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ON-LINE MONITORING OF THE REACTIVITY AND CONTROL RODS WORTH AT THE IPR-R1 TRIGA REACTOR

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ABSTRACT

On-line monitoring of several new process variables of the IPR-R1 TRIGA Reactor of the Nuclear Technology Development Center – CDTN became possible after the data acquisition and processing system implementation and the installation of one instrumented fuel rod in the reactor core. Several neutronics and thermo-hydraulics parameters are now registered, such as the operation power, the reactivity insertion in the core, the control rod position, the fuel and the water temperature, and so on. Since the inherently safe operation of a reactor is dependent on the reactivity control, it is essential to have information on this parameter over many different temperature ranges. The fuel elements have been designed to provide a significant prompt negative temperature coefficient that allow safe reactor operation. The developed monitoring system gives the reactivity worth of the control rods, when the rod considered is inserted or withdrawn in the core and also the loss of reactivity during the reactor operation. This paper describes the methodology and the results found with in the on-line monitoring of the reactivity behavior of the IPR-R1 TRIGA Reactor.

1. INTRODUCTION

The IPR-R1 TRIGA Nuclear Research Reactor is a pool type reactor cooled by natural circulation, and having as fuel an alloy of zirconium hydride and uranium enriched at 20% in ^{235}U. Nuclear reactors must have sufficient excess reactivity to compensate the negative reactivity feedback effects such as those caused by the fuel temperature and power defects of reactivity, fuel burnup, fission poisoning production, and also to allow full power operation for predetermined period of time. To compensate for this excess reactivity, it is necessary to introduce an amount of negative reactivity into the core which one can adjust or control it at will. In the IPR-R1 Reactor the reactivity control is done by three control rods that can be inserted into or withdrawn from the core.

The data acquisition system used in the IPR-R1 Reactor consolidates information about the reactor status and provides an on-line data analysis [1]. The data acquisition program responds to recommendations of the International Atomic Energy Agency - IAEA [2]. It will be shown here the methodology used to find the equations that were used in the data acquisition program to monitor, in real-time, the control rods worth, the reactor temperature coefficient of reactivity and the loss of reactivity during the reactor operation.

2. CONTROL RODS WORTH

The effectiveness, or worth, of a control rod depends largely upon the value of the neutron flux at the location of the rod. The determination of the control rods reactivity is a very important aspect of nuclear reactor core design. All three-control rods were calibrated by the positive period method. The method consists of withdrawing the control rod from a known critical position through a small distance. Each successive step is compensated by lowering the other control rod just enough to reestablish criticality. In this process the control rod under calibration proceeds from the most inserted position (maintaining the reactor critical) to fully removed. The Safety and Shim rods were intercalibrated. The idea was to measure one control rod in presence of another rod, used for compensating the reactivity introduced by step withdrawal of the measure rod. The reactivity measurements were performed at a low power so the temperature increase during the experiment was negligible. The period was obtained using the Doubling Time – DT, that is the time required for the power to increase by a factor of two. To obtain the DT it is necessary to wait approximately for 2 minutes, after withdrawing the control rod under calibration, to finish the transition region. The doubling time was measured with two digital chronometers, observing the power showed in the console. The reactivity associated with the measurement was gotten from the graphical form of the Inhour equation [3].

Figure 1 show the IPR-R1 core configuration. The experimental data obtained in [3], and the integral fitted worth curves of the Regulating, Shim and Safety control rods as a function of their positions are shown graphically in Fig. 2, Fig. 3 and Fig. 4. The equations representing the fitted model, and the coefficients of determination R^2, that confirm the goodness of the fit are also shown in the figures. The integral control rod worth curve is particularly important in research reactor operation. The equations were added to the data acquisition program.

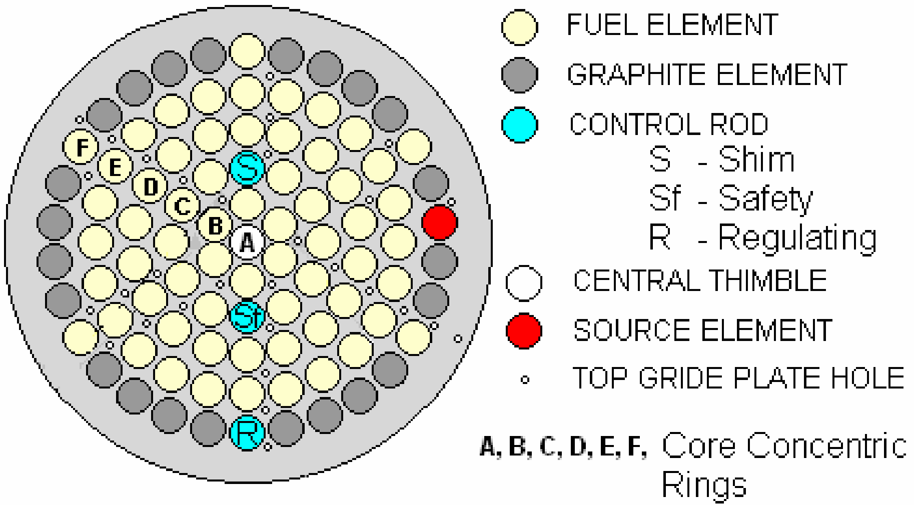


Figure 1. Core configuration of the IPR-R1 TRIGA Reactor.

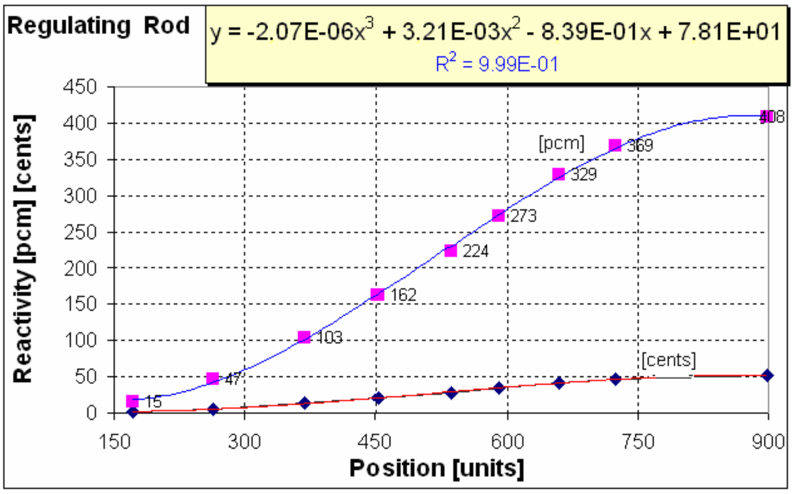


Figure 2. Reactivity as function of insertion of Regulation control rod.

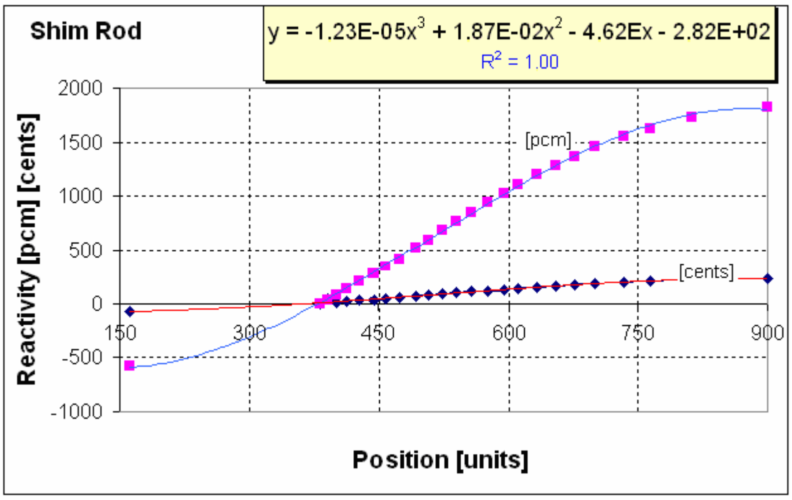


Figure 3. Reactivity as function of insertion of Shim control rod.

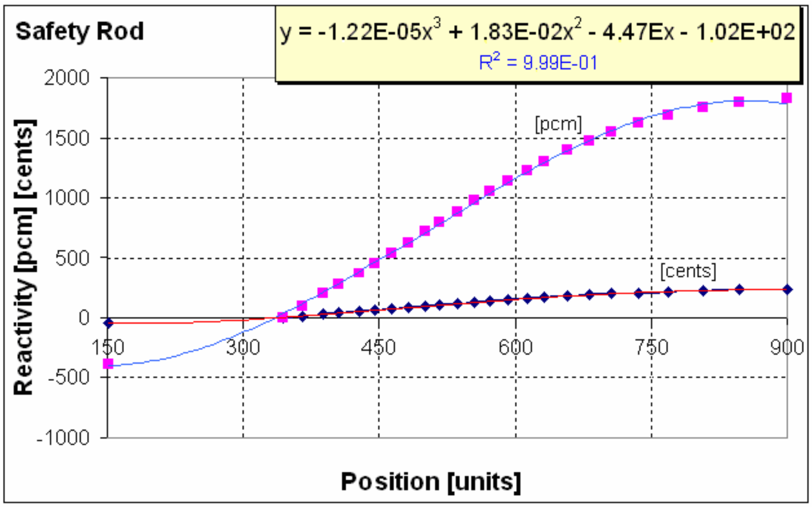


Figure 4. Reactivity as function of insertion of the Safety control rod.

3. THE OVERALL TEMPERATURE COEFFICIENT OF REACTIVITY

The temperature coefficient of reactivity is a very important safety parameter of research reactors, it is defined as the change in reactivity for a unit change in the fuel system temperature. A negative temperature coefficient of reactivity is desirable since it tends to counteract the effects of transient temperature changes during reactor operation. In TRIGA reactors the moderator is the hydrogen that is mixed with the fuel itself. If the fuel temperature increases when the control rods are suddenly removed, the neutrons inside the hydrogen-containing fuel rod become warmer than the neutrons outside in the cold water. These warmer neutrons inside the fuel cause less fissioning in the fuel and escape into the surrounding water. The end result is that the reactor automatically reduces the power within a few thousandths of a second, faster than any engineered device can operate. The inherent safety of the TRIGA reactor arises from the prompt negative temperature reactivity coefficient, whose measured value was (-1.1 ± 0.2) ¢/ºC [4], which effectively limits the power when excess reactivity is suddenly inserted. The prompt temperature coefficient refers only to fuel temperature, and the overall temperature coefficient of the reactor refers to the change in the total core temperature.

The purpose of this experiment was to measure the core temperature reactivity coefficient as function of the core temperature and the loss of reactivity as function of the fuel temperature and reactor power. The equations found were added to the data acquisition program. Fuel temperatures were measured by three thermocouples in the center of the instrumented fuel element at location B1. This location is the hottest position in the core. To obtain the overall temperature coefficient it is necessary to know the average temperature in the core. This value was found using the temperatures distribution in the core shown in Fig. 5 [5]. The average temperature as function of the maximum temperature in the core rings follows the equation shown in Fig. 6. The axial temperature distribution in the fuel follows the same distribution of neutron flux, maximum/average = 1.25 (Fig. 7). The radial temperature distribution inside the fuel, in several operation power, is approximately 1.11 (Fig. 7).

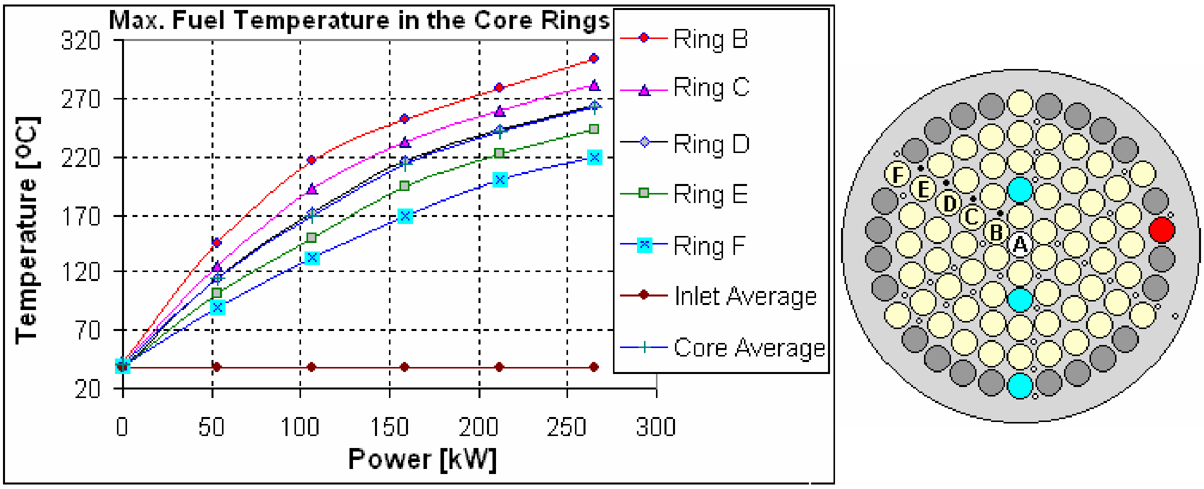


Figure 5. The IPR-R1 temperature distribution in the core rings [5].

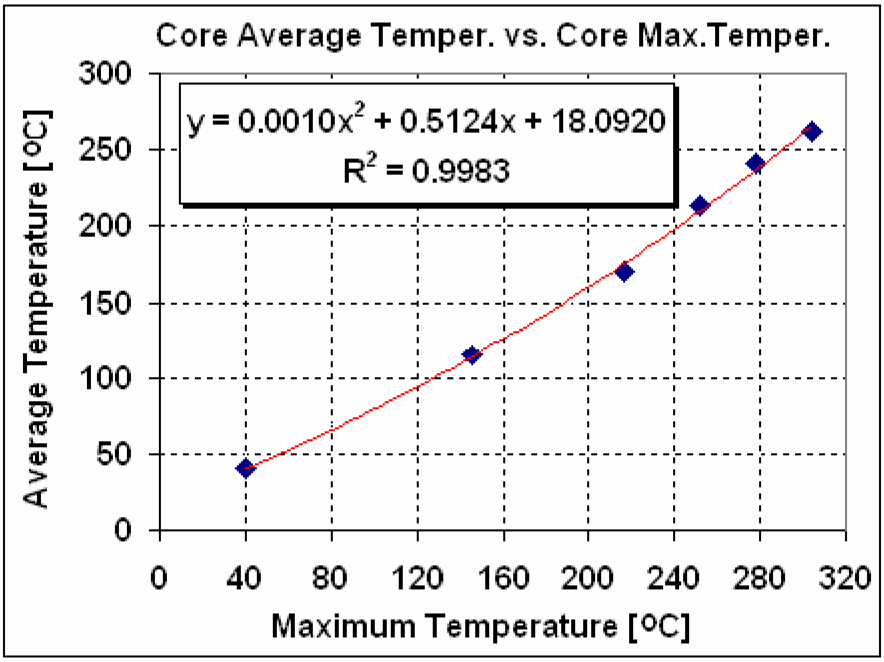


Figure 6. Core average temperature as function of core maximum temperature [5].

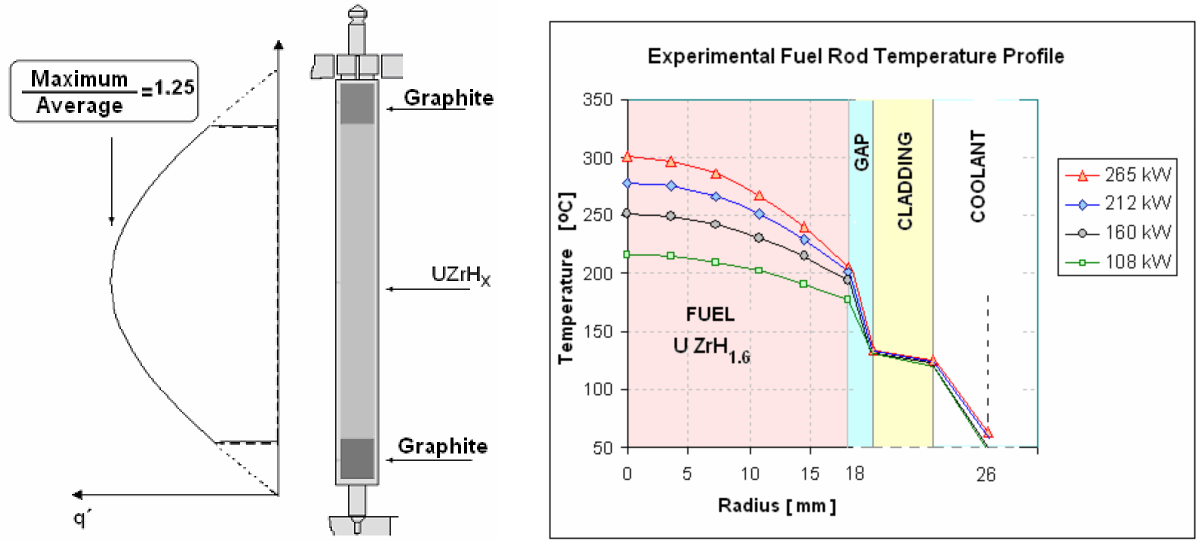


Figure 7. Experimental axial and radial fuel rod temperature profile [5].

In the reactivity experiment, performed in [6], the reactor power was increased, and, consequently, the fuel temperature by withdrawing the Shim control rod in steps. All other control rods were completely withdrawn. The power increased with each increasing step, then reached a new, steady, higher level. The reactivity was determined from the calibrated Shim rod curve (Fig. 3), considering each critical rod position. The forced reactor cooling system was not operating during the experiment, and the initial fuel and water temperature at zero power was 24 ºC. Table 1 presents the experimental results, and Fig. 8 shows the curve and equation of the total temperature reactivity coefficient versus the core average temperature.

Table 1. Experimental results

Reactor Power (kW)	Fuel Temp. Max. (º C)	Core Temp. Average (º C)	ΔT (º C)	Δρ (cents)	Δρ/ΔT (cents/º C)
0.01	24.3	24.3		0.0	
5.3	40.8	29.3	5.0	-7.0	-1.40
17.0	59.2	37.4	8.1	-10.5	-1.29
21.2	67.0	41.0	3.6	-3.5	-0.97
40.3	94.3	54.3	13.3	-14.5	-1.09
66.8	129.0	72.7	18.4	-16.5	-0.90
111.3	185.5	106.3	33.7	-27.0	-0.80
154.8	225.8	133.2	26.8	-26.5	-0.99
208.8	251.7	151.7	18.5	-29.5	-1.60
238.5	263.5	160.4	8.7	-14.0	-1.60
254.4	269.4	164.8	4.4	-7.0	-1.57
262.9	271.4	166.4	1.5	-3.5	-2.31

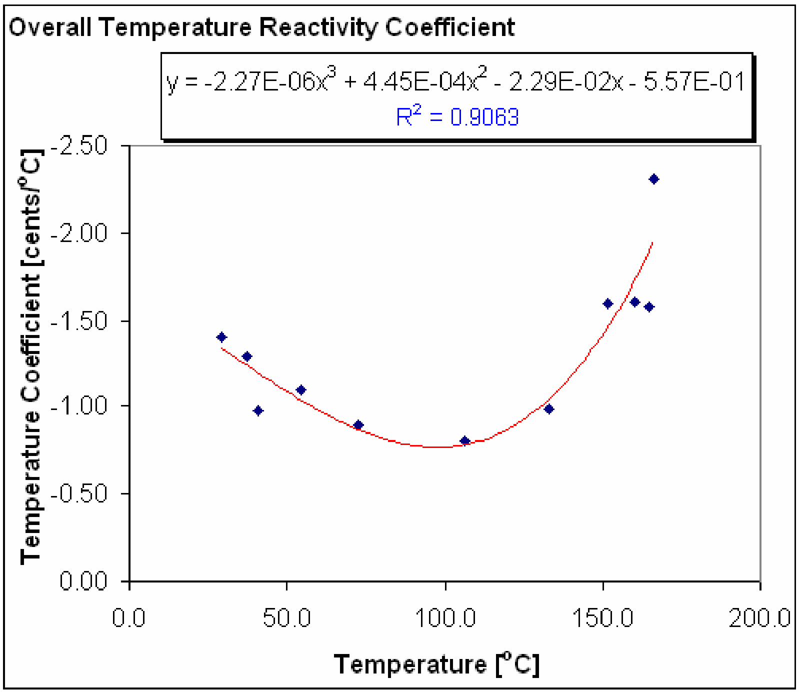


Figure 8. Overall temperature reactivity coefficient.

Figure 9 shows the core reactivity evolution as a function of the fuel temperature and Fig. 10 presents the associated reactivity loss to achieve a giving power level [6].

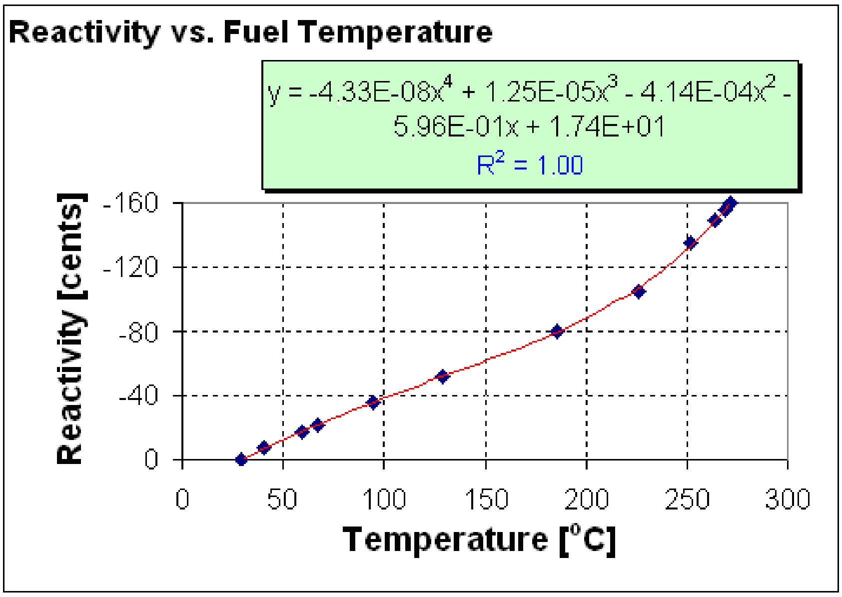


Figure 9. Change in reactivity as function of fuel temperature.

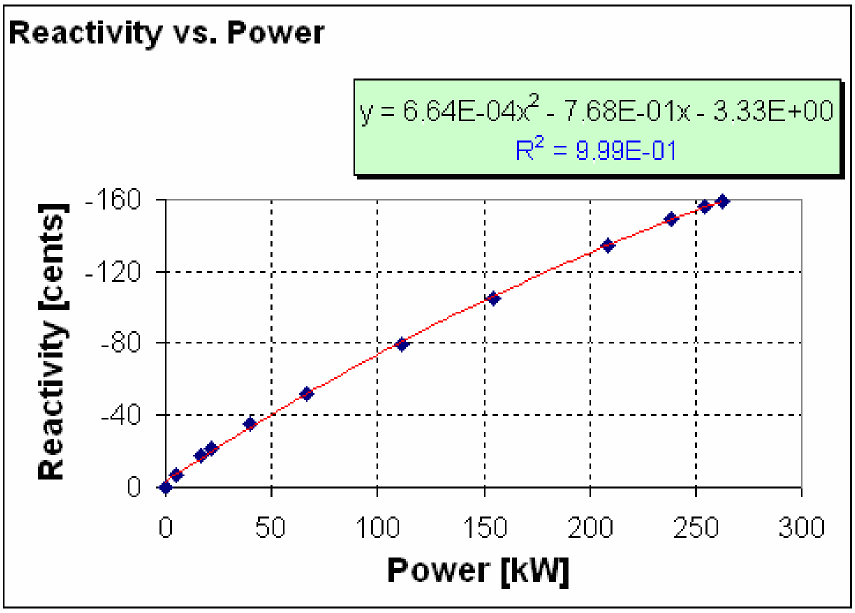


Figure 10. Change in reactivity as function of reactor power.

4. FISSION PRODUCT POISONING

During the course of operation of a nuclear reactor, the fission fragments and their many decay products accumulate. The xenon-135 is the mainly substance, because it has large cross section for thermal-neutron absorption. Figure 11 shows the loss of reactivity caused by the ^{135}Xe poisoning during the reactor operation at 100 kW and Fig. 12 shows the same loss at 250 kW [3]. The two regression equations and their coefficient of determination (R^2) are given in the figures.

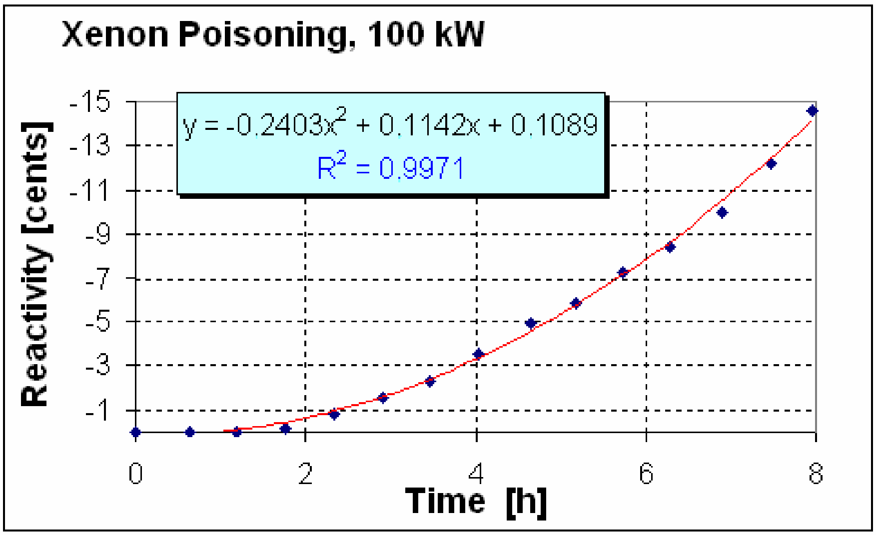


Figure 11. Xenon poisoning during power operation at 100 kW.

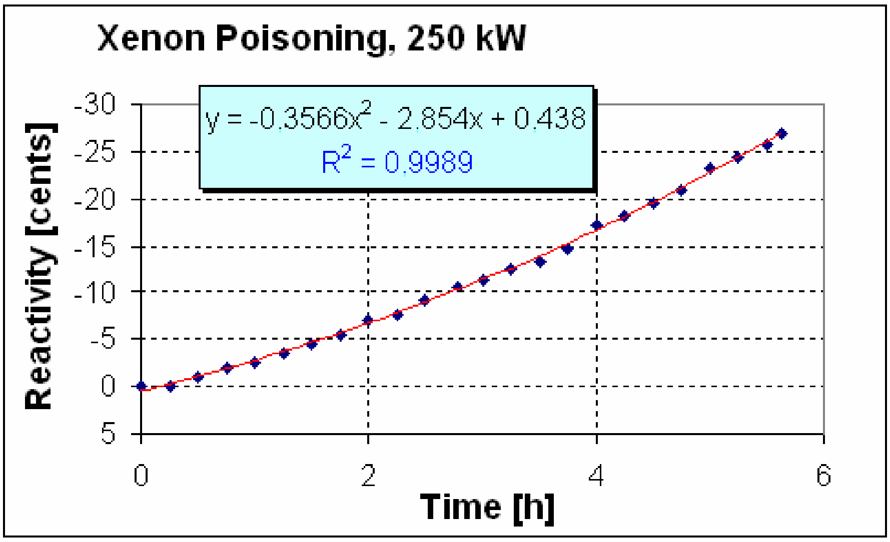
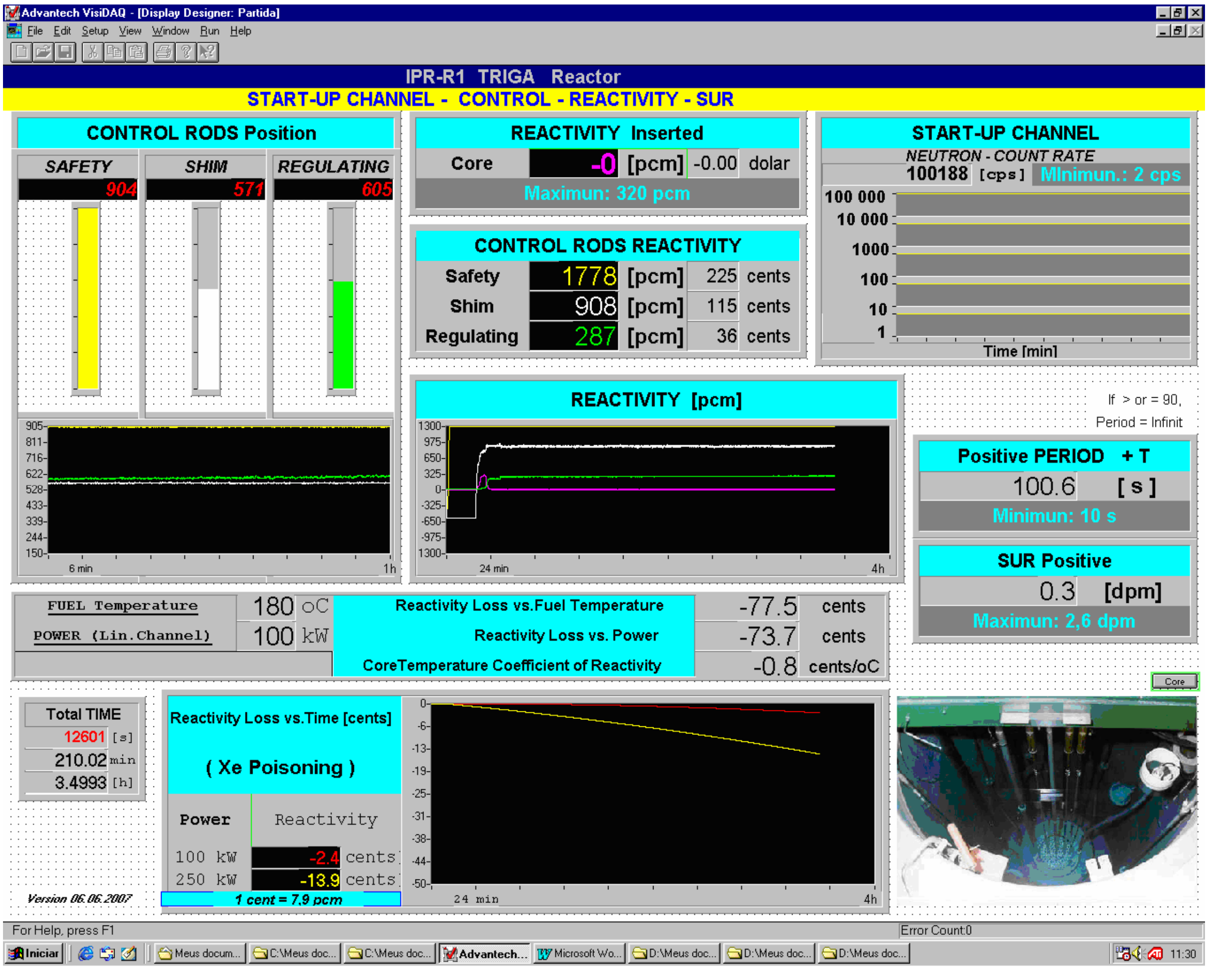


Figure 12. Xenon poisoning during power operation at 250 kW.

The equations of the control rods reactivity as function of their positions in the core, and the core reactivity as function of the temperature and the operation time were added to the data acquisition program. Figure 13 shows the acquisition system screen where the operator can monitoring, during the reactor operation, the consolidated reactivity information.



IPR-R1 TRIGA Reactor

START-UP CHANNEL - CONTROL - REACTIVITY - SUR

CONTROL RODS Position

SAFETY 904

SHIM 571

REGULATING 605

REACTIVITY Inserted

Core -0 [pcm] -0.00 dolar

Maximun: 320 pcm

CONTROL RODS REACTIVITY

Safety	1778	[pcm]	225	cents
Shim	908	[pcm]	115	cents
Regulating	287	[pcm]	36	cents

START-UP CHANNEL

NEUTRON - COUNT RATE

100188 [cps] MInimun.: 2 cps

REACTIVITY [pcm]

If > or = 90,
Period = Infinit

Positive PERIOD + T

100.6 [s]

Minimun: 10 s

SUR Positive

0.3 [dpm]

Maximun: 2,6 dpm

FUEL Temperature 180 oC

POWER (Lin.Channel) 100 kW

Reactivity Loss vs.Fuel Temperature -77.5 cents

Reactivity Loss vs. Power -73.7 cents

CoreTemperature Coefficient of Reactivity -0.8 cents/oC

Total TIME

12601 [s]

210.02 min

3.4993 [h]

Reactivity Loss vs.Time [cents]

(Xe Poisoning)

Power	Reactivity
100 kW	-2.4 cents
250 kW	-13.9 cents

1 cent = 7.9 pcm

Version 06.06.2007

Figure 13. Reactivity monitoring on the screen of the data acquisition system.

5. CONCLUSIONS

The control of reactivity is one of the most important items that must be performed to ensure the safe and efficient operation of a nuclear research reactor. The reactor operators need to know, in real-time, the basic reactor behavior in order to understand and safely operate a nuclear reactor.

The data acquisition system has been designed and developed to automatically monitor and record all operational parameters of the IPR-R1 TRIGA Reactor. The color monitor provides on-line information about important operating parameters such as: the control rods positions; the control rods worth; the reactivity inserted in the core; the loss of reactivity caused by the xenon poisoning and the fuel temperature; the reactor operation graphics, etc. Hard copies of the displays can be made using the graphics printer. The records of the reactor process variables are important for immediate or subsequent safe analyze, and for reporting the reactor operations to the organization and to external authorities [2]. The system does not propose to control the reactor operation, but to help the operator to get more information about the safety status of systems, and, if necessary, to be used to identify manual actions.

The data acquisition and processing system implemented in the IPR-R1 TRIGA Reactor is the beginning of the control and instrumentation update to this reactor. In the future all the reactor operation will be made by programmable logical controllers (PLC's), like other modern research and power reactors [7], [8] e [9]

The overall temperature coefficient of reactivity presented in this work is a preliminary result. The uncertainty of this parameter is about ± 15%, mainly due to the uncertainty in power calibration of the reactor, which estimated value is ± 7.2% [10].

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