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The Rod-Insertion Technique at the TRIGA Reactor Using Signal From Multiple Fission Cells

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ABSTRACT

A digital meter of reactivity (DMR) is applied for the measurements of physical parameters of the reactor cores of the TRIGA reactor and in the Nuclear power plant Krško (NEK). In the past the DMR used uncompensated ionization chambers in order to obtain the neutron flux signal. One of the outstanding features of the DMR is the measurement of control rod cluster worth with the rod-insertion method. At the TRIGA reactor only one ionization cell is currently used for flux measurements. During the insertion of one control rod the neutron flux distribution is significantly altered affecting the flux measurements if using only a single radiation detector. The problem is presently solved by assigning a correction factor to each control rod what introduces an additional uncertainty.

The implementation of four fission cells for the rod-insertion measurements is presented. In this way the correct gamma background determination and subtraction, performed by DMR algorithms, becomes less important as previously by using ionization chambers. The larger number of detectors also reduces the flux redistribution effects on the signal during individual control rod movements. The reduction of the error in the new type of measurements is analyzed.

1 INTRODUCTION

The control rod worth in research reactors and power plants can be determined by different methods [1]. In this paper the rod-insertion method, which is particularly convenient because it is very quick and simple to perform, is studied. The principle of the rod-insertion method is to start from a critical reactor operating at low power and to measure the time-dependent reactivity change while a control rod is inserted into the core with the drive mechanism at normal speed. By analyzing the flux trace using six-group point-kinetics equations, not only the total rod worth but also the differential and the integral control rod worth curves are obtained.

During the rod-insertion measurement the flux may drop by several orders of magnitude. The analysis is performed by transferring the data to a digital reactivity meter (DMR) consisting of a high-quality electrometer to monitor the neutron flux signal and a computer using special software for analysis of the signal.

2 NEUTRON FLUX DEPRESSION FACTOR

Control rods are large neutron absorbers and have a large impact on the neutron flux spatial distribution. In the TRIGA research reactor of the "Jožef Stefan" Institute (JSI) four control rods are employed [2]. The flux in the core is frequently presented as $\Phi(\mathbf{r},t)=T(t)\cdot S(\mathbf{r},t)$ [3] (it is a standard derivation and will not be repeated here). The neutron flux amplitude term $T(t)$ in the point kinetics equation [3] is representative of the integral neutron flux. This quantity cannot be measured directly. Generally we measure the neutron flux $\Phi(\mathbf{r},t)$ at one or more points outside the core and assume that the signal is proportional to the integral of the flux in the core. This assumption is acceptable if the relative change in $S(\mathbf{r},t)$ is negligible during the measurement. Otherwise, a correction on $T(t)$ due to the flux redistribution is necessary. The correction depends on the positions of the control rods and of the detector. An ionization chamber neutron detector measures essentially the flux of neutrons thermalized in the vicinity of the detector. The thermal flux for a core in which a control rod in the vicinity of the detector is inserted is much lower at the detector location and correspondingly higher at a location far from the inserted rod and the detector, compared to the unrodded core assuming that the flux distributions are normalized to unit fission neutron density in the core, which is assumed proportional to the neutron amplitude function $T(t)$. The two flux distributions therefore correspond to the same $T(t)$, but the measured flux values, $T_m(t)$ at the detector locations are different. To reconstruct $T(t)$ from the measured $T_m(t)$ (neglecting the proportionality constant) when an arbitrary rod Y is being inserted into the core, the following correction can be introduced [4]:

$$\boldsymbol{T(t)} = \frac{\boldsymbol{T_m(t)}}{1+(\boldsymbol{f_Y}-1)\boldsymbol{g(l)}}$$

The parameter f_Y is called the flux depression factor for rod Y; it represents the required correction factor for the neutron flux radial redistribution. The function $g(1)$ is the interpolation function for the correction factor between the fully withdrawn (g = 0) and the fully inserted (g = 1) control rod positions and takes into account the actual axial control rod position dependence of the redistribution effect. The parameters F_Y and F_0 correspond to the thermal neutron flux for the rodded and the unrodded core at the location of the detector, respectively. They can be obtained easily from calculations. The flux depression factor for rod Y, f_Y, is obtained as the ratio of F_Y/F_0. In the rod-insertion method the control rod is inserted uniformly with the drive mechanism, therefore a linear transformation can be performed between the time t and the inserted depth 1 during rod travel. The interpolation function $g(t)$ is assumed proportional to the reactivity worth of the inserted part of rod Y during the measurement:

$$\boldsymbol{g(t)} = \frac{1}{\boldsymbol{W_Y}}\rho(\boldsymbol{t})$$

where W_Y is the total rod Y integral worth. This assumption is based on experience and supported by measurements [4].

The measurements, presented in the paper, were performed on a particular core configuration of the TRIGA reactor of the "Jožef Stefan" Institute, which is presented in Figure 1. The flux depression factors for the four control rods for this core configuration were calculated [4] and are presented in Table 1.

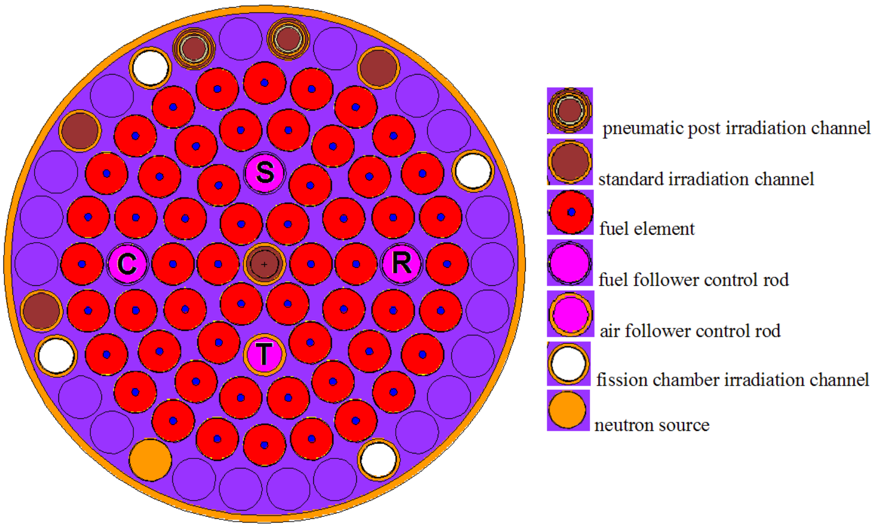

Figure 1: TRIGA core configuration. The control rods are labeled as (T) transient, (R) regulating, (C) shim, (S) safety. The ionization chamber is located behind the reflector (both are not visible in the figure) on the left side of the core.

Table 1: Flux depression factors (TRIGA) [4]:

transient (T)	1.025
regulating (R)	1.116
shim (C)	0.858
safety (S)	0.975

By using the signal from the ionization chamber and the rod insertion method, which algorithms employ the point kinetic equations only, the redistribution of the flux has to be taken into account by using the above redistribution factors. This is done more or less by multiplying the point kinetic result by the appropriate factor for a specific control rod.

3 USING SIGNAL FROM MULITPLE FISSION CELLS

The drawback of using a signal from one ionization chamber is the necessary calculation of the flux form factors, which can be dependent also on core configuration. For this reason, in the frame of this work, the rod insertion measurements for all control rods were performed by using four fission chambers instead; they were located symmetrically around the core (see Figure 1). By using the average signal from all four fission chambers the difference of the signal from the average flux in the core is greatly reduced with respect to the case of measuring the flux at only one location.

The integral values of the control rods were measured and calculated with the rod-insertion method by using signals from both described sources – a) signal from one ionization chamber or b) signal from four fission cells, located symmetrically around the core. Both results were compared in order to evaluate the new technique. They are presented in Table 2.

Table 2: Integral values of control rods without/with using the flux form factor. Measurements performed either with one ionization chamber or a set of four fission cells; presented are also the relative differences.

	Integral worth [pcm]				
	1 ionisation chamber, whithout flux form factor (A)	1 ionisation chamber, with flux form factor (B)	4 fission cells (no flux form factor (C)	relative difference B-C [%]	relative difference A-C [%]
transient	3031	3099	3088	-0.36	1.88
regulating	2715 *	2919 *	2692	-8.09	-0.85
shim	3166 *	2725 *	2567	-5.97	-18.92
safety	3934	4177	4193	0.38	6.58

* regulating and shim control rods experienced large uncertainties in the case of measurement with the ionization chamber due to the high noise.

It can be seen from Table 2 that for three of the control rods the measurement with four fission cells resembles well the introduction of the flux form factor in the case of measuring the flux at only one location. The difference between the values for the shim rod is large, but it should be noted that the measurement with one ionization chamber had a large uncertainty due to the noise, which is much smaller in case of the fission cells.

3.1 Measurement Background / Noise

In case of the rod insertion measurements with one uncompensated ionization chamber, which has been the practice up to now, the value of the gamma background is substantial; since the reactor becomes highly subcritical during the measurement the background is often a few

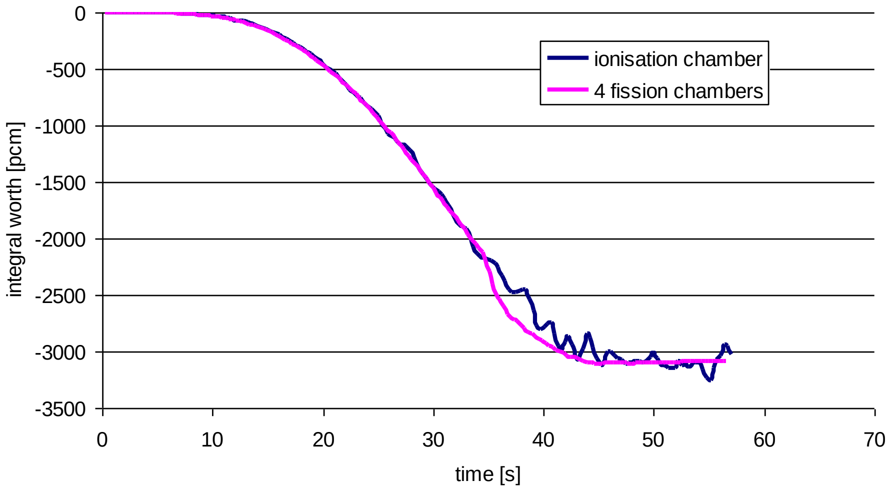

Figure 3: A typical calculation of the reactivity with the DMR for the two cases of obtaining the signal from ionization chambers or fission cells. The larger noise in the former measurement is visible.

times larger than the signal due to the neutron flux – hence the background noise and exact determination of the background also become important. In case of measurements with fission cells the gamma background is much less important due to their insensitivity to gammas. Figure 3 displays a typical calculation of reactivity with the DMR for the two cases of obtaining the signal from an ionization chamber or fission cells.

As can be seen from Figure 3 the noise due to the fluctuation in the gamma background is greatly reduced by using the signal from fission cells and reflected in a smaller noise in the reactivity signal.

3.2 Multiple fission cell usage

Using four symmetrically positioned fission cells reduces the need for flux form factor usage. The integral control rod worth can, however, still be determined from signals from individual fission cells. The differential control rod curves for the transient rod, measured and calculated by the rod insertion method for the four individual fission cells, are presented in Figure 4. On the figure the average curve by using the combined signal from all fission cells is also presented. The individual integral values are given in Table 3.

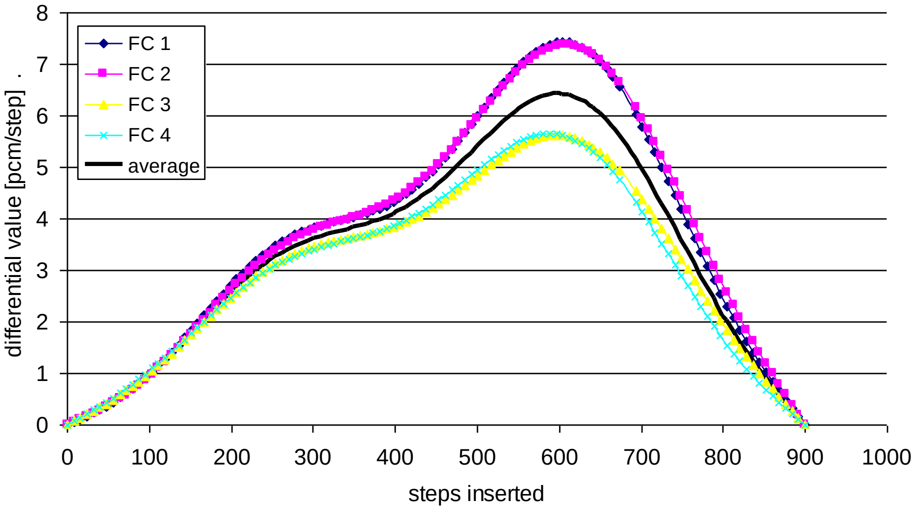

Figure 4: The differential control rod curves for the transient rod, measured and calculated by the rod insertion method for the four individual fission cells, and the average curve by using the combined signal from all fission cells.

Table 3: Integral values for the transient rod as obtained by using individual fission cells and the combined signal from all fission cells.

	Integral value of the pulse rod [pcm]
Fission cell 1	3407
Fission cell 2	3429
Fission cell 3	2826
Fission cell 4	2796
combined (average) signal	3088

It can be seen from the last figure and table that the location of the fission cell with respect to the measured control rod is of crucial importance for the correct integral value; the two fission cells which are on the same side of the reactor as the measured transient rod experience an excessive large change in neutron flux and hence a too large value of the calculated integral value, whereas for the other two cells, located on the far side of the pulse rod, the situation is reversed.

4 CONCLUSIONS

The rod insertion method for measuring integral and differential worth of control rods using a digital meter of reactivity was extended by collecting the signal from four fission cells rather than the usual signal source from a single uncompensated ionization chamber. In this way the correct gamma background determination and subtraction, performed by DMR algorithms, became less important. The larger number of detectors was also found to reduce the flux redistribution effects on the signal during individual control rod movements. Four fission cells, symmetrically positioned around the reactor core, were found to be a suitable configuration for control rod measurements using the rod insertion method, in which case the usage of flux redistribution factors is reduced or banished.

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