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ISOTHERMAL TEMPERATURE REACTIVITY COEFFICIENT MEASUREMENT IN TRIGA REACTOR

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ABSTRACT

Direct measurement of an isothermal temperature reactivity coefficient at room temperatures in TRIGA Mark II research reactor at Jožef Stefan Institute in Ljubljana is presented. Temperature reactivity coefficient was measured in the temperature range between 15ºC and 25ºC. All reactivity measurements were performed at almost zero reactor power to reduce or completely eliminate nuclear heating. Slow and steady temperature decrease was controlled using the reactor tank cooling system. In this way the temperatures of fuel, of moderator and of coolant were kept in equilibrium throughout the measurements. It was found out that TRIGA reactor core loaded with standard fuel elements with stainless steel cladding has small positive isothermal temperature reactivity coefficient in this temperature range.

1 INTRODUCTION

TRIGA reactor core contains several fuel elements filled with homogeneous metallic mixture of uranium and zirconium hydride. U-ZrH fuel for the TRIGA reactor exhibits unique safety features including a prompt negative fuel temperature coefficient of reactivity [1]. Fuel temperature reactivity coefficient (or shortly fuel TRC) as a function of average fuel temperature in a TRIGA reactor is usually determined indirectly through the power reactivity coefficient measurement [2]. This indirectly determined TRC is normally burdened with relatively high experimental uncertainty. For one reported measurement [2] the relative error in TRC is 25% at room temperature and 40% at 100ºC. For benchmarking purposes of new cross section libraries and for other reactor physics calculation purposes higher accuracy of experimental data would be desirable. Reliable experimental data on temperature reactivity coefficient for zirconium hydride fuels [3] are also very interesting for possible new reactor designs using this type of fuel.

The purpose of this paper is to present the measurement of isothermal TRC, which can be measured directly, if we control all temperatures in the reactor very precisely, and if we can in the same time also measure the reactivity of the reactor with the same degree of accuracy.

2 DESCRIPTION OF THE EXPERIMENT

Isothermal TRC could be measured directly and without any additional assumptions using the reactor cooling system to control the reactor temperature. With primary cooling system pump we promoted mixing of water in reactor pool. Using valve on secondary system cooling we controlled the flow trough the heat exchanger and in this way also the rate of cooling on the primary side. We were able to control the change of reactor core region temperature isothermally, keeping all temperatures (fuel temperature, cladding temperature and water temperature) within at least 0,5^{o}C depending on reactor power. The rate of isothermal cooling was approximately 5^{o}C per hour. Having reactor operated at zero power (below 100W), no nuclear heating was observed, and measured temperatures of the water in the core region were almost identical to the fuel temperatures. Under such conditions isothermal TRC can be directly calculated using the formula as follows:

$$\alpha_{ISO} = \frac{\Delta\rho}{\Delta T_{ISO}} . \qquad (1)$$

The isothermal temperature T_{ISO} used for calculating isothermal TRC was defined as average of all measured temperatures in the fuel elements. During the experiments under the isothermal conditions all measured temperatures in fuel elements were found to be within 0,2^{o}C. The experimental uncertainty of temperature measurement was 0,1^{o}C.

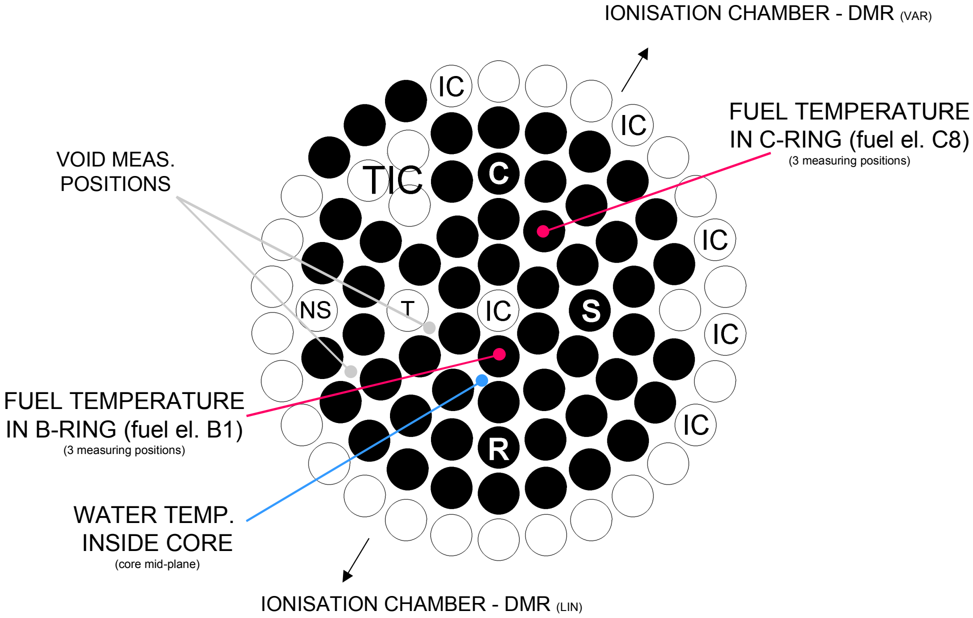

Figure 1: Core configuration number 176 used in experiment. Black circles denote standard TRIGA fuel elements. T, R, S and C are control rod positions, IC are irradiation channels, TIC is triangular irradiation channel and NS stands for neutron source. Temperature and neutron flux measuring positions are also indicated.

The reactivity ρ was measured using digital reactivity meter DMR-043 [6] in the core configuration number 176 (presented in Fig. 1). Core configuration number 176 consists of 54 standard TRIGA fuel elements with stainless steel cladding containing 20% enriched uranium in U-ZrH fuel. In this core configuration there were also three fuelled follower control rods, one transient control rod, seven irradiation channels and neutron source. Prior to the measurements the reactor was shut down for a period longer than one week, so the reactor was xenon poisoning free with relatively low background signal. These conditions were proved trough very accurate reactivity measurements one day before TRC experiments started. In these measurements reactivity was found to be very stable and with low background and noise levels.

The temperature in the core was measured using several thermocouples in the fuel and in the water around and above the fuel in the reactor pool. All together fuel temperature was measured in six points and water temperature in three points, one water temperature in the core region and two water temperatures in pool above core region. Besides these we observed also reactor concrete temperature and air temperature in reactor hall.

Measured fuel and water temperatures and reactivity during isothermal cooling for two experiments are presented on Figures 2 and 3. During the first experiment (fig. 2) the digital reactivity meter DMR-043 [6] was connected to VAR channel and the reactor power was approximately 100W. Secondary cooling system valve was opened at 12:44 hours and closed at 13:30 hours. During cooling time, constant isothermal cooling was observed and constant loss of reactivity measured. The measured isothermal TRC was found to be 3,4 ±0,3 pcm/°C.

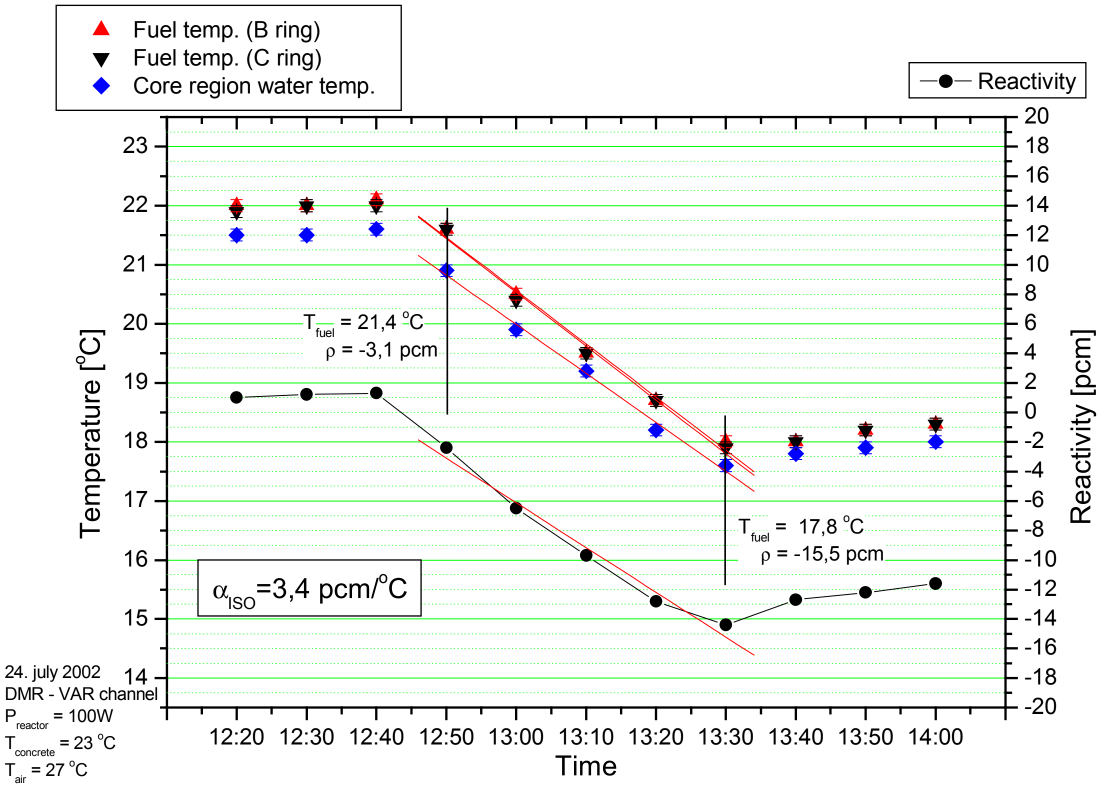

Figure 2: Isothermal TRC measurement using DMR connected to VAR channel at approximately 100W reactor power. The measured isothermal TRC is 3,4 ±0,3 pcm/°C.

In the case of repeated experiment (presented in fig. 3) the digital reactivity meter was connected to LIN channel and the reactor was kept at very low power of approximately 5W. Secondary cooling system valve was opened at 11:12 hours and closed at 12:14 hours. During cooling time, constant isothermal cooling was observed and constant loss of reactivity measured. The difference in water and fuel temperature is even smaller than in previous case (due to smaller reactor power – 5W is almost zero power for this reactor). The measured isothermal TRC in this case was also found to be positive (3,6 ±0,3 pcm/^{o}C) and consistent with previous measurement.

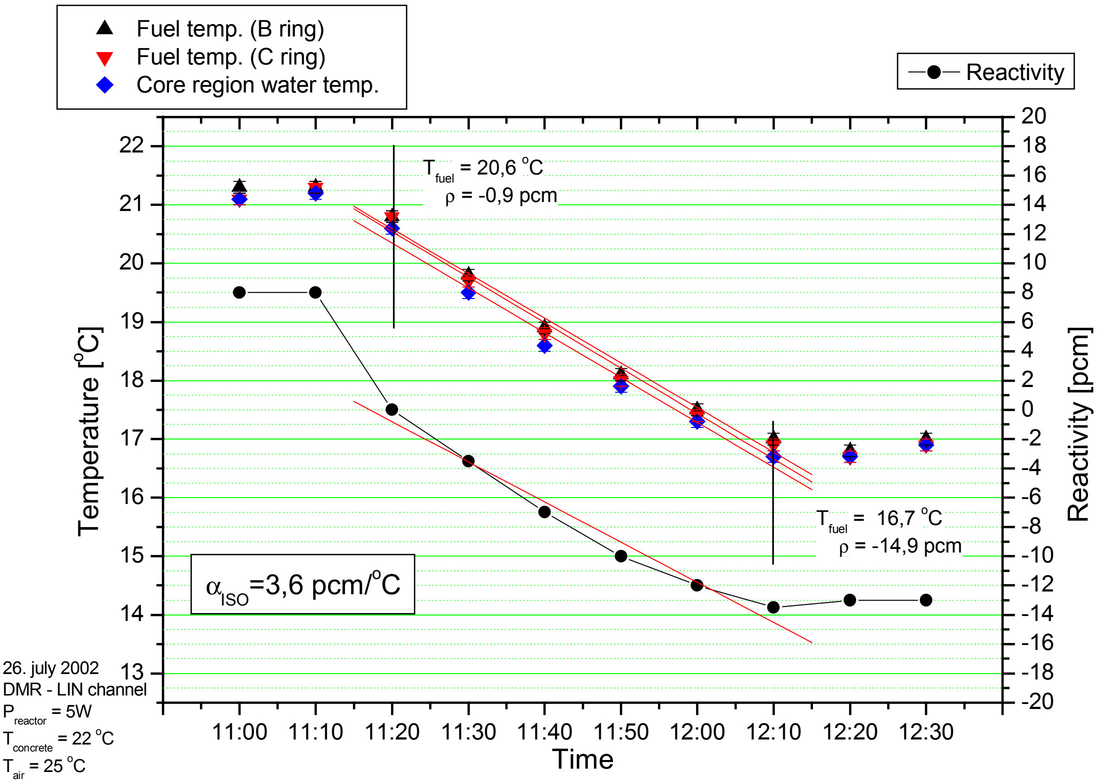

Figure 3: Isothermal TRC measurement using DMR connected to LIN channel at reactor power of approximately 5W. The measured isothermal TRC in this case was 3,6 ±0,3 pcm/^{o}C.

To confirm unexpected measured positive value of isothermal TRC, we repeated measurements several times and also measured other safety-related parameters of TRIGA reactor such as fuel TRC and void reactivity coefficient. Void reactivity coefficient was measured directly, by inserting small void into measuring positions indicated on Figure 1. Measured void coefficient for reactor core number 176 was found to be negative in both measuring locations.

On the other hand, the fuel temperature reactivity coefficient cannot be calculated in straight-forward manner as the isothermal TRC or power coefficient [2]. Formally, it can be calculated using the formula as follows:

$$\alpha_f = \frac{\Delta \rho}{\Delta \bar{T}}. \tag{2}$$

Here, in the equation for the fuel TRC, $\overline{T}$ corresponds to the temperature, averaged over the whole volume of the fuel in the core. The value $\Delta\overline{T}$ is not equal to the change in temperature ΔT, measured in a particular point in core, e.g. in one or two instrumented fuel elements available in the core. We can overcome this problem by taking into account radial and axial temperature distribution within the fuel rods. If we assume that relative fuel temperature depends mainly on the power density distribution then we can calculate average fuel temperature $\overline{T}$ from small number of fixed fuel temperature measuring positions within the instrumented fuel element. However this approach is burdened with relatively large experimental uncertainty. Fuel TRC measurement for fuel temperature in B ring showed expected negative values. Fuel TRC for fuel temperature in B ring for our experimental set-up was found to be –4,8 ± 0,5 pcm/ ^{o}C for fuel temperatures around 22^{o}C and reactor power approximately 600W. This value of fuel TRC is in very good agreement with previously known data [2].

3 PRELIMINARY TRC CALCULATION

To verify the experimental data and to found a solid physical explanation for the observed positive isothermal TRC in TRIGA reactor we started different reactor physics calculations. Only preliminary results of these calculations are presented in this paper. These calculations will be in the near future used also for nuclear cross section data library testing and benchmarking and to validate the new IAEA-WIMS-D library [4] for the well-known lattice code WIMSD-5B [5].

The calculations were performed with WIMSD-5B code using simple one unit cell calculation model. The unit cell model consisted of one standard TRIGA fuel element surrounded with appropriate amount of water in infinite lattice. The results of calculations were values of k_{inf} (and ρ_{inf}) for different temperature conditions in unit cell. The parameters varied in calculations were:

- water temperature (23^{o}C and 43^{o}C)
- water density (0,9976 g/cm^3 density at 23^{o}C and, 0,9916 g/cm^3 density at 43^{o}C)
- fuel temperature (23^{o}C and 43^{o}C)
- and isothermal conditions for two temperatures.

Calculated isothermal TRC was defined as follows:

$$\alpha_{TRC\text{-}calculated} = [\rho_{inf}(43^{o}\mathrm{C}) - \rho_{inf}(23^{o}\mathrm{C})]/20^{o}\mathrm{C}, \qquad (3)$$

where ρ_{inf} is calculated reactivity of infinity lattice of unit cells at selected temperature and density. For isothermal conditions the temperature was varied for all materials present in the unit cell model together. The variation of densities with temperature was also studied but no influence on reactivity was observed for density changes of fuel, zirconium metal and cladding. Only water density change within this temperature range has any influence on reactivity.

The results of preliminary calculations and comparison of results is presented in Table 1. Measured and calculated fuel TRC agrees very well taking into account the simplicity of the model. The sum of calculated water temperature, water density and fuel temperature coefficients give the calculated isothermal coefficient. The positive value of calculated isothermal TRC confirms our experimental results. The discrepancy between measured and calculated values should decrease with more elaborate calculation models and using whole core diffusion calculations for leakage prediction.

Table 1: Results of preliminary calculation of TRC for standard TRIGA fuel with stainless steel cladding using WIMSD-5B code.

WIMSD calculation model	**Measured TRC [pcm/^{o}C]**	**Calculated TRC [pcm/^{o}C]** (from k_{inf}) library used		
		JEF 2.2	ENDF/B-VI.5	IAEA-WIMS-D
Water temperature and density	n/a	+5,1	+5,2	+5,4
Fuel temperature	-4,8 (± 0,5)	-3,5	-3,6	-3,5
Isothermal	+3,5 (± 0,3)	+1,6	+1,6	+1,9

4 CONCLUSION

The results presented in this paper show, that the isothermal temperature reactivity coefficient in TRIGA research reactor loaded with standard TRIGA fuel (20% enriched uranium) with stainless steel cladding has positive value at temperatures around 20^{o}C. To our knowledge this phenomenon was never before reported in open literature.

Even if isothermal temperature reactivity coefficient was found to be positive, all important safety parameters of TRIGA reactor in Ljubljana are not affected. This was shown also in the course of presented experiments where negative fuel temperature reactivity and negative void coefficients were measured and documented.

Measured positive isothermal temperature coefficient was also successfully calculated with simple unit cell model using WIMSD-5B code. Measured and calculated values show good agreement. Additional work on this subject is already planned in the near future.

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