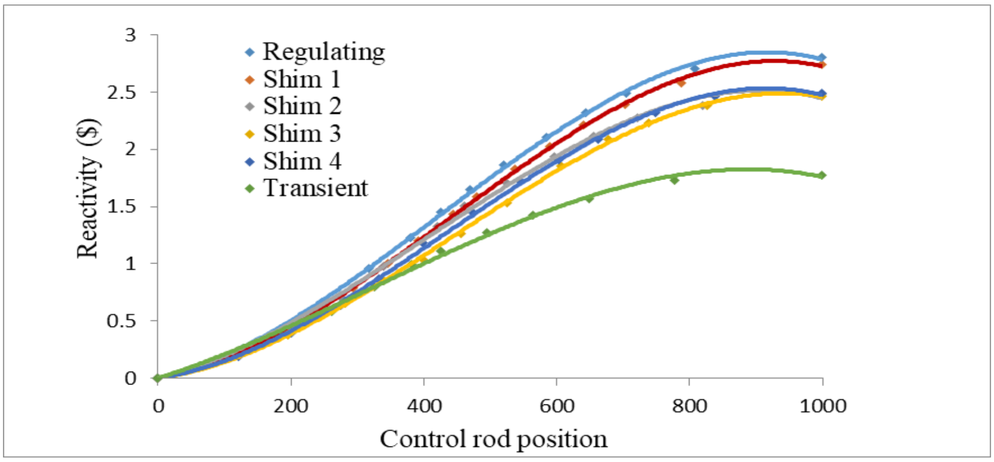

Fig. 2. Integral worth curves of BTRR control rods

Integral rod worth curves show the change of reactivity variation with the control rod movement. From Fig. 2, it is observed that the slope of each curve is maximum at around half (500) of the whole control rod length (999) as it is expected (Hosan *et al*, 2015).

Fuel temperature changes when the reactor power changes. FCCM is used to change the fuel temperature sharply. Fig. 3 shows the variation of fuel temperature as the reactor power changes in FCCM and in NCCM.

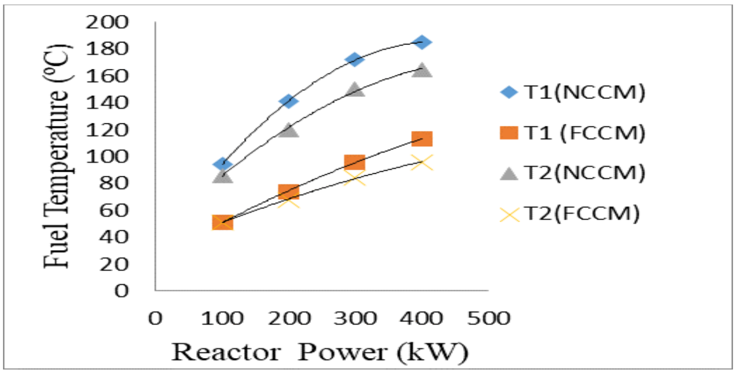

Fig. 3. Fuel temperature change with reactor power

Fuel temperature coefficient was measured at two different core locations using two instrumented fuel elements (IFE) embedded with two thermocouples. The results obtained for fuel temperature coefficient at C_1 and D_3 positions are 0.664 $¢/°C$ and 0.794 $¢/°C$ for 300 kW reactor power. For various power levels, it is observed that fuel temperature coefficient increases as the reactor power increases (Fig. 4).

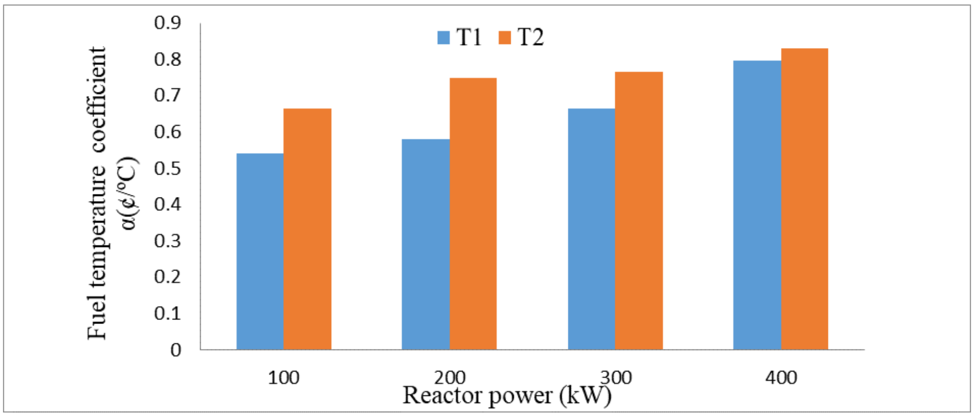

Fig. 4. Fuel temperature coefficient vs reactor power at $C_1(T_1)$ and D_3 (T_2) core locations

Moderator temperature coefficient was measured at the steady state reactor power at 500 kW and the obtained result is 0.419 $¢/°C$. It is seen that the reactivity coefficient for moderator is smaller than the coefficients for fuel. Fuel elements response almost immediately after any change in temperature compared to the moderator (Igor and Matjaz, 2010). For the research reactors, moderator temperature does not change as much as fuel temperature does. But importance must be given to the moderator temperature coefficient for the light water thermal type power reactors (DOE, 1993).

Power coefficient of reactivity for different power ranges is shown in Fig. 5. At 100 kW reactor power, the power coefficient obtained was 0.0538 $¢/kW$. As the reactor power increases, the negative feedback of reactivity also increases as a result the power coefficient also increases. Power coefficient was found to be 0.0993 $¢/kW$ for 2.5 MW reactor power. From Fig. 5, it is also observed that, "reactivety must" be inserted if it is desired to make the reactor critical at any higher power level from the previous critical condition

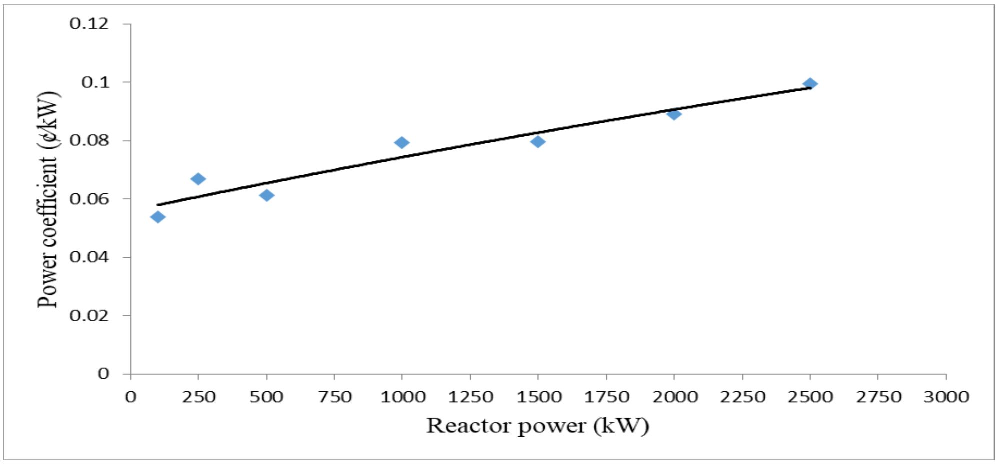

Fig. 5. Variation of power coefficient with reactor power

The little discrepancy about the linearity of the power coefficient versus reactor power curve may arise due to the fact that, the power intervals considered in this experiment was not uniform (Table 2).

CONCLUSION

Evaluation of feedback reactivity effects is very important to understand the reactivity effects on temperature, fuel burn up and reactor power. Based on the control rod calibration data, fuel temperature coefficient, moderator temperature coefficient and power coefficient of reactivity has been measured using digital instrumentation and control (I&C) system of BTRR. The average of the results obtained for fuel temperature coefficients at C_1 and D_3 positions are 0.654 $¢/°C$ and 0.751 $¢/°C$ for different reactor power levels. Moderator temperature coefficient is found to be 0.419 $¢/°C$ at 500 kW reactor power. The average of the power coefficients obtained is 0.0756 $¢/kW$ for 50 kW to 2.5 MW reactor power range. The precision of the results obtained from the present study depends on the level of accuracy to the measurement of $d\rho$, dp and dT.

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