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Research Article

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# Analysis of Time Dependent Regulating Rod's Positional Behavior and Coolant Temperature Behavior in BAEC TRIGA Mark-II Research Reactor

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## Abstract

The experiments presented in this paper were conducted by keeping the BAEC TRIGA Mark-II research reactor in the AUTO mode in two consecutive days and approximately three hours of reactor operation per day. The regulating rods position was automatically varied in this mode to ensure constant power operation. Regulating rod's position variation over time, and coolant temperature changes with regulating rod's position were observed and analyzed. It has been found that the regulating rod's position changes necessary for the desired constant power operation were more frequent in the first day compared to the second day which is an indication that the core conditions were different in the two days of operation. Causes of the core condition differences were also briefly explained in this work. The analysis presented in this work is useful to understand reactor core environment at different operating states.

**Keywords:** Research reactor; Reactivity; Regulating rod; Coolant; Fission poisoning element

## Introduction

Ensuring safety in nuclear reactors is of utmost importance all through the lifespan of a reactor e.g. reactor commissioning, operation period, decommissioning, waste disposal etc. [1]. For both the power reactor and research reactor, the power of the reactor can be controlled by the coolant (e.g. boron injection system), fuel rod and control rods. Among all these controlling power with control rods is the most effective and technically convenient. Control rods are moving parts consisting of neutron absorbing material which alter the multiplication factor directly. Hence control rod can make a reactor critical and operate a reactor at a desired power level [2]. Reactivity insertion or reactivity withdrawal can be done by control rods considering fission poisoning products [3]. Understanding the correlation between the reactivity changes and control rod positioning is an essential knowledge required for a reactor operator [4]. Hence, control rod's performance analysis is a necessary task control rod worth may vary at different core conditions [5]. At the same position a particular control rod's worth could be different in different days of operation due to the different core conditions. Conditions like power level, fission poisoning elements, operational time, fission rate, fuel temperature, and moderator or coolant temperature can influence the control rods worth. Control rods worth dependency on fission poisoning has been reported. The effect of fuel burn-up on the control rod worth has been investigated by Boafo et al. [6].

Analysis of such conditions is essential for proper understanding of reactor control system at a particular period to ensure reactor safety. Different worth at different conditions is the measure of control rods positions in that period. For same power level but at different core conditions, a specific control rod's position might be different, and it is the indication that control rod worth is not the same [7]. Due to the same reason the coolant temperature changing behavior may also be different at different core conditions. The main purpose of this work is to investigate the trend in one of the control rod's the regulating rod position variation at different core conditions to maintain a fixed power level and also to find a correlation between coolant temperature changing trend and regulating rod's position for those core conditions.

## BAEC TRIGA Mark-II Research Reactor

The TRIGA Mark-II research reactor in Bangladesh is a center for manpower training, radioisotope production and various R and D activities. This research reactor has a graphite reflected core with light water coolant. The reactor can operate up to a power level of 3 MW thermal with square wave mode and maximum pulse power of 852 MW in pulse mode for about 18.6 ms [8]. The reactor is controlled by has six control rods. They are known as transient rod, shim-1, shim-2 shim-3, shim-4 and regulating rods. All six control rod consists of neutron absorbing material Boron Carbide (B4C). The reactor core consists of 100 fuel elements (93 standard fuel elements, 5 fuel follower control rods, and 2 instrumented fuel elements), six control rods, 18 graphite elements, one dry central thimble, one pneumatic transfer system irradiation terminus, and one neutron source [9]. The reactor uses low enriched uranium fuel with enrichment of 19.7% U-235, ZrH1.6. The core is situated near the bottom of water filled tank, and the tank is surrounded by a concrete bio-shield. The reactor cooling system is designed to maintain the flow of demineralized water through the reactor core at a rate of 13230 L/min so as to remove the 3 MW thermal powers being produced in the core from thermal fission Figure 1 shows internal core configuration with control rods position.

The six control rods in the TRIGA Mark-II research reactor are with marked positions from 0 to 999. In this research regulating rod is the test control rod whose position is correlated with reactor operating time and function of several parameters affecting the core.

## Experimental Method

During the operation of reactor neutron absorbing elements are produced. Among these 135Xe carries high significance due to its large neutron absorption cross section of 2.6 million barns which is about

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5128 time larger than the cross section of 235U, which are 570 barns. One stage of fission reaction is the formation of 135I by subsequent beta decay of 135Te. Again, the beta decay of 135I introduces 135Xe and after some subsequent beta decay it reaches stable 135Ba. This process continues after reactor shutdown. Depletion of 135Xe occurs via absorption of neutron (by forming 136Xe) and also by subsequent beta decay, forming stable 136Ba [10]. In summary, the process is as follows, 135 Te (Beta Decay) 135I (Beta decay)135Xe (Beta decay)135Cs (Beta decay)135Ba (stable).

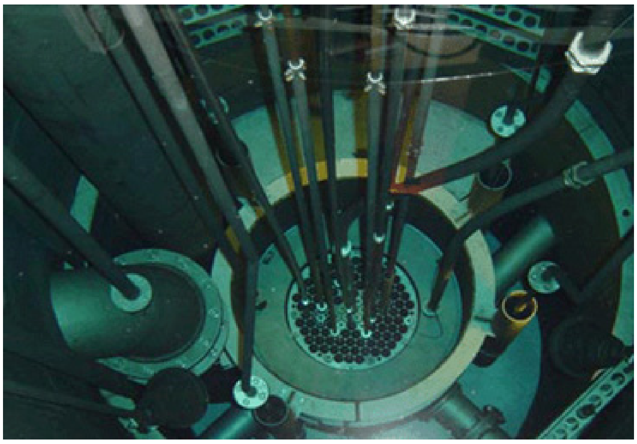

**Figure 1:** BAEC TRIGA Mark-II research reactor core configuration.

This effect of xenon is more dominant during the shutdown period. After shutdown Xe is produced only through decay process and reaches a maximum peak values within few hours [11]. Thus, after shutdown core condition is a barrier for start up the reactor again until the time period for removal of this poison. This decay time duration due to Xe is termed as xenon dead time. 135Xe build-up after shutdown depends on the operating flux before shutdown; the greater the operating flux, the higher will be the xenon peak. Generally, the 135Xe concentration gradually decays back to low levels within a few days after shutdown.

The experiments presented in this work involved two days of reactor operation. Before the first day of operation the reactor core was made xenon free by shutting down the reactor for a sufficiently long amount of time. The reactor was started with the AUTO mode to reach a constant 2.4 MW power level. In the AUTO mode shim-1, shim-2, shim-3, shim-4 and transient rods are fixed in their respective positions depending on the core conditions, and only the regulating rod is allowed to move for power control. After reaching criticality at 2.4 MW, the critical time is marked for both days. All through the three hours of operation all the mentioned control rods were fixed while only the regulating rod was active to control the power level. Depending on the core dynamic environment the regulating rod attempted to change its position. Change of time for regulating rod's position change was tabulated sequentially for both days. The time duration for the experiments was fixed, around three hours (180 mins) in both days. It's not possible in AUTO mode to operate the reactor for exact three hours as the regulating rod position is changed automatically with reactor core dynamic condition and is not manually controlled. Hence the change closest to 180 minutes was tabulated as the final value. Hence, for the first day reactor operating experimental time was 177 mins and for the second day coincidentally it was almost 180 mins. The event time, regulating rod's position and coolant temperature have been monitored through sensors in a digital display Table 1 and Table 2.

**Table 1:** Regulating rod position variation and coolant temperature change with time at day one.

| Time on clock (hh:mm) | Time interval (Minutes) | Cumulative time (Minutes) | Regulating rod positions | Coolant temperature (°C ) |
|---|---|---|---|---|
| 10:20 | 0 | 0 | 568 | 25 |
| 10:35 | 15 | 15 | 565 | 29 |
| 10:39 | 4 | 19 | 563 | 29 |
| 10:40 | 1 | 20 | 559 | 30 |
| 10:41 | 1 | 21 | 555 | 30 |
| 10:42 | 1 | 22 | 551 | 30 |
| 10:48 | 6 | 28 | 549 | 30 |
| 10:50 | 2 | 30 | 545 | 31 |
| 10:57 | 7 | 27 | 543 | 31 |
| 11:01 | 4 | 41 | 540 | 32 |
| 11:14 | 13 | 54 | 536 | 33 |
| 11:22 | 8 | 62 | 534 | 34 |
| 11:36 | 14 | 76 | 530 | 34 |
| 11:43 | 7 | 83 | 523 | 35 |
| 11:55 | 12 | 95 | 519 | 35 |
| 12:33 | 38 | 133 | 523 | 35 |
| 13:05 | 32 | 165 | 517 | 35 |
| 13:06 | 1 | 166 | 519 | 35 |
| 13:09 | 3 | 169 | 521 | 35 |
| 13:10 | 1 | 170 | 525 | 35 |
| 13:17 | 7 | 177 | 527 | 35.4 |

**Table 2:** Regulating rod position variation and coolant temperature change with time at day two.

| Time on clock (hh:mm) | Time interval (minutes) | Cumulative time (minutes) | Regulating rod positions | Coolant temperature (°C ) |
|---|---|---|---|---|
| 10:45 | 0 | 0 | 538 | 25 |
| 10:51 | 6 | 6 | 534 | 27 |
| 10:55 | 4 | 10 | 532 | 28 |
| 10:58 | 3 | 13 | 524 | 28 |
| 11:18 | 20 | 33 | 521 | 32 |
| 11:23 | 5 | 38 | 519 | 33 |
| 11:35 | 12 | 50 | 517 | 34 |
| 13:05 | 90 | 140 | 521 | 36 |
| 13:09 | 4 | 144 | 524 | 36 |
| 13:22 | 13 | 157 | 529 | 36 |
| 13:29 | 7 | 164 | 531 | 36 |
| 13:38 | 9 | 173 | 535 | 36 |
| 13:45 | 7 | 180 | 537 | 35.5 |

## Analysis of the Captured Data and Discussion

During the first day of experiment the reactor was operated at a constant power level of 2.4 MW by AUTO mode. Only the regulating rod was allowed to change positions to adjust power level. And the other control rods positions were automatically fixed by the process. The reactor reached criticality at 10:20 am in the morning. Then the change in the regulating rod positions which occurred to keep the power level constant were tabulated. The regulating rod position changes do not occur at regular time intervals, as these changes have dependency on the dynamic environment of reactor core. After reaching criticality, the source neutron is enough to increase the power level further. To stop this and to keep the reactor at the fixed power level, regulating rod is automatically inserted into the core. Figure 2 shows a continuous decrease in regulating rods position level up to around 90 mines, which indicates more and more insertion into the core to hold the power at 2.4 MW. After that the change in the position does not vary much and stays between 517 to 527 for the remaining part of the operation.

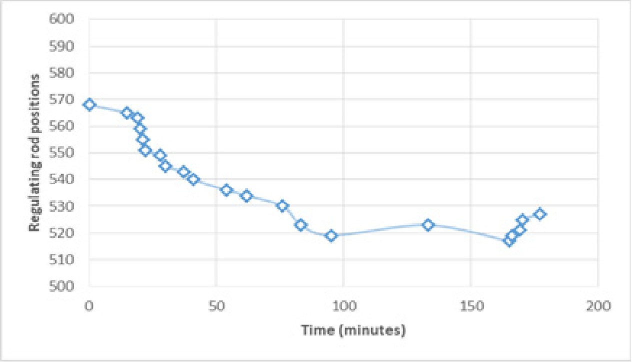

**Figure 2:** Variation of regulating rod positions with time while reactor is operating at a constant power (2.4 MW) during the first day of experiment.

For the second day of operation the research reactor was started after the shutdown in the previous day's operation which means the reactor was not xenon free completely at the beginning of the operation. During reactor operation, absorption of thermal neutron by 135Xe means reduction of chain reaction and hence negative reactivity. More positive reactivity needs to be added to keep the reactor at the desired level which is accomplished by the control rods.

In the second day, criticality of the reactor was achieved at time 10:45 am and power was maintained at 2.4 MW with AUTO mode similar to the previous day. Due to the presence of xenon from the previous day's operation the power tends to reduce. To hold the power at the constant power level, the regulation rod started to rise up automatically. This process is called control rod withdrawing, which allows more neutron to increase the fission rate. This process compensates the neutron availability for fission reaction which was reduced by 135Xe. The variation in regulating rod position in the second day operation is shown in Figure 3.

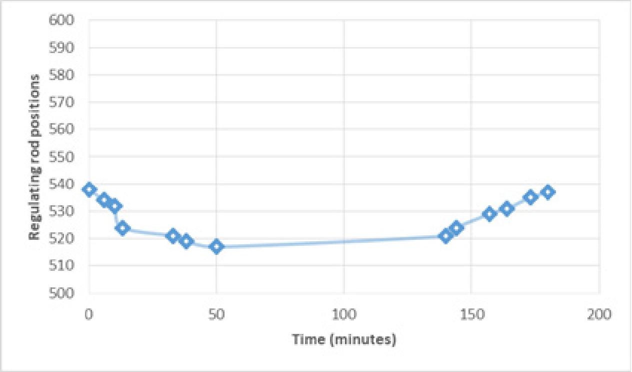

**Figure 3:** Variation of regulating rod positions with time while reactor is operating at a constant power (2.4 MW) during the second day of experiment.

From Figure 3 it can be observed that the regulating rod position varies from 538 to 537 during the three hours reactor operation. The regulating rod started to vary from position 538 after attaining criticality and then reached the minimum position of 517 and then it starts to rise up and finally reaches position 537 after three hours of operation. This nearly concave shape is due to the effect of pre-existing xenon due to which the regulation rod started to rise up automatically after some time. Compared to this the previous days experiment showed a decreasing trend and then stabilized at a particular range where it varied a little.

The coolant in this research reactor is normal water. Due to the low thermal power of the reactor, coolant temperature remains nearly in the room temperature range during the operation. The coolant temperature at the time of reaching criticality was 250°C in both days of the operation and reached around 350°C after the three hours operation. Figure 4 and Figure 5 show similarity in the temperature change.

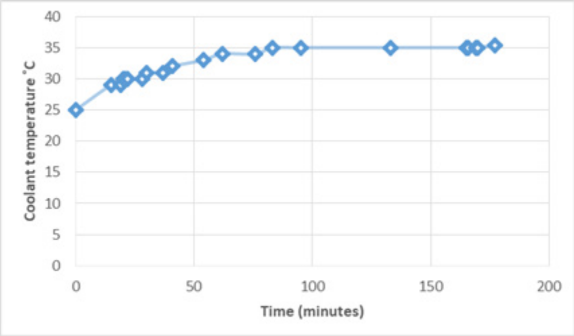

**Figure 4:** Coolant temperature change during the first day of reactor operation.

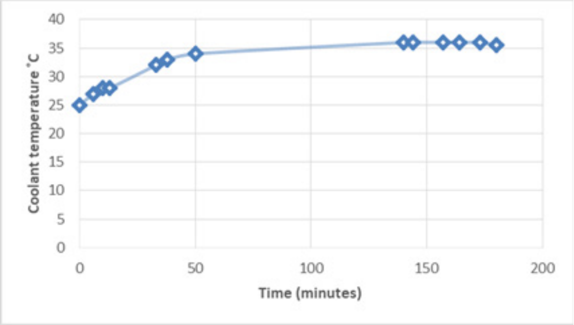

**Figure 5:** Coolant temperature change during the second day of reactor operation.

The regulating rod position variation with coolant temperature are investigated next. Regulating rod was intended to raising and barking for power control. As the power level was maintain at 2.4 MW, so it is expected that after some time the coolant temperature will be similar for both days. In Figure 6 and Figure 7 the regulating rod position

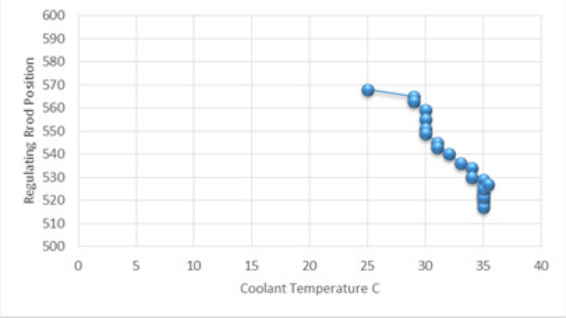

**Figure 6:** Regulating rod position variation with coolant temperature during the first day of experiment.

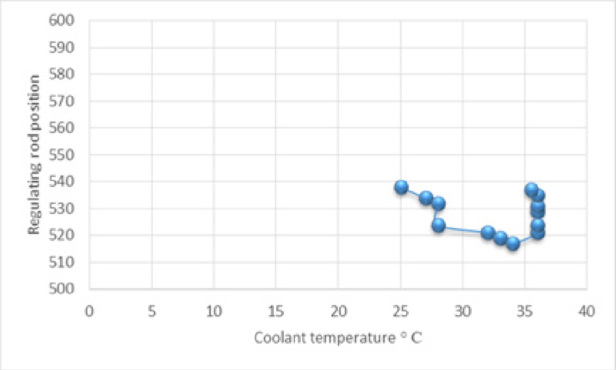

**Figure 7:** Regulating rod position variation with coolant temperature during the second day of experiment.

change with coolant temperature are shown for the first and second days of operation respectively. At first day after reaching criticality, the coolant temperature started to increase with the insertion of regulating rod. Form 250°C for the rod position of 568 the temperature continued to increase up to 350°C for the rod position of 517. After reaching around 350°C the temperature did not change much as the control rod position also varied a little.

In the second day of operation, similar to the first day, the initial coolant temperature was 250°C and it started to increase with the insertion of regulating rod from 538 to 517 positions. The coolant temperature continues to increase to 350°C and does not change much even with withdrawing of regulating rod form 517 to 537 position. Overall, compared to the first days operation, in the second day with fewer control rod position changes the temperature increases the same amount and for the lower rod positions the steps in temperature increase is more compared to the first day. This happens as in those lower positions the regulating rod stays longer in the second day of operation and rod position changes to keep the same power level are less frequent.

## Conclusion

In this work, using the experimental data from two separate days of operation of the BAEC TRIGA-II research reactor, the regulating control rods position variation, rate of coolant temperature change and coolant temperature change versus regulating rod's position are observed and analyzed. Some observable differences have been detected in the parameters under consideration between the two days of operation. These differences indicate differences in core conditions. It has been observed that for the desired constant power operation, the regulating rod's position changes were more frequent in the first day compared to the second day. The coolant temperature behavior shows a temperature increase from 25°C to around 35°C. Similar temperature increasing trends were observed with lot less changes in the control rod positions for the second day of operation compared to the first day. These behaviors support the prediction of core condition differences between the two days of operation. The analysis presented in this work is helpful to understand reactor core environment at different operating states and would be useful for reactor operators to understand the behavior of the reactor in those states.

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