CORRECTION FACTORS IN THE OUT-OF-CORE DETECTOR SIGNALS TO CONSIDERER NEUTRON FLUX REDISTRIBUTION EFFECTS

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SUMMARY

The present work has been motivated to determine the relation between detector signals and reactor power for fifteen detectors located around the core of a Research Reactor. The dependency to several configurations of control rods is also studied. Correction factors are obtained from computational calculations using HAMMER and CITATION codes. Three ex-core detectors have been utilized and integral reactivity values have been compared. Good results have been obtained with the application of the correction factors to the detector signals. Satisfatory results were obtained in the present method. We could recomend that other nuclear installations utilize it to monitor neutron flux to improve safety.

INTRODUCTION

Safe operation of nuclear reactors requires permanent monitoration of several important parameters as neutron flux, pressure and temperature. Especific equipments installed in strategical sites of a nuclear sistem are utilized to monitor these parameters. Ex-core and in-core detectors are used to monitor the neutron flux. For detectors viewing the whole core, we can consider that the detector signal variations are aproximately proportional to the changes in the reactor power. However, this assumption is not valid for detectors which are sensible to local perturbations in the flux, induced for example, by control rod movements. In these cases, detector signal variations are not proportional to the reactor power. This fact is due to spacial redistribution of the neutron flux [1]. Thus, the monitoring of neutron flux and all parameters related to neutron flux, such as reactivity, are not accurate. This is observed when we use various detectors in different positions in the reactor monitoring a transient caused by control rod motions. Comparing the detector signals, it is noted different time behavior among them due to same perturbation.

Reactivity is also a fundamental parameter to a safe operation of a nuclear reactor. At each new fuel cycle, it is necessary to measure some reactivity parameters as critical boron concentration, control rod worths and temperature coefficients of reactivity. There are various techniques to measure the system reactivity [2-3]. Therefore, most of them require sophisticate equipments and theoritical models which demand long time of processing and data analyses. To pratical measurements, an advantageous technique is the one that involves the solution of the inverse kinetic equation [4], which make possible the computation of reactivity in real time. In this technique, a signal from an out-of-core detector is fed to a reactivity computer. This reactivity computer solves the inverse kinetic equation. The inverse kinetic equation is derived from the point kinetic equations:

$$\frac{dn(t)}{dt} = \frac{\rho(t) - \beta}{\Lambda} \cdot n(t) + \sum_{i=1}^{6} \lambda_i \cdot C_i(t) \qquad (1)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} \cdot n(t) - \lambda_i \cdot C_i(t) \qquad (2)$$

The inverse kinetic equation is derived integrating the precursors equation, equation (2), substituting it in the neutron population equation, equation (1), and expliciting the reactivity in the resultant equation. Then:

$$\rho(t) = \beta + \Lambda \cdot \frac{\dot{n}(t)}{n(t)^2} \sum_{i=1}^{6} \lambda_i \beta_i \int n(t') \, e^{\lambda_i (t'-t)} \, dt' \qquad (3)$$

With a computational program that solves equation (3) and interfacing experimental instruments that provide proportional signals of power, or n(t), we have an instrument to measure the reactivity in real time, a reactivity-meter.

Most of the instruments that monitor the neutron population in a reactor are neutron detectors. This detectors normally are positioned out-of-core. In many situations, it can be considered that the detector signal $R(r_o,t)$ (where r_o is the detector position) and the neutron population, n(t), are proportional, i.e.,

$$R(r_o,t) \propto n(t)$$

Most of neutron detectors have a sensible volume relatively small, and in some situations the above consideration is not valid. $R(r_o,t)$ is not proportional to n(t) principally in the cases of control rod motion, where there is a space-time redistribution of the neutron flux. For a reactivity space determination through experiment be accurate, it is necessary to take into account these effects.

In this work we describe: i) the method required to compute these space–time effects of neutron distribution, ii) the calculation of the correction factors for the incore detectors for the reactor studied and iii) perform an experiment to evaluate the proposed method.

CALCULATIONAL METHOD

The space–time effects in transients are obtained factorizing the neutron flux as:

$$\phi(r,E,t) = \varphi(r,E,t) \cdot n(t) \qquad (4)$$

where n(t) is the amplitude function and $\varphi(r,E,t)$ is the shape function. The kinetic parameters are defined as:

$$\bar{\beta}(t) = \sum_i \beta_i(t) \qquad (5)$$

$$\beta_i(t) = \frac{< \phi_o^*(r,E) , M_{di}(r,E,t) \cdot \psi(r,E,t) >}{< \phi_o^*(r,E), \aleph(E) \cdot P(r,E,t) \cdot \psi(r,E,t) >} \qquad (6)$$

$$\Lambda(t) = \frac{< \phi_o^*(r,E) , 1/v \cdot \psi(r,E,t) >}{< \phi_o^*(r,E), \aleph(E) \cdot P(r,E,t) \cdot \psi(r,E,t) >} \qquad (7)$$

where M_{di} is the production operator for delay neutrons for i–th group, P is the production operator for all neutrons, $\aleph$ is the fission spectrum, v is the neutron speed, ϕ_o^* is the adjoint neutron flux and "< >" represents the integral over energy and volume of the reactor.

In the reactivity–meter, the equation of inverse kinetic gives the reactivity basead on the count rates from detectors located in different places in the reactor. The detector signal $R(r_o,t)$ represents the evolution of the neutron flux in time and at position r_o. The correction factor necessary to obtain the amplitude function, n(t), out of the detector signal, $R(r_o,t)$, is given by:

$$n(t) = \frac{R(r_o,t)}{< T(r,r_o,E), \psi(r,E,t) >} \qquad (8)$$

where $T(r,r_o,E)$ is a weight function. This function determines the region viewed by the detector located at r_o. The neutron flux appears factorized in terms of the product between $\psi(r,E,t)$ and n(t).

Observing the equation (8), we can verify that the term

$$\frac{1}{< T(r,r_o,E), \psi(r,E,t) >} \qquad (9)$$

is the correction factor. This factor must be applied to the detector signal, $R(r_o,t)$, in order to obtain the amplitude function, n(t). The correction factors can be estimated theoretically as the ratio between perturbated and reference flux at the detector position, r_o. The *reference flux*, ϕ_{ref}, *refers* to a *critical* state of the reactor and the perturbated flux, ϕ_{pert}, refers to a state in which a control rod movement has occured (a transient state). Then:

$$\text{Correction Factor} = F_c \cong \frac{\phi_{ref}}{\phi_{pert}} \qquad (10)$$

where ϕ_{ref} and ϕ_{pert} are obtained from computer codes.

In this work, we calculed the correction factors of a Research Reactor. For this, we utilised the HAMMER and CITATION codes to obtain the ϕ_{ref} and ϕ_{pert} fluxes. The correction factors are obtained from equation (10).

The correction factors depend strongly of control rod configuration. Therefore, these factors will be presented in terms of the detector position, r_o, and positions of all control rod, z_{bc}.

CALCULATION AND APPLICATION OF THE CORRECTION FACTORS

Figure 1 shows the detector positions around the reactor core. Utilizing the HAMMER and CITATION codes we processed many cases, where we changed the critical and perturbated rod positions. With this, we get the ϕ_{ref} and ϕ_{pert} fluxes at several detector positions. To check the performance of the proposed method a rod drop experiment was carried out. Three ex–core detectors were used. The detector signals were recorded and sent to a reactivity–meter initially without any correction. In Figure 2 we show the integral reactivity control rod from each detector used. In a second stage we reanalyze the detector signals corrected through equation (8). In the Figure 3 the integral reactivitity control rod corrected are shown. In Table 1 we have the experimental results and the control rod project value.

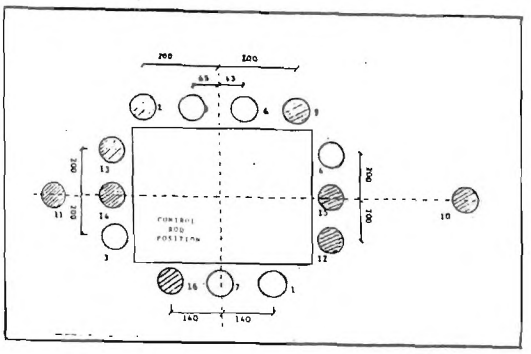

Figure 1. Detector Positions Around Reactor Core.

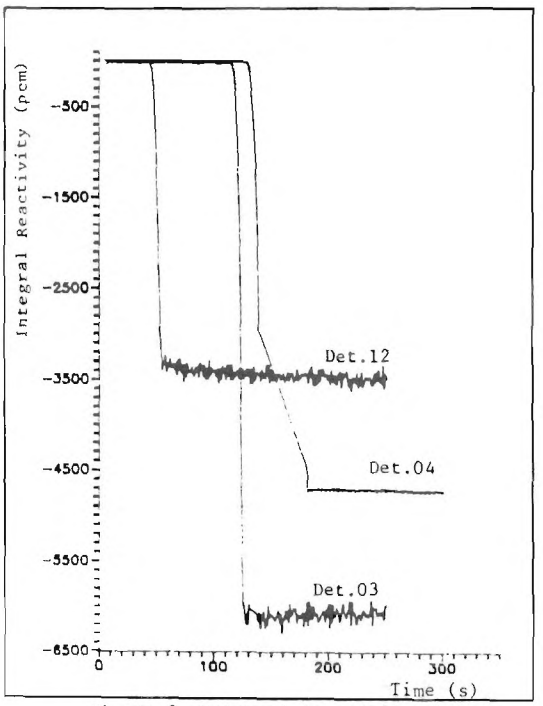

Figure 2. Integral Reactivity without Correction Factors.

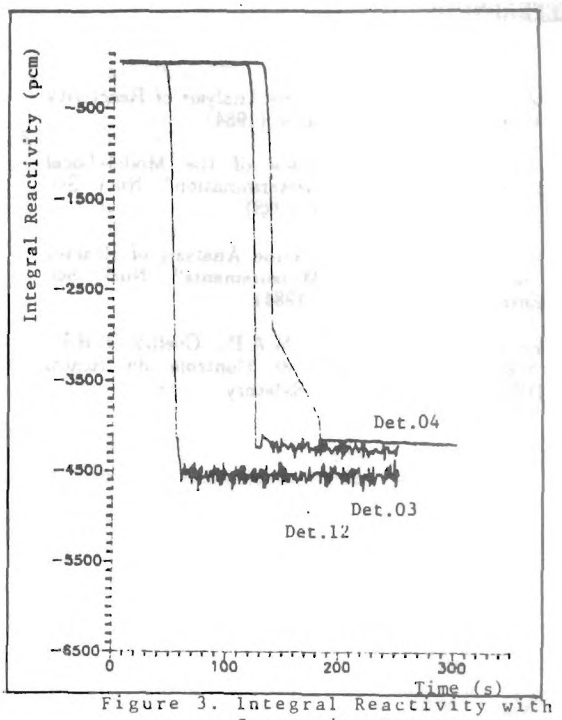

Figure 3. Integral Reactivity with Correction Factors.

Table 1. Integrals Reactivities Without and With Correction Factors for a Rod Drop Experiment.

Detector	Integral Reactivity Without Correction (pcm)	Integral Reactivity With Correction (*) (pcm)
03	– 6000 ± 200	– 4500 ± 200
04	– 4750 ± 100	– 4200 ± 100
12	– 3500 ± 200	– 4250 ± 200

(*) Integral Reactivity Project Value: – 4350 pcm.

CONCLUSION

In Figure 2 we can observe that the three experimental reactivity values are different among them and the project value. However, in Figure 3 we can verify that the reactivity values converged to a value of about – 4200 pcm. The new reactivity values are near to the project value (cf. Table 1). From the results of this work, we can verify that the methodology employeed has been satisfatory. It is necessary consider correction factors in the detector signals in order to compute reactivity correctly.

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