Reactivity Monitoring with Imposed Beam Trips and Pulsed Mode Detectors in the Subcritical Experiment YALINA-Booster

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Abstract. Reactivity monitoring is one of the urgent problems that require a solution in order to achieve a license for a future full-scale ADS. As a part of the EUROTRANS experiments at the YALINA-Booster facility, presented in this conference, a set of measurements with imposed beam-trips has been performed. Traditionally, the source jerk method has been used in subcritical systems to obtain the reactivity by comparing the total neutron flux before the neutron source removal to the semi-stable delayed neutron flux after the source removal. The deuterium-tritium neutron source of the YALINA-Booster facility can, in addition to pulsed mode operation, operate with continuous beam with short imposed millisecond-scale interruptions, thus providing the possibility to monitor the reactivity at each beam trip in the source jerk manner. In order to test the validity of the beam-trip reactivity values determined by using detectors operating in current-mode (also presented in this conference), the reactivity values of the YALINA-Booster assembly obtained through the beam-trip technique using pulsed-mode detectors is presented in this work. In these experiments, a beam-trip frequency of 1 Hz and an interruption time of ~20 ms have been chosen and two different core loadings with effective multiplication factor around 0.95 have been investigated. These two different loadings with close to equal reactivity but different source multiplication characteristics make it possible to explore the effect of the different source multiplications. In addition, the response of the imposed beam-trip reactivity monitoring technique to reactivity insertions and removals has been studied through control rod movements. Experimental data from fission chambers have been acquired from all three zones of the core: the fast booster zone, the thermal zone and the reflector.

1. Introduction

In the framework of the IP-EUROTRANS [1], within the 6th FW Program of the UE, an experimental campaign has been started at the YALINA-Booster facility located at JIPNR-Sosny (Belarus). The YALINA experiments will continue the work performed during the MUSE program (5th FW Program of the UE) [2]. The main objective is the qualification of the reactivity monitoring techniques as well as to develop the electronic chains that can be used in a power ADS. For this purposes, YALINA couples a D-T neutron generator to a flexible zero-power subcritical assembly with an intermediate neutron spectrum. The high intensity of the accelerator and the possibility to work in continuous or pulsed modes allow the study of the current-to-flux relationship, beam trip experiments and dedicated experiments for loading and start-up procedures. In this paper are presented the results of the analysis of the source jerk technique to determine the reactivity applied to the beam trip experiments.

2. The YALINA-Booster subcritical assembly

The YALINA-Booster subcritical assembly (*FIG. 1*) is formed by two main zones: a central fast zone (booster) composed of 36% enriched UO_2 fuel in a lead matrix and a thermal zone around it composed of 10% enriched UO_2 in polyethylene. Surrounding these two zones there is a graphite reflector. A number of experimental channels for detectors are available in all three zones. See [3] for further details. All the measurements used for this paper were taken with U-235 fission chambers.

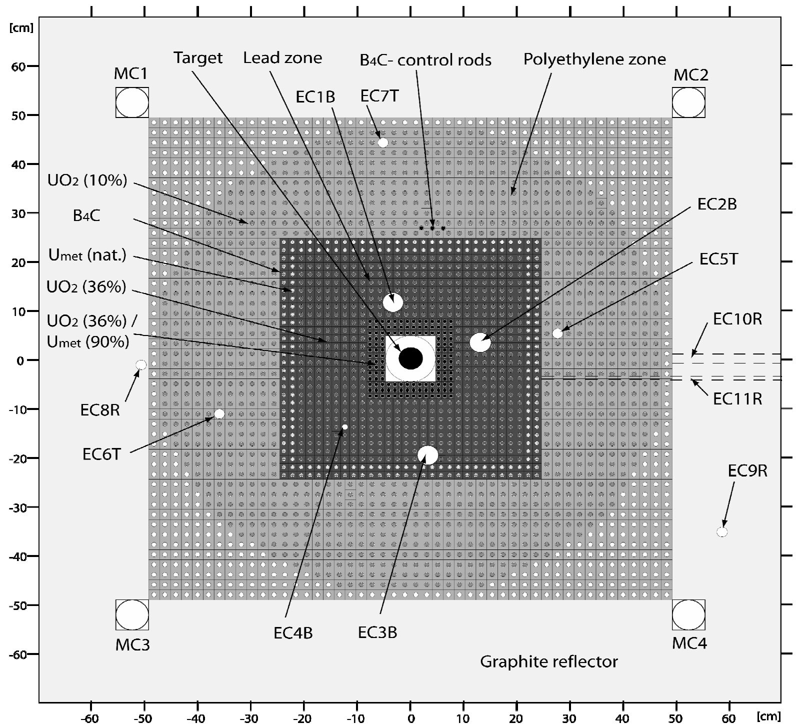

FIG. 1. Schematics of the YALINA-Booster facility showing the different regions and the locations of the different experimental channels.

The facility is coupled to a deuteron accelerator and tritium or deuterium targets can be used. The results presented here were taken with a tritium target, but due its high depletion degree it also had a significant deuterium content.

The facility allows for great flexibility in core loading patterns. The results presented here were measured in the configurations described in Table I. The values of k_{eff} have been calculated using MCNPX 2.5.0 and the JEFF – 3.1. library.

TABLE I. YALINA-BOOSTER CONFIGURATIONS

	Internal booster	External booster	Thermal zone	Calculated k_{eff}
SC3a	132 pins	563 pins	1077 pins	~ 0.95
SC3b	0 pins	563 pins	1090 pins	~ 0.95

3. The source – jerk technique

The source jerk technique to determine the reactivity relies in measuring the neutron densities in the system before and after a source removal. From the point kinetics model it can be obtained that [4]:

$$\frac{\rho}{\beta} = -\frac{n_0 - n_1}{n_0}$$

Where n_0 is the neutron density before the removal and n_1 is the neutron density after it, as shown in FIG. 2, which has been taken from the experiments. The oscillations observed in the neutron density are due to an oscillation in the magnetic dipole causing the deuterons beam to impinge on a tritium free region of the target. However, these oscillations do not cause any bias in the reactivity values provided by the source jerk method as its period (0.02 s, corresponding to a frequency of 50 Hz) is much smaller than the half lives of the different families of delayed neutrons (ranging from 0.23 s to 55.72 s in the case of the thermal fission of U-235, see [4] for instance), so the delayed neutrons level after the beam trips is not affected by these oscillations and it is the same as if the neutron density before the beam trip had a constant value equal to the average value. Therefore the source jerk method will give a correct estimate of the reactivity providing that the neutron density before the beam trip is calculated as the average over an entire number of periods of the oscillation.

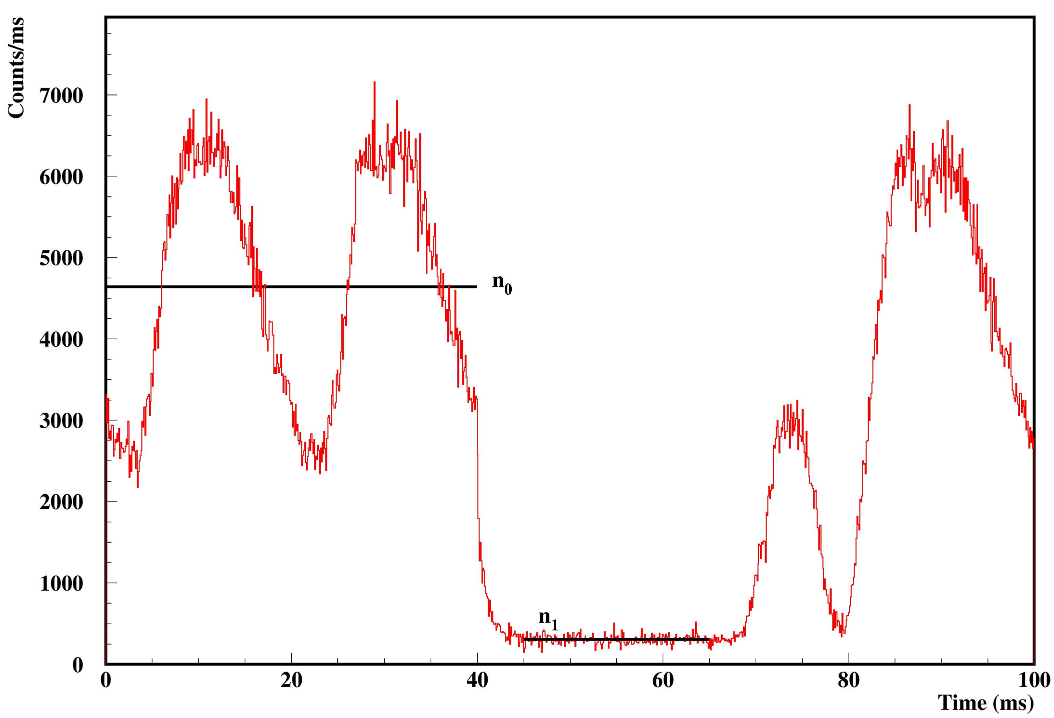

FIG. 2. Typical beam trip measured during these experiments.

The results thus obtained are listed in Table II. No results from the reflector are presented due to poor statistics.

TABLE II

Zone	Channel	SC3a		SC3b	
		CR In	CR Out	CR In	CR Out
Booster	EC1B	-18.75 ± 0.28	-16.22 ± 0.30	---	---
	EC2B	-15.96 ± 0.44	-14.22 ± 0.30	-15.71 ± 0.24	-14.12 ± 0.18
Thermal zone	EC5T	-9.72 ± 0.56	-9.04 ± 0.52	-10.17 ± 0.41	-9.35 ± 0.39

It can be seen from this table that the reactivity values measured with detectors at different locations present large variations. These variations are due to spatial effects. So, to be able to give an estimate of the reactivity of the system it is necessary to obtain a correction factor for every detector location that takes into account the complete description of the system. These correction factors can be obtained from MCNP calculations [5]. With these correction factors the reactivity of the system is obtained in the following way:

$$\rho = \frac{\rho_{\text{experimental, detector}}}{C_{\text{detector}}}$$

The correction factors computed using MCNPX 2.5.0 and the JEFF-3.1. library and the corrected reactivity values are listed in Table III.

TABLE III.

Zone	Channel	SC3a			SC3b		
		C_{de}	CR In	CR Out	C_{de}	CR In	CR Out
Booster	EC1B	1.813 ± 0.027	-10.34 ± 0.21	-8.95 ± 0.21	1.960 ± 0.035	---	---
	EC2B	1.626 ± 0.023	-9.81 ± 0.30	-8.74 ± 0.22	1.741 ± 0.028	-9.02 ± 0.30	-8.11 ± 0.17
Thermal zone	EC5T	0.979 ± 0.016	-9.92 ± 0.59	-9.23 ± 0.55	1.010 ± 0.018	-10.07 ± 0.44	-9.26 ± 0.42
Weighted average			-10.15 ± 0.17	-8.88 ± 0.15		-9.20 ± 0.18	-8.27 ± 0.15

For comparison, Table IV shows the corrected values for the reactivity obtained from the PNS measurements, also presented in this conference [6].

TABLE IV.

Zone	Channel	SC3a		SC3b	
		CR In	CR Out	CR In	CR Out
Booster	EC1B	-9.40 ± 0.18	-8.17 ± 0.15	-9.72 ± 0.33	-8.37 ± 0.16
	EC2B	-9.33 ± 0.16	---	-8.76 ± 0.17	-7.82 ± 0.15
Thermal zone	EC5T	-9.61 ± 0.28	-8.88 ± 0.38	-10.08 ± 0.50	-9.05 ± 0.29

It can be observed that the values obtained by the two methods are close, although further analysis of these results will be required to assure the compatibility of the two methods.

4. Reactivity evolution during one experiment

FIG. 3 shows the evolution of the reactivity values obtained with the source jerk technique during one experiment alongside with the counting rate during the same experiment. It can be seen that the source jerk technique allows the monitoring of the reactivity in a continuous or quasi – continuous manner. However it has the limitation that after an external source loss the value of the reactivity obtained will be overestimated (in absolute value) as the delayed neutron level takes some time to reach a stable value after changes in the neutron density. Notice how after the beam loss the reactivity estimates by the source jerk method take some time to reach a stable value. For comparison, the results for the prompt decay constant method of reactivity measurement, which is not affected by changes in the delayed neutrons level, are also plotted. In the case of Yalina – Booster, because the neutron spectrum is mostly thermal, the prompt neutron decay slopes follow a nearly point – like model and thus this method can give good reactivity estimates.

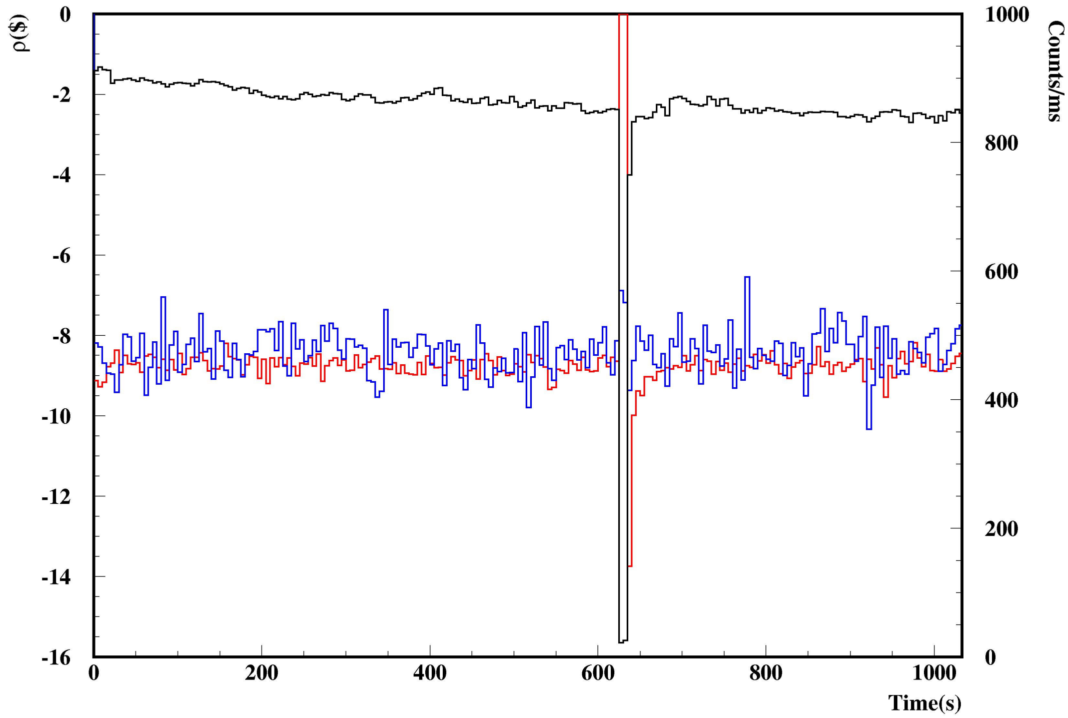

FIG. 3. Corrected values of the reactivity obtained by the source jerk method (red) and the prompt decay constant method (blue) during one experiment, alongside with the counting rate during these periods (black).

5. Summary and conclusions

We have shown that the source jerk technique can be used to monitor the reactivity in a continuous or a quasi-continuous manner but it will drive us to overestimate the subcriticality level in case of beam losses. Still, in this case, the prompt decay constant method can give correct values of the reactivity. However, the results present large spatial effects. Hence, in order to be able to give an estimate of the reactivity of the system MCNP simulations will be needed to obtain correction factors. Further analysis is still required to compare with the results obtained from the prompt decay constant method and the results from the PNS measurements.

6. Acknowledgements

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7. References

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