THERMAL POWER CALIBRATION OF TRIGA 2000 RESEARCH REACTOR

Prasetyo Basuki[1]*, Nuri Trianti[2], Santiko Tri Sulaksono[2], Cici Wulandari[2], Fahma Roswita[2], Hisyam Zulkarnain[1], Nina Widiawati[2], Haryo Seno[3]

[1]*Directorate of Nuclear Facility Management, National Research & Innovation Agency (Tamansari 71, Bandung, Indonesia 40132)*

[2]*Research Centre for Nuclear Reactor Technology, Nuclear Energy Research Organization, National Research and Innovation Agency (Building No. 80, PUSPIPTEK, South Tangerang 15314)*

[3]*Research Centre for Nuclear Analytical and Radiation Detection Technology, Nuclear Energy Research Organization, National Research and Innovation Agency (Building No. 720, 2nd floor, PUSPIPTEK, South Tangerang 15314)*

**** Corresponding author:***
e-mail: prasetyo.basuki@brin.go.id
phone/WA: +622282130520926

Received: 26-07-2023
Revision Received: 03-08-2023
Accepted: 29-09-2023
Published: 16-10-2023

DOI :
10.17146/jstni.2023.24.2.6899

Keywords: *power calibration, calorimetric method, temperature, TRIGA 2000 research reactor.*

Abstract *The thermal power calibration of the TRIGA 2000 research reactor is very important to determine power and neutron flux accuracy. Bandung's TRIGA 2000 research reactor has undergone fuel reshuffling and requires thermal power calibration. Thermal power calibration has been conducted by calorimetric method; it is performed at 100 kW – 500 kW using seven thermocouples connected to a data logger. The computed average power was lower than the indicated power shown in the control room for all power generation. When observing channel 1 for each power generation, a higher precision can be seen at 500 kW since the calibration process was carried out sequentially from 100 kW to 500 kW. In contrast, the stirring process was continually operated. The treatment led to a uniform temperature distribution over time. Each measurement channel exhibited inconsistent deviations, indicating that certain power levels had better accuracy in some channels than others. These observations demonstrate that the measurement position does not determine the accuracy of power calculations.*

INTRODUCTION

TRIGA (Training, Research, Isotopes production by General Atomics) reactor is the world's most widely used research reactor. TRIGA 2000 Bandung is the first research reactor built in Indonesia. TRIGA 2000 was named after its current power capacity, 2000 kW, which was upgraded in 2000. TRIGA 2000 has operated for over 50 years with an initial power of 250 kW (1–5). Ensuring the continuous preservation of reactivity is essential to maintain the operational condition. Therefore, the fuel elements loaded in the core must be reshuffled and refuelled if necessary (6) by the changes in the fuel elements configuration in the TRIGA 2000 core, and thermal power calibration needs to be carried out (7). Since its establishment, the TRIGA 2000 usually calibrated thermal power using the calorimetric method. The practice used to be done under a low power level (≤ 100 kW).

Thermal power calibration in a research reactor is typically carried out at the initial start-up of the system. The calibration is also required either when a reconfiguration (reshuffling and or refuelling) of the fuel element in the reactor takes place or if there is a change in the reactor instrumentation system (8–10).

The reconfiguration of the reactor fuel element is usually necessary for several purposes, including changing the reactor thermal power capacity or replacing the preceding fuel element with a new one. Several means exist to calibrate research reactor power (11–13). The calorimetric method is the most common thermal power calibration procedure in TRIGA reactors (14,15). The calorimetric method measures the rate of increase in water temperature generated by an electric heater. The reactor is operated to generate the same rate of increase in water temperature. Thus, the power generated by the reactor is at the value generated by the electric heater. Thermal power calibration using calorimetry applies to reactors with low power generation (< 2MW) and natural convection feature capability. Thermal power calibration is usually done under 100 kW in the calorimetric method. Although it has been used for a long time and in many research reactors, the calorimetric method has a drawback, i.e., high uncertainty. Several studies reported in the literature showcased innovative approaches to overcome the high uncertainty. For example, *Žagar et al.* corrected the heat losses and considered the perturbation factor to correct the position of the control rod (16). Furthermore, Štancar et al. reported an innovative way to reduce uncertainty, i.e., by reducing the estimated error of the heat capacity constant, C, or the temperature increase rate, $\Delta T/\Delta t$ (8).

Recently, the TRIGA 2000 carried out the calorimetric method by generating reactor power at a certain value, and the rate of increase in water temperature is measured using a set of thermocouples connected to the data logger.

This study focuses on analyzing the consistency of the power monitoring versus the power generation due to core reconfiguration and finding the potency in developing the current practice to improve the safety quality in TRIGA 2000 operation. The calorimetric method must be performed under specific and controlled conditions to reduce heat losses from the reactor pool and ensure that the convective water flow from the heated reactor core is stationary. With this condition, the reactor wall is assumed to be adiabatic.

EXPERIMENTAL SECTION

Cooling System of TRIGA 2000 Research Reactor Facility

TRIGA 2000 has natural convection capability in its cooling mode. To facilitate heat removal, TRIGA 2000 is supported by two loops of the cooling system: the primary and the secondary systems, as shown in Figure 1. The heat exchanger connects these two cooling systems.

The primary system transfers heat from the core to the secondary system through a heat exchanger. The heat from the core is transferred to the primary coolant through a natural convection. Since the inlet section of the primary pipe is not directly discharged towards the bottom of the core and the outlet section is located far above the core, the water stream is considered in an upward direction, so the natural convection mechanism can be considered to occur. The secondary system will then transfer the heat from the primary cooling system to the ambient air by forced convection through the cooling tower. These two cooling systems redundantly operate two pumps at each loop (17).

During the calibration activities, a set of thermocouples is positioned around the tank randomly, axially, and radially. The stirrer is operated during calibration to ensure the heat is well distributed.

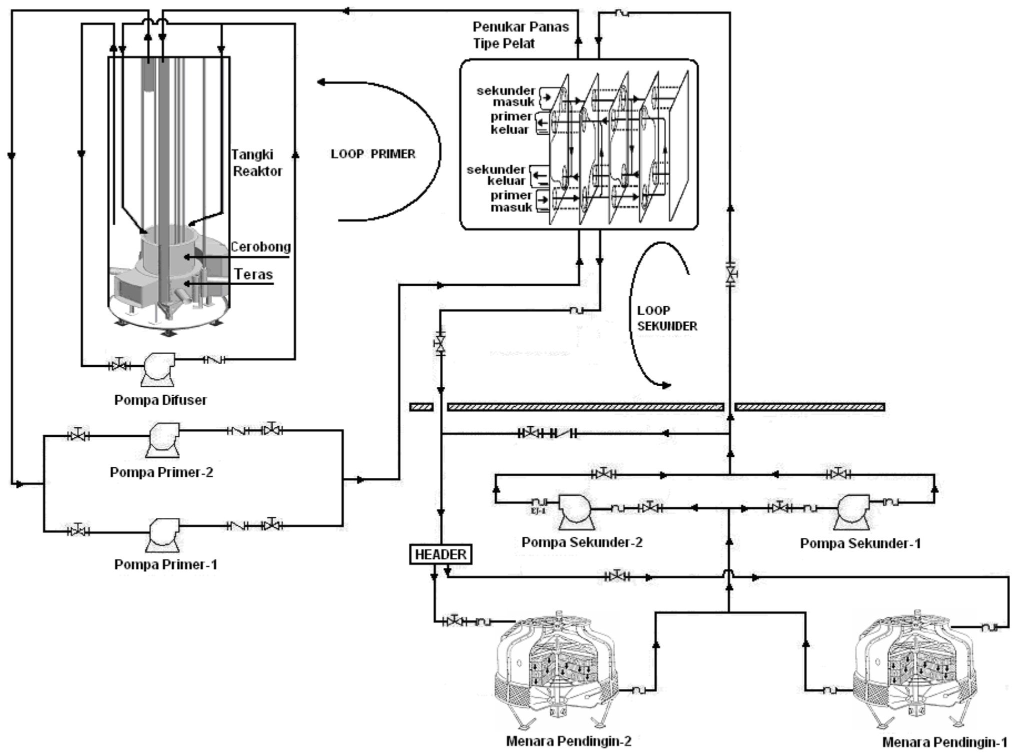


Figure 1. TRIGA 2000 cooling system.

Procedure and Experimental Setup

In this study, sequential procedures were implemented to gather experimental data systematically. The experimental data collection encompassed a systematic sequence of processes, including establishing the cooling system, implementing a precision temperature measurement system for the coolant, and the controlled mixing procedure within the reactor pool. The detailed process is described in the following explanation:

1. Preparation of coolant system

The temperature of the reactor pool water was carefully maintained at a consistent level, closely resembling the ambient temperature, to minimize the dissipation of heat from the surface of the reactor tank to the surrounding air. The experiment was carried out without active operation of the reactor cooling systems. The online purification system for the reactor tank water was deliberately deactivated to mitigate heat dissipation from the reactor pool to the demineralized plant. The reactor tank was effectively isolated by closing primary cooling valves within the primary cooling system and deactivating valves within the demineralized plant.

2. Temperature measurement system for the coolant

Seven thermocouples are set in the pool water with the radial and axial position variations. Each thermocouple is individually calibrated for precise measurement and monitoring purposes.

3. Mixing of pool water

A stirrer connected to the variable speed drive was employed to facilitate thoroughly mixing the pool water, ensuring the maintenance of a homogeneous temperature throughout the reactor pool.

Under the shutdown condition, the reactor cooling system (primary and secondary) was operated to remove the remaining heat and ensure the water temperature was near the ambient temperature. The process was done for about 15 minutes. The temperature of the bulk water was continuously monitored until it reached a stable state. This temperature was considered as the initial temperature of the pool water, denoted as (T_1). After 15 minutes, the cooling system was shut down, and all valves were closed. The stirrer then operated.

The reactor was brought to a critical state at a power level of 100 kW. After 15 minutes of critical power reached, the bulk water temperature was recorded at intervals of 10 seconds for 10 minutes. These recorded data points were then used to create a graph depicting the relationship between temperature (in degrees Celsius) and time (in minutes). From this graph, the slope, representing the rate of temperature rise, was calculated. Finally, the reactor's thermal power was determined using a specified equation. Perform the same treatment at a power higher than 100 kW at 200 kW, 300 kW, 400 kW, and 500 kW. In this study, the temperature data from the thermocouple as a function of time will be processed into a power thermal output using the TRIGA 2000 Power Calibration application.

Reactor Thermal Power Calculation

The thermal power output of the reactor is calculated based on the basic formulation shown in equation (1).

$$q = k\frac{dT}{dt} \quad (1)$$

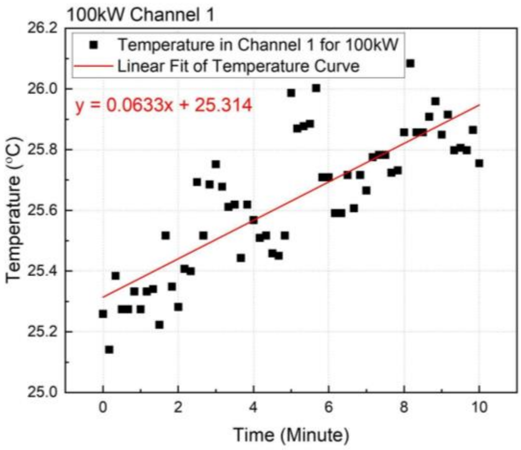
Where *k* is a heat capacity constant (kWh/^{o}C), temperature (^{o}C), and *q* is a thermal power output (kW). The heat capacity constant can be calculated. The first approximation assumes that the reactor pool temperature is constant throughout the pool (15). The determination of the heat capacity constant can be obtained through its relationship with the density of coolant (ρ) in kg/m^3, the specific heat capacity of coolant (C_p) in J/kg^{o}C, and the wet pool volume (v_w) in m^3, which can be calculated using equation (2).

$$k = \rho \upsilon_w C_p \quad (2)$$

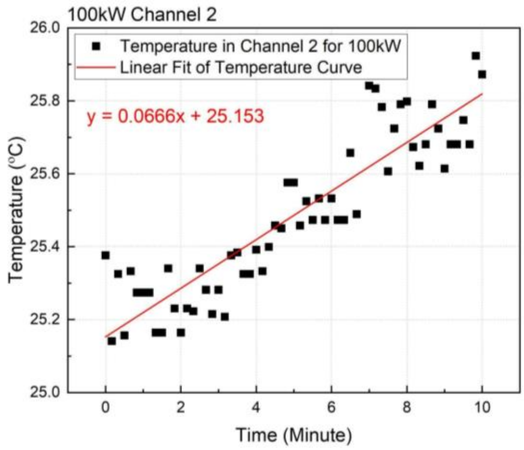
In this measurement, the inverse of the heat capacity constant is known as a reactor tank constant (1/k). The reactor tank constant for the present study is 0.04108 °C/kWh, which refers to the water level condition at 10 cm below the tank height. Based on equation (1), the thermal power output can be derived by analyzing the slope of the temperature change in the reactor coolant over time during operation and its relationship with the reactor tank constant.

RESULTS AND DISCUSSION

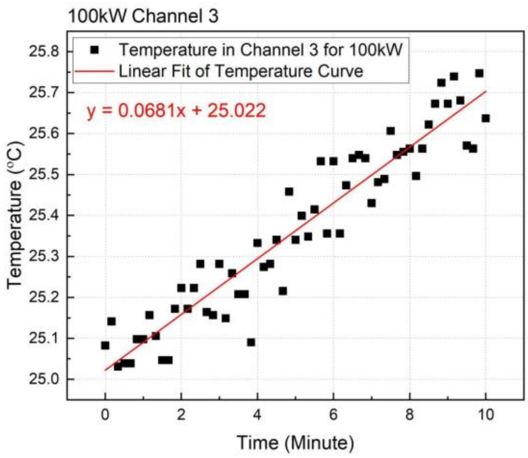
The power calibration has been carried out in the TRIGA 2000 reactor by the calorimetric method. Preconditions must be met before calibration begins, including the cooling water system preparation, the thermocouples setup, and the pool water homogenization. These preconditions were intended to achieve adiabatic conditions where there is no heat loss and the heat is even at all positions. Then, it leads to a stable state of bulk water temperature and is considered the initial temperature. The temperature measurement was set for seven positions of thermocouples type K connected to the eight channels of the USB 4718 data logger. It was made under critical and steady-state reactor conditions at 100 kW, 100 kW, 300 kW, 400 kW, and 500 kW. Figure 2 shows the water temperature of 100 kW power changes gradually within one-minute interval measurement for ten minutes. The change in temperature shows a linearly increasing trend, although each channel shows a different measured temperature within the same interval time, which leads to a different deviation. Channels 1, 2, 3, and 5 show relatively large deviations, while channels 4, 6, and 7 have a small deviation or good precision.



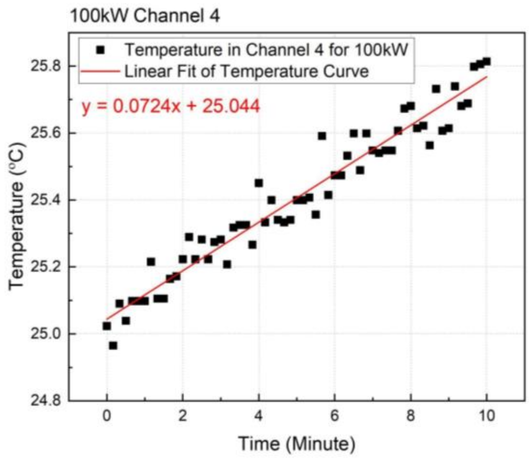
(a)



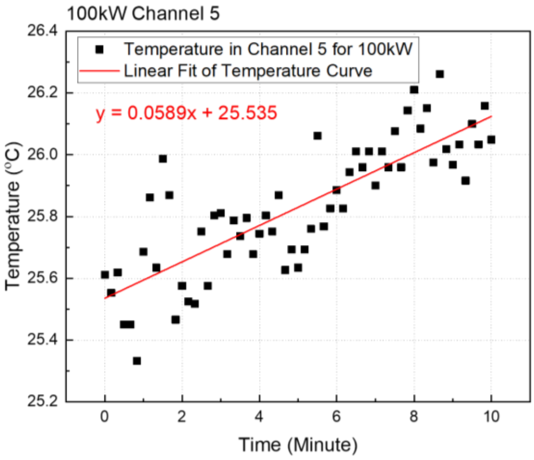
(b)



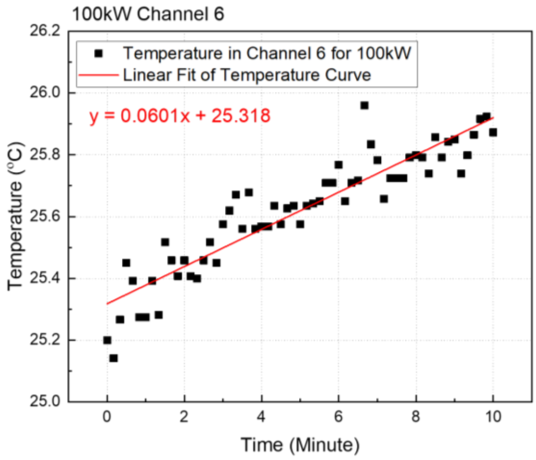
(c)



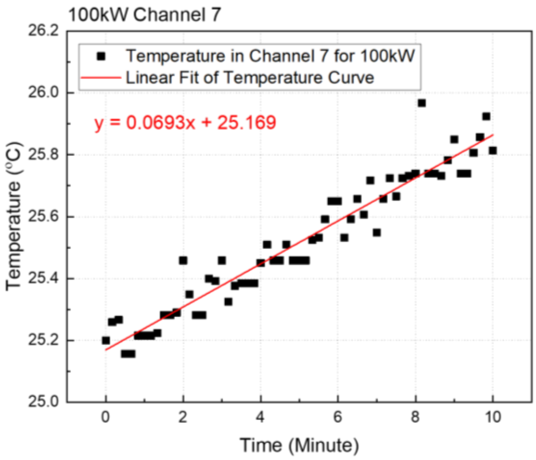
(d)



(e)



(f)



(g)

Figure 2. Temperature as a function of time for power 100 kW where (a) in Channel 1, (b) Channel 2, (c) Channel 3, (d) Channel 4, (e) Channel 5, (f) Channel 6, and (g) Channel 7.

A comparison of temperature data for channel 1 with a power between 100 kW and 500 kW can be seen in Figure 3. The data shows the distribution with a significant deviation for channel 1, as seen in the graph with a power of 300 kW. Data with minor deviations are seen at 500 kW power. These findings indicate that the data distribution at one measurement point can have a different deviation at each power value.

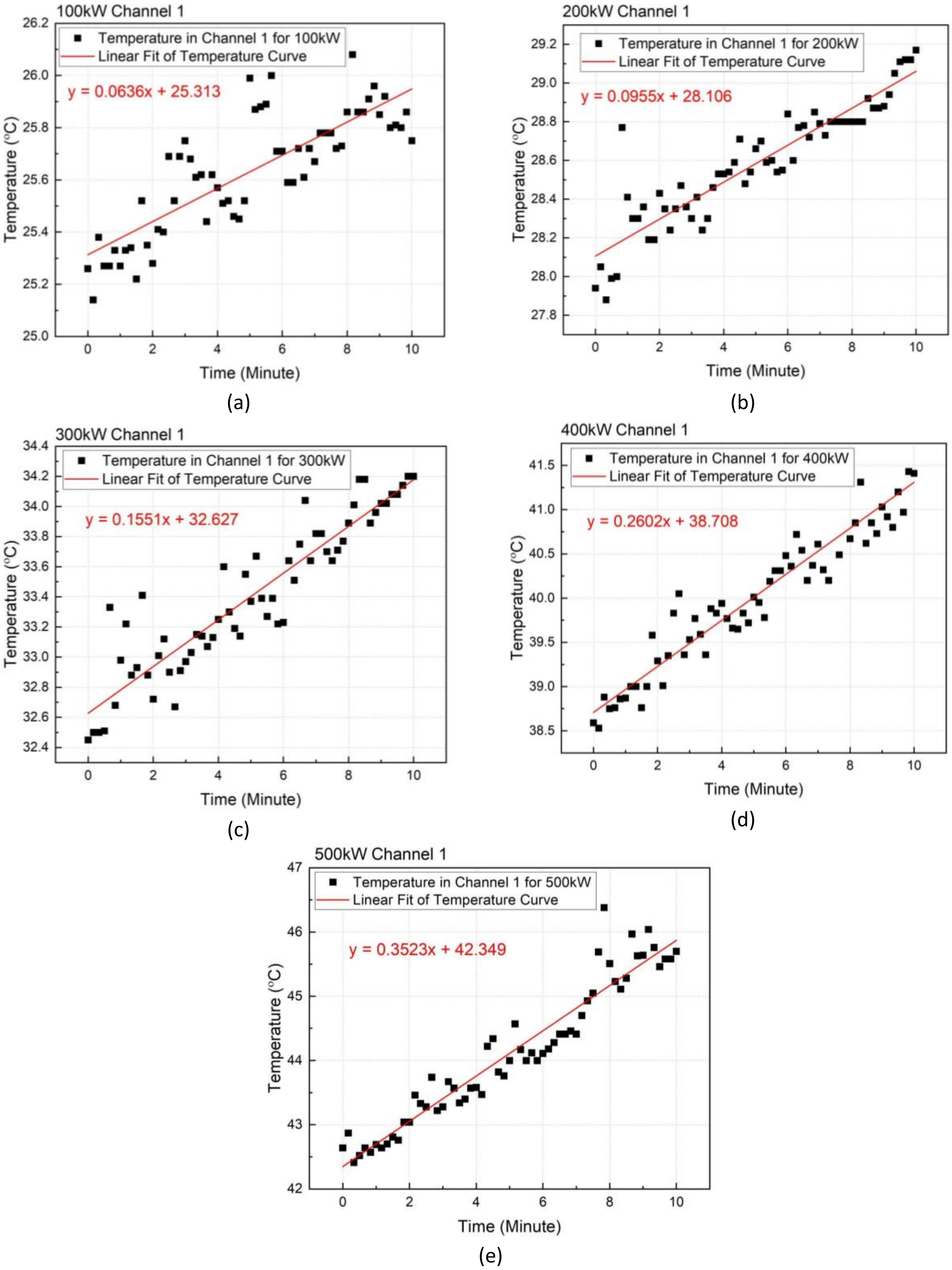


Figure 3. Temperature as a function of time for channel one at (a) 100 kW, (b) 200 kW, (c) 300 kW, (d) 400 kW, (e) 500 kW.

Figure 4. The output of Power Calibration for (a) 100 kW, (b) 200 kW, (c) 300 kW, (d) 400 kW, (e) 500 kW.

A linear regression is made from the measured temperature data to get the slope value from the graph. Then, the calculated power results are obtained, as shown in Figure 4. The average calculated power is 94.764 kW, 180.795 kW, 263.852 kW, 369.006 kW, and 445.939 kW, respectively, for 100 kW, 200 kW, 300 kW, 400 kW, and 500 kW. The power calculated in detail for each channel can be compared with the power displayed on the panel. For 100 kW, the calculated power on channel 7 is 100.262 kW, which is the closest. Channel 3 is close to the power value of 200 kW and 300 kW, and channel 5 is close to the power value of 400 kW and 500 kW. These results show that the measurement position does not determine the accuracy of the power calculation.

From the calibration activities, the power value and fuel temperature were obtained. Table 1 compares the power value measured by the instrument with the power value indicated on the display.

Table 1. Comparison of power value indicated on the display with the measured value during calibration activities

Indicated Power (kW)	Measured Power during Calibration (kW)
100	94.764
200	180.795
300	263.852
400	369.006
500	445.939

CONCLUSION

The thermal power was calibrated in the TRIGA 2000 Reactor using the calorimetric method at its latest core configuration. The calibration was performed at various power levels ranging from 100 kW to 500 kW. It has been obtained several results which available for observation by employing seven thermocouples connected to the data logger. The average power calculated was smaller, with the indicated power shown in the control room for all power generation. By monitoring channel one throughout each power generation, we can observe better precision, especially at 500 kW, because the calibration process is carried out sequentially, from 100 kW to 500 kW, with the stirring process continually operated. As a result of the treatment mentioned earlier, the temperature distribution becomes uniform as a function of time. Every measurement channel was inconsistent in terms of deviation, which can be observed that at a certain power, some channels have better accuracy than any other power measurement. These findings show that the measurement position does not determine the accuracy of the power calculation. Further improvement of the practice can be implemented to increase the accuracy of the current method.

ACKNOWLEDGEMENTS

The authors acknowledge the technical support from the Directorate of Nuclear Facility Management, National Research and Innovation Agency, Indonesia.

REFERENCES

1. Huda K, Wibowo Y, Suprawhardana MS. Experiences in Controlling the Upgrading of TRIGA 2000 Bandung Reactor. IAEA. 2001;
2. Pinem S, Sembiring TM, Surbakti T. Core conversion design study of TRIGA Mark 2000 Bandung using MTR plate type fuel element. International Journal of Nuclear Energy Science and Technology. 2018 Jan;12(3):222–38.
3. Umar E, Rohim Iso A, Aziz A, Ilmar Ramadhan A. Theoretical and experimental investigation of the thermal–hydraulic parameters of the Bandung TRIGA research reactor. Annals of Nuclear Energy. 2023 Dec 1;193:110020.
4. Hastuti EP, Alfa SK, Sudarmono S. ANALYSIS ON THE PERFORMANCE OF THE BANDUNG CONVERSION FUEL-PLATE TRIGA REACTOR IN STEADY STATE WITH CONSTANT COOLANT FLOW RATE. JURNAL TEKNOLOGI REAKTOR NUKLIR TRI DASA MEGA. 2020 May 30;22(2):41–8.
5. Pinem S, Surbakti T, Kuntoro I. ANALYSIS OF UNCONTROLLED REACTIVITY INSERTION TRANSIENT OF TRIGA MARK 2000 BANDUNG USING MTR PLATE TYPE FUEL ELEMENT. GANENDRA Majalah IPTEK Nuklir. 2020 Sep 24;23(2):69–76.
6. Alfa SK, Hastuti EP, Basuki P, Sulaksono ST, Fitriana R. BANDUNG TRIGA 2000 REACTOR POWER ANALYSIS AS A FUNCTION OF THE NUMBER OF FUEL ELEMENTS AND THE POWER PEAKING FACTOR. JURNAL TEKNOLOGI REAKTOR NUKLIR TRI DASA MEGA. 2020 Jun 10;22(2):68–75.
7. Agbo SA, Ahmed YA, Yahaya B, Iliyasu U. The use of heat balance method in the thermal power calibration of Nigeria Research Reactor-1 (NIRR-1). Progress in Nuclear Energy. 2015 Nov 1;85:344–51.
8. Štancar Ž, Snoj L. An improved thermal power calibration method at the TRIGA Mark II research reactor. Nuclear Engineering and Design. 2017 Dec 15;325:78–89.
9. Agbo SA, Ahmed YA, Ewa IOB, Jibrin Y. Analysis of Nigeria Research Reactor-1 Thermal Power Calibration Methods.

Nuclear Engineering and Technology. 2016 Jun 1;48(3):673–83.

10. Joo S, Lee JB, Seo SM. Calibration of digital wide-range neutron power measurement channel for open-pool type research reactor. Nuclear Engineering and Technology. 2018 Feb 1;50(1):203–10.
11. Mesquita AZ, Rezende HC, Gomes do Prado Souza RM. Thermal power calibrations of the IPR-R1 TRIGA reactor by the calorimetric and the heat balance methods. Progress in Nuclear Energy. 2011 Nov 1;53(8):1197–203.
12. Farouki I, Albati M. Uncertainties in the Power Alignment at the Jordan Research and Training Reactor. Progress in Nuclear Energy. 2020 Jan 1;119:103175.
13. Dewan J, Haque A, Huq F, Salam MA, Kabir KA. Thermal Power Calibration and Correlation of Reactor Tank Constant with Pool Water Level of TRIGA Mark–II Research Reactor. DUJASE. 2017;Vol. 3(2):189–93.
14. Reynard-Carette C, Kohse G, Brun J, Carette M, Volte A, Lyoussi A. Review of Nuclear Heating Measurement by Calorimetry in France and USA. EPJ Web Conf. 2018;170:04019.
15. Salam MA, Haque A, Uddin MM, Shohag MB, Soner MAM. Thermal Power Calibration and Error Minimization of 3MW TRIGA Mark-II Research Reactor. International Journal of Scientific & Engineering Research,. 2016;7(5).
16. Žagar T, Ravnik M, Peršič A. Analysis of TRIGA Reactor Thermal Power Calibration Method. International Conference Nuclear Energy in Central Europe. 1999;
17. Anonymous, Safety Analysis Report of Bandung TRIGA 2000 Reactor.2016