

Analysis of Water Volume Changes and Temperature Measurement Location Effect to the Accuracy of RTP Power Calibration

T.Lanyau^{1,a)}, N.S.Hamzah^{1,b)}, A.M.Jalal Bayar^{1,c)}, J.Abdul Karim¹,
P.K.Phongsakorn¹, K.Mohammad Suhaimi¹, Z.Hashim¹, H.Md Razi¹, Z.Mohd Fazli¹,
A.S.Ligam¹, M.K.A.Mustafa¹, M.Maskin¹

¹Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia.

^{a)}tonny@nuclearmalaysia.gov.my

^{b)}naimsyauqi@nuclearmalaysia.gov.my

^{c)}abi@nuclearmalaysia.gov.my

Abstract. Power calibration is one of the important aspect for safe operation of the reactor. In RTP, the calorimetric method has been applied in reactor power calibration. This method involves measurement of water temperature in the RTP tank. Water volume and location of the temperature measurement may play an important role to the accuracy of the measurement. In this study, the analysis of water volume changes and thermocouple location effect to the power calibration accuracy has been done. The changes of the water volume are controlled by the variation of water level in reactor tank. The water level is measured by the ultrasonic measurement device. Temperature measurement has been done by thermocouple placed at three different locations. The accuracy of the temperature trend from various condition of measurement has been determined and discussed in this paper.

1. Introduction

Reaktor TRIGA PUSPATI (RTP) is the only nuclear reactor in Malaysia, designed for research, training and radioisotope production. It comes to more than 35 years of operation since its first criticality in June 1982. The RTP is a pool type reactor, using demineralized light water as coolant. The operational power up to 1MWth with mixed core configuration. The core is cooled by natural convection. Heat removal is provided by the primary and secondary cooling system, whereby the reactor coolant water is circulated by the primary loop through the heat exchangers. The heat carried by the coolant water is transferred to the secondary loop for rejection to the ambient through cooling tower.

In nuclear research reactor, power monitoring is done by detection of neutron flux. The main reason to monitor neutron flux in a reactor is that it is proportional to the power density [1]. In RTP, the reactor power is measured by fission chambers installed inside the reactor pool. Three fission chambers are used for power monitoring. The output from the fission chamber is translated into electrical power through Reactor Digital Instrumentation and Control System (ReDICS). In order to maintain functionality and



accuracy of the power measurement, calibration have to be conducted prior to major changes in the core including maintenance activities. The main reason to conduct the power calibration is to ensure that the power measured by the fission chamber agrees with the thermal power released by the reactor in the form of temperature rise. In the existence of deviation between indicated power by the fission chamber with the measured thermal power through power calibration, the position of the fission chambers need to be adjusted physically or alternatively by tuning the electronic gain. The common practice of TRIGA reactor worldwide is to use calorimetric method for power calibration. This method is widely used in research reactor through measurement of thermal power released from the reactor. The heat produced during the operation of the reactor will contribute to temperature rise in the coolant water. With knowing the heat capacity constant K , the thermal power can be obtained by [2]–[8] :

$$P = K \frac{\Delta T}{\Delta t} \quad (1)$$

where P is the reactor power [kW], $\frac{\Delta T}{\Delta t}$ is temperature-rise rate [$^{\circ}\text{C}/\text{h}$] and K is experimentally determined heat capacity constant [$\text{kWh}/^{\circ}\text{C}$] given by

$$K = V_w \rho C_p \quad (2)$$

Where V_w is coolant volume [m^3], ρ is coolant density [kg/m^3] and C_p is the coolant specific heat capacity [$\text{kJ}/\text{kg}^{\circ}\text{C}$]. The reactor pool heat capacity constant can be calculated as well with assumption that reactor pool temperature is constant throughout the pool and heat losses are neglected hence the reactor pool is treated as insulated when water temperature is close to ambient temperature[2], [3], [6]. For TRIGA system, the mass is mainly the water in the tank because of its large heat capacity[2], [3], [6]. Therefore, water volume in the reactor tank is an important parameter that may influence the accuracy of the power calibration.

For RTP, power calibration is done using the power calibration constant also called tank constant furnished by General Atomic at its early operation. The tank constant of the RTP is $9.56^{\circ}\text{C}/200\text{kW-hr}$ [9]. The reactor tank is filled with demineralized light water about 17.41m^3 [9]. Considering no major modification of the original design of the reactor tank that possibly contribute to significant changes in the water volume, therefore the tank constant still being used in the power calibration.

This paper presents the study conducted through the experiments to evaluate the effect of water volume changes and measurement location to the power calibration result. With the assumption that the total water volume is maintained, so the tank constant can be used in this experiment. Therefore, the water volume changes are introduced by changing the water level. The result obtained from this study is very important to improve the effectiveness of temperature measurement in order to reduce error of the power calibration.

2. Experimental set-up and procedure

The experiments that have been conducted are based on the procedure of power calibration conducted at RTP. The set-up of the experiment is illustrated in Figure 1. During the normal operation, the water level is control within 15.24cm to 19.30cm from the pool top. To introduce the water volume changes, the level is set to 15.24cm (high), 17.53cm (intermediate) and 19.30cm (low) from the pool top. The water level is measured by the ultrasonic measurement device and monitored through the display panel located at the top of the reactor pool. Three multi-meters attached with two thermocouples type K each are installed at

various location in the pool for temperature measurement. Combination of multi-meter and thermocouples are shown in Table 1. These combinations are used in each experiment condition as mentioned in Table 2. The bulk temperature detector also used for temperature measurement. The temperature of bulk is measure by the Resistance Temperature Detector (RTD) installed under the bridge. The arrangement of the thermocouples and location of bulk temperature detector is illustrated in Figure 1. Two thermocouples are installed for each combination, such as TC1A and TC1B in order to observe the effect of particular location to the temperature measurement at same depth of the thermocouple.

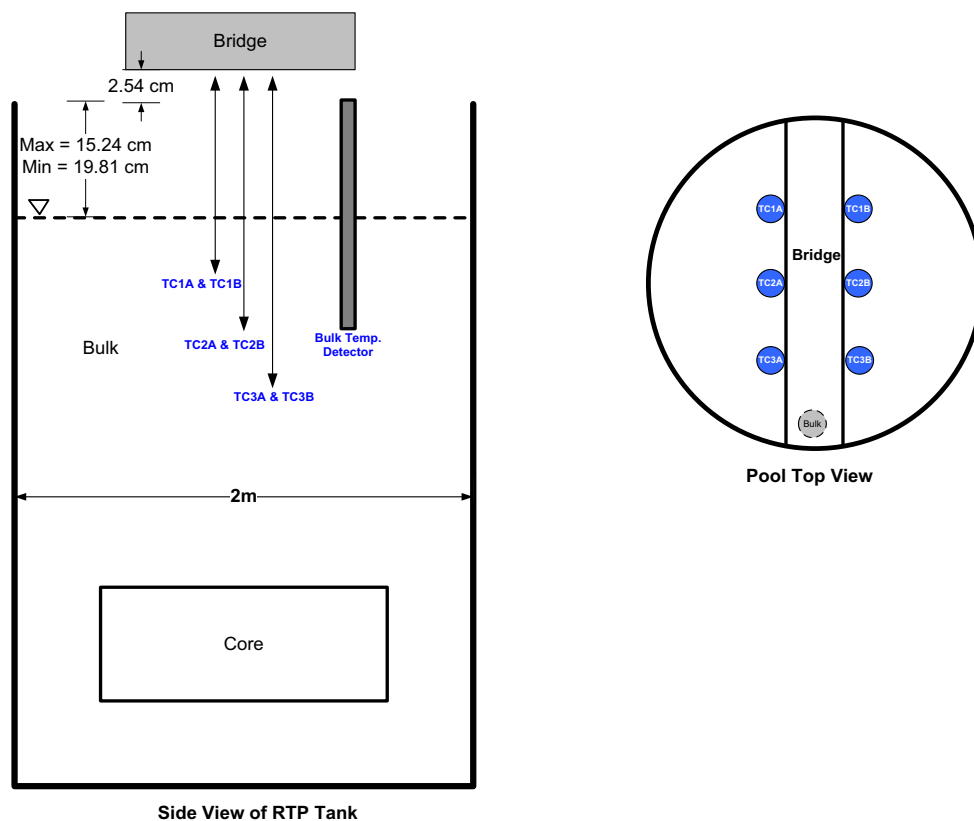


Figure 1. Set-up of experiment

Table 1. Devices Set-up

Multi-meter ID	Thermocouple ID	Thermocouples Depth from bottom of bridge [cm]
M1	TC1A & TC1B	50.8
M2	TC2A & TC2B	63.5
M3	TC3A & TC3B	76.2

Table 2. Experiment Condition

Experiment Set	Water Level [cm]
1.1	15.24
1.2	15.24
2.1	17.53
2.2	17.53
3.1	19.30
3.2	19.30

The experiment was conducted by the following procedure.

1. Install the multi-meters and thermocouples based on the combination in Table 1.
2. Set pool bulk water temperature close to ambient temperature ($25^{\circ}\text{C} \sim 30^{\circ}\text{C}$) by running the cooling system. After the temperature achieve an equilibrium state, then switch-off the primary pump and demineralizer pump.
3. Switch-off cooling tower and secondary pump.
4. Isolate the reactor tank by closing the incoming and outgoing valve (PV1, PV2, PV7, and PV8).
5. Set the water level to specified level. Water topping and draining can be done through the demineralizer system if necessary.
6. Operate the reactor at power constant power 200kW in auto mode for 75 minutes. In the event of temperature of the RTD (bulk temperature detector) reach near 45°C , the reactor will be shutdown manually.
7. Record reading from all thermocouples and bulk temperature every 5 minutes time interval.
8. Shutdown the reactor after completing 75 minutes.
9. Run primary and secondary cooling system to cool down the water until ambient temperature.

3. Result and discussion

The results of temperature rise at different water level are presented in Figure 2, Figure 3 and Figure 4. These results show the agreement of linear relationship between temperature rise and time period of the reactor operation at constant power 200kW. The slope of the graphs which represent the temperature rise rate show about the same value of $0.15^{\circ}\text{C}/\text{min}$. This taught shows that the variation of water level which indicate the changes in the water volume within the defined range of water level 15.24cm to 19.30cm has minimum effect to the accuracy of the temperature measurement. The calculated average power based on the slope of each experiment using Equation (1) are presented in Table 3.

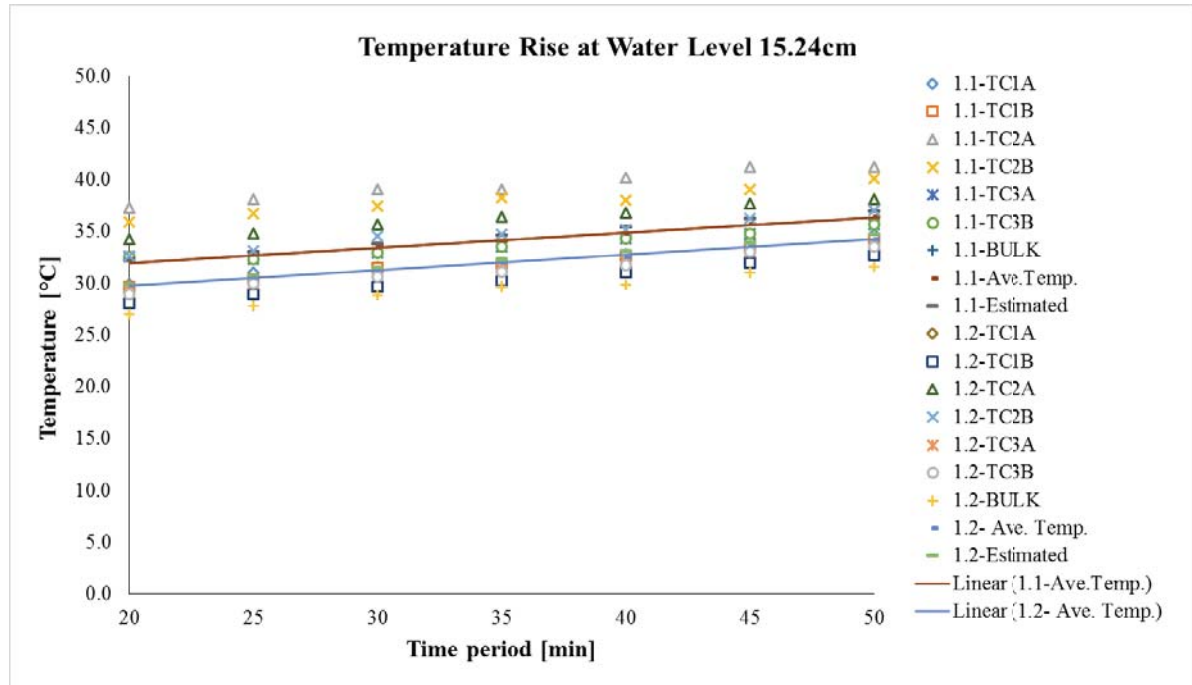


Figure 2. Temperature rise at water level 15.24cm

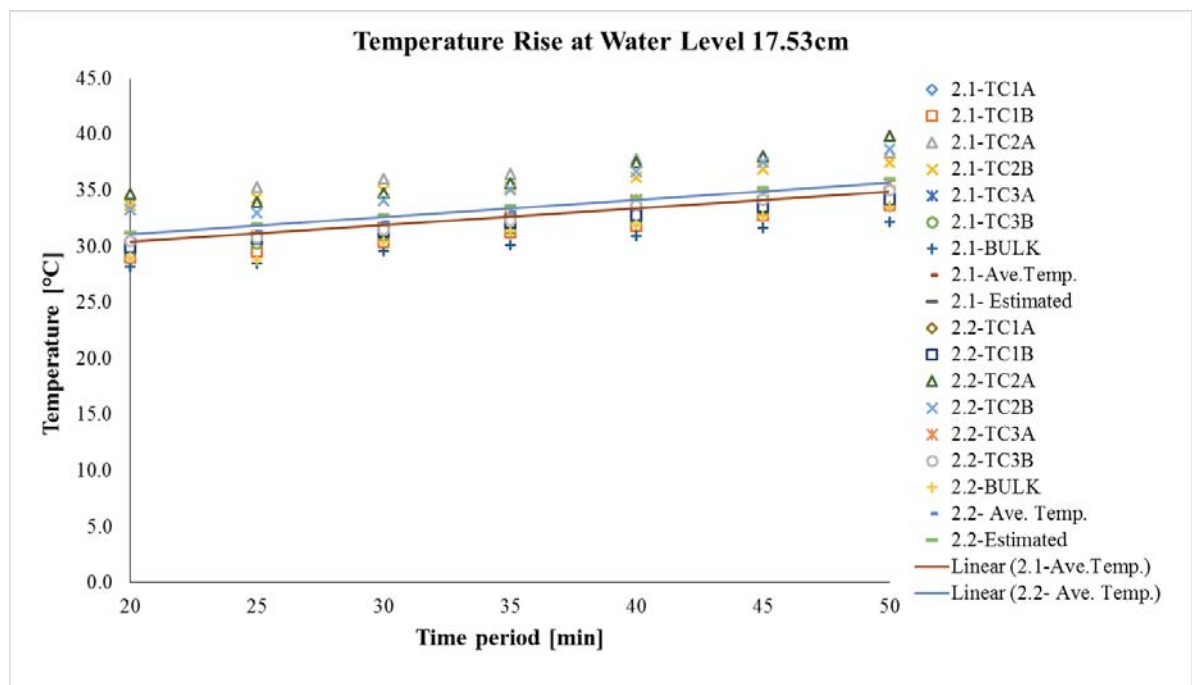


Figure 3. Temperature rise at water level 17.53cm

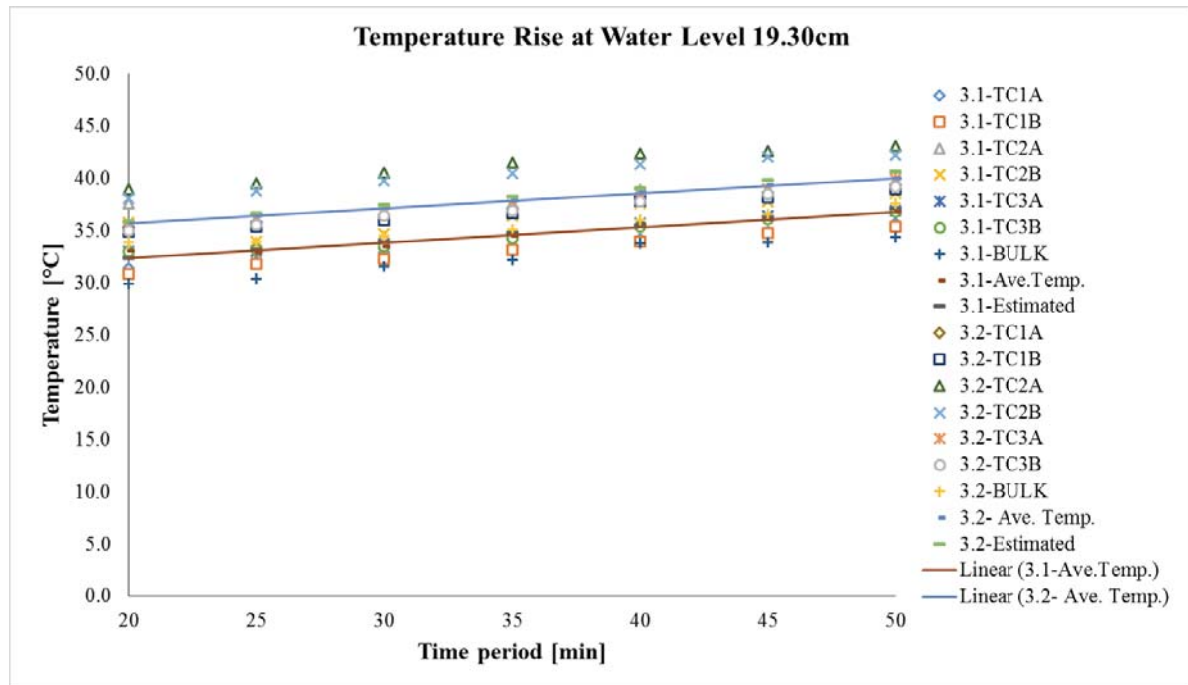


Figure 4. Temperature rise at water level 19.30cm

Table 3. Evaluation of power measurement accuracy at different water level

Water Level [cm]	Experiment ID	Slope [°C/min]	Average Power [kW]	Standard Deviation	Error from indicated power 200kW [%]
15.24	1.1	0.147	186.59	2.66	6.70
	1.2	0.150			
17.53	2.1	0.150	189.85	3.11	5.07
	2.2	0.153			
19.30	3.1	0.148	183.0	3.54	8.40
	3.2	0.144			

The analysis of the temperature rise at different measurement location shows that different depth of the thermocouples has small influence to the result of temperature measurement. The trend of the temperature rise shows the linear relationship with the slope is about the same. The average temperature rise at different measurement point are plotted in Figure 5, Figure 6 and Figure 7. Table 4 shows the evaluation of the accuracy of measurement at different thermocouple depth. The deviation of average power at different depth of thermocouples is very small.

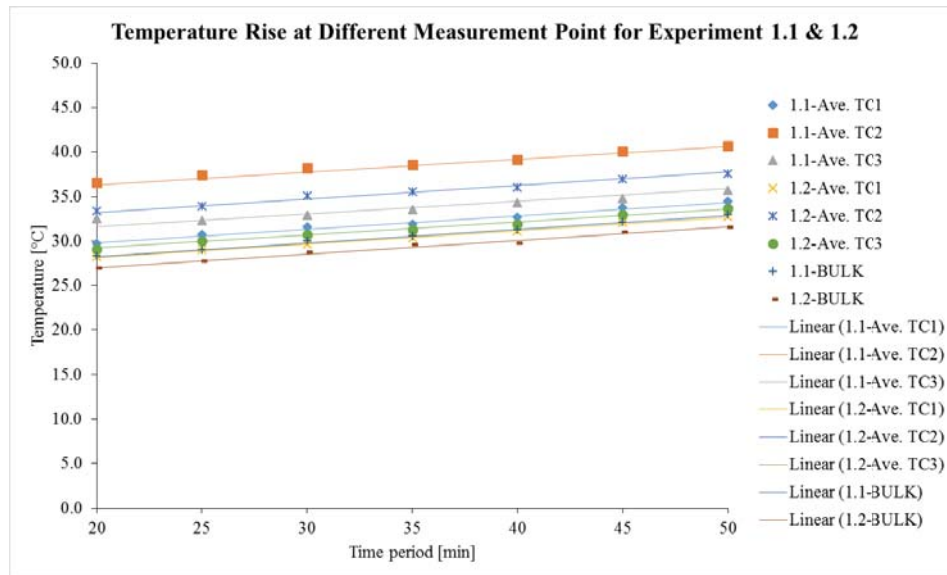


Figure 5. Temperature rise at different measurement point for experiment 1.1 and 1.2

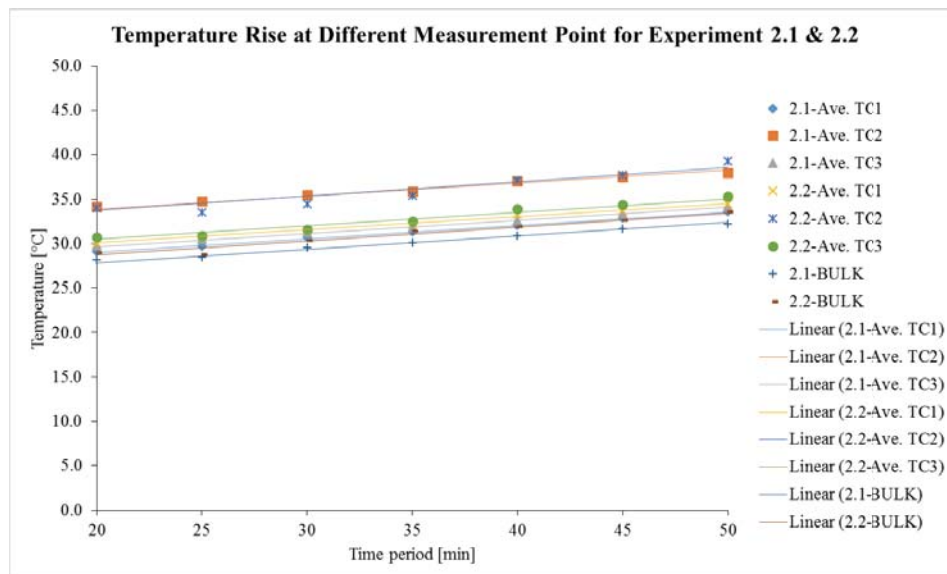


Figure 6. Temperature rise at different measurement point for experiment 2.1 and 2.1

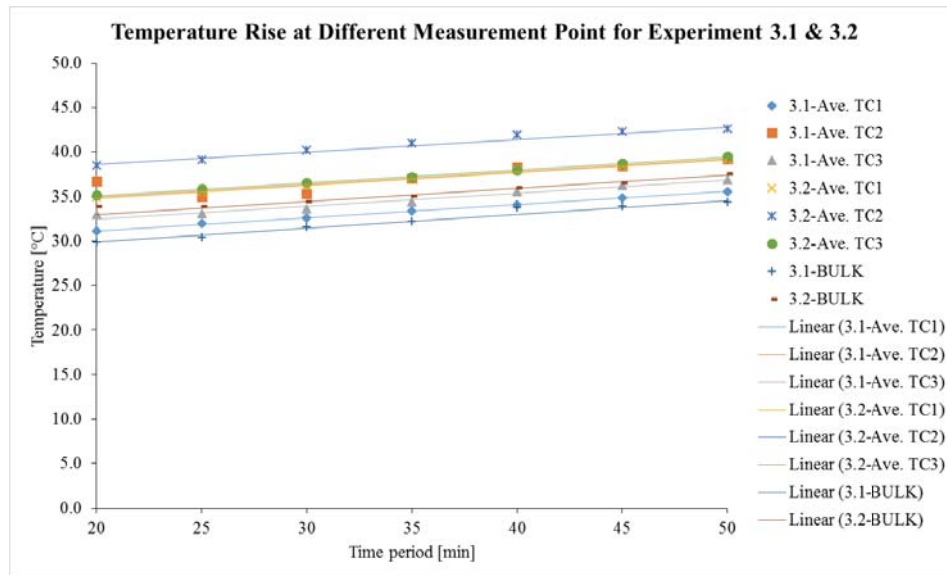


Figure 7. Temperature rise at different measurement point for experiment 3.1 and 3.2

Table 4. Evaluation of power measurement accuracy at different measurement point

Depth of thermocouple [cm]	Experiment ID	Average Slope [°C/min]	Average Power [kW]	Standard Deviation	Error from indicated power 200kW [%]
50.8	1.1	0.151	186.61	3.41	6.7
	1.2	0.150			
	2.1	0.150			
	2.2	0.146			
	3.1	0.150			
	3.2	0.145			
63.5	1.1	0.144	185.77	9.85	7.12
	1.2	0.153			
	2.1	0.147			
	2.2	0.161			
	3.1	0.144			
	3.2	0.139			
76.2	1.1	0.143	184.10	3.52	7.95
	1.2	0.146			
	2.1	0.150			
	2.2	0.150			
	3.1	0.146			
	3.2	0.145			

4. Conclusion

This paper conclude that the water volume changes introduced by the variation of the water level at range 15.24cm to 19.30cm has small influence to the temperature measurement. The measurement position also does not affect much the temperature measurement result. From the thermal power calculation based on the slope of the graph shows some error from the indicated power by the fission chamber. Therefore, parallel to the objective of power calibration, some adjustment on the position of fission chambers need to be done to tune the indicated power level.

Acknowledgement

The authors express their sincere thanks to those involved directly or indirectly in the experiments especially to the staffs in Reactor Technology Centre, Malaysian Nuclear Agency for their kind help, comments and recommendations all the way to complete this paper. Their contributions are highly appreciated.

References

- [1] IAEA, "Triga Reactor," *Nucl. Install. Saf. Div. IAEA*, 2005.
- [2] A. Z. Mesquita, H. C. Rezende, and A. Augusto, "Development of Methods for Monitoring and," vol. 13, no. 1, pp. 24–27, 2012.
- [3] A. Z. Mesquita, H. C. Rezende, and R. M. Gomes Do Prado Souza, "Thermal power calibrations of the IPR-R1 TRIGA reactor by the calorimetric and the heat balance methods," *Prog. Nucl. Energy*, vol. 53, no. 8, pp. 1197–1203, 2011.
- [4] A. P. Tomaz Azgar, Matjaz Ravnik, "Analysis of TRIGA Reactor Thermal Power Calibration Method," 1999.
- [5] G. Zerovnik, L. Snoj, A. Trkov, L. Barbot, D. Fourmentel, and J. F. Villard, "Measurements of thermal power at the TRIGA Mark II reactor in Ljubljana using multiple detectors," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 5, pp. 2527–2531, 2014.
- [6] M. A. Salam, A. Haque, M. M. Uddin, M. B. Shohag, and M. A. Malek Soner, "Thermal Power Calibration and Error Minimization of 3MW TRIGA Mark-II Research Reactor," *Int. J. Sci. Eng. Res.*, vol. 7, no. 5, pp. 710–716, 2016.
- [7] S. A. Agbo, Y. A. Ahmed, I. O. B. Ewa, and Y. Jibrin, "Analysis of Nigeria Research Reactor-1 Thermal Power Calibration Methods," *Nucl. Eng. Technol.*, vol. 48, no. 3, pp. 673–683, 2016.
- [8] Ž. Štancar and L. Snoj, "Thermal Power Calibration of the TRIGA Mark II reactor," *Proc. 23rd Int. Conf. Nucl. Energy New Eur.*, pp. 1–8, 2014.
- [9] Malaysian Nuclear Agency, "Safety Analysis Report for PUSPATI TRIGA Reactor 2017," 2017.