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THE NIGERIAN RESEARCH REACTOR-1 (NIRR-1) POWER AND ISOTHERMAL TEMPERATURE PARAMETERS MEASUREMENTS

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ABSTRACT

This study analyses the accuracy in method of heat balance as well as its efficiency for measuring the power(ρ) and isothermal temperature(θ) of the Nigerian Research Reactor-1 (NIRR-1), a low power miniature neutron source reactor (MNSR). The results showed that the three power levels: full power(30kW), half power(15kW) and low power(3.6kW) were maintained at various isothermal temperature measurements. The average isothermal temperature at full power, half power and low power levels were measured to be (0.2853 ± 0.00058) m^0K, (0.2945 ± 0.0014) m^0K and (0.2989 ± 0.00183) m^0K respectively. The findings have shown a strong dependence of the reactor power at the three levels on the isothermal temperature which were directly proportional. Hence, the behavior of the NIRR-1 operation at the measured parameters will enhance its life span and improve safety.

Keywords: NIRR-1, Isothermal temperature, Miniature neutron source reactor, power levels

INTRODUCTION

The Nigerian Research Reactor-1 (NIRR-1) is a MNSR type (miniature neutron source reactor) licensed mainly to perform the NAA technique (Neutron activation analyses), reactor training, as well as production of radioisotopes; And it's mounted in Zaria, Ahmadu Bello University's Centre for energy research and training. It first criticality was achieved in February, 2004(Ahmed, *et al.*, 2010).

NIRR-1 which is fuel with high enriched uranium-235 in an Al cladding has a type Tank-in-pool of highest/full power ~ 30,000W being equivalent to thermal neutron flux of $1000G$ n.cm^{-2}.s^{-1} in each of the irradiation 5 inner channels (Yang, 1992; Agbo *et al.*, 2016; Ahmed *et al.*, 2008). In any miniature neutron source reactor, there are 374 fuel rods in its central core, 3 dummy elements with 4 tie rods unvarying spread on overall of 10 concentric circles. Cadmium which performs the functions of shim, safety and regulatory control remains the single control rod for NIRR-1 and is cladded using a stainless steel. Its safety and compatibility properties make it possible to be mounted in a densely populated community without any harm and danger to the inhabitants of the area (Qazi *et al*., 1996 and Agbo *et al*., 2016). Detail description of NIRR-1 is shown in Table 1.

Isothermal temperature measurements of a research reactor is the determination of the actual reactor power as a result of the fission reactions taking place in the core of the reactor which can be achieved by using neutron measuring instruments that measure the neutron flux in the core using fission chambers. The importance of correct power calibration of a nuclear reactor is for safe monitoring and dynamic behavior evaluation, burnup fuel determination, as well as dose rate and neutron fluxes normalization (Asuku *et al*., 2020, Agbo *et al*., 2016).

Table 1: NIRR-1 detailed description (Agbo, *et al*., 2016)

Parameters	Description
Reactor type	Tank-in-pool
Power rating	30, 000W
Fuel	UAl4I
^{235}U enrichment	90.2%
^{235}U mass	999.36g
Fuel element numbers	347
Core height	23.0cm
Core shape	23.0cm
Core diameter	23.0cm
Number of irradiation sites	10
Inner channels	5
Inner channel flux	1×10^{12} $\eta cm^{-2}S^{-1}$
Outer channel flux	5×10^{11} $\eta cm^{-2}S^{-1}$
Mode of cooling	Natural convection
Inlet orifice height	6.0mm
Outlet orifice height	7.5mm
Fuel meat diameter	4.3mm
Fuel element diameter	5.50mm
Excess reactivity	3.77m^0K
Cadmium control rod length	230mm

Prompt criticality is an unacceptable condition in reactor design and safety, to ensure the reactor has no prompt critical condition, moderator temperature must be monitored and control such that the reactivity must be within limited value specified by the regulatory authorities (Ahmed *et al*, 2010). The isothermal temperature is a very important physical parameter that enables us calculate the reactivity defect when the reactor is loaded or beryllium shims are added.

Since commissioning of NIRR-1 in 2004, several studies by different scholars have been made to determine its thermal power calibration conversion (Asuku *et al*., 2020), Thermal Power Calibration Methods (Agbo *et al*., 2016), peak temperatures under several reactivity accidents test (Salawu and Balogun, 2017), burn-up and core life time expectancy (Yahaya *et al*., 2017) as well as its radial and axial neutron flux distribution (Musa *et al*., 2012). Despite these efforts, studies on measurements of NIRR-1 power and isothermal temperatures parameters is still very scanty according to the existing literatures in spite of its usefulness in experimental work as well as its utilizations. Hence, the present work is aimed at exploring the heat balanced method in the measurement of power and isothermal temperature parameters for the Nigerian research reactor-1 (NIRR-1).

MATERIALS AND METHODS

In any nuclear research reactor such as NIRR-1, the rise in the water temperature usually determines the thermal power over a given period (Bullock, 1965; Zagar *et al*., 1999 and Asuku *et al*., 2020). And in the calorimetric method, the time rate of change of temperature (ΔT/Δt) is measured and the power of the reactor as a function of temperature rise is also determined. This calibration power method has been reported to be dependent on factors such as transfer of heat, water natural convention effect, heat losses and other similar effects. Furthermore, reactor safety demands that more than a single safety feature measurement have to be adopted in the study of its neutron moderator and isothermal temperature. At any given power level of a water-cooled nuclear reactor, its isothermal temperature can be estimated by measuring the change in temperature of the water over a period of time (t).

$$\theta(t) = 2.0601\times10^{-3} + 0.026445\times10^{-3}t - 0.00173776\times10^{-3}t^{-2} \qquad (1)$$

The basic formulation assumes that the level of reactor power is calculated by taking the slope in temperature-time graph (i.e time rate of change in temperature) and multiplying the slope by a constant known as the reactor pool constant (Zagar *et al*., 1999; Mesquita *et al*., 2011):

$$Q = \frac{\Delta T}{\Delta t}K \qquad (2)$$

Where: Q = the power and k = heat capacity given by

$$K = \rho V_w C_p \qquad (3)$$

Where: ρ = density of water, Vw = volume of the water and C_P = specific heat capacity of water.

RESULTS AND DISCUSSIONS

The results obtained at the three power level: full power (30,000W), Half power (15,000W) and low power (3600W) are dipicted in figures 1-3 respectively. Figure 1 shows the results of temperature(θ) increasing with control rod slowly removal which was inline; since Cd material has the characteristics of large neutron absorption cross-section. Furthermore, as the control rod removal length contineous risen, more neutrons will be created and less will be absorbed by the rod. This makes the temperature(θ) to also rise. At the point where the temperature(θ) is greater than unity, the reactor assembly has reached its supercritical pont while for a temperature(θ) value less than unity, the reactor is said to be at subcritical assembly point. Figure 2 decsribes the temperature (θ) range of values between 0.288013 and 0.298431 respectively; which is in good agreement with reactor design document for NIRR-1. Thus criticality had been reached since the Cd (control rod) critical insertion depth was measured to be 0.145m at low power (3600kW) level.

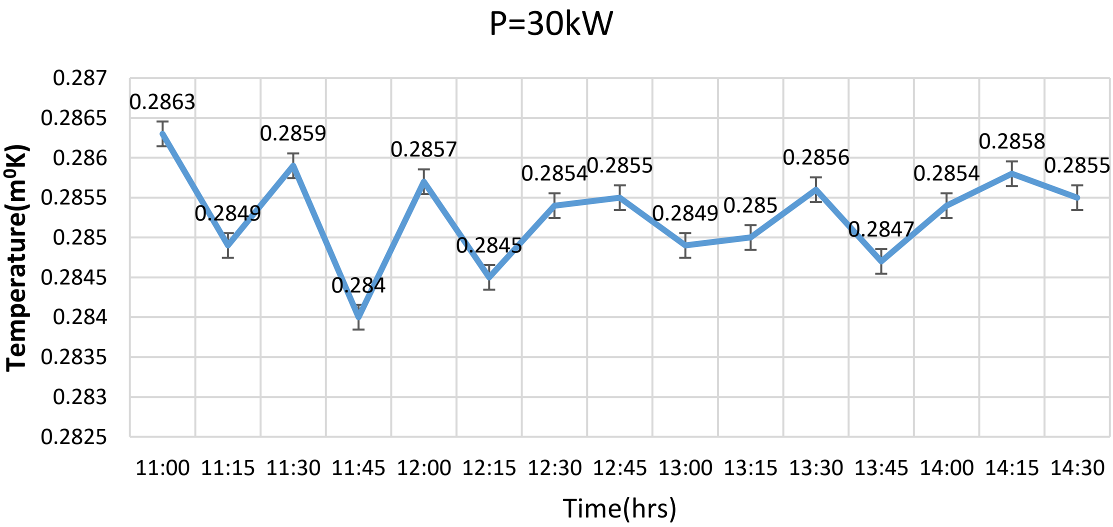

Figure 1: Isothermal temperature graph at full power(15kW)

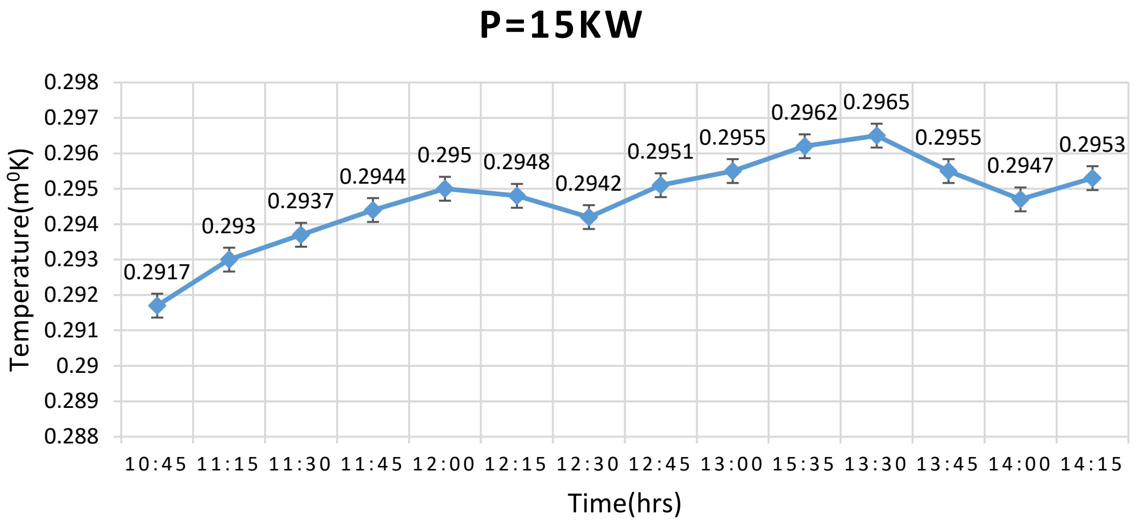

Figure 2: Isothermal temperature graph at half power(15kW)

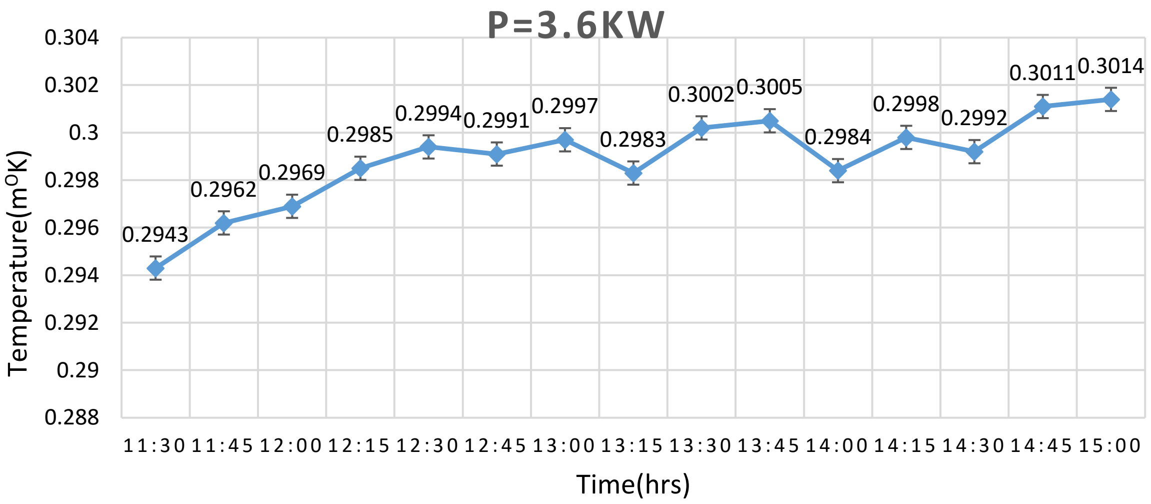

Figure 3: Isothermal temperature graph at low power(3.6kW)

The present study, power and isothermal temperature((θ) analysis carried out on NIRR-1 had demonstrated the nature of its alternating operation as against the contineous operation since the excess reactivity gives a linear decreasing reltionship of 216 equivallent full power days of operations in 12 years at 3 hours per day and 3 days per week for 48 weeks per year operational calender.

CONCLUSION

NIRR-1 power and isothermal temperature have been investigated in this study using heat balance method. The average measured isothermal temperature at full power (30,000W), at half power (15,000W) and at low power (3,600W) were found to be (0.2853±0.00058) m^{0}K, (0.2945±0.0014) m^{0}K and (0.2989±0.0018) respectively. The result findings established that ^{239}Pu weight has increase by a factor 0.035g while the top Br shim plate produced a reactivity of about 19,072 ^{0}K. These were in agreement with similar works by different nuclear scientist using different methods on this MNSR and other research reactors around the continent. Similarly, to achieve more than one decade reactor operation, high maintenance level as well as good chemistry of water should be ensured; and only in doing so that the findings of the present study will compare favorably with measured experimental values by other literatures.

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